POTENTIAL HYDROLOGIC IMPACTS OF GROUND-WATER WITHDRAWAL FROM THE CAPE COD NATIONAL SEASHORE, TRURO, MASSACHUSETTS

By Denis R. LeBlanc

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FACTORS FOR CONVERTING INCH-POUND UNITS TO
INTERNATIONAL SYSTEM OF UNITS (SI)

The following factors may be used to convert the inch-pound units used in this report to the International System of Metric Units (SI).

Multiply	By	To obtain
inch (in)	25.40	millimeter (mm)
foot (ft)	.3048	meter (m)
mile (mi)	1.60	kilometer (km)
acre	.4047	hectare (ha)
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3.785×10^3	cubic meter (m^3)
foot per day (ft/d)	3.528×10^{-6}	meter per second (m/s)
gallons per minute (gal/min)	.0631	liter per second (L/s)
million gallons per day (Mgal/d)	.04381	cubic meter per second (m^3/s)
parts per million (ppm)	1.000	milligrams per liter (mg/L)

National Geodetic Vertical Datum (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." NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

The hydrologic impacts of continuous ground-water withdrawals at 0.75, 1.0, and 1.25 Mgal/d (million gallons per day) from a test-well site in the Cape Cod National Seashore, Truro, Massachusetts, were evaluated with a three-dimensional finite-difference steady-state-flow digital model. The digital model was prepared during an earlier study and is only briefly described in this report.

Continuous withdrawal of more than 1.0 Mgal/d from a well screened from 10 to 40 feet below sea level at the test site will result in upward movement of the freshwater-saltwater interface and most likely saltwater will eventually contaminate the well. Pumping from a shallower well will decrease the potential for the movement of saltwater into the well, but the water table may be drawn down to the well screen. It is unlikely that movement of the freshwater-saltwater interface in response to pumping from the test site at the simulated rates will result in saltwater contamination of the shallow domestic supply wells in Truro. For the simulated pumping schemes, the water-table decline below average (1963-76) levels did not exceed 0.6 foot except near the pumping wells. Continuous withdrawal at the average year-round rate and the average summer rate will decrease freshwater discharge to the wetland and ocean along the northeastern boundary of the aquifer.

INTRODUCTION

In July 1978, one of the two well fields in the town of Truro that supply drinking water to the town of Provincetown was closed as a precautionary measure after an estimated 3,000 gallons of gasoline leaked from a service station storage tank located about 600 feet from the well field. The gasoline reportedly had been detected in several nearby private wells. The National Park Service granted a permit to Provincetown to install and pump a temporary supply well within the boundaries of the Cape Cod National Seashore in Truro while the contaminated part of the aquifer is being reclaimed. The well was used in 1979 to supply 32 percent of the town's water needs.

At the request of the National Park Service, the U.S. Geological Survey has estimated the potential impacts of withdrawal from the temporary well at pumping rates of 0.75, 1.0, and 1.25 Mgal/d. A digital model of the Truro aquifer previously prepared, calibrated, and documented by the Geological Survey (Guswa and LeBlanc, 1981) during an earlier study of Cape Cod's ground-water resources was used for this evaluation. The original computer code and input data, except for the pumping rates, were not modified during this evaluation. Therefore, this report only briefly describes the digital model. The reader is referred to Guswa and LeBlanc (1981) for a detailed description of the computer code, the hydrology of Cape Cod, the preparation of the model input data, and the model calibration.

PROVINCETOWN WATER-SUPPLY WELLS

Provincetown is located at the outer end of the Cape Cod peninsula (fig. 1). Ground-water quality within the town is poor (Frimpter and Gay, 1979, p. 7), and Provincetown has obtained its drinking water from wells in the adjacent town of Truro since 1908.

Before 1978, Provincetown obtained its drinking water from the Knowles Crossing and South Hollow well fields (fig. 2). Characteristics of the two well fields are included in table 1. Monthly pumpage from the two well fields from 1975 to 1979 is shown in table 2. Each field supplied about half of the water used by Provincetown during 1975-77.

Gasoline Leak

In December 1977, a leak was discovered in a gasoline storage tank located about 600 feet southwest of the nearest well in the South Hollow well field. Approximately 3,000 gallons of gasoline had leaked into the ground, and much of it reached the water table (R. A. Weimar, Camp, Dresser, and McKee, Inc., oral commun., 1980). The South Hollow well field was shut down in July 1978 to avoid inducing movement of the gasoline from the contaminated area toward the wells. Efforts to remove the gasoline from the unsaturated zone and the aquifer at the site of the leak began in March 1979 and were continuing in May 1980 (R. A. Weimar, oral commun., 1980). Detailed information on the gasoline leak, the testing program to determine the nature and extent of the contamination, and efforts to recover the gasoline and reclaim the aquifer is given in a report by Camp, Dresser, and McKee (1978b).

Supplemental Water Sources

The town of Provincetown cannot supply all of its requirements for drinking water from the Knowles Crossing well field. The three wells in this field are located approximately 1,500 feet from Cape Cod Bay, and pumping for extended periods at the field's rated capacity, 0.86 Mgal/d, results in increased sodium and chloride concentrations owing to seawater intrusion (Frimpter and Gay, 1979, p. 6). The chloride concentration rose from 105 mg/L in November 1978 to 225 mg/L in March 1979 after the well field was pumped continuously for 4 months at 0.6 to 0.7 Mgal/d (J. E. Smith, Provincetown Water Department, oral commun., 1980).

To supplement water pumped from the Knowles Crossing well field during 1978-79, Provincetown also obtained water from two wells within the boundaries of the Cape Cod National Seashore (Camp, Dresser, and McKee, Inc., 1978a; National Park Service, 1979). In July 1978, a temporary supply well was completed at Test Site No. 4 (fig. 2). The site had been identified previously by Whitman and Howard, Inc., (1966, 1969) as a potential source of drinking water for Provincetown. The Test Site No. 4 well supplied water to the town from July to November 1978 and May to November 1979 (table 2). During 1978 and 1979, the pumping rate was restricted to 0.75 Mgal/d or less by the Park Service. The second source of supplemental water, a well that supplies the North Truro Air Force Station (fig. 2), supplied water to Provincetown from June to December 1978 and April to November 1979 (table 2). The characteristics of these wells are summarized in table 1.

The South Hollow well field remained closed during the summer of 1980 while efforts to rehabilitate the aquifer at the site of the gasoline leak continued. Provincetown was granted permission by the National Park Service and the U.S. Air Force to pump water from the emergency supply wells in 1980. Pumping from the Air Force well resumed in April 1980; pumping from the Test Site No. 4 well resumed in May 1980.

THE TRURO AQUIFER

The aquifer in Truro is Pleistocene glacial outwash composed of unconsolidated sand and gravel with some silt and clay (Oldale, 1976; Koteff and others, 1967). Fresh ground water is contained in the unconsolidated sediments under unconfined conditions. The sediments generally are very permeable and yield water readily to wells. The ground-water hydrology of the Truro area has been described by many investigators (Delaney and Cotton, 1972; Strahler, 1972; Burns, Frimpter, and Willey, 1975; Guswa and Londquist, 1976; Guswa and LeBlanc, 1981) and is briefly reviewed below.

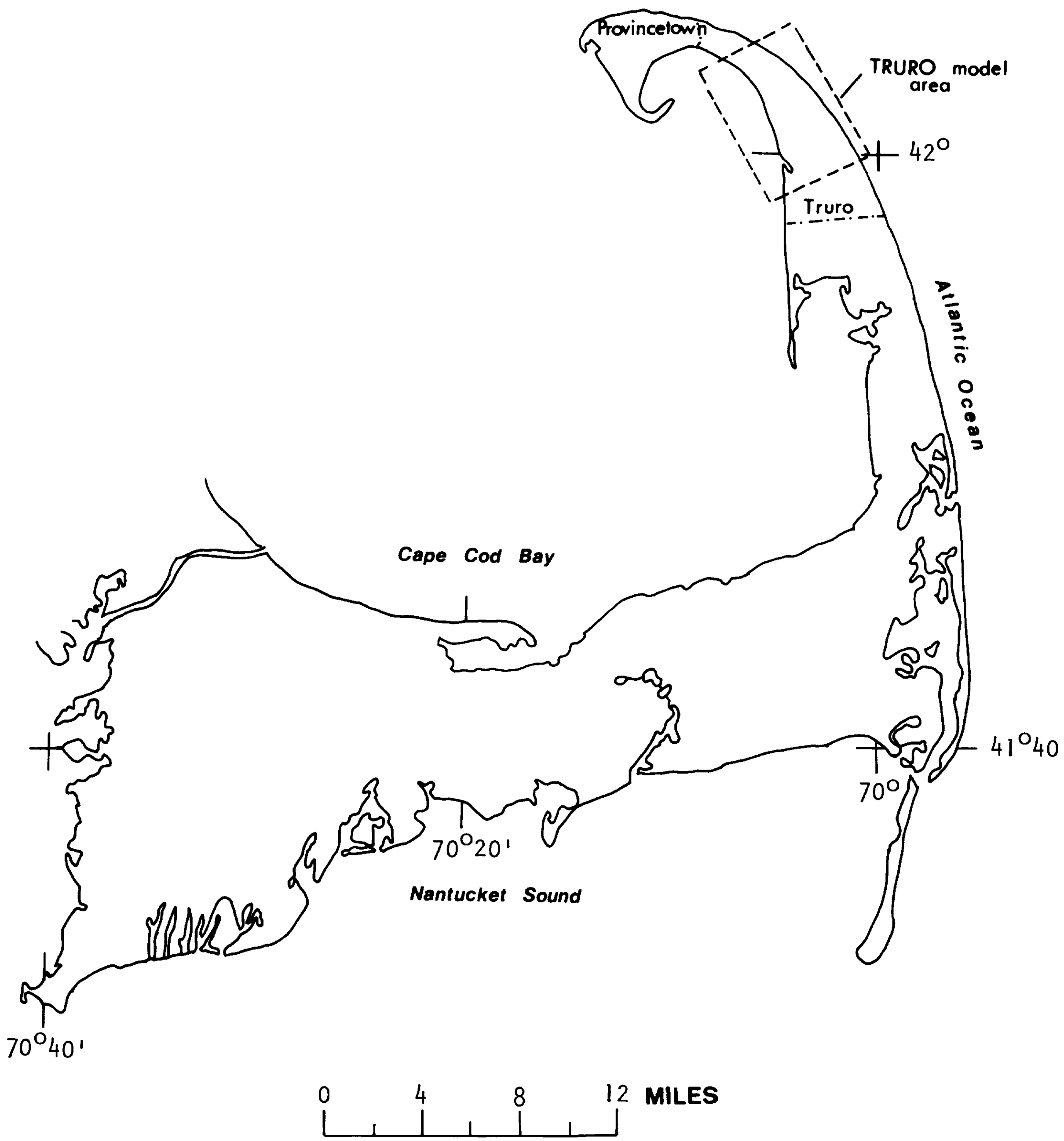


Figure 1.--The Cape Cod Peninsula

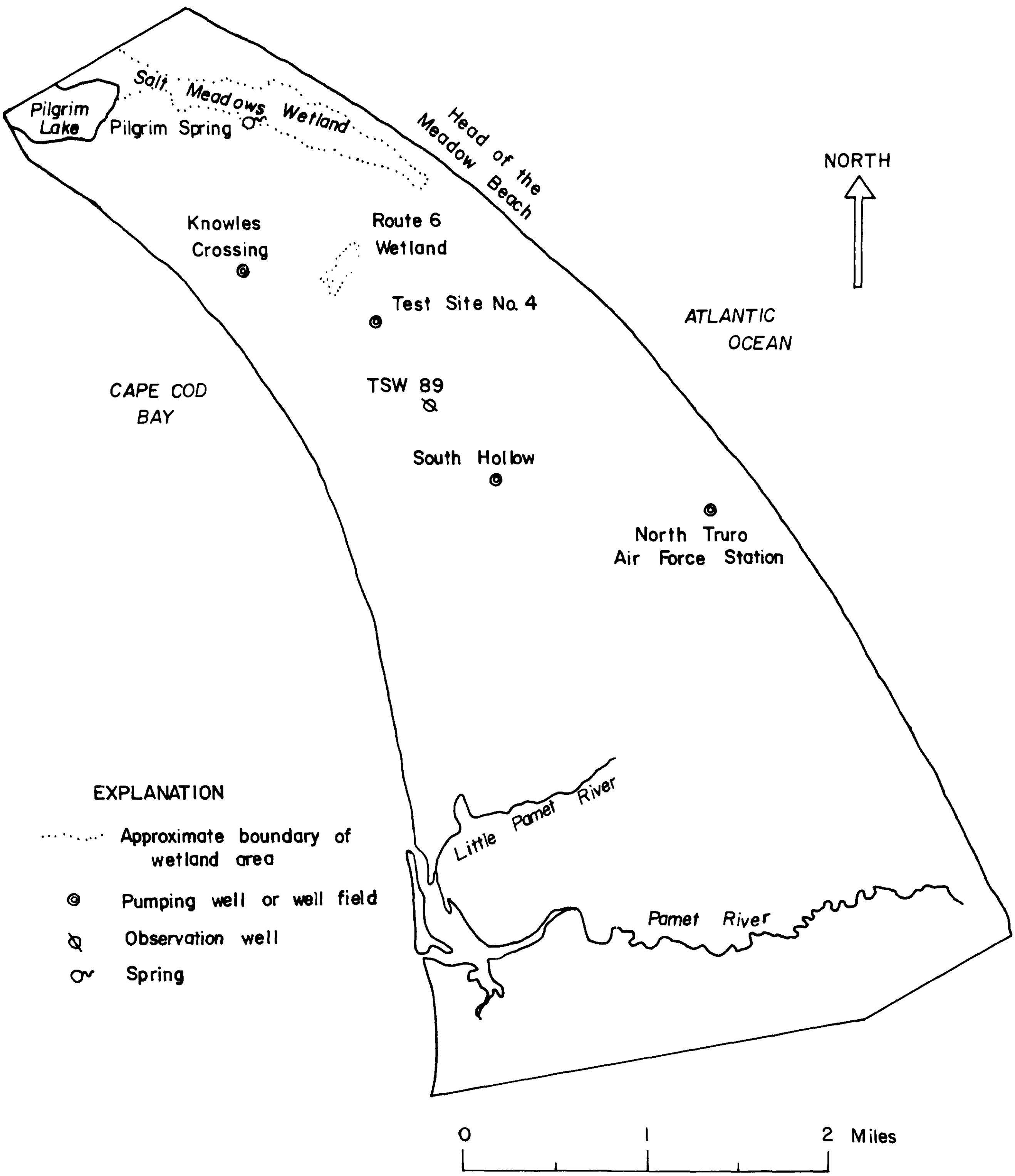


Figure 2.--The study area, Truro, Massachusetts

Table 1.--Characteristics of pumping wells in Truro, Provincetown Water Department

(Sources of data: Provincetown Water Department and well drillers. Location of wells shown in fig. 2.)

	Knowles Crossing	South Hollow	Test Site No. 4	North Truro Air Force station
Altitude of screened interval, in feet below sea level	22-36	28-50	34-54	35-55
Number of wells	3	7	1	1
Diameter of smallest circle enclosing all wells, in feet	1,200	600	--	--
Maximum rated capacity (Mgal/d)	0.86	1.2	1.0	0.55
Node in TRURO model (row, column, layer)	8, 21, 6	10, 14, 6 11, 14, 6	10, 19, 6*	14, 11, 6

*For simulations D-1, D-2, and D-3, Test Site No. 4 node was (10, 19, 7).

Table 2.--Monthly pumpage, in millions of gallons, by pumping station: Provincetown Water Department, 1975-79

(Source of data: Provincetown Water Department.)

	1975* Knowles Crossing	1975* South Hollow	1976* Knowles Crossing	1976* South Hollow	1977* Knowles Crossing	1977* South Hollow
January	5.96	11.94	9.51	11.05	21.33	3.71
February	7.54	9.89	8.82	12.44	15.53	8.06
March	11.87	7.66	7.70	11.19	7.50	13.38
April	10.24	9.82	8.02	9.50	10.80	12.18
May	13.30	14.58	7.90	17.53	17.54	14.95
June	10.71	21.49	15.98	19.99	18.92	17.66
July	21.93	26.00	21.61	26.02	23.69	27.56
August	23.55	24.00	21.02	26.63	23.24	27.24
September	9.70	18.60	16.21	17.57	9.32	24.41
October	14.00	10.78	21.10	8.11	9.38	15.33
November	8.46	9.99	22.34	1.24	7.96	12.80
December	7.43	9.34	23.45	2.49	16.28	5.12
TOTAL	144.69	174.09	183.66	163.76	181.49	182.40

	1978 Knowles Crossing	1978 South Hollow	1978 Test Site No. 4	1978 North Truro Air Force Station	1979** Knowles Crossing	1979** Test Site No. 4	1979** North Truro Air Force Station
January	22.13	--	--	--	18.93	--	--
February	18.64	0.99	--	--	20.95	--	--
March	9.74	9.85	--	--	23.43	--	13.38
April	14.88	7.88	--	--	16.92	--	4.15
May	18.33	10.16	--	--	14.41	8.52	5.21
June	20.73	11.45	--	0.42	5.94	18.69	9.05
July	16.69	3.34	15.81	14.00	14.48	21.41	9.44
August	16.84	--	22.97	8.05	12.84	20.96	10.37
September	6.80	--	17.03	5.80	4.67	15.16	9.45
October	6.32	--	14.46	2.45	2.51	9.77	8.43
November	12.22	--	2.48	6.02	1.83	9.35	4.92
December	15.30	--	--	3.94	--	--	--
TOTAL	178.62	43.67	72.75	40.68	156.01	103.86	61.02

*The Test Site No. 4 and North Truro Air Force Stations wells did not supply water to Provincetown during 1975, 1976, and 1977.

**The South Hollow Station did not supply water to Provincetown during 1979.

Aquifer Boundaries

The fresh-ground-water flow system in the Truro aquifer is bounded laterally by surface-water bodies and vertically by the water table and the interface (transition zone) between fresh and saline ground water. The lateral boundaries are the ocean to the east and west (fig. 3) and wetlands, streams, and ponds at or near sea level to the north and south. These boundaries separate the ground-water flow system in Truro from adjacent flow systems in Provincetown and Wellfleet (Guswa and LeBlanc, 1981). Under present hydrologic conditions, ground water does not flow between these nearly independent aquifers.

The top boundary of the Truro ground-water flow system is the water table (fig. 3). The average maximum altitude of the water table above sea level is 6.5 feet. At most locations in Truro, the water table is more than 5 feet below land surface. However, some kettle holes intersect the water table and contain ponds or wetlands that are expressions of the water table. The Route 6 wetland, 1,500 feet north of Test Site No. 4 (fig. 3), includes 12 acres and seems to be an expression of the water table. Water levels in wells and in an adjacent pond or wetland generally are the same unless the pond or wetland is perched above the water table on low-permeability sediments.

The lower boundary of the freshwater flow system in Truro is the boundary between fresh and saline ground water (fig. 3). The interface between freshwater and saltwater in the aquifer is not a sharp boundary, but rather is a zone of mixing called the transition zone. Data collected at four sites in Truro where test wells penetrate the transition zone (J. H. Guswa, written commun., 1981) show that the transition zone at those locations is less than 50 feet thick. The digital model used in this study treats the transition zone as a sharp interface (Guswa and LeBlanc, 1981).

