UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EFFECTS OF ARTIFICIAL-RECHARGE EXPERIMENTS AT SHIP CREEK ALLUVIAL FAN ON WATER LEVELS AT SPRING ACRES SUBDIVISION, ANCHORAGE, ALASKA

By William Meyer and Leslie Patrick

U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 80-1284

Anchorage, Alaska
1980

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

U.S. Geological Survey
Water Resources Division
733 West 4th Avenue, Suite 400
Anchorage, Alaska 99501

CONTENTS

	Page
Metric conversion factors	iv
Abstract	1
Introduction	1
Recharge project	3
Geohydrologic setting of the Anchorage area and recharge basins	5
Hydraulic characteristics of the aquifer system	9
Ground-water flow	9
Water-level changes	13
Water levels at the artificial-recharge site	18
Water-level rises after 58 and 80 days of artificial recharge, 1974 and 1975	18
Model design	27
Model calibration	30
Model predictions	34
Summary and conclusions	37
References	42

ILLUSTRATIONS

1a.	Map showing location of the study area	2
1b.	Map showing location of observation wells	4
2.	Map showing generalized extent and saturated thickness of the unconfined aquifer, as modeled	7
3.	Map showing generalized extent and thickness of the clay unit, as modeled	8
4.	Map showing areal variation in generalized transmissivity of the artesian aquifer, as modeled	10
5.	Map showing areal variation in generalized vertical hydraulic conductivity of the confining clay unit, as modeled	11
6.	Idealized direction of ground-water movement along Ship Creek	12
7a.	Hydrographs of observation wells AK1412 and AK17	14
7b.	Graph showing mean monthly discharge of Ship Creek, 1968-1977	14
8.	Hydrographs of observation wells AK1137, AK2396, and AK2130	15
9.	Hydrographs of AK2128, AK1848, AK1851, and AK1843	16
10.	Geologic section through recharge basin	19
11.	Graph showing altitude of water levels at selected dates in the unconfined aquifer near the recharge basin	24
12a.	Graph showing water-level rise in observation wells in the unconfined aquifer, May 20 to July 19, 1974, and May 20 to July 18, 1975	25
12b.	Graph showing water-level rise in the unconfined aquifer near the recharge basin, May 20 to August 7, 1974 and 1975	26
13.	Graph showing mean daily discharge for Ship Creek, March-September 1974 and 1975	28
14.	Finite-difference grid used in model construction	29
15a&b.	Graph showing model-predicted vs. observed water-level rises, 1974 and 1975 - Model A	32

ILLUSTRATIONS--Continued

		Page
16a&b.	Graph showing model-predicted vs. observed water-level rises, 1974 and 1975 - Model B	33
17.	Graph showing model-predicted water-level rises at Spring Acres Subdivision, Model A	35
18.	Graph showing model-predicted water-level rises at Spring Acres Subdivision, Model B	36
19.	Map showing model-predicted water-level rises for artesian aquifer, July 19, 1973 through August 7, 1975, Model A	38
20.	Map showing model-predicted water-level rises for unconfined aquifer, July 19, 1973 through August 7, 1975, Model A	39
21.	Map showing model-predicted water-level rises for artesian aquifer, July 19, 1973 through August 7, 1975, Model B	40
22.	Map showing model-predicted water-level rises for unconfined aquifer, July 19, 1973 through August 7, 1975, Model B	41

TABLES

1.	Total recharge rate, ft^3/s	6
2.	Depth to water, in feet below land surface, of observation wells	20

METRIC CONVERSION FACTORS

Multiply	By	To obtain
Foot (ft)	0.3048	Meter (m)
Square foot (ft^2)	0.0929	Square meter (m^2)
Acre	0.4047	Hectometer (hm)
Mile (mi)	1.609	Kilometer (km)
Square mile (mi^2)	2.590	Square kilometer (km^2)
Cubic foot per second (ft^3/s)	0.02832	Cubic meter per second (m^3/s)

EFFECTS OF ARTIFICIAL-RECHARGE EXPERIMENTS AT SHIP CREEK ALLUVIAL FAN ON WATER LEVELS AT SPRING ACRES SUBDIVISION, ANCHORAGE, ALASKA

By William Meyer and Leslie Patrick

ABSTRACT

A subdivision developer encountered water while digging trenches associated with developing property at Spring Acres Subdivision, Anchorage, Alaska, during the summer of 1975. He reported encountering water at a depth of about 8 feet in June 1975 and also reported a rise in water level to approximately land surface by early August. Neither incident was expected by the developer. The U.S. Geological Survey, in cooperation with the Municipality of Anchorage, had conducted an artificial-recharge experiment approximately 9,000 feet southeast of Spring Acres Subdivision from May 20 through September 19, 1975. Recharge experiments were also conducted in 1971, 1973, and 1974. The proximity of the 1975 recharge experiment to the subdivision caused speculation on the possible connection between the experiment and the water problems encountered by the developer.

The effect of the artificial-recharge experiments on water levels at Spring Acres Subdivision was evaluated by using two digital-computer models constructed to simulate the water-level rises induced by the artificial recharge. The models predicted that the artificial recharge would have caused water levels in the aquifer immediately underlying Spring Acres Subdivision to rise approximately 0.2 foot from May 20 to August 7, 1975. The models also predicted a total rise in ground-water levels of 1.1 feet at this location from July 16, 1973, to August 7, 1975, as a result of the artificial-recharge experiments.

Water-level data collected for auger holes in March 1975 by a consulting firm for the contractor indicated a depth to water of 6 to 7 feet below land surface at Spring Acres Subdivision at this time. Water levels measured in and near Spring Acres Subdivision several years before and after the 1973-75 artificial-recharge experiments showed seasonal rises of 2 to 12.4 feet. A depth to water below land surface of 2.6 feet was measured 600 feet from the subdivision in 1971 and in the subdivision in 1977. Average depth to water in the area was 7.0 feet from early 1976 to September 1979.

INTRODUCTION

In cooperation with the Municipality of Anchorage, the U.S. Geological Survey conducted artificial-recharge experiments on the Ship Creek alluvial fan in 1971, 1973, 1974, and 1975 (fig. 1a). The experiments were designed to determine the capacity of the major aquifer in the glacial drift that underlies the Anchorage area to accept water by artificial means, and to evaluate the effect of artificial recharge on the ground-water system. The study method consisted of diverting a part of Ship Creek summer flow into recharge basins constructed on the alluvial fan and observing the response of ground-water levels in test wells specifically constructed for the experiment.