Ground-Water Flow System

Water in the Truro aquifer is constantly flowing from areas of recharge to areas of discharge. Recharge to the aquifer is by precipitation. Although the recharge rate has not been measured directly, an average recharge rate of 18 inches per year was estimated by an empirical technique (Thornthwaite and Mather, 1957) that relates recharge to climatologic data (Guswa and LeBlanc, 1981).

Water discharges to streams, wetlands, and the ocean at the lateral boundaries of the aquifer at an estimated average rate of 7 Mgal/d (Guswa and LeBlanc, 1981). This discharge estimate does not include discharge to the northern and southern boundaries of the Truro aquifer from adjacent flow systems in Provincetown and Wellfleet. Some of this discharge occurs as springs where land surface intersects the water table. Springs are common where headlands, such as Pilgrim Heights, drop steeply to the edges of coastal wetlands. Pilgrim Spring, a historic spring in the Cape Cod National Seashore (fig. 2), is a well-known example. Water is also withdrawn from the Truro aquifer by wells. Most of the water pumped from low-yield private wells in Truro is returned to the aquifer through onsite wastewater-disposal systems. Average ground-water withdrawal (1979) for export to Provincetown is 0.9 Mgal/d.

The rate of recharge from precipitation fluctuates seasonally and over longer periods and causes water levels in the Truro aquifer to fluctuate. The water table at the U.S. Geological Survey observation well TSW-89 (fig. 2) fluctuates about 1.2 feet each year in response to the seasonal changes in recharge (Maevsky, 1976). The maximum range of water levels measured in TSW-89 during the last 17 years (1963-79) is 2.6 feet. The freshwater-saltwater interface responds much more slowly than water levels to fluctuations in recharge. Movement of the interface in response to recharge variations has not been observed (1980) in Truro or elsewhere on Cape Cod.

Although recharge and discharge vary seasonally and over longer periods, the flow system in the Truro aquifer is in a state of dynamic equilibrium. Average recharge by precipitation is in balance with discharge to streams, ponds, wetlands, and wells, and no long-term trend of rising or declining water levels has been observed.

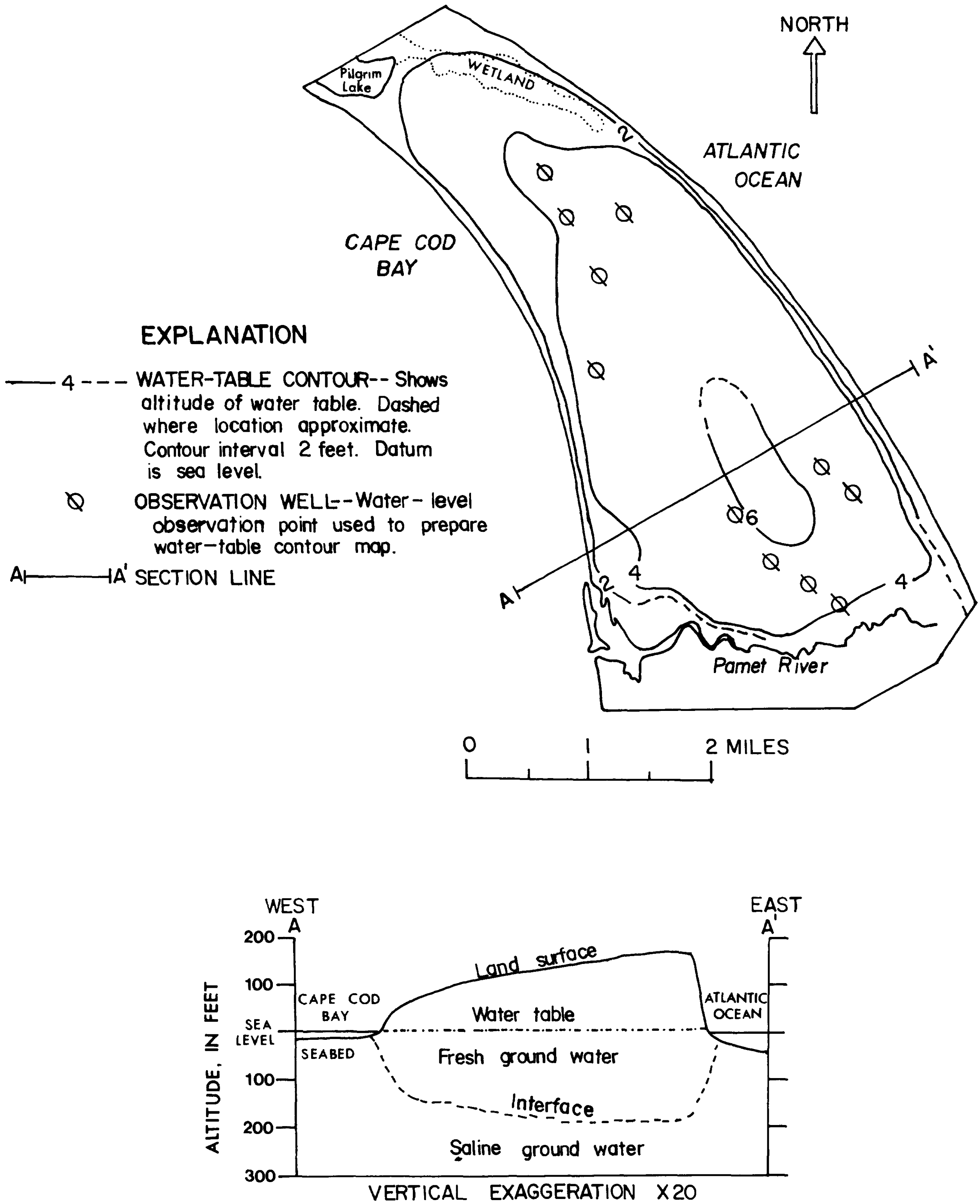


Figure 3.--Observed average water table for the period of 1963 to 1976 and idealized aquifer cross section (from Guswa and LeBlanc, 1981)

A significant sustained change in the average rate of recharge by precipitation or in the rate of withdrawal from wells can alter this dynamic balance. As a result, the positions of the water table and the freshwater-saltwater interface, and the rate of discharge to the lateral boundaries of the aquifer also will change. Wetland and pond water levels and the discharge rates of springs will be affected by the water-level fluctuations. However, ponds, wetlands, and springs that are perched above the main ground-water body will not be directly affected by fluctuations of the water table.

DIGITAL MODEL

The potential hydrologic impacts of 21 pumping schemes in Truro were evaluated with a digital model of ground-water flow. The model, referred to as the TRURO model in this report, was prepared as part of an earlier study of ground-water resources on Cape Cod (Guswa and LeBlanc, 1981). The TRURO model simulates flow in the aquifer bounded by the Pamet River, the ocean, Pilgrim Lake, and Cape Cod Bay (fig. 3). The original computer code and the input data, except for well locations and withdrawal rates, were not modified during this study. Therefore, this report contains only a brief description of the TRURO model. A detailed description of the hydrology of Cape Cod, the computer code, the preparation of the model input data, model boundary conditions, and calibration is included in Guswa and LeBlanc (1981).

The TRURO model is a three-dimensional finite-difference digital model. The computer code presented by Trescott (1975) was modified by Guswa and LeBlanc (1981) to simulate the transition zone between fresh and saline ground water as a sharp interface. The modification also assumes no flow in the saltwater zone of the aquifer. Use of the modified Trescott code is restricted to steady-state simulations.

Calibration

The TRURO model was calibrated against average observed water levels in 13 observation wells and observations of head with depth and position of the transition zone at three sites (Guswa and LeBlanc, 1981). Based on analysis of long-term water-level records from 13 observation wells on Cape Cod, the observed water levels represent approximate equilibrium conditions in the Truro aquifer. Calculated water levels were matched within 0.3 foot of the observed water levels at 7 of the 13 sites. Eleven of the 13 sites matched within 0.6 foot. At two of three sites, the calculated position of the freshwater-saltwater interface was within 30 feet of the observed approximate position of the zone of transition.

During the model calibration, the input data, such as hydraulic conductivity, were adjusted to obtain a match between calculated and observed water levels and depth to the interface (Guswa and LeBlanc, 1981). The initial estimates of hydraulic conductivity generally were changed by 10 percent during calibration. The final hydraulic conductivity values used in the model generally range from 90 feet per day in the deeper parts of the aquifer to 470 feet per day in the shallower parts. The initial estimate of the recharge rate, 18 inches per year, was not changed during calibration.

The ability of the calibrated TRURO model to simulate the aquifer response to other sets of hydrologic stresses (changes in recharge or pumping rates, for example) has not been tested because necessary historical data are not available. The accuracy of the predicted changes in the ground-water flow system that would result from implementing the 21 pumping schemes cannot be determined. However, the general error associated with the simulated changes is probably small.

Finite-Difference Representation of Aquifer

In the TRURO model, the continuous aquifer is approximated by an array of discrete blocks arranged in 20 rows, 26 columns, and 7 layers. Each block is 1,320 feet long by 1,320 feet wide (fig. 4). The seven layers increase in thickness from layer 7, the top layer, to layer 1, the bottom layer (fig. 5). Each block in the finite-difference grid is represented in the numerical simulation by a node, or point, at the center of the block. Each block, with its node, is identified by its row, column, and layer numbers. For example, node (12, 11, 5) is located in row 12, column 11 (fig. 4), and layer 5 (fig. 5).

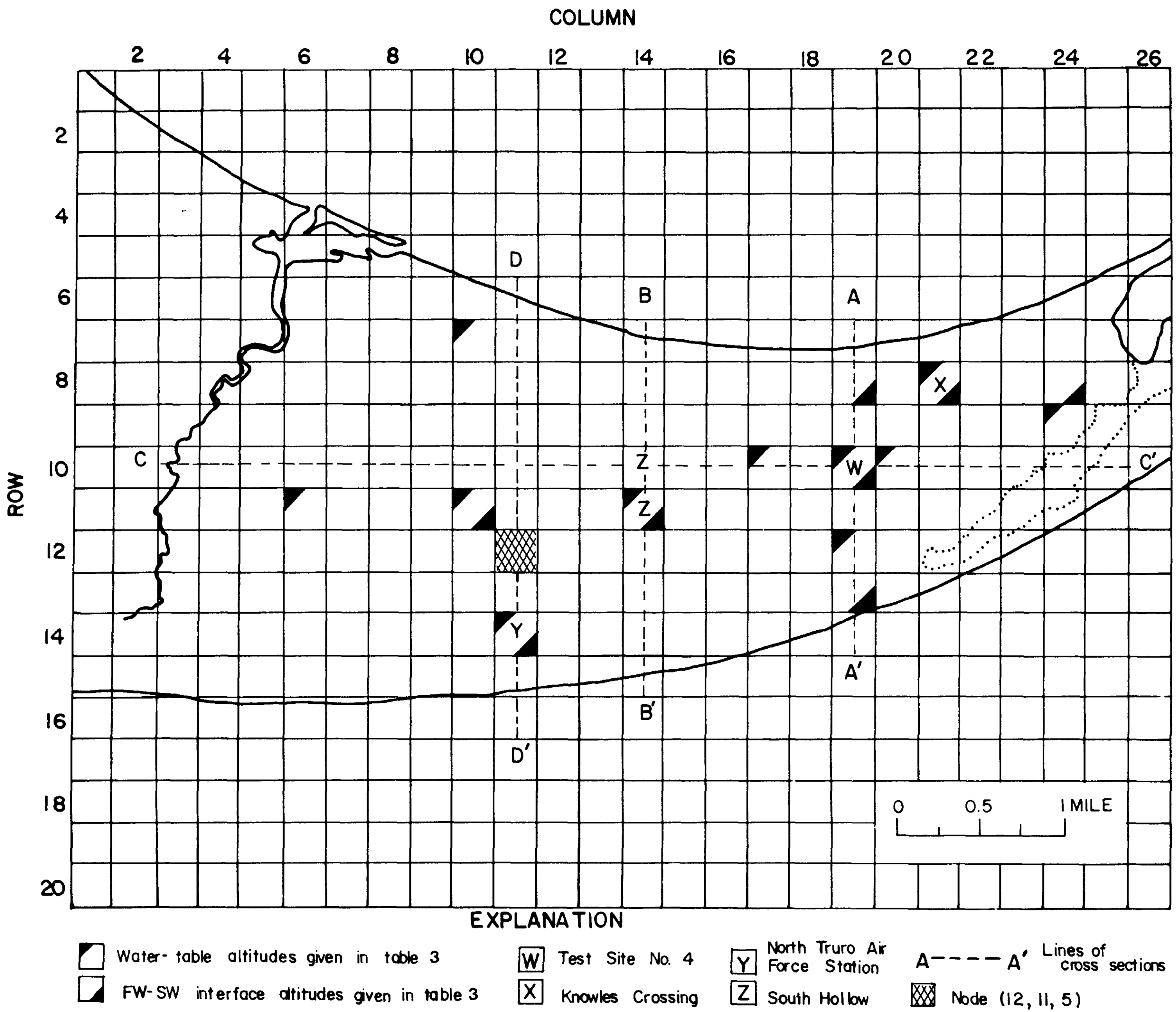


Figure 4.--TRURO model finite-difference grid

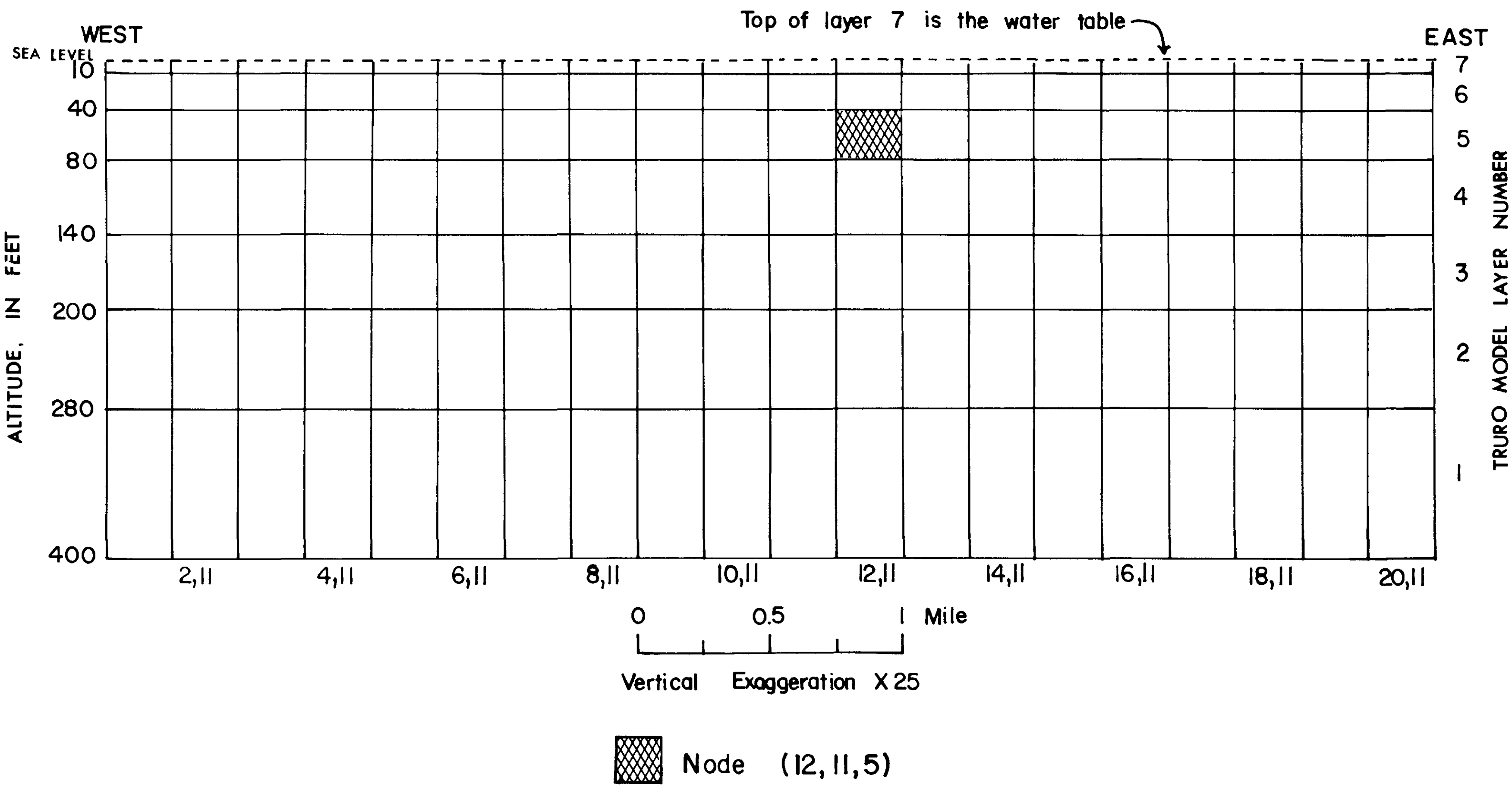


Figure 5.-- Cross section of TRURO model finite-difference grid along column 11 of figure 4

The values for water level, horizontal permeability, vertical permeability, and recharge from precipitation that are assigned to each node at the beginning of a simulation are generally average values that are assumed to be uniform throughout the block containing the node. All withdrawals by wells within a block are assigned to the node at the center of the block, even though the wells may not be located at the center of the block. The total pumpage from the node is assumed to be withdrawn uniformly throughout the block containing the wells. The calculated positions of the water table and the freshwater-saltwater interface obtained from the simulation of a set of hydrologic stresses generally represent average values for each block. Cross sections through the aquifer constructed from the TRURO model simulations show a calculated stepwise approximation of the water-table and freshwater-saltwater interface positions that would result from implementing the simulated pumping schemes (fig. 8).

Because water levels, pumping rates, aquifer properties, and freshwater-saltwater interface position are averaged within a block, the model should not be used to study hydrologic conditions at specific locations within a block. For example, the actual water-level drawdown and upward movement of the interface at a pumping well will be larger than the calculated values for the vertical column of blocks at the well site.

Flow-System Assumptions

The TRURO model is a steady-flow model. The water levels, discharge rates, and positions of the freshwater-saltwater interface calculated by the TRURO model represent the flow system in which recharge and discharge are balanced. The ground-water flow system does not establish a new equilibrium instantly in response to a change in withdrawals, although water levels in the aquifer adjust quickly to new stresses when compared to movement of the freshwater-saltwater interface. Conditions that are not sustained long enough to achieve steady flow cannot be simulated with the TRURO model. Examples of such conditions may include seasonal fluctuations in recharge and withdrawal from wells, and short (1- or 2-year) periods of below and above average precipitation. Therefore, the simulations discussed in this report assume that, for each scheme tested, pumping rates and recharge from precipitation are constant and continuous, and steady-flow conditions exist. The time required to reach equilibrium in response to a new stress is not calculated by the TRURO model.

Due to restrictions in the modified computer code, the TRURO model was not designed to simulate a flow system in which a pumping well is withdrawing water from the saline ground-water zone, a condition referred to as unstable upconing of the interface. The model also was not designed to simulate a flow system in which a node in the top, water-table, layer of the model is dewatered. In these cases, the model calculations terminate before a numerical solution is reached. Several of the simulated pumping schemes resulted in the above conditions (table 3). For these simulations, water-level changes, ground-water discharge, and interface position were not calculated. Under actual conditions, unstable upconing probably would result in termination of pumping owing to increased salinity of the water pumped.

Ground-Water Discharge and Leakage Nodes

Discharge of ground water to streams, wetlands, and the ocean is simulated by leakage out of nodes along the lateral boundaries of the aquifer (fig. 6). The leakage nodes are grouped into zones A through F to facilitate discussion of discharge from various areas.

The discharge boundaries in areas A, B, and F (the Head of the Meadow wetlands, Pilgrim Lake, and associated wetlands, and the Pamet River) also are no-flow boundaries between the modeled area and adjacent freshwater-flow systems in Wellfleet and Provincetown. The simulated discharge of ground water to these boundaries represents only discharge from the Truro aquifer. Discharge to these boundaries from adjacent areas and the net effect on the total discharge to these streams and wetlands due to withdrawals in Truro are not calculated in the Truro model. Within the areas shown in figure 6, stream-wetland leakage nodes are not differentiated from ocean leakage nodes. The hydrology of the streams and wetlands along the coast is poorly understood. There are little data that describe the hydrologic characteristics of the wetlands and the relationship between adjacent freshwater lenses and the wetlands. The coarse grid spacing used in the TRURO model required that the location of wetland areas and water levels in the wetlands be roughly approximated. Therefore, only total discharge from the Truro aquifer to each of the six areas in figure 6 is discussed.

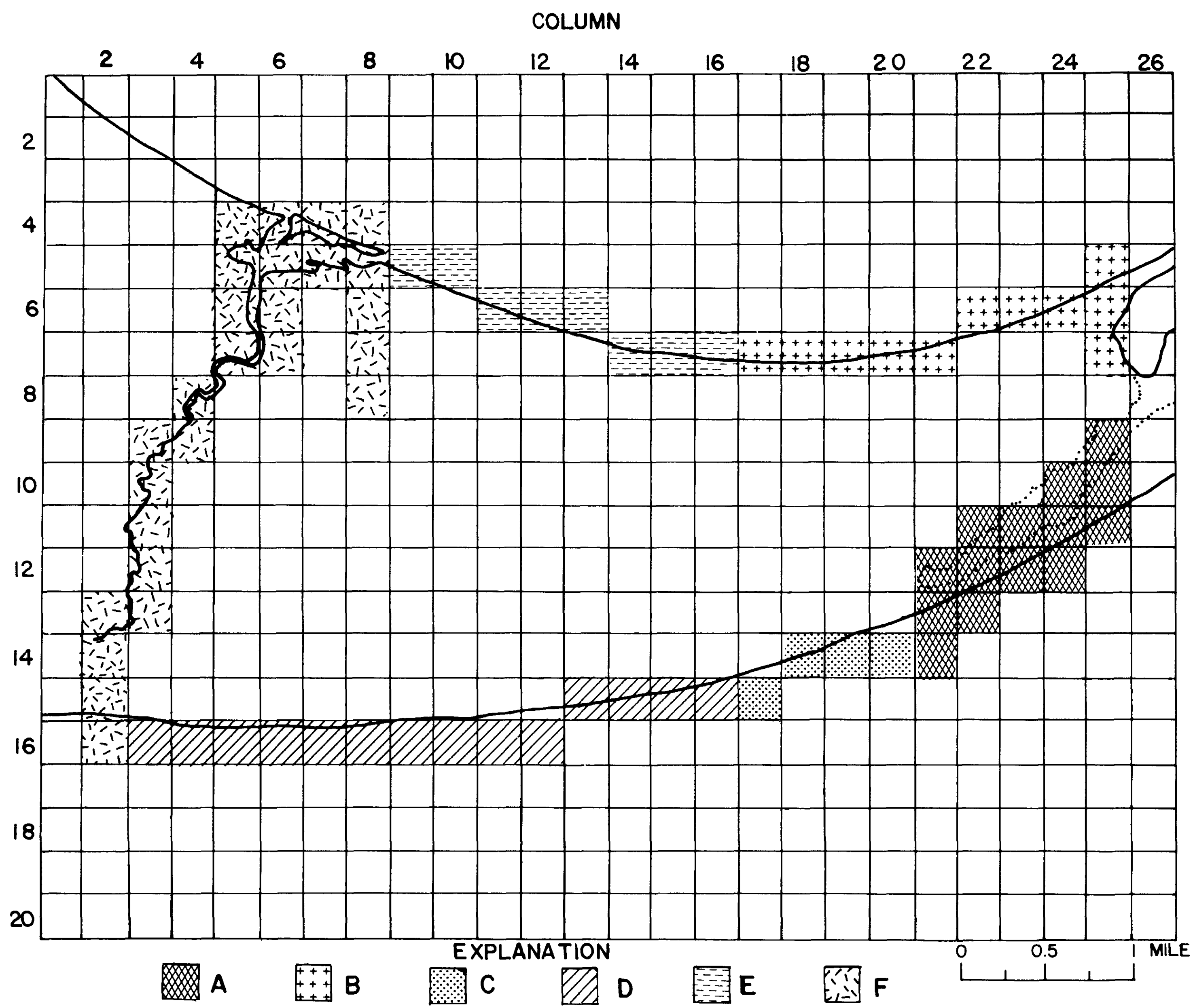


Figure 6.--Ground-water leakage nodes in the TRURO model, grouped into areas A to F

APPLICATION OF MODEL--RESULTS AND DISCUSSION

Model Simulations and Pumping Schemes

The TRURO model was used to evaluate the potential hydrologic impacts of 21 different pumping schemes. These simulations are summarized in table 3 (in sleeve at back of report). The simulations are divided into six sets. A brief description of each set follows.

Set A--All pumpage from the South Hollow and Knowles Crossing well fields: These well fields would probably have continued to supply all of Provincetown's water during 1978 and 1979 if South Hollow had not been closed in 1978. In Simulation A-1, about half the average daily 1979 pumpage (0.88 Mgal/d) is withdrawn from each of these two well fields.

Set B: No pumpage from the TRURO model area: Simulation B-1 represents assumed conditions before ground-water withdrawal in Truro to supply Provincetown began. Recharge from precipitation is balanced by natural discharge to the lateral boundaries of the aquifer.

Set C: All pumpage from Test Site No. 4, layer 6: Only pumpage from Test Site No. 4 is simulated in this set. Withdrawal is from the node in layer 6 (10 to 40 feet below sea level) at row 10 and column 19 of the TRURO model. Simulations C-1 to C-5 use five different pumping rates from Test Site No. 4.

Set D: All pumpage from Test Site No. 4, layer 7: Only pumpage from Test Site No. 4 is simulated in this set, as in set C. However, the withdrawals at three different rates in simulations D-1 to D-3 are from layer 7 (water table to 10 feet below sea level), the top layer of the TRURO model.

Set E: Pumpage from the Test Site No. 4, Knowles Crossing, and Air Force wells at 1979 average year-round rate: During 1979, the average year-round pumping rate from the modeled area was 0.88 Mgal/d. Four different schemes for withdrawing a total of 0.88 Mgal/d from the Test Site No. 4, Knowles Crossing, and Air Force wells are simulated in Set E (E-1 to E-4). The pumping scheme actually used in 1979 is represented by simulation E-1.

Set F: Pumping from the Test Site No. 4, Knowles Crossing, and Air Force wells at 1979 average summer rate: During July and August 1979, the average pumping rate from the modeled area was 1.44 Mgal/d. Seven different schemes for withdrawing a total of 1.44 Mgal/d from the Test Site No. 4, Knowles Crossing, and Air Force wells are simulated in Set F (F-1 to F-7). The pumping scheme actually used during July and August 1979 is represented by simulation F-1.

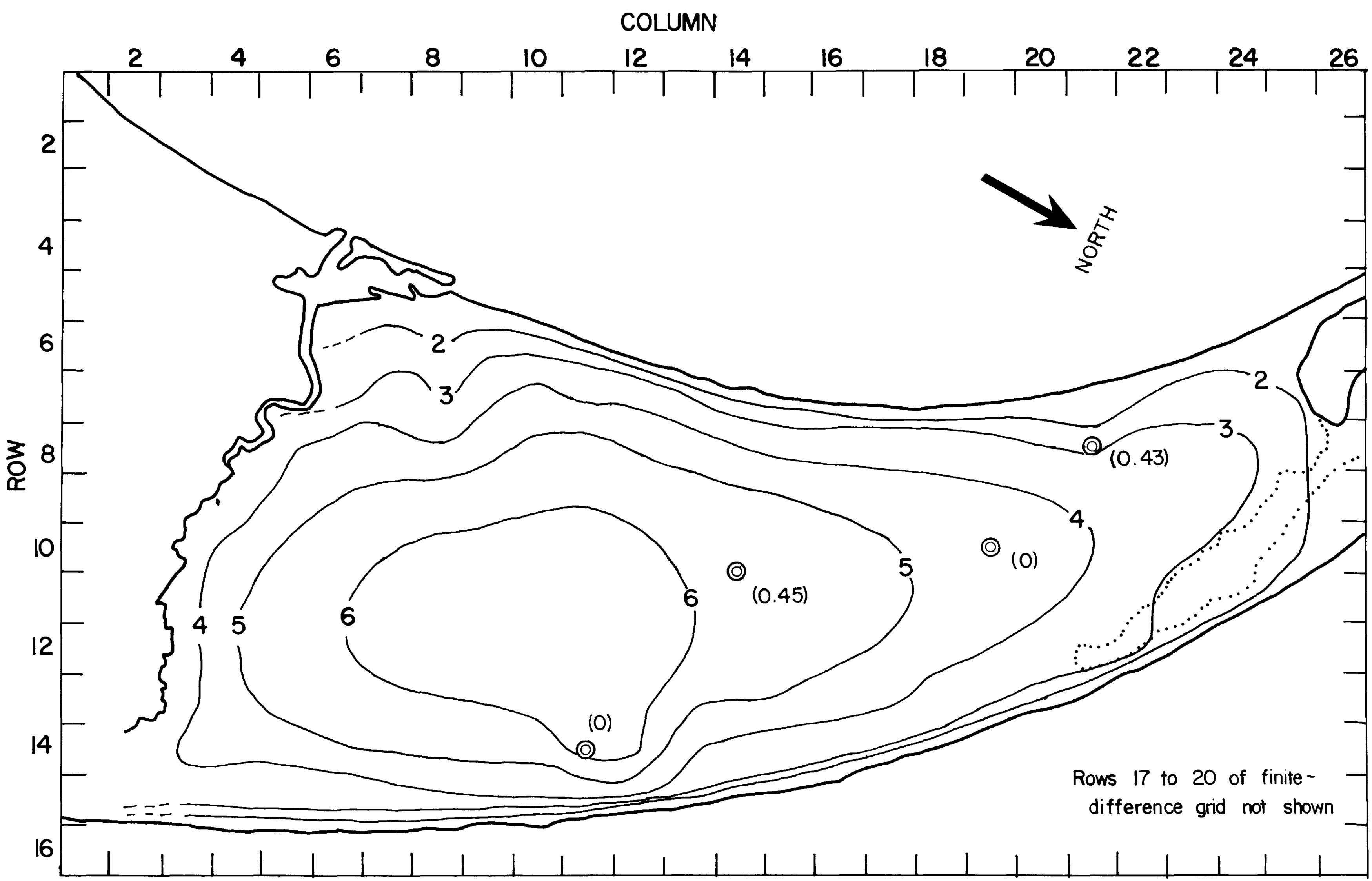
Set A--Pumping from Knowles Crossing and South Hollow Wells at 1979 Average Rate

The withdrawal scheme in Simulation A-1 represents conditions before the South Hollow well field was closed. Therefore, the simulated flow system approximates steady-flow conditions that would have prevailed if Knowles Crossing and South Hollow wells continued to supply all of Provincetown's water. Simulated flow systems resulting from other withdrawal schemes can be compared to the results of this "status quo" condition.

The water-table map for Simulation A-1, obtained by contouring the water levels for each node in layer 7, is shown in figure 7. Water-table altitudes at selected nodes are given in table 3.

Steady-state recharge from precipitation for the modeled area in Simulation A-1 is 7.97 Mgal/d. Discharge to the aquifer's lateral boundaries is 7.09 Mgal/d, and a total of 0.88 Mgal/d is pumped from the Knowles Crossing and South Hollow well fields and transported out of the modeled area. Ground-water discharge to the six areas shown in figure 6 is given in table 3. Approximately 0.6 Mgal/d is discharged to the Meadows area and adjacent ocean (Area A in fig. 6).

Cross sections through the fresh ground-water body show the position of the freshwater-saltwater interface calculated in Simulation A-1 (figs. 8, 9, and 10). The greatest thickness of fresh ground water is about 200 feet. The position of the freshwater-saltwater interface along the lateral boundaries of the aquifer cannot be determined precisely from the TRURO model because of the coarseness of the grid spacing. However, it is evident from the cross sections that the interface slopes steeply downward and landward at the shoreline. Test-well observations in Truro and elsewhere on Cape Cod confirm this conclusion.



EXPLANATION

—— 6 —— WATER-TABLE CONTOUR--Shows altitude of water table. Dashed where approximately located. Contour interval 1 foot. Datum is sea level.

◎ (0.43) WELL OR WELL FIELD--Number in brackets is A-1 pumping rate in Mgal/d

0 0.5 1 MILE

Figure 7.--Calculated water table, Simulation A-1

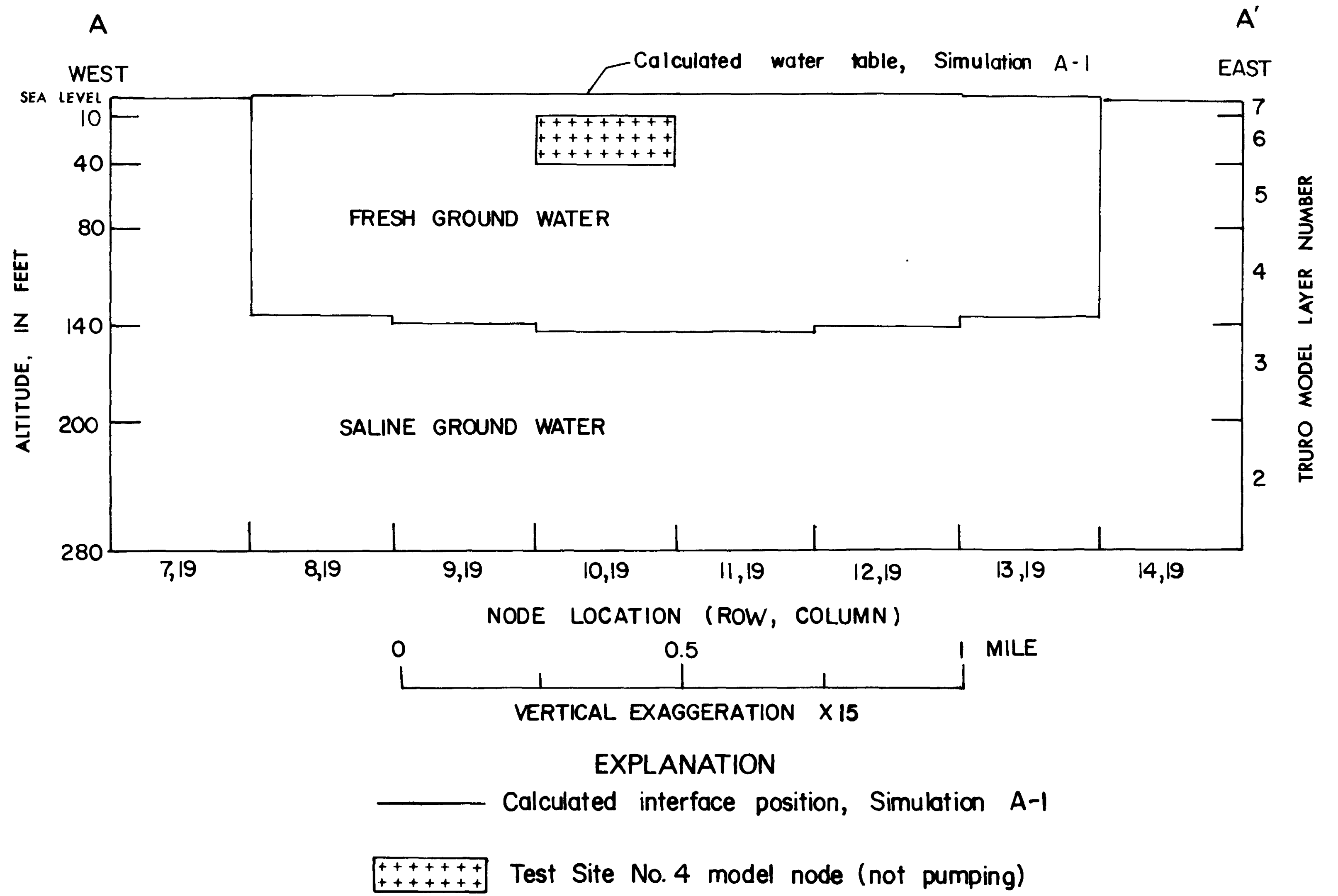


Figure 8.--Calculated freshwater-saltwater interface position, Simulation A-1, for cross section A-A' of figure 4

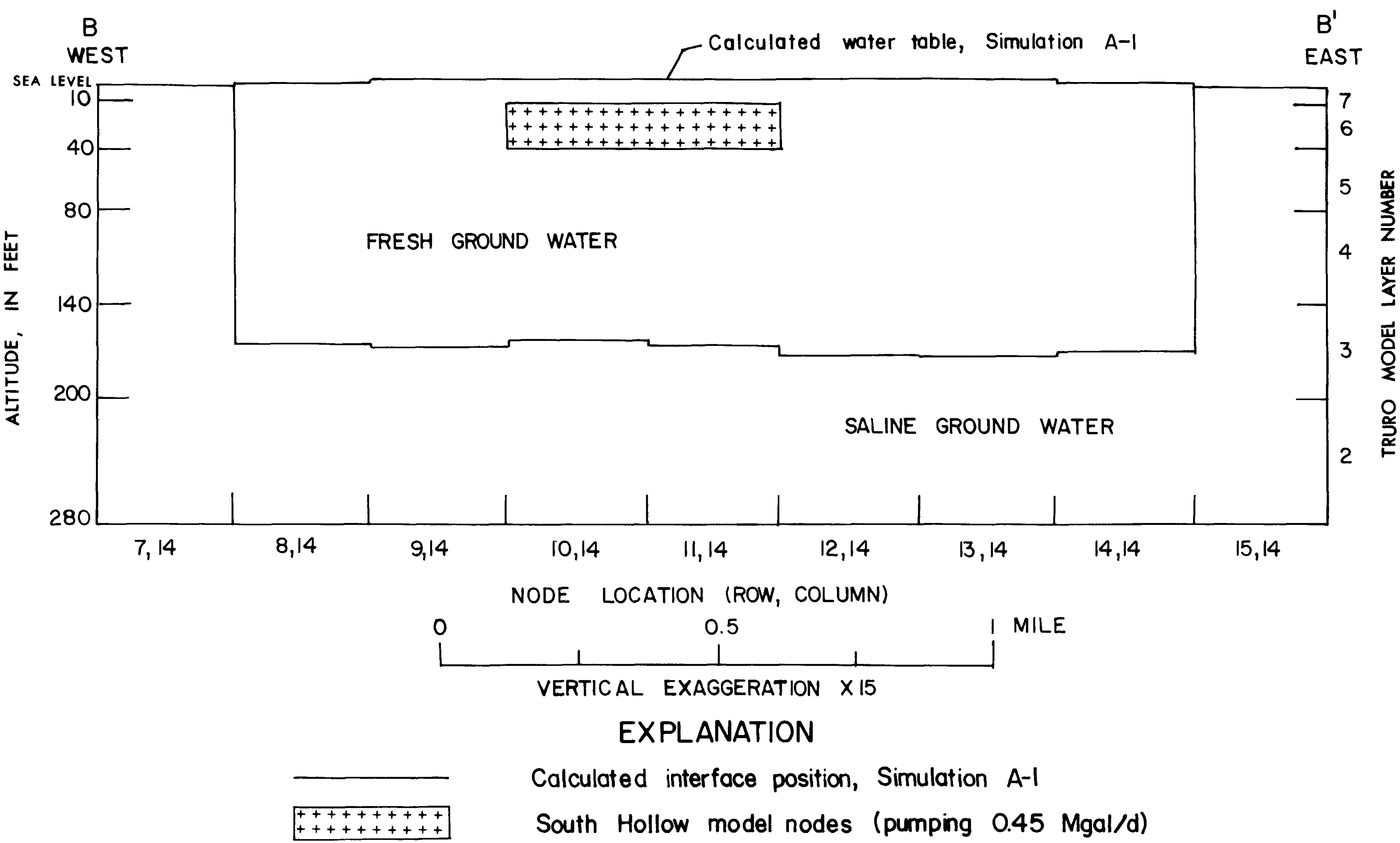


Figure 9.--Calculated freshwater-saltwater interface position, Simulation A-1, for cross section B-B' of figure 4