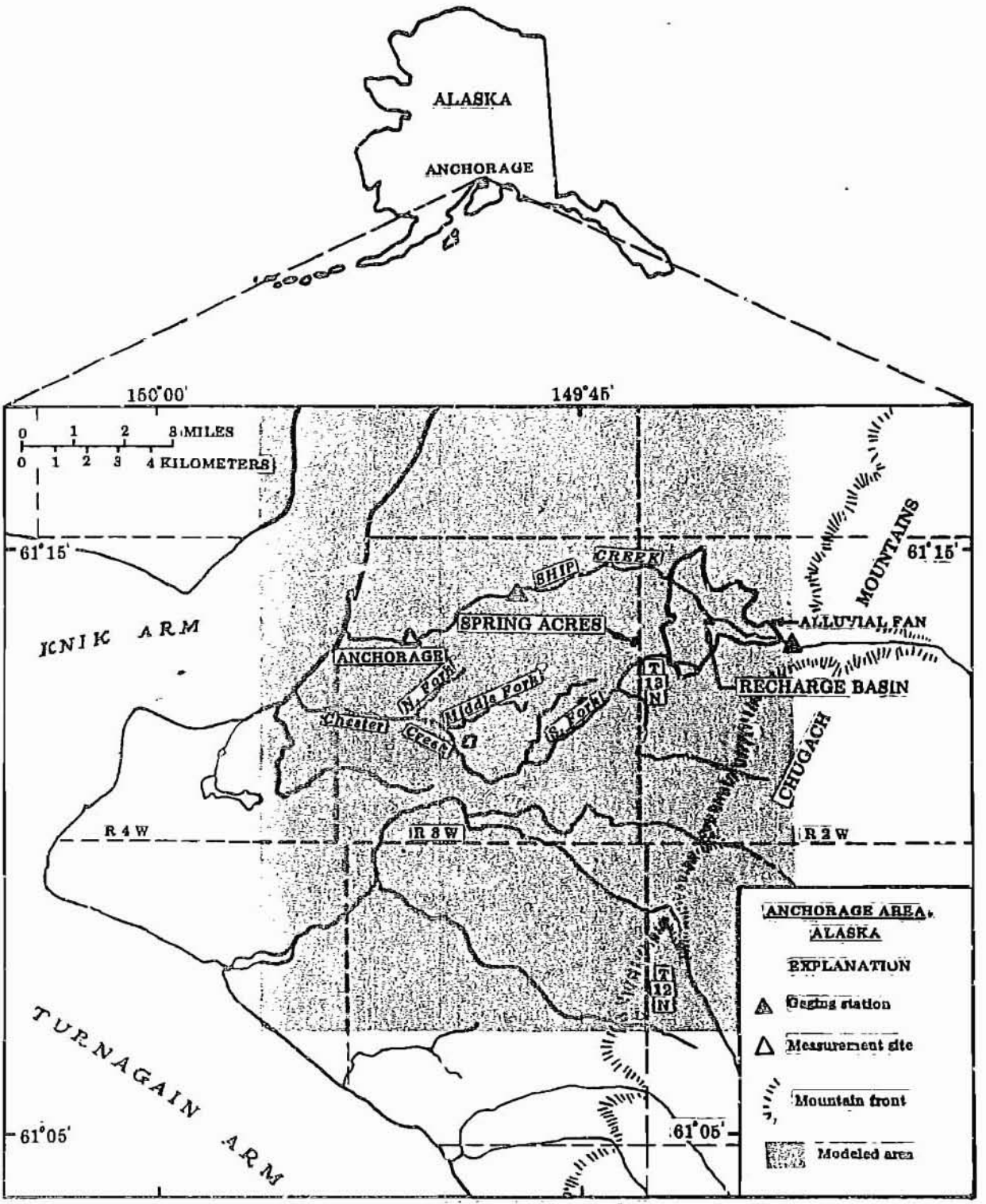


Figure 1a.– Location of the study area.

Glacial drift underlies the land surface in most of the Anchorage area. In the immediate vicinity of the recharge basins, the glacial drift is overlain by the alluvial-fan deposits of Ship Creek. Two aquifers have been identified in the drift. The lowermost aquifer is artesian (confined), represents the major aquifer in the Anchorage area, and is the aquifer from which most pumping in the Anchorage area occurs. Overlying the artesian aquifer and acting as a partly-confining bed is a clay unit of varying thickness that extends throughout most of the area. This unit varies in its lithologic nature, often containing silt and gravel. The clay unit is missing in the immediate vicinity of the recharge basins. Well logs indicate that it begins approximately ½ mi west of the recharge basins. Above the clay unit is an unconfined aquifer which immediately underlies the land surface in most of the Anchorage area.

During the summer of 1975, a subdivision developer reportedly encountered water at a depth of about 8 ft while drilling trenches 10-12 ft deep at a site approximately 9,000 ft southwest of and downhill from the recharge basin. The trenches were being dug to lay sewer and water lines for a housing development (Spring Acres Subdivision, fig. 1a) that he was constructing. Water was reportedly encountered first during June at about 8 ft, and by late July-early August the water was reportedly overflowing from a trench. It has been questioned as to what extent the recharge operation is responsible for the presence of this water and the reported water-level rise during the period June through August.