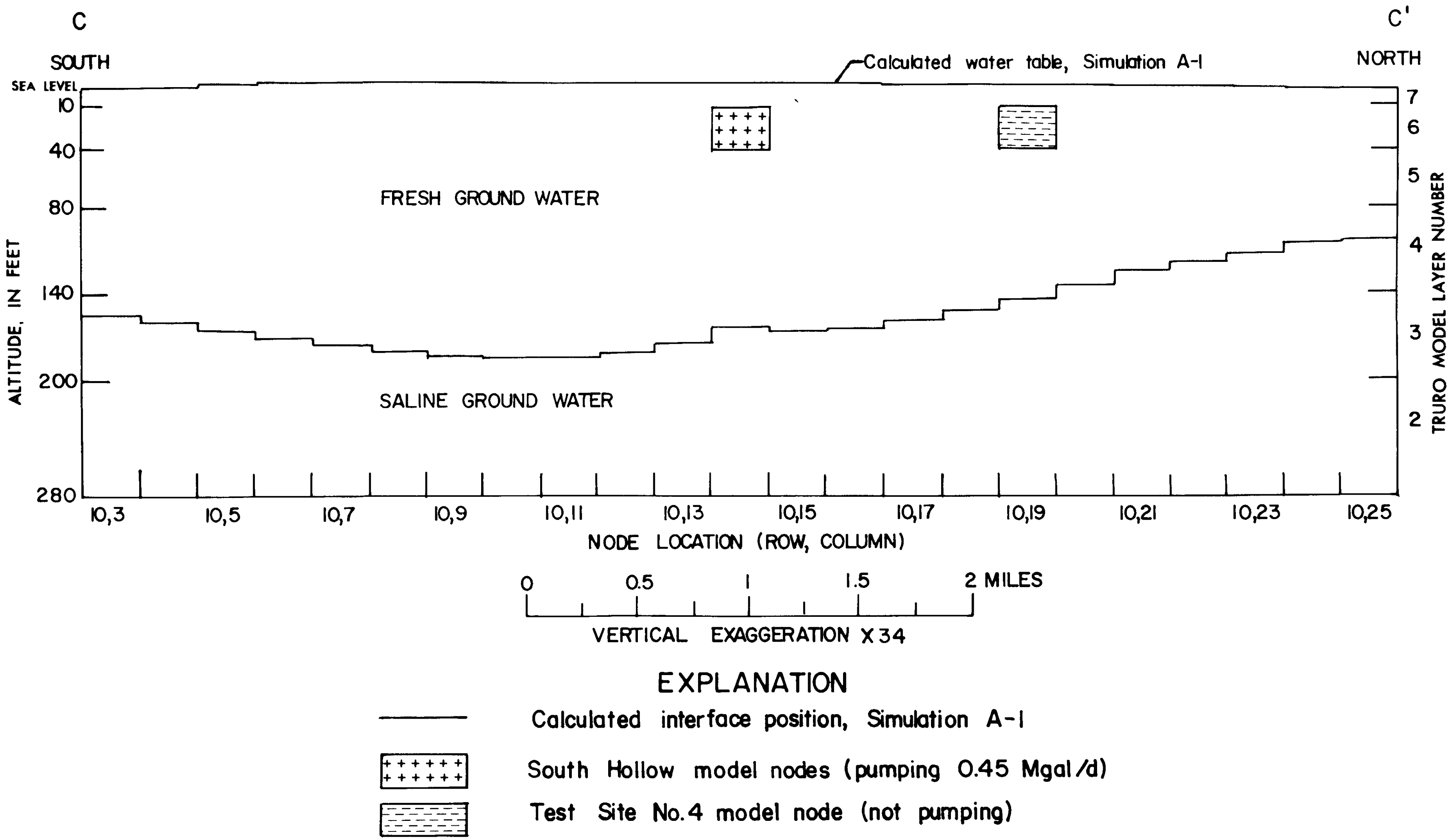


Figure 10.--Calculated freshwater-saltwater interface position, Simulation A-1, for cross section C-C' of figure 4

Set B--No Pumping

In Simulation B-1, recharge from precipitation is balanced by natural discharge, a condition that existed before development of the aquifer. No water is withdrawn from wells and exported out of the modeled area. Therefore, the water table is higher (figs. 11 and 12), the freshwater-saltwater interface is deeper (table 3), and discharge to streams, wetlands, and the ocean is greater (table 3) than in Simulation A-1.

The difference between the water-table altitudes calculated in Simulation A-1 and in Simulation B-1 is greatest at and between the Knowles Crossing and South Hollow well fields (fig. 12). Discharge to the lateral boundaries of the aquifer in all six areas (fig. 6) is greater than in Simulation A-1 (table 3) because water is not being pumped and exported from Truro. Discharge to areas A, B, and C increases the most because these areas are adjacent to the part of the aquifer most affected by the withdrawals in Simulation A-1.

Set C--Pumping from Test Site No. 4, 10 to 40 Feet Below Sea Level

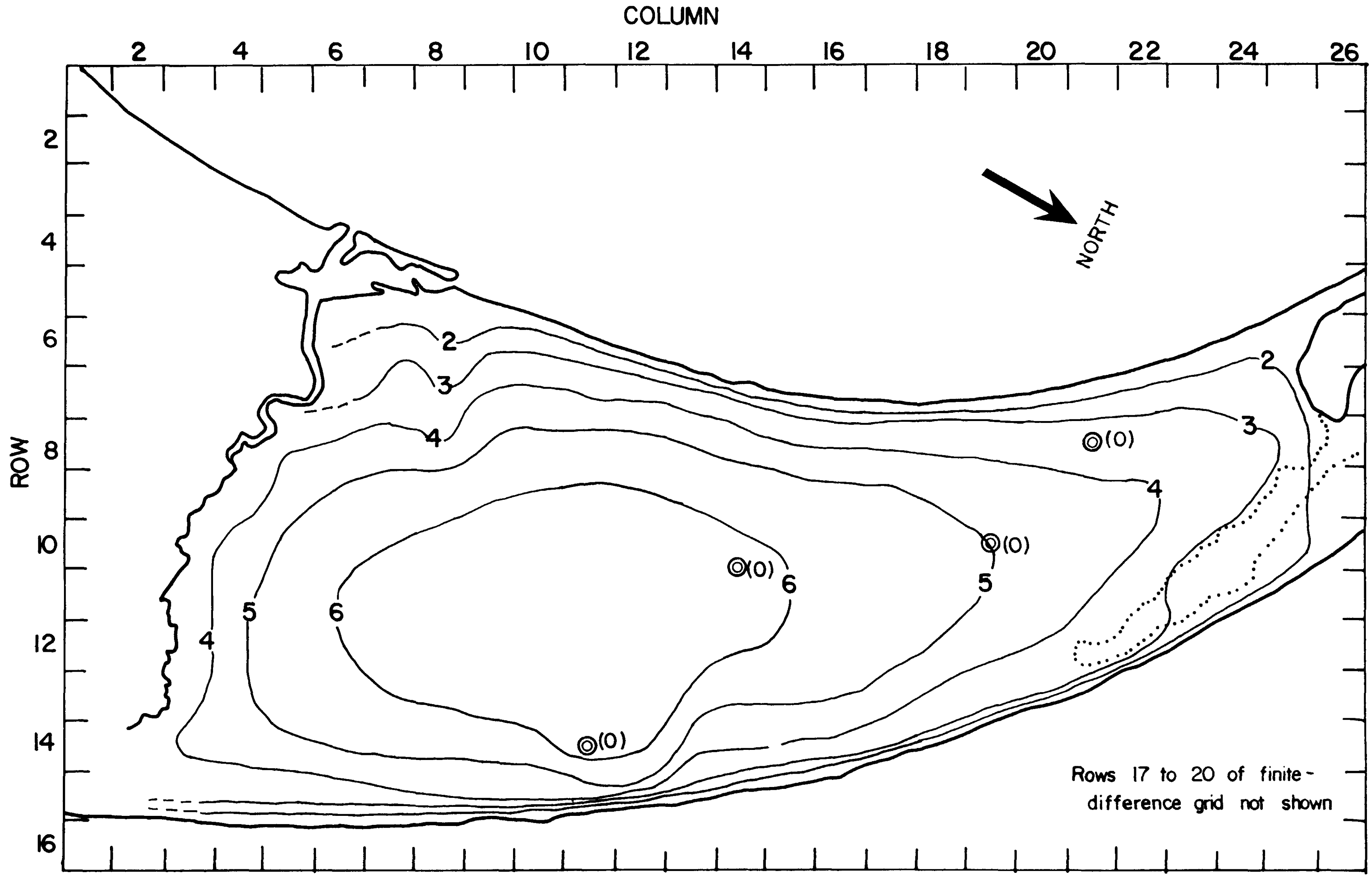
Withdrawal from Test Site No. 4 alone is simulated in Sets C and D, although it is unlikely that this site would be the sole source of Provincetown's water. These simulations were made to examine the response of the flow system to pumping this well without interference from simultaneous withdrawals at other sites. The results of the Set C and D simulations are compared to the predevelopment conditions evaluated in Simulation B-1. In Sets E and F, the hydrologic effects of more realistic withdrawal schemes are simulated.

In Set C, withdrawals from Test Site No. 4 are simulated by pumping from model layer 6 (10 to 40 feet below sea level). Layer 6 in the TRURO model best approximates the screened interval of the emergency supply well in use at Test Site No. 4 during 1978 and 1979.

The effects of pumping 0.75 Mgal/d (C-1), 1.0 Mgal/d (C-2), and 1.08 Mgal/d (C-3) from Test Site No. 4 on the altitude of the water table at 11 selected grid locations are shown in table 3. Pumping lowers water levels below pre-development levels at all 11 locations. Withdrawal from Test Site No. 4 lowers the water table not only at Test Site No. 4, but also at the Knowles Crossing and South Hollow well field sites. The simulated water table at the Knowles Crossing site is lowered approximately 0.4 foot by withdrawal of 1.0 Mgal/d from Test Site No. 4 (fig. 13). Development of Test Site No. 4 as a major water supply for Provincetown would reduce the withdrawal rate that could be sustained from the Knowles Crossing well field without pumping saline water.

Most of the calculated decrease in discharge to the lateral boundaries of the aquifer (table 4) as a result of withdrawal from Test Site 4 and export from the modeled area occurs in areas A, B, and C of figure 6. Because Test Site No. 4 is in the northern and narrow part of Truro, discharge to adjacent coastal areas will decrease more than discharge to the boundaries south of the South Hollow area.

The calculated movement of the freshwater-saltwater interface in response to withdrawals from Test Site No. 4 is greatest at the well and smallest at the shoreline (fig. 14). Simulated withdrawal of more than 1.1 Mgal/d from Test Site No. 4 results in movement of saltwater into the well (Simulations C-4 and C-5, table 3). If 1.08 Mgal/d is withdrawn from Test Site No. 4 (Simulation C-3), the simulated position of the interface at the grid location of the well (row 10, column 19) is 15 feet below the screened interval (10 to 40 feet below sea level). If 1.0 Mgal/d is withdrawn (Simulation C-2), the simulated interface position is 32 feet below the screened interval. However, the upconing shown in figure 14 generally represents the average upconing for the 1,320-foot-square area that contains the well. Upconing directly beneath the well will be greater than the simulated upconing for the block. Therefore, sustained withdrawal from Test Site No. 4 at rates of 1.0 and 1.08 Mgal/d could result in movement of saltwater into the well.



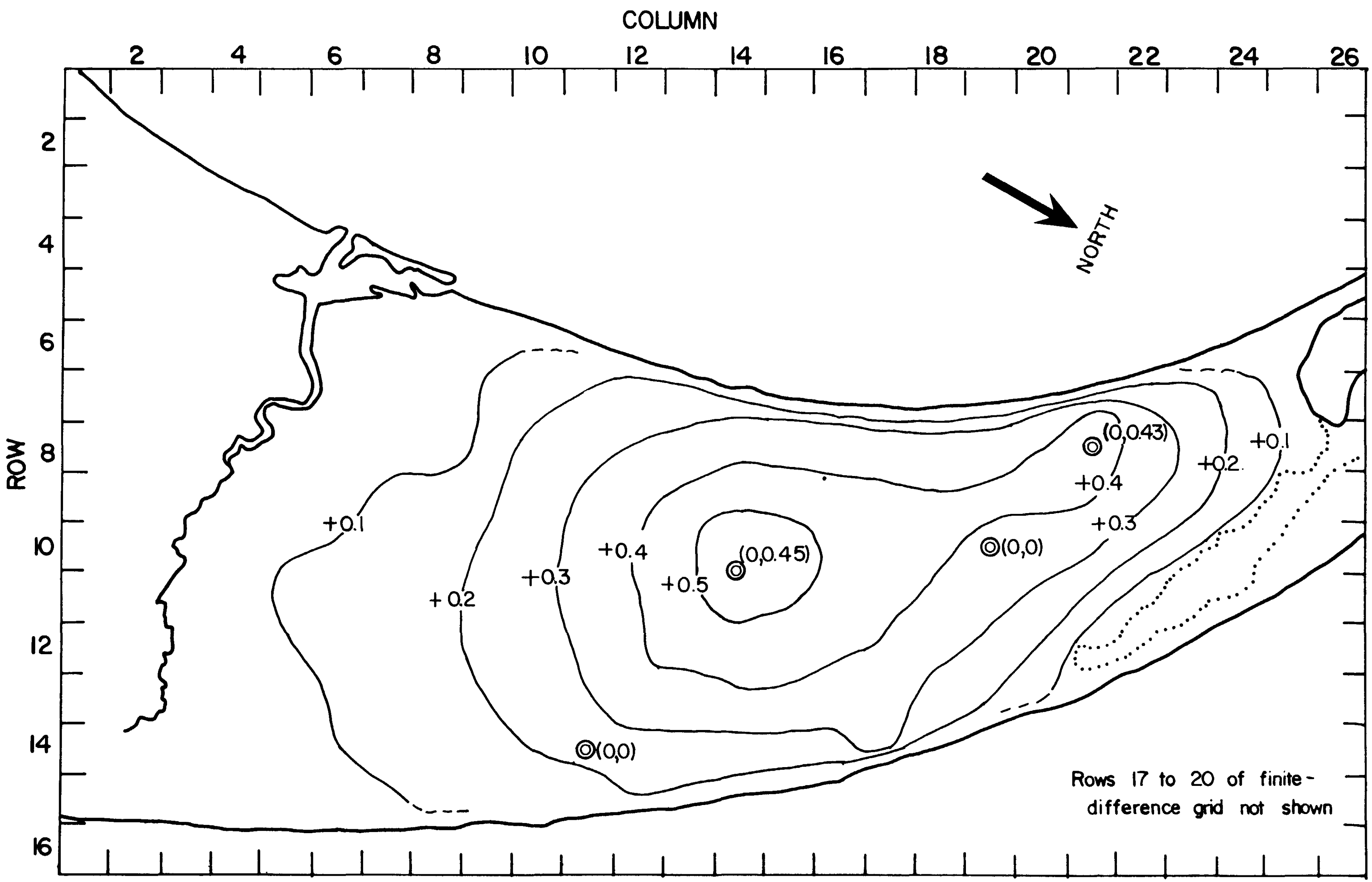
EXPLANATION

—— 6 —— WATER-TABLE CONTOUR--Shows altitude of water table. Dashed where approximately located. Contour interval 1 foot. Datum is sea level.

◎(0) WELL OR WELL FIELD--Number in brackets is B-1 pumping rate in Mgal/d

0 0.5 1 MILE

Figure 11.--Calculated water table, Simulation B-1

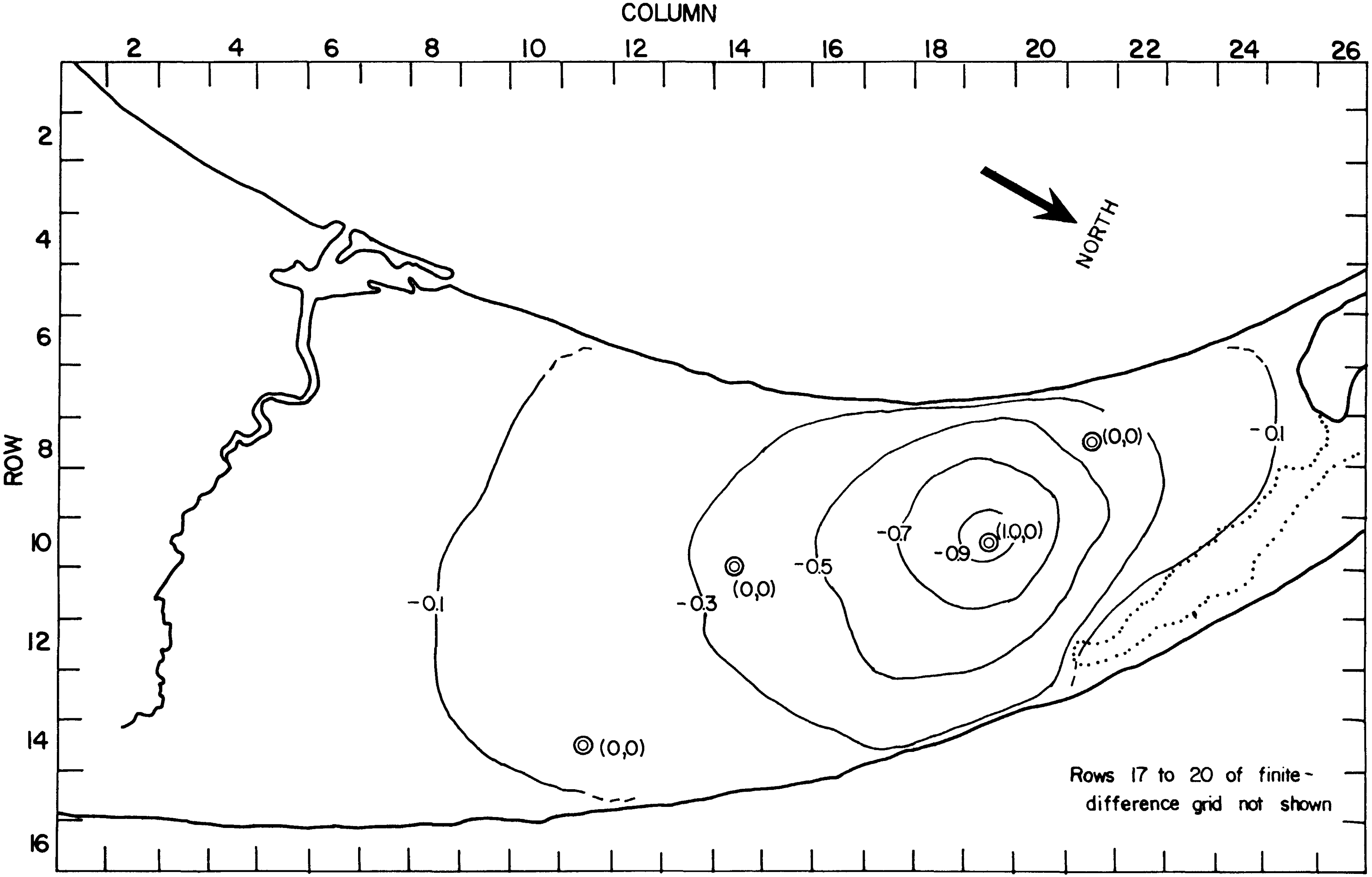


EXPLANATION

—+0.2 — LINE OF EQUAL DIFFERENCE BETWEEN CALCULATED WATER-TABLE ALTITUDES--Plus (+) indicates B-1 water-table altitude higher than A-1 water-table altitude. Interval 0.1 foot.