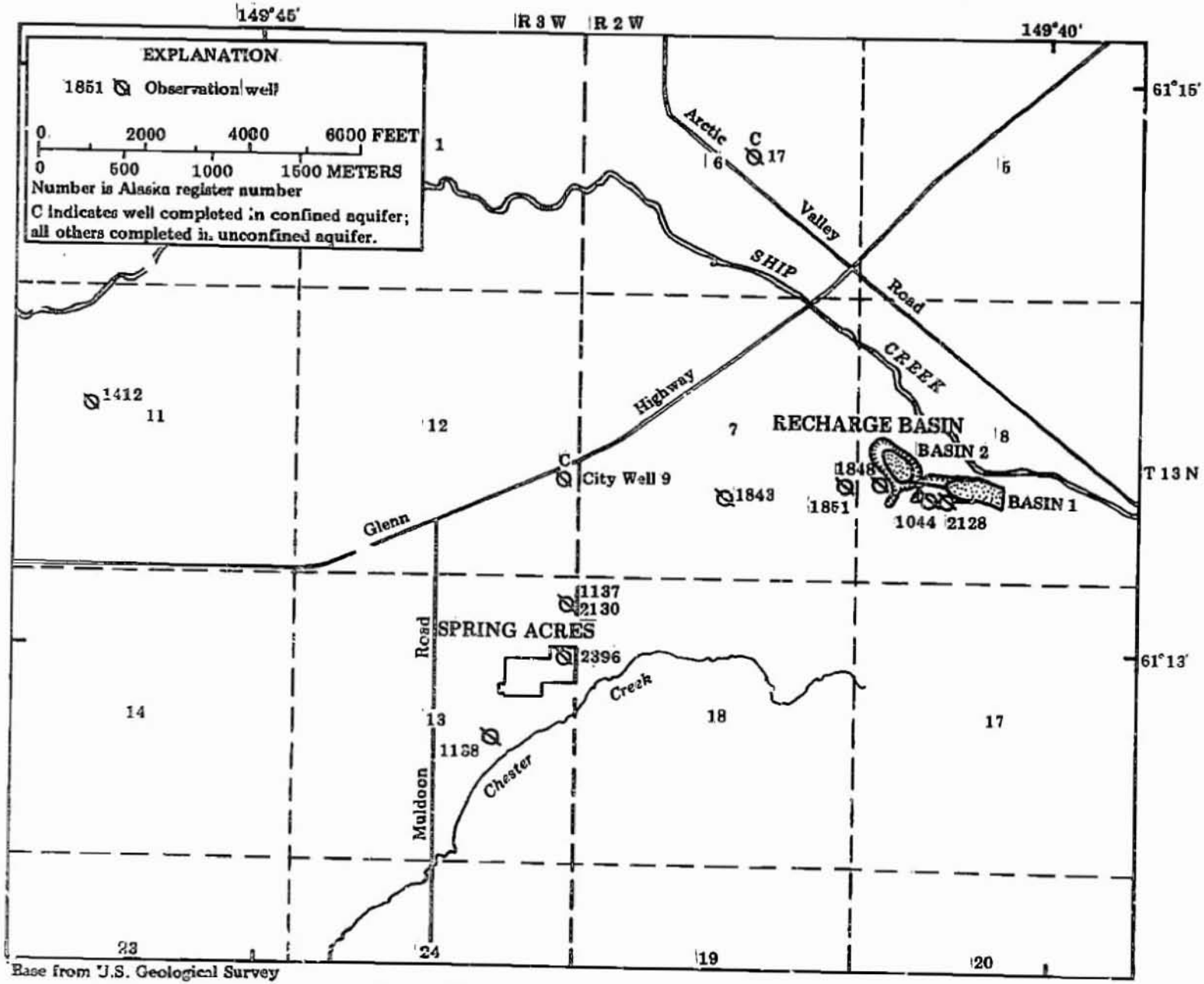
This report examines the natural water-level fluctuations in the areas of the Spring Acres Subdivision and the recharge basins. These fluctuations are examined in terms of seasonal or annual trends and their magnitudes and causes. Also, this report describes the construction of and results obtained from a three-dimensional digital model used to analyze the temporal and spatial effects of the recharge operation. The model was designed to simulate only water-level rises induced by the artificial-recharge experiments.

For the most part, this study used data collected by the U.S. Geological Survey during previous investigations and activities, including earlier studies of the recharge basins.

THE RECHARGE PROJECT

Over half of the water presently (1980) used in the Anchorage area is obtained from ground water derived mainly from the artesian aquifer. This withdrawal has caused water levels in the aquifer to decline, and since the early 1950's artificial recharge has been discussed as a method to alleviate this decline.

In 1970 the U.S. Geological Survey, in cooperation with the Municipality of Anchorage, began studying the feasibility of recharging the artesian aquifer by spreading water into recharge basins constructed in the Ship Creek alluvial fan. The first recharge basin was constructed in 1971. This basin was approximately ½ acre in area, and water was first introduced August 9, 1971. Artificial recharge was continued through September 27 at an average rate of 0.54 ft^3/s. In order to observe the impact of this recharge on the ground-water system, water levels were monitored in a line of observation wells installed as part of the artificial-recharge experiments, extending westward from the recharge basin to a distance of about 4,250 ft from the edge of the recharge basin. The location of these wells is shown in figure 1b.



Base from U.S. Geological Survey

Figure 1b.--Location of observation wells.

No artificial-recharge experiments were conducted in 1972.

In 1973 the ½-acre recharge basin was replaced with an 11-acre basin, and beginning July 25 water diverted from Ship Creek was introduced into it via a flume. Artificial recharge continued through November 19 and was then terminated for the year. Artificial recharge from this basin was begun again on May 20, 1974, and continued until November 11. The 1975 artificial recharge from this basin was also begun on May 20, but was terminated September 19. Artificial recharge from another 8-acre basin located just west of the 11-acre basin was begun August 14, 1975, and this recharge was also terminated September 19. The average volumetric recharge rates from these basins for the 3 years of operation are shown in table 1. As indicated by the table, 1974 recharge rates from the first basin exceeded those of 1973 and 1975, except for small periods of time. When the second recharge basin was added on August 14, 1975, combined 1975 recharge rates greatly exceeded those of 1974.

GEOHYDROLOGIC SETTING OF THE ANCHORAGE AREA AND RECHARGE BASINS

The unconfined aquifer generally extends from the flanks of the Chugach Mountains on the east to Cook Inlet, including the Turnagain and Knik Arms, on the north, west, and south (fig. 2). This aquifer consists of sand and gravel lenses intermixed with silty-sand and gravel. Its saturated thickness ranges from a few feet to about 80 ft and averages 20 ft (fig. 2). The aquifer is naturally recharged by rain, snowmelt, and leakage from streambeds.

The semipermeable clay unit that underlies the unconfined aquifer throughout most of the area (fig. 3) ranges in thickness from about 5 to 250 ft. This unit is saturated and provides hydraulic connection between the unconfined and artesian aquifers.

The artesian aquifer exists everywhere beneath the clay unit and merges with the unconfined aquifer where the clay unit is missing. This aquifer is composed of several layers of interbedded sand-and-gravel, till, and silty-clayey deposits. The more permeable sand-and-gravel layers are hydraulically connected and are considered to be a single aquifer. The thickness of the artesian aquifer is not known for much of Anchorage.

Between the mountain front and the eastern limit of the clay unit, the artesian and unconfined aquifers merge into a single unconfined aqufier. This composit aquifer primarily contains coarse alluvial-fan material with discontinuous silt and clay beds. Because of the absence of the confining clay layer, recharge to both the artesian and unconfined aquifers occurs in this area.

In the immediate area of the recharge basins, the unconfined composite aquifer is underlain by a till layer that ranges in thickness from about 10 to 50 ft. This unit is in turn underlain by consolidated bedrock. Movement of water in the till and bedrock is negligible and, for the purposes of this study, was neglected.

The thickness of the unconfined aquifer in the area of Spring Acres Subdivision is estimated to range from 0 to 20 ft. The clay unit in this area is estimated to range from 20 to 40 ft.

Table 1.--Total recharge rate, in cubic feet per second

Recharge period	1973	1974	Basin 1 1975	Basin 2 1975
May 22 - June 8	--	3.20	3.95	--
June 9 - June 28	--	5.07	4.98	--
June 29 - July 18	--	5.77	[c]5.47	--
July 19 - August 7	[a]3.54	6.31	5.66	--
August 8 - August 27	5.09	6.32	6.30	[e]13.71
August 28 - September 16	6.06	6.48	7.00	[f]15.14
September 17 - October 6	6.55	6.49	[d]4.28	18.30
October 7 - October 26	[b]6.32	6.10	1.72	--
October 27 - November 10	[b]3.27	5.98	--	--

[a]July 26 - August 7
[b]October 27 - November 19
[c]Recharge for 1973, 1974, and 1975 through August 7 modeled
[d]October 7 - October 19
[e]August 14 - August 27
[f]September 17 - September 19

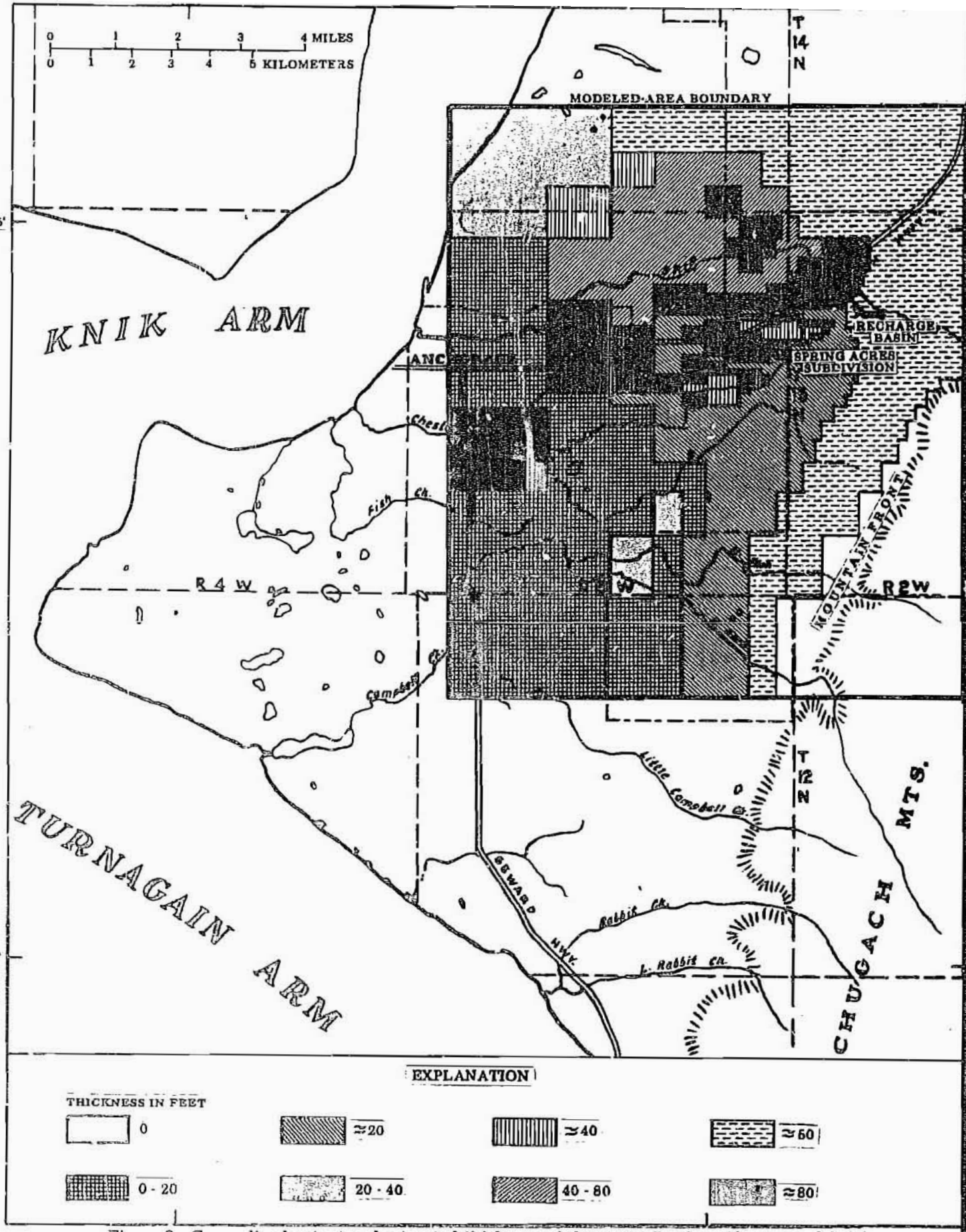


Figure 2.--Generalized extent and saturated thickness of the unconfined aquifer, as modeled.