◎ (0,0.43) WELL OR WELL FIELD--Numbers in brackets are B-1 pumping rates and A-1 pumping rates in Mgal/d.

Figure 12.--Difference between the calculated water tables of Simulation B-1 and Simulation A-1



EXPLANATION

—-0.3— LINE OF EQUAL DIFFERENCE BETWEEN CALCULATED WATER-TABLE ALTITUDES--Minus(-) indicates C-2 water-table altitude lower than B-1 water-table altitude. Interval 0.2 foot.

◎ (0,1.0) WELL OR WELL FIELD--Numbers in brackets are C-2 pumping rates and B-1 pumping rates in Mgal/d.

0 0.5 1 MILE

Figure 13.--Difference between the calculated water tables of Simulation C-2 and Simulation B-1

Table 4.--Comparison between the ground-water discharge rates to areas A-F (shown in fig. 6) calculated in Simulation B-1 and ground-water discharge rates calculated in Simulations C-1, C-2, and C-3

Simu-lation	Ground-water discharge rates calculated in Simulations C-1, C-2, and C-3 minus ground-water discharge rates calculated in Simulation B-1 (difference in million gallons per day)					
	Area					
	A	B	C	D	E	F
C-1	-0.368	-0.109	-0.064	-0.040	-0.045	-0.058
C-2	-.485	-.148	-.084	-.052	-.064	-.078
C-3	-.543	-.168	-.090	-.052	-.071	-.078

Simu-lation	Change in ground-water discharge rates from the rates calculated in Simulation B-1 to the rates calculated in Simulations C-1, C-2, and C3 (percent change)					
	Area					
	A	B	C	D	E	F
C-1	-39	-9	-10	-2	-4	-3
C-2	-52	-13	-13	-2	-5	-4
C-3	-58	-15	-14	-2	-6	-4

Simulation B-1: No wells pumping.
Simulation C-1: Pumping 0.75 Mgal/d from Test Site No. 4.
Simulation C-2: Pumping 1.0 Mgal/d from Test Site No. 4.
Simulation C-3: Pumping 1.08 Mgal/d from Test Site No. 4.

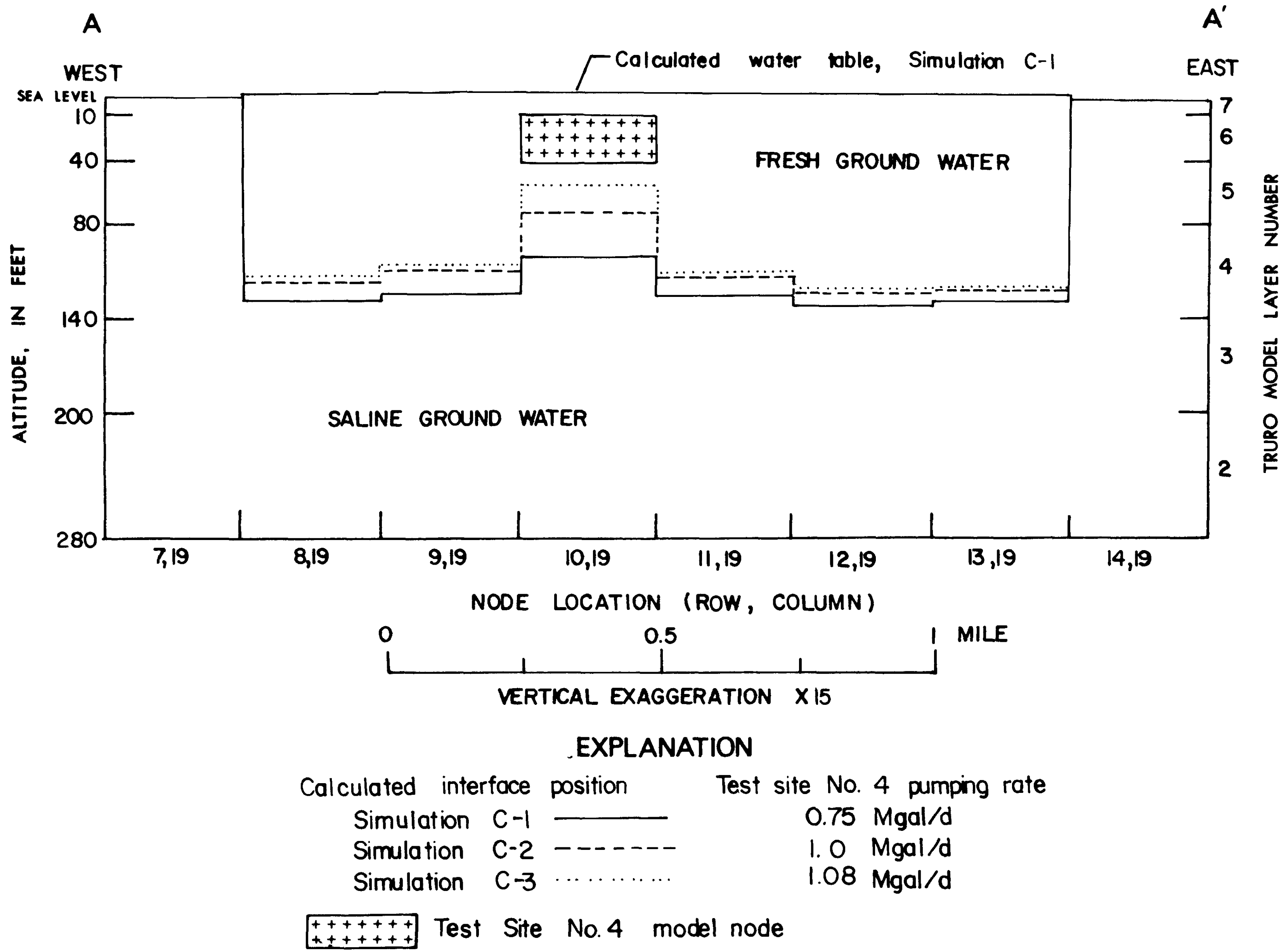


Figure 14.--Calculated freshwater-saltwater interface positions, Simulations C-1, C-2, and C-3, for cross section A-A' of figure 4

Set D--Pumping from Test Site No. 4, Water Table to 10 Feet Below Sea Level

The depth of the screened interval of a well affects the response of the water table and the freshwater-saltwater interface to pumping. In Set D, the response of the flow system to pumping at Test Site No. 4 from layer 7 (water table to 10 feet below sea level) is simulated. This screen setting is shallower than the present depth of the screen of the Test Site No. 4 well (table 1).

The simulated effects on the water table and the freshwater-saltwater interface of pumping from the shallower screen are shown in figures 15 and 16. Upconing of saltwater is less beneath the well screen when pumping from layer 7 (fig. 15) than when pumping from layer 6 (fig. 14). Pumping 1.0 Mgal/d from the shallow screen setting results in greater water-table drawdown (fig. 16) than pumping at the same rate from the deeper screen setting (fig. 13). Simulated withdrawal of 1.08 Mgal/d from layer 7 (Simulation D-3) lowered the water table below the bottom of layer 7, dewatering the block containing the pumping well, and terminating calculations before a steady-state solution could be reached.

Therefore, by withdrawing water from a well screened near the water table rather than deeper in the aquifer, the potential for upconing of saltwater into the well is decreased. However, the lowering of the water table around the well will be much greater, and the possibility that the water level will be drawn down into the well screen is increased.

Set E--Pumping from Test Site No. 4, Knowles Crossing, and Air Force Wells at 1979 Average Year-Round Rate

The average pumping rate from all the wells supplying Provincetown in 1979 was 0.88 Mgal/d (table 2). The TRURO model was used to simulate average pumpage in 1979, and the modeled flow system represents approximate average hydrologic conditions during the year.

In Set E, the average pumping rate during 1979, 0.88 Mgal/d, is simulated by pumping from the Test Site No. 4, Knowles Crossing, and Air Force wells. The four pumping schemes are outlined in table 3. The flow-system characteristics simulated in Set E are compared to the water-table and freshwater-saltwater interface positions and ground-water discharge rates calculated in Simulation A-1. The scheme for pumping 0.88 Mgal/d in Simulation A-1 would probably have been used by Provincetown if the South Hollow well field had been operational in 1979.

The changes in the calculated water-table altitude from Simulation A-1 to Simulations E-1, E-2, and E-3 are shown in figures 17, 18, and 19, respectively. Because the total pumping rate is the same in Simulations A-1, E-1, E-2, and E-3, calculated changes in the water-table altitude due to implementing the schemes that rely on Test Site No. 4 instead of South Hollow are less than 0.4 foot except in the immediate vicinity of the wells. The water table is higher near South Hollow and lower near Test Site No. 4, reflecting the more northerly location of the large withdrawals in Simulations E-1, E-2, and E-3.

Cross sections through the fresh ground-water body (figs. 20 and 21) show the steady-state positions of the freshwater-saltwater interface calculated in Simulations A-1, E-1, and E-3. Changes in the interface position resulting from the simulated changes in the pumping scheme are smallest near the lateral boundaries of the aquifer and greatest beneath the pumping wells. Therefore, movement of the interface most likely will not affect the quality of water pumped from shallow domestic wells near the coast in Truro.

Ground-water discharge to the lateral boundaries of the aquifer (table 5) increases slightly along southern boundaries (areas D, E, and F in fig. 6) and decreases along the northern boundaries (areas A, B, and C) owing to the change from the Simulation A-1 pumping scheme to the Simulations E-1, E-2, E-3, and E-4 pumping schemes. Discharge to area A, which includes the coastal wetlands and ocean between Head of the Meadow Beach and Pilgrim Lake, changes more than discharge to other areas of the coast when pumping from Test Site No. 4 is increased.

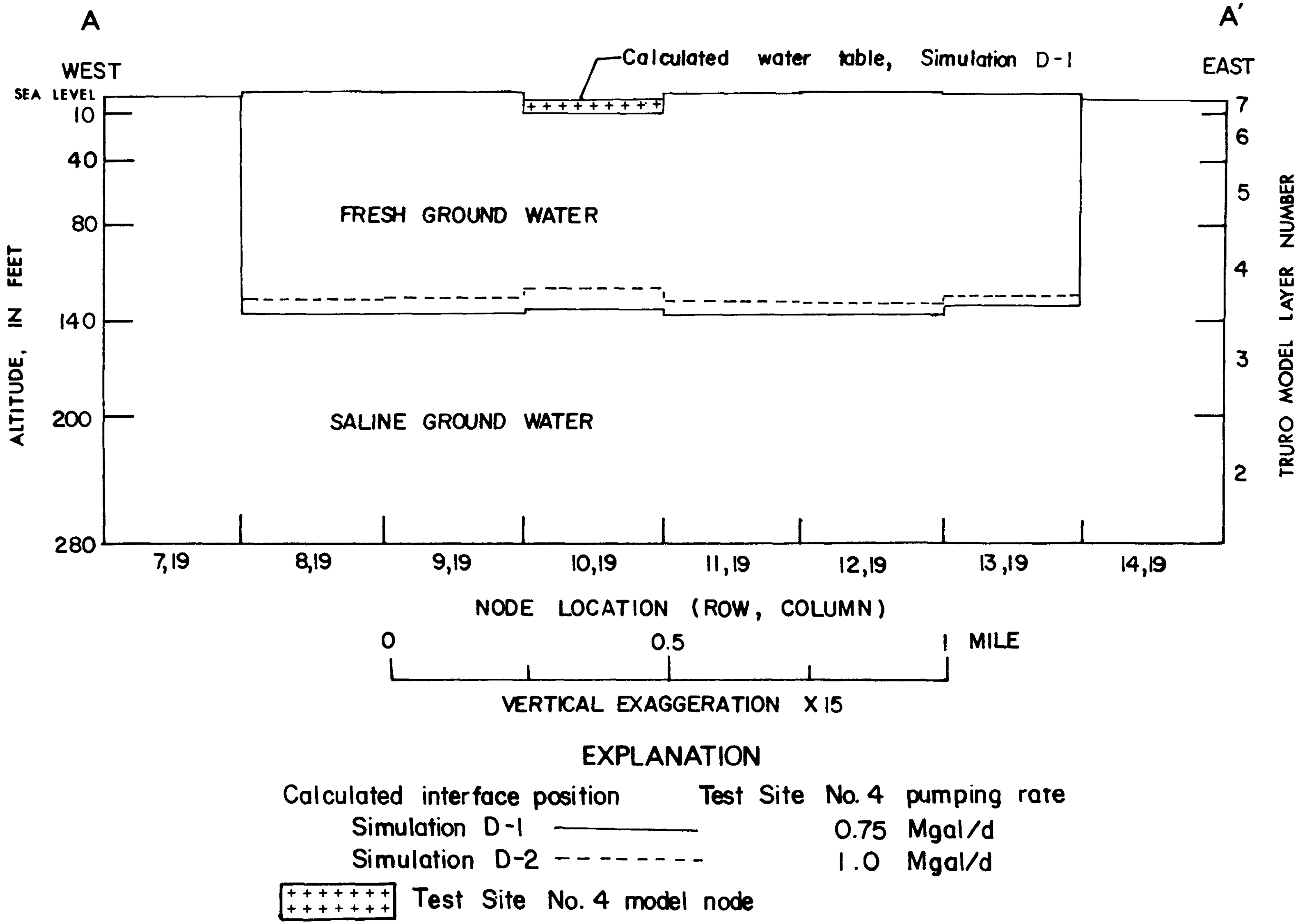
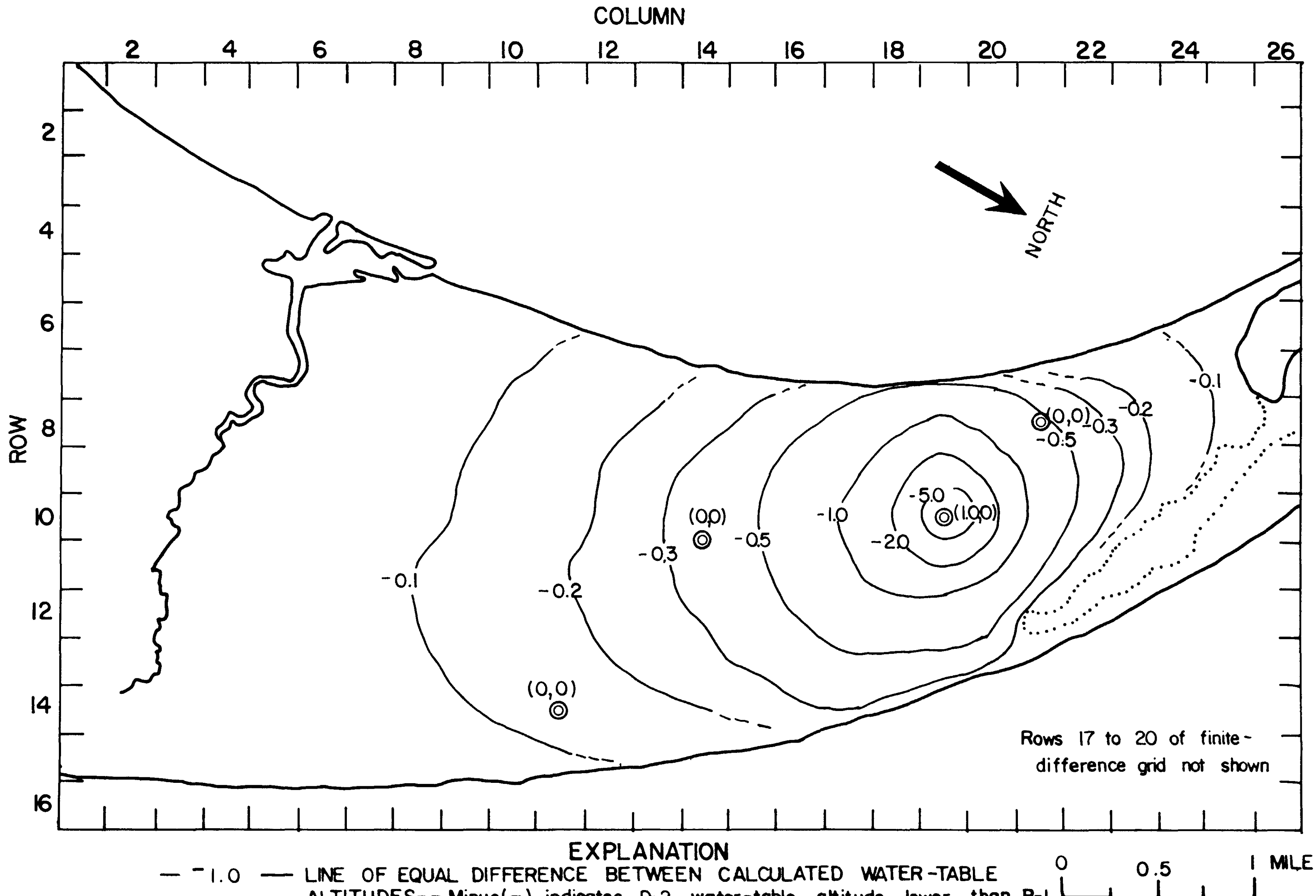


Figure 15.--Calculated freshwater-saltwater interface positions, Simulations D-1 and D-2, for cross section A-A' of figure 4