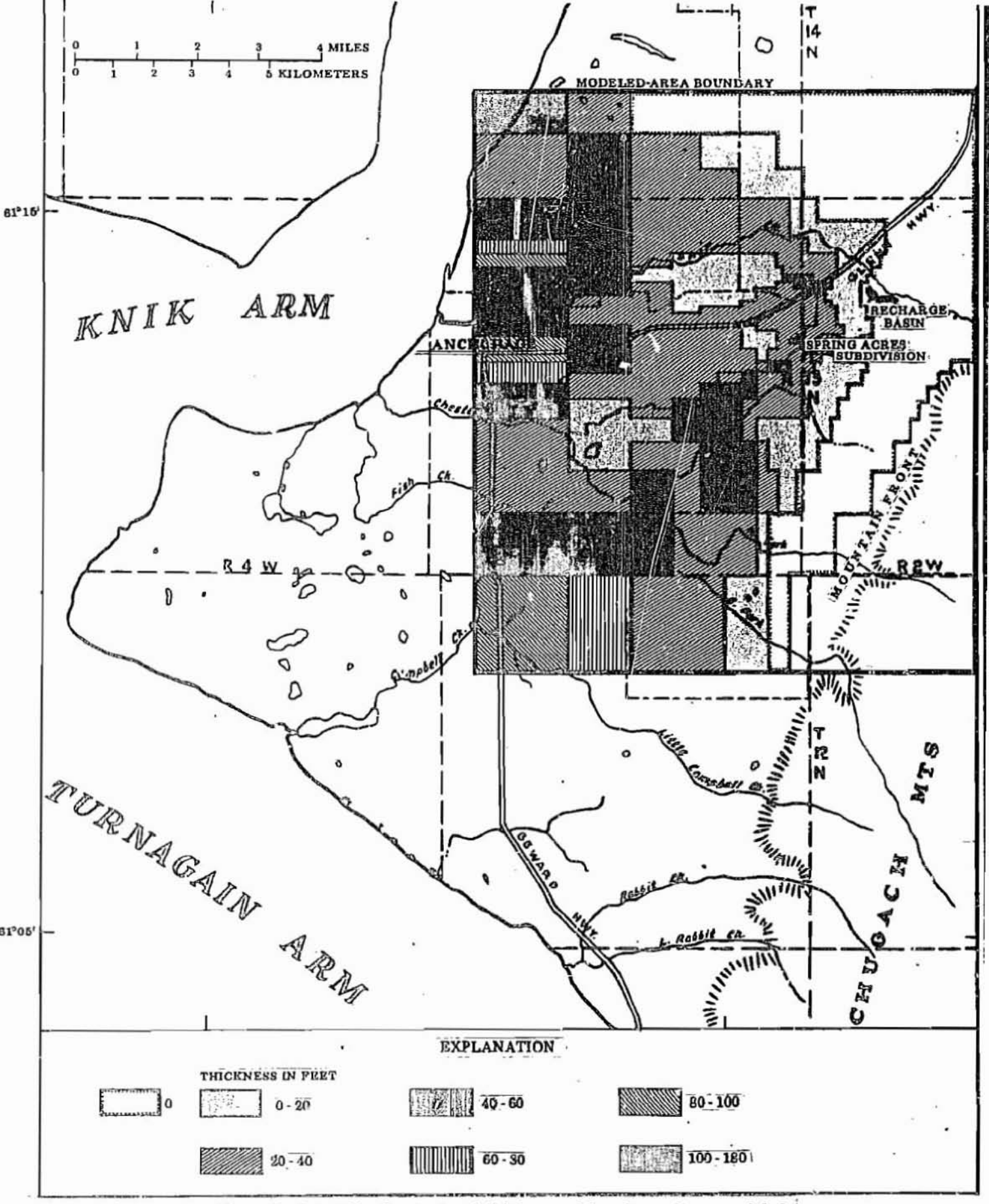


Figure 3.—Generalized extent and thickness of the clay unit, as modeled.

HYDRAULIC CHARACTERISTICS OF THE AQUIFER SYSTEM

The rate at which water can flow laterally through a material is proportional to the lateral hydraulic conductivity of the material. Similarly, the vertical flow rate is proportional to the vertical hydraulic conductivity. If lateral hydraulic conductivity is averaged through the saturated thickness of the deposit, then the thickness times the average lateral hydraulic conductivity equals the transmissivity of the deposit, or aquifer.

The storage coefficient of a deposit describes the amount of water released from or taken into storage by the deposit for a head change of 1 ft. The specific storage is the amount of water released from or taken into storage per unit volume of material per unit change in head. In a confined aquifer, storage coefficient is equal to the specific storage times aquifer thickness.

Previous work in the area of the recharge basins has resulted in a range of values being reported for the lateral hydraulic conductivity of the unconfined aquifer in this area. Anderson (1977) identified an average value of 225 ft/day for this parameter. An aquifer test and a specific-capacity test conducted in the area gave values for aquifer transmissivity of approximately 11,000 ft^2/day and 4,000 ft^2/day, respectively. The first value corresponds to an average lateral hydraulic conductivity of 220 ft/day and the second value an average lateral hydraulic conductivity of 80 ft/day. Freethey (written communication, 1980) used a transmissivity value of 3,400 ft^2/day for this area in a two-dimensional model of th Anchorage basin. This value corresponds to a value of 68 ft/day for the average lateral hydraulic conductivity of the aquifer.

Anderson established a value of 0.15 for the coefficient of storage of the unconfined aquifer in the area of the recharge basins. Freethey (written communication, 1980) also estimated values for the transmissivity of the artesian aquifer (fig. 4) and vertical hydraulic conductivity of the clay unit (fig. 5). He established a value for the specific storage of the clay unit ranging from 10^{-5} to 10^{-6} per foot. Freethey also indicates that storage coefficients calculated from aquifer tests in the artesian aquifer generaly range from 10^{-4} to 10^{-5} through the Anchorage area. The lateral movement of water in the clay unit is insignificant for the purposes of this study, although, as will be discussed later, lateral flow in the clay unit was simulated for model convenience.

Based on the sustained infiltration rates from the recharge basins and the lithology of the unconfined aquifer, the vertical hydraulic conductivity of the unconfined aquifer was estimated to range from a low value of 1.4 ft/day to a maximum value of approximately one-tenth the lateral hydraulic conductivity of the aquifer.

GROUND-WATER FLOW

The general direction of ground-water movement in the study area is depicted in figure 6, which represents an idealized geologic section along the course of Ship Creek. Approximately 8 to 15 ft^3/s of water are lost by Ship Creek to the ground-water system between the Fort Richardson and Elmendorf gaging stations (Waller, 1964). This water, along with water entering the ground-water system from

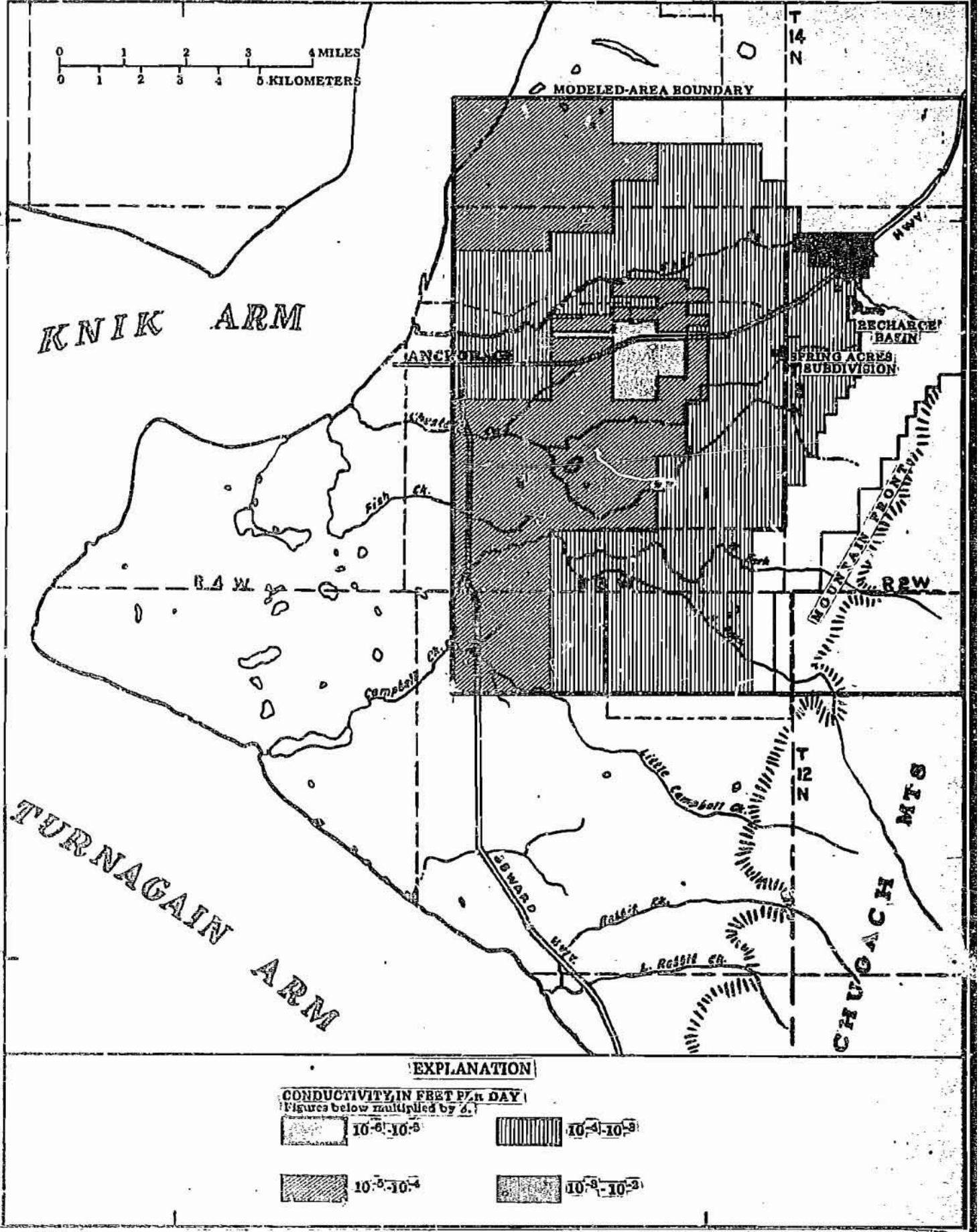


Figure 5.--Areal variation in generalized vertical hydraulic conductivity of the confining clay unit, as modeled.

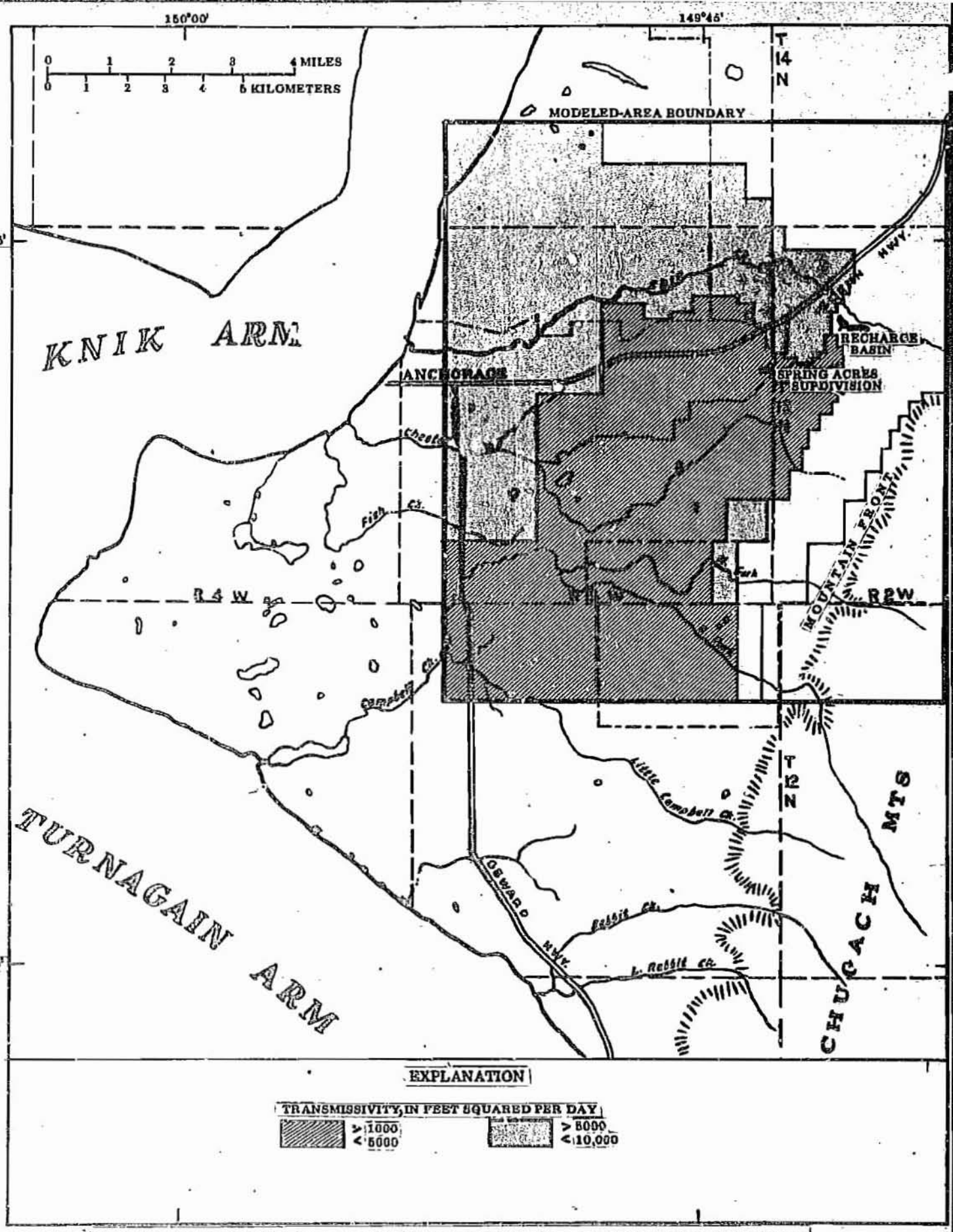
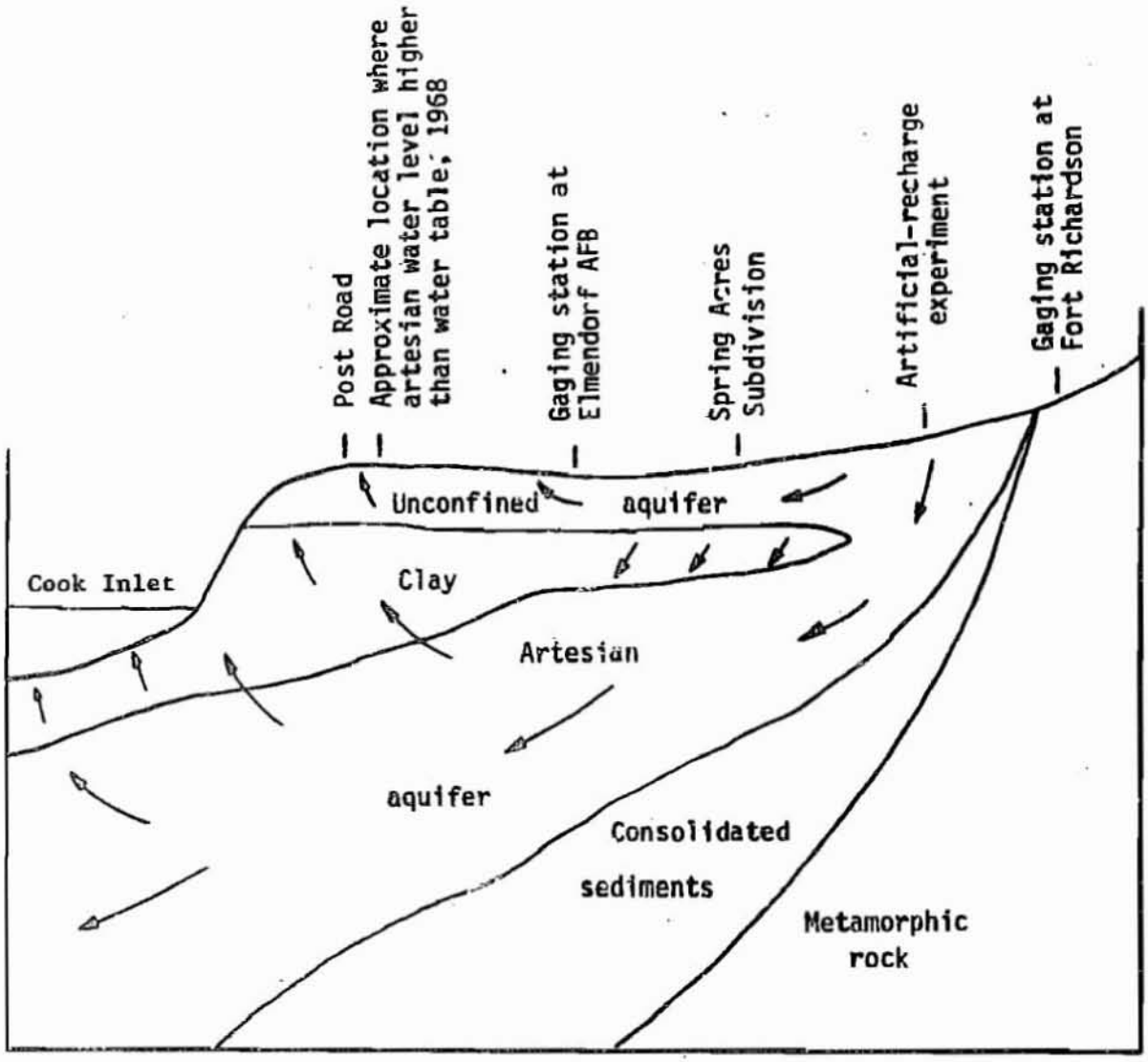