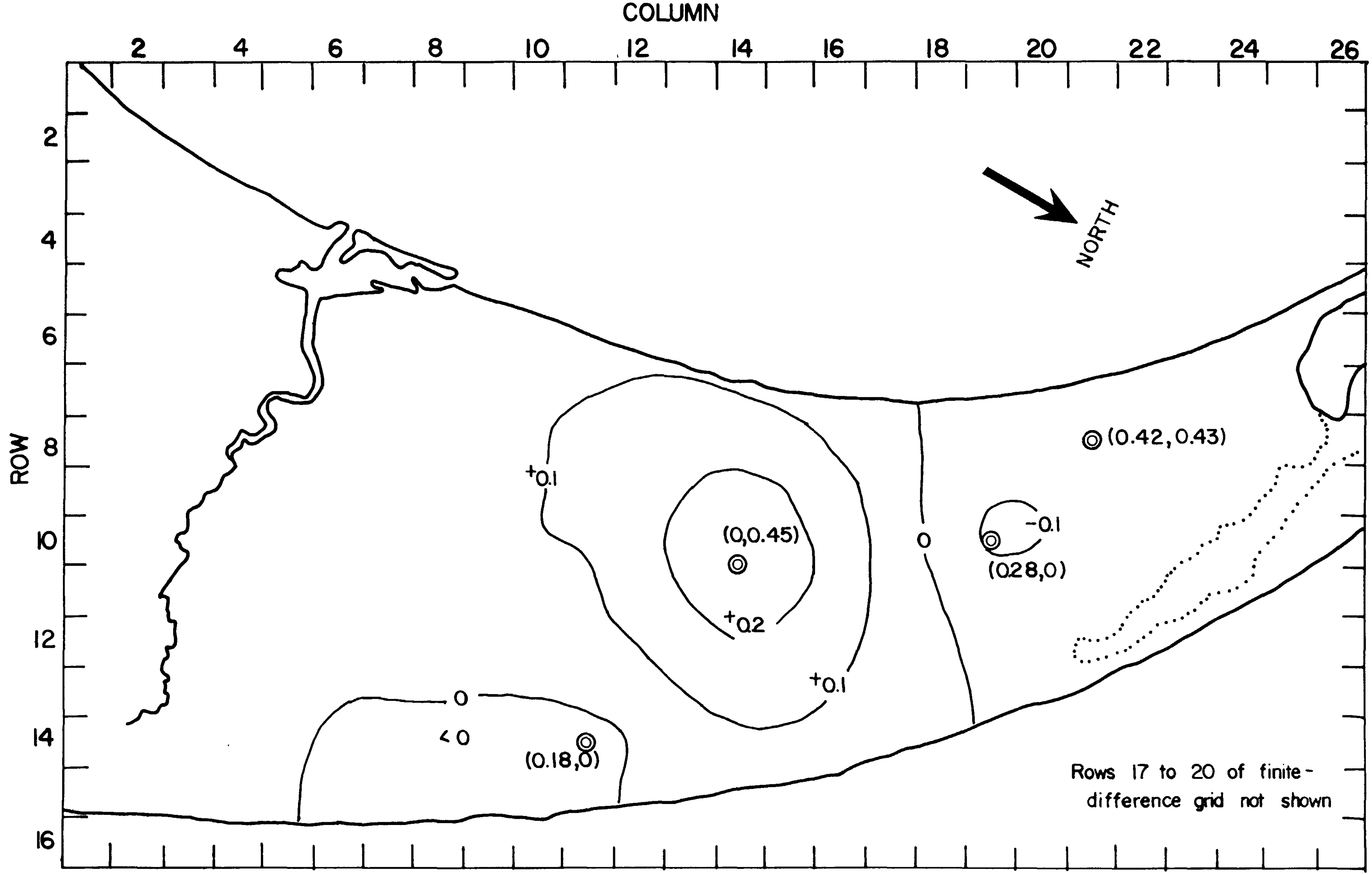


EXPLANATION

— -1.0 — LINE OF EQUAL DIFFERENCE BETWEEN CALCULATED WATER-TABLE ALTITUDES--Minus(-) indicates D-2 water-table altitude lower than B-1 water-table altitude. Interval varies.

◎ (0,1.0) WELL OR WELL FIELD--Numbers in brackets are D-2 pumping rates and B-1 pumping rates in Mgal/d.

Figure 16.--Difference between the calculated water tables of Simulation D-2 and Simulation B-1



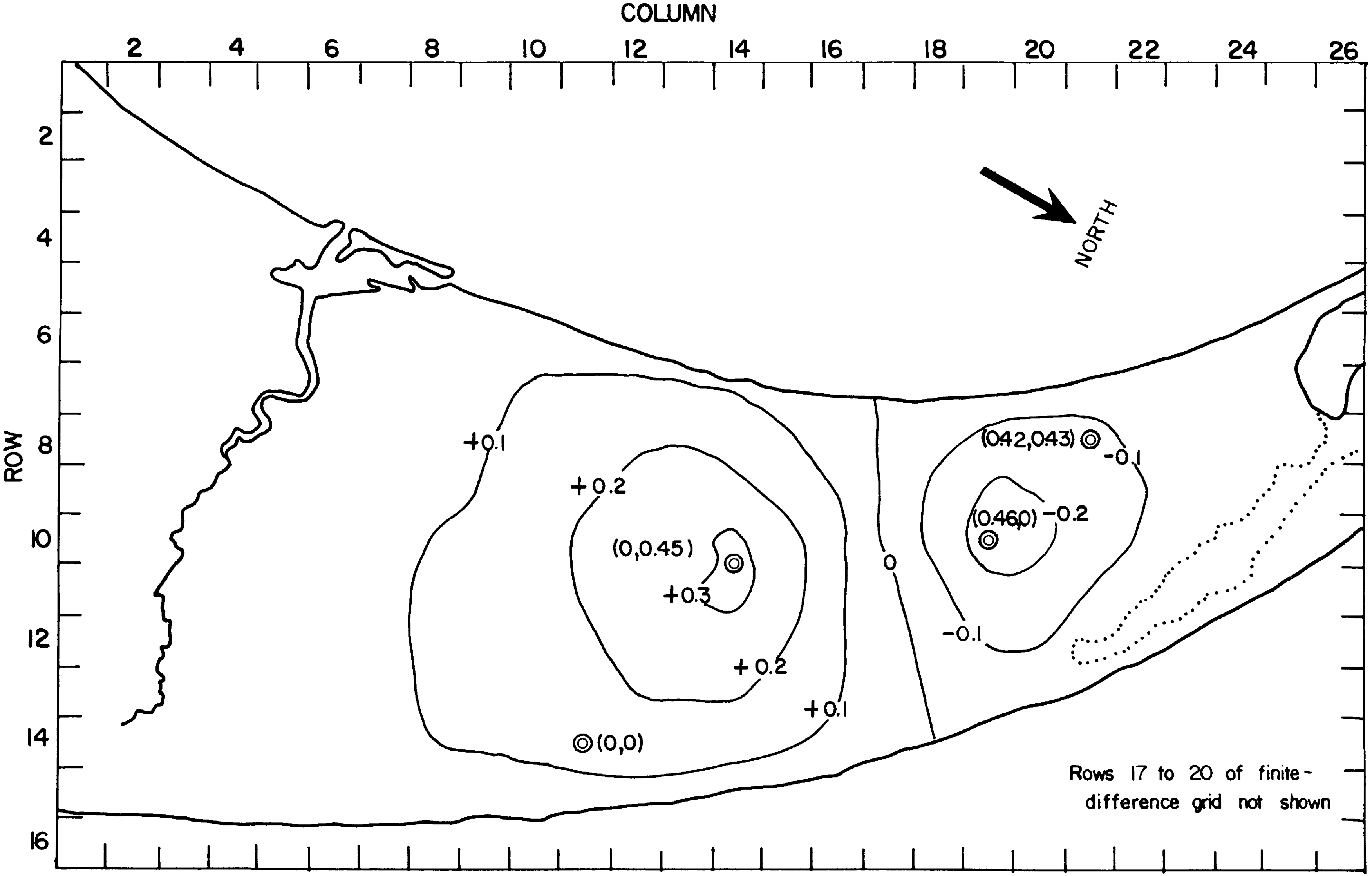
EXPLANATION

—— +0.1 —— LINE OF EQUAL DIFFERENCE BETWEEN CALCULATED WATER-TABLE ALTITUDES--Plus (+) indicates E-1 water-table altitude higher than A-1 water-table altitude. Interval 0.1 foot.

◎ (0.18,0) WELL OR WELL FIELD--Numbers in brackets are E-1 pumping rates and A-1 pumping rates in Mgal/d.

0 0.5 1 MILE

Figure 17.--Difference between the calculated water tables of Simulation E-1 and Simulation A-1



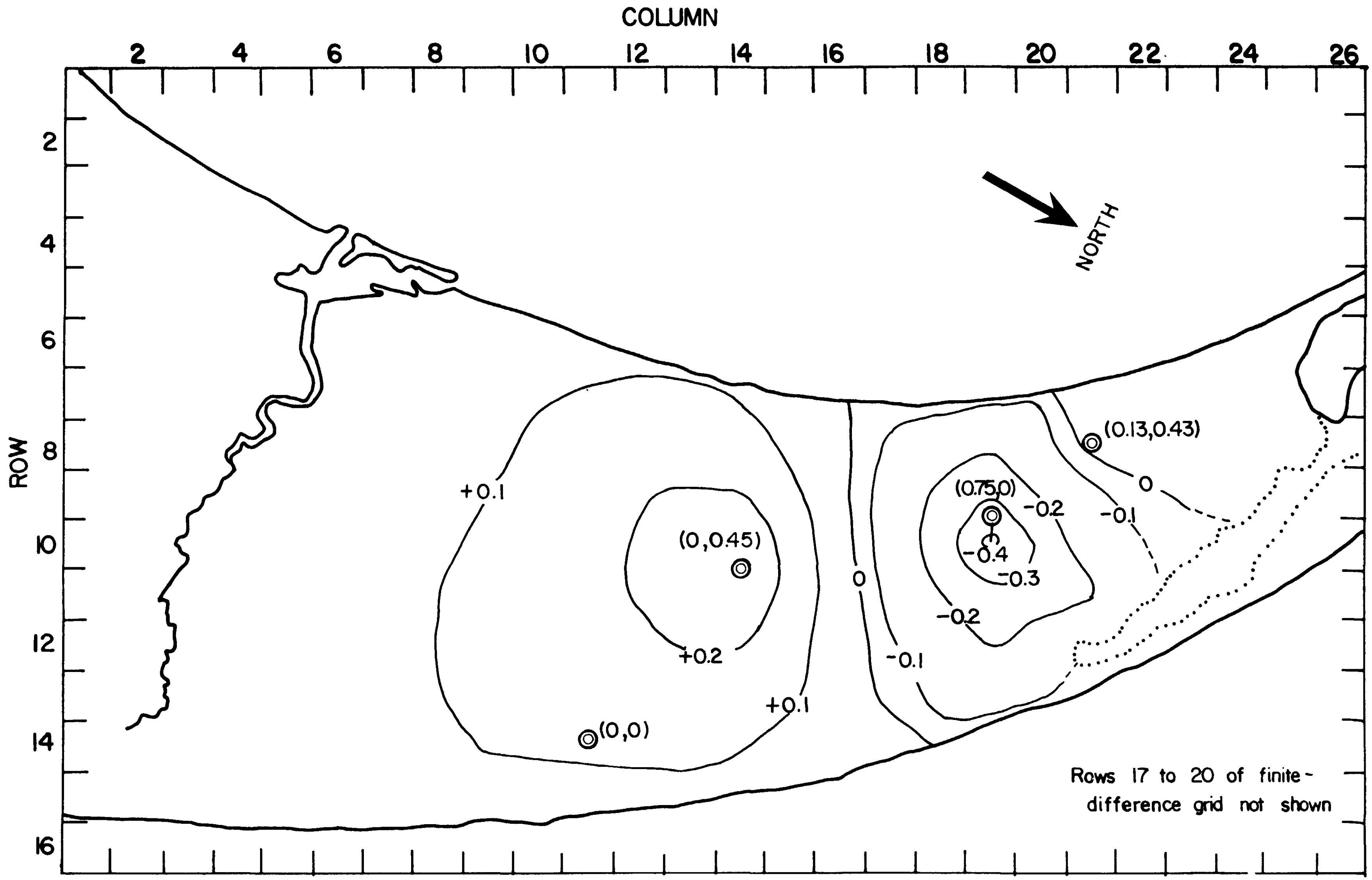
EXPLANATION

—+0.3— LINE OF EQUAL DIFFERENCE BETWEEN CALCULATED WATER-TABLE ALTITUDES--Plus (+) indicates E-2 water-table altitude higher than A-1 water-table altitude. Interval 0.1 foot.

◎ (0,0.45) WELL OR WELL FIELD--Numbers in brackets are E-2 pumping rates and A-1 pumping rates in Mgal/d.

0 0.5 1 MILE

Figure 18.--Difference between the calculated water tables of Simulation E-2 and Simulation A-1



EXPLANATION

—+0.1— LINE OF EQUAL DIFFERENCE BETWEEN CALCULATED WATER-TABLE ALTITUDES--Plus (+) indicates E-3 water-table altitude higher than A-1 water-table altitude. Interval 0.1 foot.

◎ (0,0.45) WELL OR WELL FIELD--Numbers in brackets are E-3 pumping rates and A-1 pumping rates in Mgal/d.

0 0.5 1 MILE

Figure 19.--Difference between the calculated water tables of Simulation E-3 and Simulation A-1

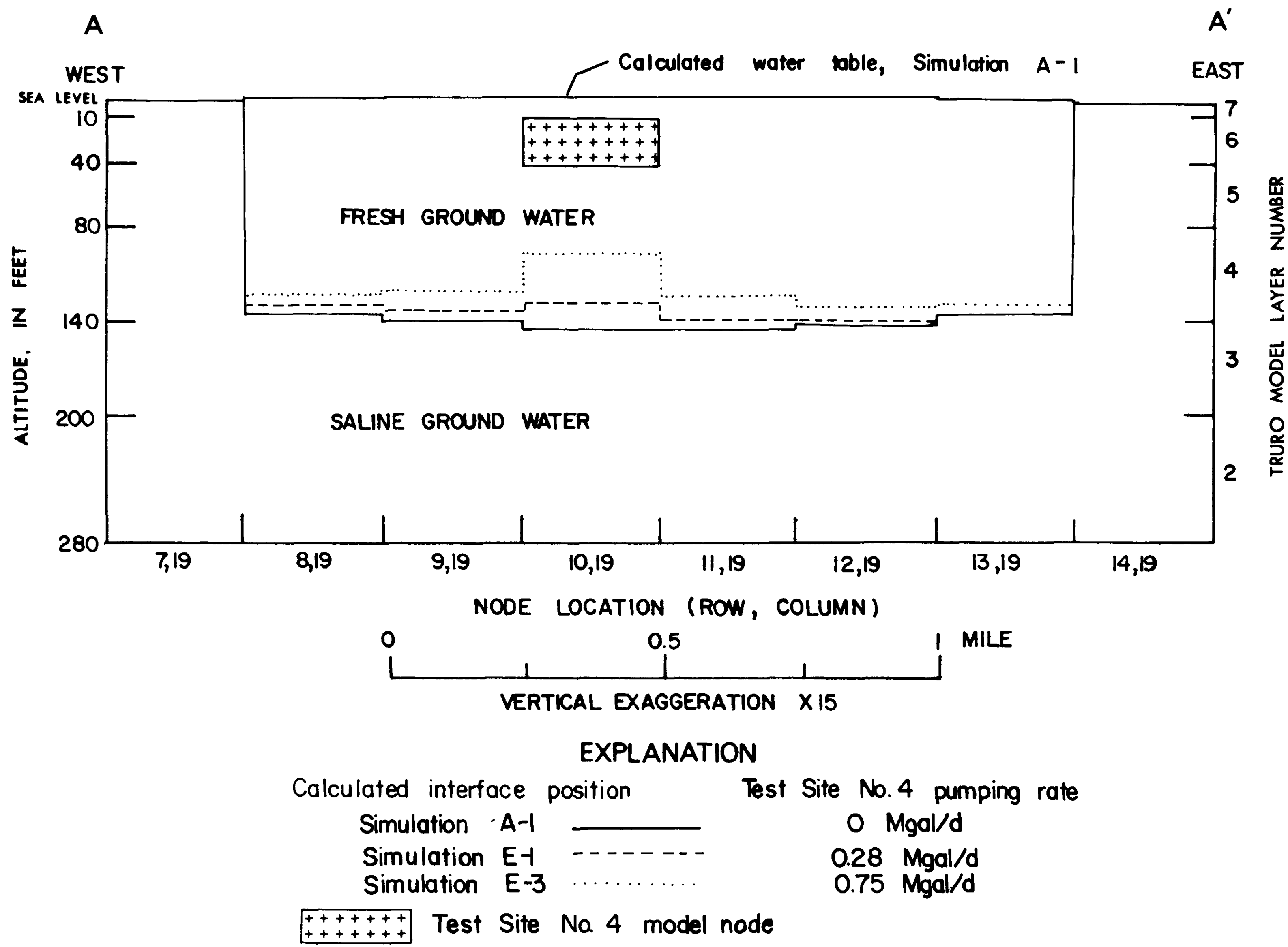


Figure 20.--Calculated freshwater-saltwater interface positions, Simulations A-1, E-1, and E-3, for cross section A-A' of figure 4

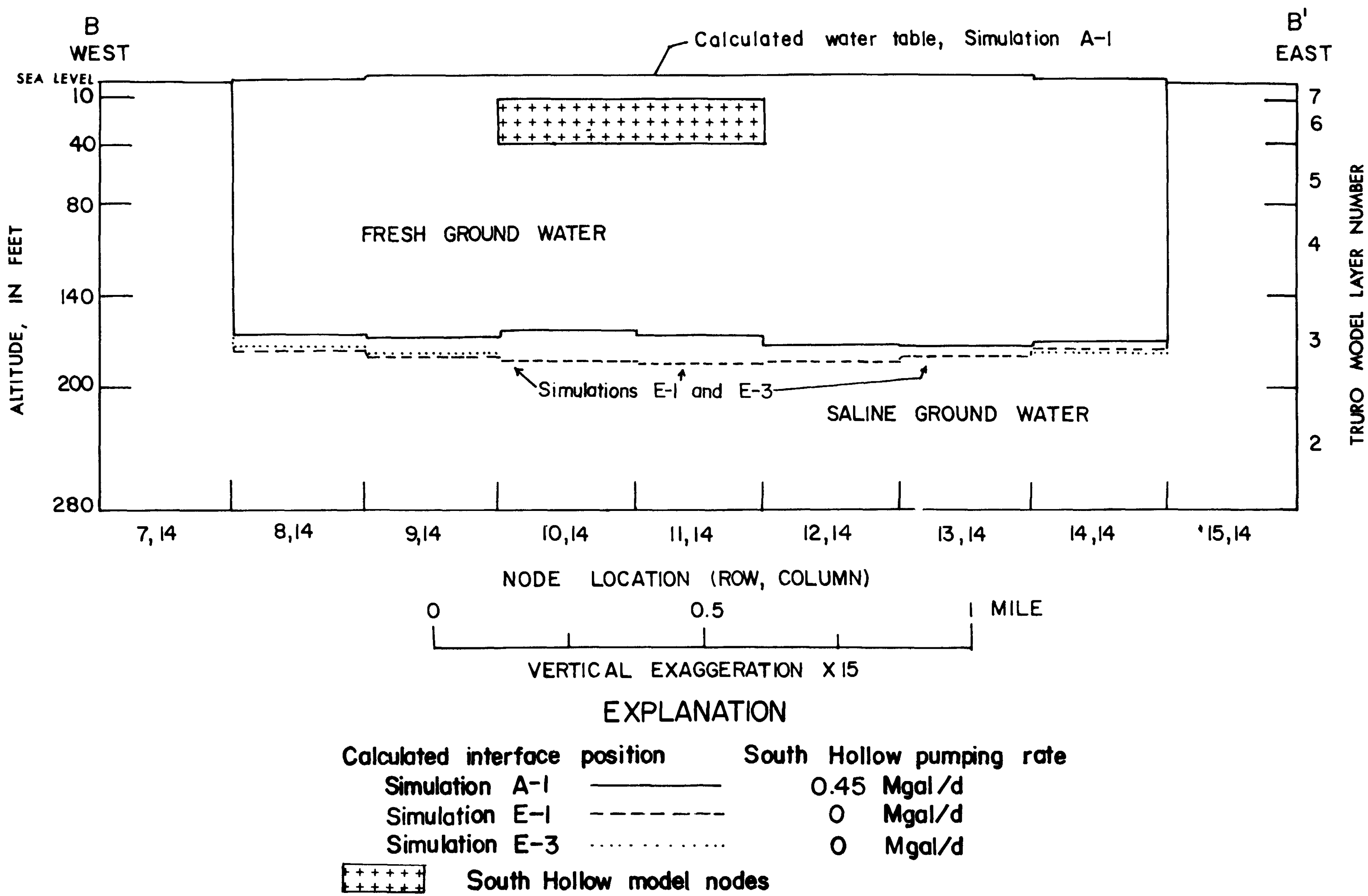


Figure 21.--Calculated freshwater-saltwater interface positions, Simulations A-1, E-1, and E-3, for cross section B-B' of figure 4