Figure 4.–Areal variation in generalized transmissivity of the artesian aquifer, as modeled.



NOT TO SCALE

MODIFIED FROM WEEKS (1970)

Figure 6.–Idealized direction of ground-water movement along Ship Creek.

rain and snowmelt, moves downward to recharge the unconfined and artesian aquifers. Upon reaching these aquifers, it then moves in a predominantly lateral direction, eventually to discharge into Cook Inlet, into Ship Creek, or as springs. Water is also discharged as well pumpage.

At least 22 ft^3/s is discharged from the unconfined aquifer to Ship Creek below the Elmendorf gaging station, changing Ship Creek from a losing to a gaining stream below this point (Weeks, 1970).

Water levels in 1968 in the upper unconfined aquifer were higher than the water levels in the artesian aquifer beginning from the eastern most extent of the artesian aquifer near the Fort Richardson gaging station to a location approximately 0.5 mi above Post Road (Weeks, 1970). Consequently, in this area water from the unconfined aquifer moves downward through the clay unit into the artesian aquifer. Where the water level in the artesian aquifer is higher than that in the unconfined aquifer, the direction of vertical flow is upward. Water from the artesian aquifer also discharges through the clay unit into Cook Inlet. Pumping from the artesian aquifer has lowered water levels and caused a progressive shift seaward of the location where artesian water levels are higher than the water table.

The relative position of Spring Acres Subdivision in the idealized flow system appears in figure 6; it is not along the course of Ship Creek.

WATER-LEVEL CHANGES

Water levels in the artesian and unconfined aquifers fluctuate seasonally, with highs occurring in late summer to early winter and lows generally occurring in the spring (fig.7a). These fluctuations are in response to recharge to the ground-water system that generally occurs during spring and early summer. Recharge to the ground-water system is derived from (1) streams originating in the Chugach Mountains that lose part of the water in their upper reaches as they cross the Anchorage lowlands, and (2) infiltration of rain and snowmelt to the water table. Seasonal rises in water levels up to 18 ft have been recorded in the Anchorage area. The greater rises occur in the vicinity of the foothills where precipitation is higher. Seasonal rises up to 4 ft are more common in the lowlands. Water-level fluctuations in the unconfined aquifer at Spring Acres Subdivision and near the artificial-recharge basin are shown in figures 8 and 9, respectively. Seasonal highs in the artesian aquifer lag 1 to 4 months behind those in the unconfined.

Water levels rise when recharge to the ground-water system exceeds discharge. As streamflow increases in Ship Creek and other streams draining the Chugach Mountains, some of this water is lost to the ground-water system. Water-level fluctuations in observation wells AK1412, screened in the unconfined aquifer, and AK[illegible], screened in the artesian aquifer, are shown in figure 7a. These wells are among the nearest wells to Spring Acres Subdivision and the recharge basin for which long-term information on water-level fluctuations in the two aquifers is available. Figure 7b is a hydrograph of Ship Creek discharge at Anchorage (Fort Richardson) from October 1968 to September 1977. Similarity between figures 7a and 7b is apparent and indicates the close connection between water-level rises in the general vicinity of Ship Creek and discharge of Ship Creek.