Table 5.--Comparison between the ground-water discharge rates to areas A-F (shown in fig. 6) calculated in Simulation A-1 and ground-water discharge rates calculated in the Set E and F simulations

Simulation*	Ground-water discharge rates calculated in Sets E and F minus ground-water discharge rates calculated in Simulation A-1 (difference in million gallons per day)					
	Area					
	A	B	C	D	E	F
E-1	-0.045	-0.013	+0.007	-0.006	+0.032	+0.033
E-2	-.129	-.033	0	+.052	-.038	-.097
E-3	-.116	+.006	-.006	+.026	+.032	+.065
E-4	-.110	+.013	-.019	+.032	+.013	+.058
F-1	-.284	-.084	-.039	-.090	-.007	-.039
F-2	-.310	-.091	-.039	-.058	-.007	-.026
F-5	-.291	-.084	-.039	-.090	-.007	-.039
F-6	-.271	-.065	-.045	-.097	-.013	-.039

Simulation*	Change in the ground-water discharge rates from the rates calculated in Simulation A-1 to the rates calculated in Set E and F simulations (percent change)					
	Area					
	A	B	C	D	E	F
E-1	-7	-1	+1	0	+3	+2
E-2	-22	-3	0	+3	+3	+6
E-3	-19	+1	-1	+1	+3	+4
E-4	-18	+1	-3	+2	+1	+3
F-1	-46	-8	-7	-4	-1	-2
F-2	-50	-9	-7	-3	-1	-2
F-5	-47	-8	-7	-4	-1	-2
F-6	-44	-6	-8	-5	-1	-2

*The simulated pumping schemes are summarized in table 3.

Set F—Pumping from Test Site No. 4, Knowles Crossing, and Air Force wells at 1979 Average Summer Rate

Several alternatives for pumping a total of 1.44 Mgal/d from the Knowles Crossing, Test Site No. 4, and Air Force wells are simulated in Set F to provide "worst case" examples of the hydrologic impacts of the development of Test Site No. 4. An average of 1.44 Mgal/d was pumped from wells in Truro and exported to Provincetown during July and August 1979. This rate is 1.6 times greater than the year-round average rate simulated in Set E. The simulated impacts on the flow system of pumping continuously at this higher rate from the three well sites (Set F) are summarized in table 3.

The changes in the calculated water-table altitude from Simulation A-1 to Simulations F-1, F-2, and F-6 are shown in figures 22, 23, and 24. The water table is lower everywhere except at the South Hollow site owing to the greater withdrawal (1.44 Mgal/d instead of 0.88 Mgal/d). At the Route 6 wetland north of Test Site No. 4 (row 10, column 20 in fig. 4), the water-table altitudes calculated in Simulations F-1, F-2, and F-6 are approximately 0.5 foot lower than the altitude calculated in Simulation A-1.

Discharge to the lateral boundaries of the aquifer also decreases due to the increased withdrawal rates simulated in Set F (table 5). The calculated discharge from the modeled area to the ocean and wetland in area A (fig. 6) decreases approximately 50 percent below the discharge calculated in Simulation A-1.

Cross sections through the fresh ground-water body (figs. 25 and 26) show the calculated positions of the freshwater-saltwater interface obtained from Simulations A-1, F-2, and F-6. The higher withdrawal rate (1.44 Mgal/d in Simulations F-2 and F-6) results in a smaller volume of freshwater in storage in the aquifer than the volume in storage under the lower withdrawal rate (0.88 Mgal/d in Simulation A-1). Changes in the simulated positions of the interface are smallest near the coast and greatest beneath the pumping wells.

Discussion of Simulated Impacts

The TRURO ground-water-flow model described by Guswa and LeBlanc (1981) was used to determine the impacts of implementing 21 schemes (table 3) for pumping water from Test Site No. 4 and other wells in Truro. The potential impacts may be summarized as follows:

1. The average water-table altitudes in the modeled area may decline less than 0.6 foot as a result of implementing the simulated schemes (Sets C, E, and F) for pumping at Test Site No. 4, Knowles Crossing, and the Air Force Station. Water levels within approximately 700 feet of the pumping wells (half the model node spacing) may decline more than 1 foot; however, the TRURO model was not designed to estimate the magnitude of these changes. Water-level changes will be greatest in the vicinity of the pumping wells. Changes will be small near the coast and in areas south of the South Hollow site that are distant from the pumping centers.

   Therefore, average water levels in wetlands and ponds that are expressions of the water table should decline less than 0.6 foot as a result of implementing the simulated pumping schemes. Discharge to water-table springs along the lateral boundaries of the aquifer will probably be affected only slightly by the pumping. Wetlands, ponds, and springs that are expressions of small perched ground-water bodies will not be affected by the withdrawals.

2. Withdrawal of 1.0 Mgal/d from Test Site No. 4 may lower the average water table at Knowles Crossing (2,000 feet away) by as much as 0.4 foot. Development of Test Site No. 4 as a major source of water for Provincetown will reduce the quantity of water that can be obtained from the Knowles Crossing site if increased chloride concentration at Knowles Crossing is to be avoided.

3. Except near pumping wells, changes in water levels in the Truro aquifer caused by implementing the withdrawal schemes simulated in Sets C, E, and F (table 3) will be smaller than the seasonal and long-term fluctuations of water levels caused by variations in recharge from precipitation. Therefore, regional changes in water levels caused by pumping will be difficult to discern from the seasonal fluctuation of water levels.

4. Simulated withdrawal of more than 1.1 Mgal/d from the Test Site No. 4 well (screened in model layer 6) results in movement of the freshwater-saltwater interface up to the pumping well. At pumping rates of 1.0 Mgal/d and 1.08 Mgal/d, the simulated steady-state positions of the interface are less than 35 feet below the block containing the Test Site No. 4 well (Set C). Because upconing of the interface directly beneath a pumping well will be greater than the average upconing calculated by the TRURO model beneath the 1,320-foot-square block containing the pumping well, continuous withdrawal of more than 1.0 Mgal/d from the Test Site No. 4 well would probably eventually result in unstable upconing.

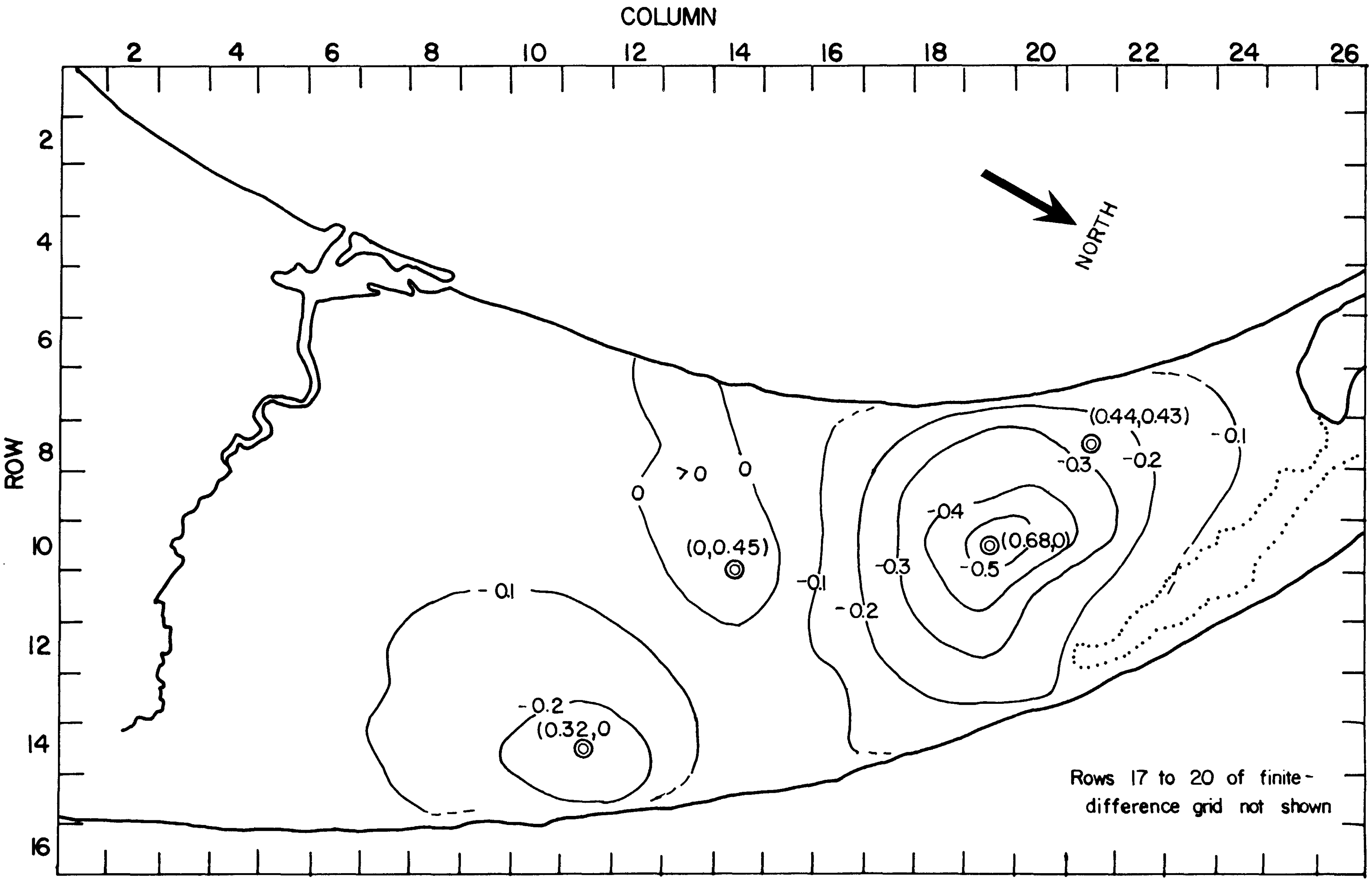
5. Evaluation of the impacts of implementing a pumping scheme must consider both the locations and depths of the wells because the depth of the screened interval of a well affects the response of the water table and the freshwater-saltwater interface to withdrawals. Pumping a well screened near the water table (Set D) rather than a well screened deeper in the aquifer (Set C) will decrease the possibility of upconing of saltwater into the well. Conversely, the decline of the water table around the shallower well will be greater, and the water table may be drawn down to the well screen.

6. Changes in the steady-state position of the interface caused by changes in the location and rate of withdrawal are greatest beneath the pumping wells and smallest near the lateral boundaries of the aquifer and at points distant from the wells. It is unlikely that the private wells that supply water to homes and businesses in the modeled area will be contaminated by saline ground water owing to movement of the interface in response to pumping at the simulated rates, including the July and August 1979 rate (Set F).

As a precaution, however, implementation of a scheme for ground-water withdrawal from Truro could include an inventory of all private supply wells within 500 feet of saline surface-water bodies, within 500 feet of the public-supply wells, or screened more than 50 feet below the water table. The well depth, distance to public-supply wells and saline surface-water bodies, and the chloride content and specific conductance of water from each well would be recorded. Periodic collection of water samples from the first wells that would be affected by the pumping and analysis of the samples for chloride content and specific conductance would provide early detection of potential chloride contamination.

7. Most of the change in discharge from the modeled area to the aquifer's lateral boundaries caused by withdrawals at Test Site No. 4 occurs in areas A, B, and C (fig. 6). Discharge to area A, which includes the wetland and ocean between Pilgrim Lake and Head of the Meadow Beach, is affected more than discharge to the other five areas because of its proximity to the pumping well site. Under the "worst case" pumping schemes simulated in Set F, discharge to area A from the Truro aquifer decreased as much as 50 percent. Calculated discharge to area A decreased as much as 20 percent as a result of simulated pumping from Test Site No. 4, Knowles Crossing, and the Air Force wells at a total rate of 0.88 Mgal/d (Set E).

The TRURO model does not simulate the total discharge to the streams and wetlands from the Truro aquifer and adjacent flow systems in Provincetown and Wellfleet. Also, the TRURO model should not be used to differentiate between discharge to the ocean and discharge to the coastal wetlands (for example, areas A and C in fig. 6). The net effect of withdrawals at Test Site No. 4 on discharge to the coastal streams and wetlands will probably be less than the calculated changes summarized in table 3. However, the 20- and 50-percent decreases in discharge to area A simulated in Sets E and F indicate that the simulated pumping schemes, if implemented, may significantly decrease freshwater discharge to some coastal wetlands. Evaluation of the impacts on these wetlands of increased withdrawals in Truro would require a better understanding of the relationship between these wetlands and the adjacent aquifer.



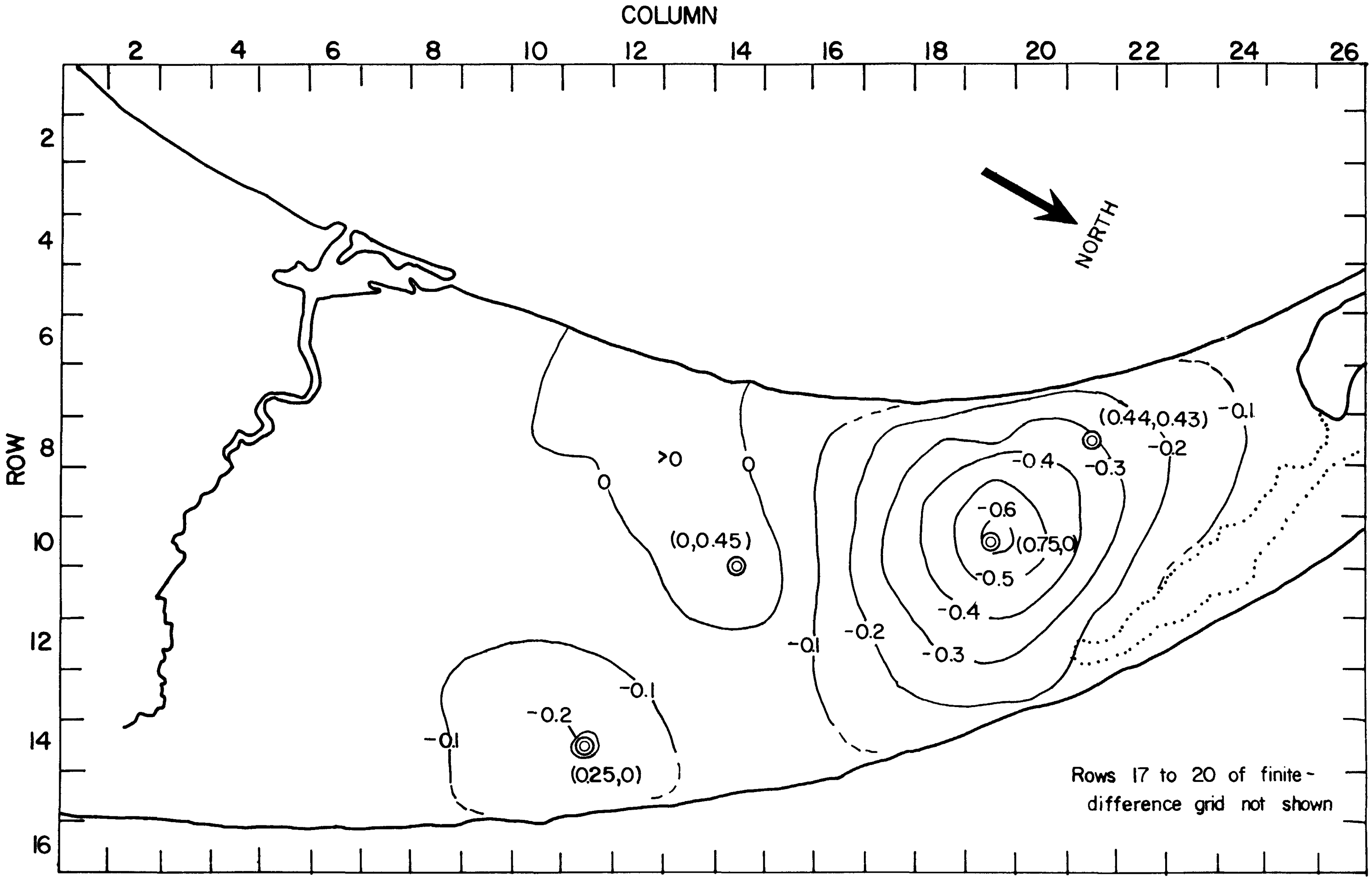
EXPLANATION

—⁻0.3— LINE OF EQUAL DIFFERENCE BETWEEN CALCULATED WATER-TABLE ALTITUDES--Minus(−) indicates F-1 water-table altitude lower than A-1 water-table altitude. Interval 0.1 foot.

◎ (0,0.32) WELL OR WELL FIELD--Numbers in brackets are F-1 pumping rates and A-1 pumping rates in Mgal/d.

0 0.5 1 MILE

Figure 22.--Difference between the calculated water tables of Simulation F-1 and Simulation A-1



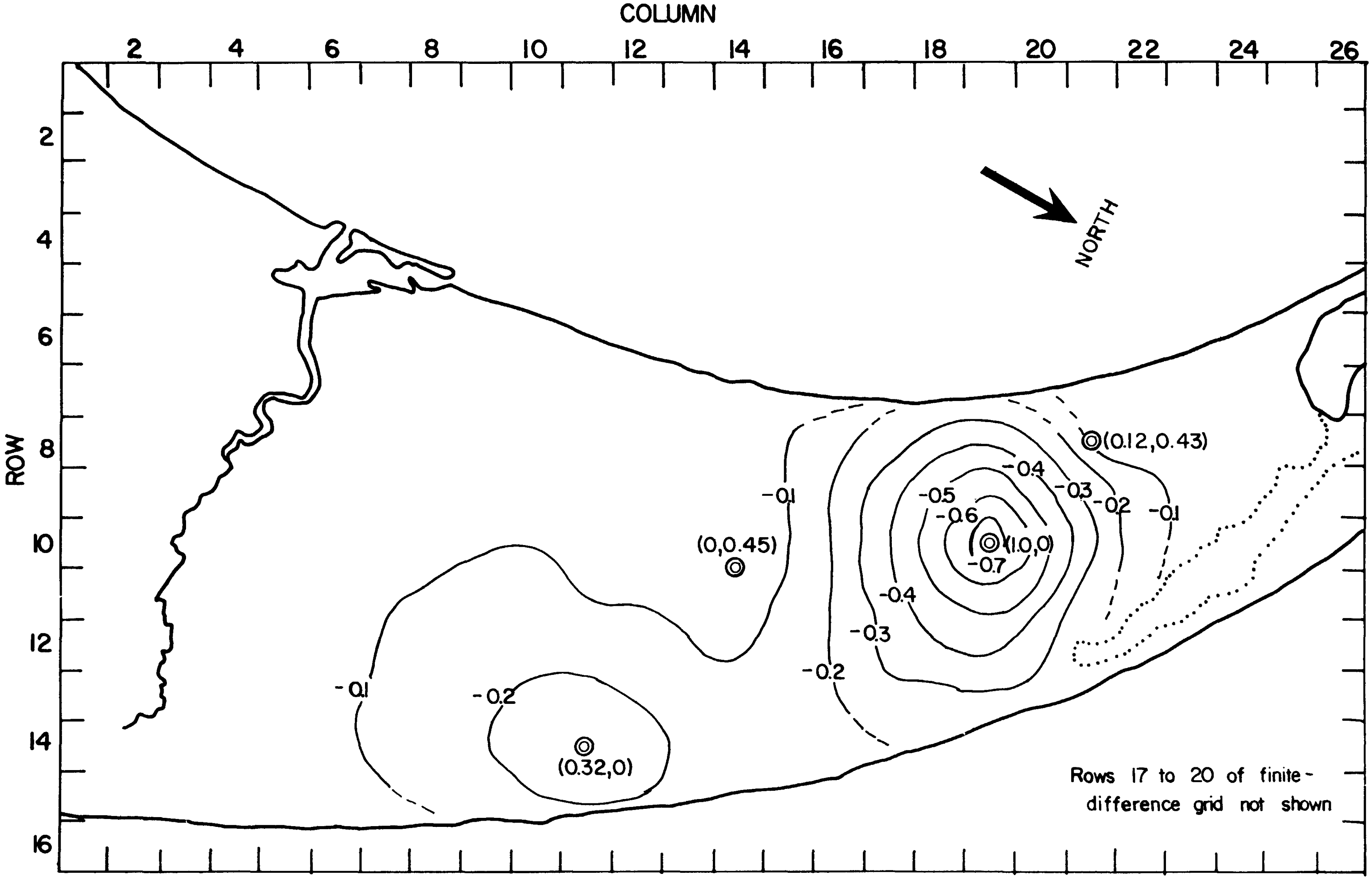
EXPLANATION

—⁻0.6— LINE OF EQUAL DIFFERENCE BETWEEN CALCULATED WATER-TABLE ALTITUDES-- Minus(-) indicates F-2 water-table altitude lower than A-1 water-table altitude. Interval 0.1 foot.

◎ (0,0.25) WELL OR WELL FIELD-- Numbers in brackets are F-2 pumping rates and A-1 pumping rates in Mgal/d.

0 0.5 1 MILE

Figure 23.--Difference between the calculated water tables of Simulation F-2 and Simulation A-1



EXPLANATION

—— -0.6 —— LINE OF EQUAL DIFFERENCE BETWEEN CALCULATED WATER-TABLE
- - ALTITUDES-- Minus(-) indicates F-6 water-table altitude lower than A-1 water-table altitude. Interval 0.1 foot.

◎ (0,0.32) WELL OR WELL FIELD--Numbers in brackets are F-6 pumping rates and A-1 pumping rates in Mgal/d.

Figure 24.--Difference between the calculated water tables of Simulation F-6 and Simulation A-1

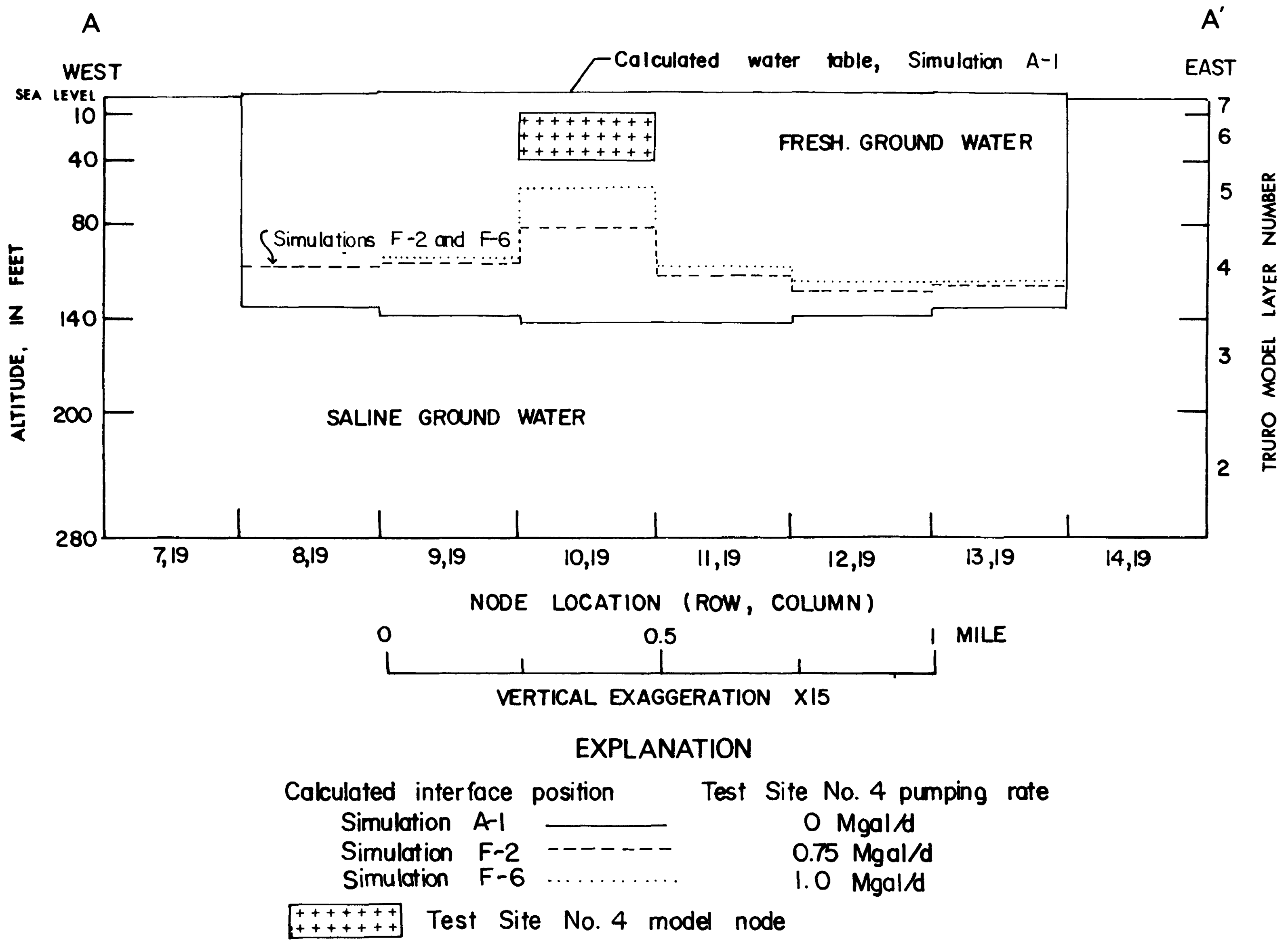


Figure 25.--Calculated freshwater-saltwater interface positions, Simulations A-1, F-2, and F-6, for cross section A-A' of figure 4

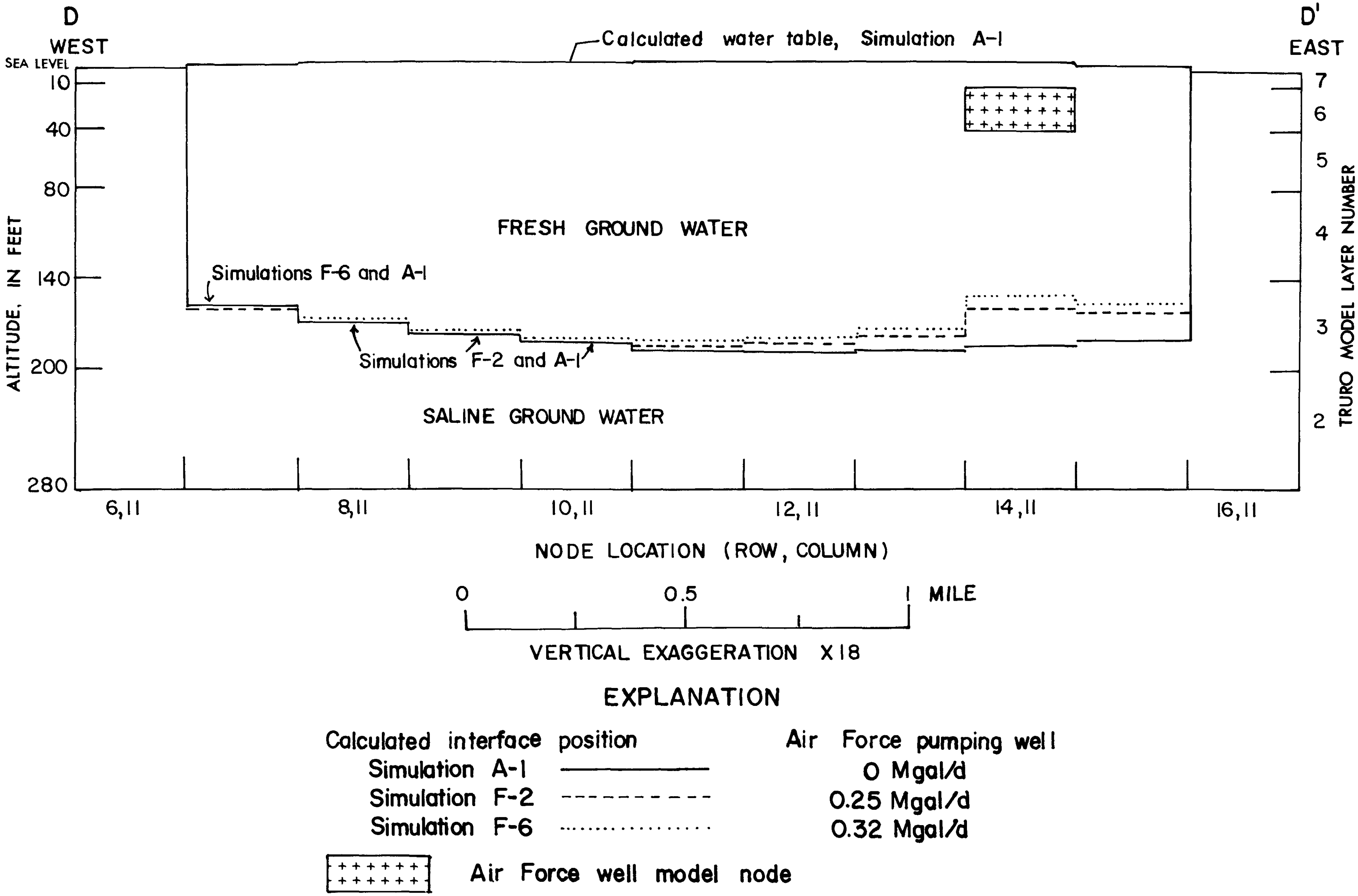


Figure 26.--Calculated freshwater-saltwater interface positions, Simulations A-1, F-2, and F-6, for cross section D-D' of figure 4

SUMMARY

The potential hydrologic impacts of withdrawals from the Truro aquifer have been evaluated by a three-dimensional digital model of steady-state ground-water flow. The model was prepared as part of an earlier study of water resources on Cape Cod and is described in Guswa and LeBlanc (1981). The impacts of 21 schemes for pumping water from Test Site No. 4 and other wells in Truro are summarized in table 3. The 21 schemes include continuous withdrawal of as much as 1.44 Mgal/d from the Truro aquifer and as much as 1.25 Mgal/d from Test Site No. 4.

For the simulated pumping schemes, the water table should decline less than 0.6 feet below average (1963-76) levels except near the pumping wells. Water-table decline near the wells will be greater, but the model node spacing is not designed to allow determination of declines near the wells.

Continuous withdrawal of more than 1.0 Mgal/d from the Test Site No. 4 well will result in upward movement of the freshwater-saltwater interface, and most likely saltwater will eventually contaminate the well. However, private wells that supply water to homes and businesses in Truro are not likely to become contaminated by saltwater owing to pumping at the simulated rates because these wells are generally near the aquifer's lateral boundaries or are far from the pumping wells. The interface movement will be smallest at these locations and greatest near the major pumping wells.

Implementation of the simulated pumping schemes will decrease freshwater discharge to some coastal wetlands near the pumping centers. Discharge to the ocean and wetlands in the Meadows area in northeastern Truro from the modeled area may decrease as much as 50 percent if the simulated schemes for pumping 1.44 Mgal/d are implemented.

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Table 3.--Summary of TRURO-model simulations

Set	Simulation	Description	Pumping rate (million gallons per day): Test Site No. 4 (TS4)	Knowles Crossing (KC)	North Truro AFS (AFS)	South Hollow (SH)	Total	Steady-state solution reached?: Yes	Unstable upconing	Dewatered layer 7 TS4	Water-table altitude, in feet above sea level, at selected nodes: 10,19 (TS4)	8,21 (KC)	14,11 (AFS)	11,14 (SH)	10,20	9,24	11,10	10,17	12,19	7,10	11,6
A	1	Hypothetical average 1979 pumpage at Knowles Crossing and South Hollow	--	0.43	--	0.45	0.88	X	--	--	4.60	2.80	6.48	5.69	4.32	3.08	6.52	5.05	4.14	4.08	5.89
B	1	No ground-water withdrawals	--	--	--	--	--	X	--	--	4.99	3.25	6.72	6.26	4.69	3.22	6.79	5.48	4.42	4.25	6.00
C	1	Test Site No. 4 only, Layer 6	0.75	--	--	--	.75	X	--	--	4.27	2.96	6.61	5.99	4.12	3.13	6.68	4.99	3.97	4.18	5.96
	2	do.	1.00	--	--	--	1.00	X	--	--	3.98	2.85	6.57	5.90	3.90	3.10	6.63	4.81	3.81	4.15	5.94
	3	do.	1.08	--	--	--	1.08	X	--	--	3.85	2.82	6.56	5.87	3.82	3.09	6.62	4.75	3.76	4.15	5.94
	4	do.	1.16	--	--	--	1.16	--	X (at TS4)	--	--	--	--	--	--	--	--	--	--	--	--
	5	do.	1.25	--	--	--	1.25	--	X (at TS4)	--	--	--	--	--	--	--	--	--	--	--	--
D	1	Test Site No. 4 only, Layer 7	.75	--	--	--	.75	X	--	--	-.68	2.87	6.61	6.00	2.92	3.13	6.68	4.64	3.70	4.18	5.96
	2	do.	1.00	--	--	--	1.00	X	--	--	-3.85	2.74	6.58	5.90	2.36	3.10	6.64	4.37	3.47	4.16	5.95
	3	do.	1.08	--	--	--	1.25	--	--	X	--	--	--	--	--	--	--	--	--	--	--
E	1	Average 1979 pumping scheme	.28	.42	.18	--	.88	X	--	--	4.48	2.75	6.45	5.98	4.22	3.07	6.59	5.10	4.10	4.15	5.90
	2	Hypothetical pumping scheme at average total pumpage in 1979	.46	.42	--	--	.88	X	--	--	4.34	2.68	6.62	6.02	4.10	3.05	6.69	5.04	4.03	4.19	5.97
	3	do.	.75	.13	--	--	.88	X	--	--	4.20	2.84	6.60	5.97	4.04	3.09	6.66	4.94	3.93	4.17	5.96
	4	do.	.88	--	--	--	.88	X	--	--	4.13	2.90	6.59	5.95	4.01	3.11	6.65	4.90	3.89	4.17	5.95
F	1	Average July and August 1979 pumping scheme	.68	.44	.32	--	1.44	X	--	--	4.02	2.52	6.21	5.74	3.85	3.01	6.42	4.76	3.81	4.07	5.82
	2	Hypothetical pumping scheme at average July and August total pumping in 1979	.75	.44	.25	--	1.44	X	--	--	3.96	2.50	6.28	5.76	3.80	3.00	6.45	4.74	3.78	4.08	5.84
	3	do.	.94	.50	--	--	1.44	--	X (at KC)	--	--	--	--	--	--	--	--	--	--	--	--
	4	do.	1.00	.44	--	--	1.44	--	X (at TS4)	--	--	--	--	--	--	--	--	--	--	--	--
	5	do.	.75	.37	.32	--	1.44	X	--	--	3.98	2.57	6.21	5.73	3.83	3.02	6.42	4.74	3.79	4.06	5.82
	6	do.	1.00	.12	.32	--	1.44	X	--	--	3.81	2.71	6.19	5.68	3.76	3.06	6.40	4.65	3.70	4.05	5.82
	7	do.	1.25	--	.19	--	1.44	--	X (at TS4)	--	--	--	--	--	--	--	--	--	--	--	--

Set	Simulation	Freshwater-saltwater interface altitude, in feet below sea level, at selected nodes: 10,19 (TS4)	8,21 (KC)	14,11 (AFS)	11,14 (SH)	8,24	8,19	13,19	11,10	Ground-water discharge to areas in figure 6, in million gallons per day: A	B	C	D	E	F
A	1	144	88	186	167	101	134	134	189	0.614	0.989	0.588	1.997	1.183	1.693
B	1	162	140	198	198	113	159	145	201	.937	1.137	.646	2.075	1.260	1.829
C	1	100	120	193	186	106	129	128	196	.569	1.028	.582	2.035	1.215	1.771
	2	72	113	191	183	103	118	122	194	.452	.989	.562	2.023	1.196	1.751
	3	55	110	190	181	102	114	120	193	.394	.969	.556	2.023	1.189	1.751
	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--
D	1	133	123	193	187	107	135	130	196	.582	.989	.588	2.049	1.221	1.784
	2	120	117	191	184	104	126	125	194	.485	.944	.556	2.023	1.196	1.758
	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
E	1	128	86	174	186	100	130	133	192	.569	.976	.595	1.991	1.215	1.726
	2	115	80	193	188	98	124	130	196	.485	.956	.588	2.049	1.221	1.790
	3	96	106	192	185	102	124	127	195	.498	.995	.582	2.023	1.215	1.758
	4	87	116	192	184	104	123	125	195	.504	1.002	.569	2.029	1.196	1.751
F	1	89	66	152	175	94	110	122	184	.330	.905	.549	1.907	1.176	1.654
	2	83	64	160	176	94	108	121	185	.304	.898	.549	1.939	1.176	1.667
	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	5	85	7[illegible]	152	175	96	110	121	184	.323	.905	.549	1.907	1.176	1.654
	6	58	9[illegible]	151	173	99	109	118	183	.343	.924	.543	1.900	1.170	1.654
	7	--	--	--	--	--	--	--	--	--	--	--	--	--	--