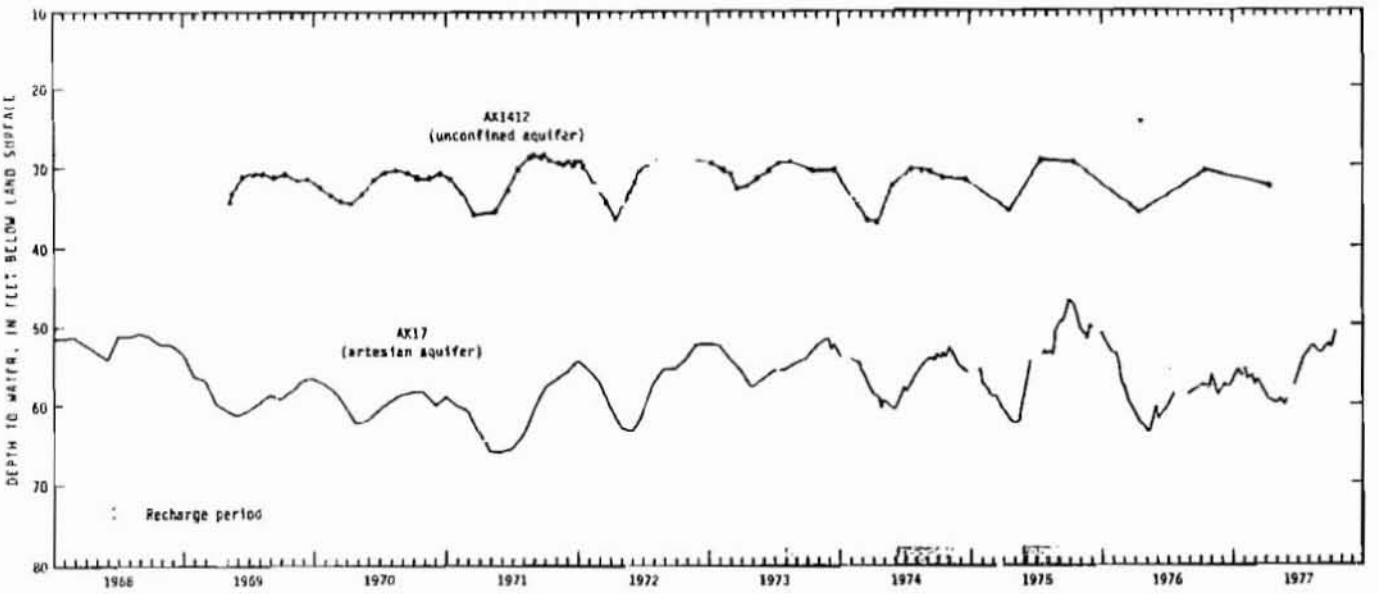


Figure 7a.–Hydrographs of observation wells AK1412 and AK17.

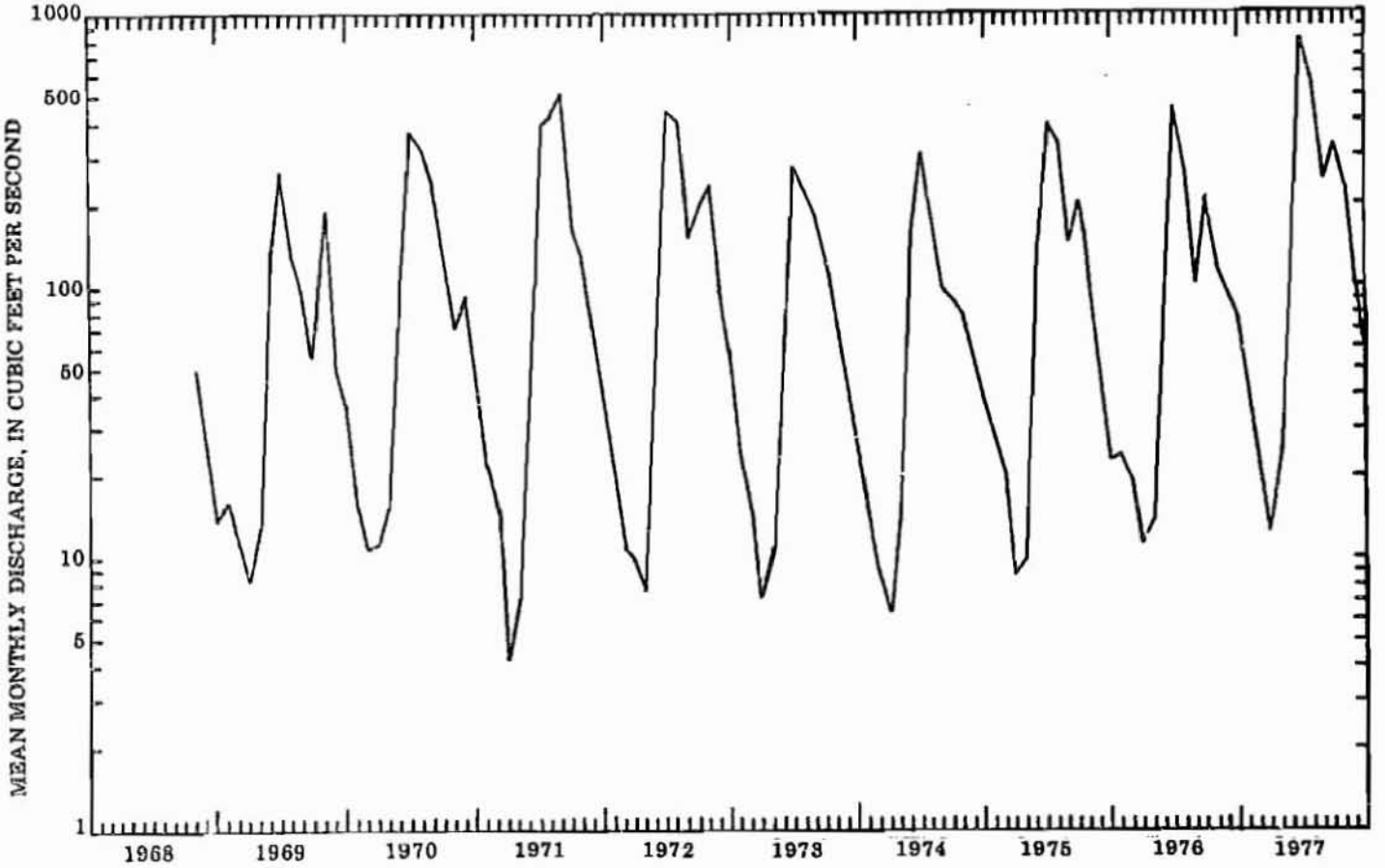


Figure 7b.–Mean monthly discharge of Ship Creek, 1968 - 1977.

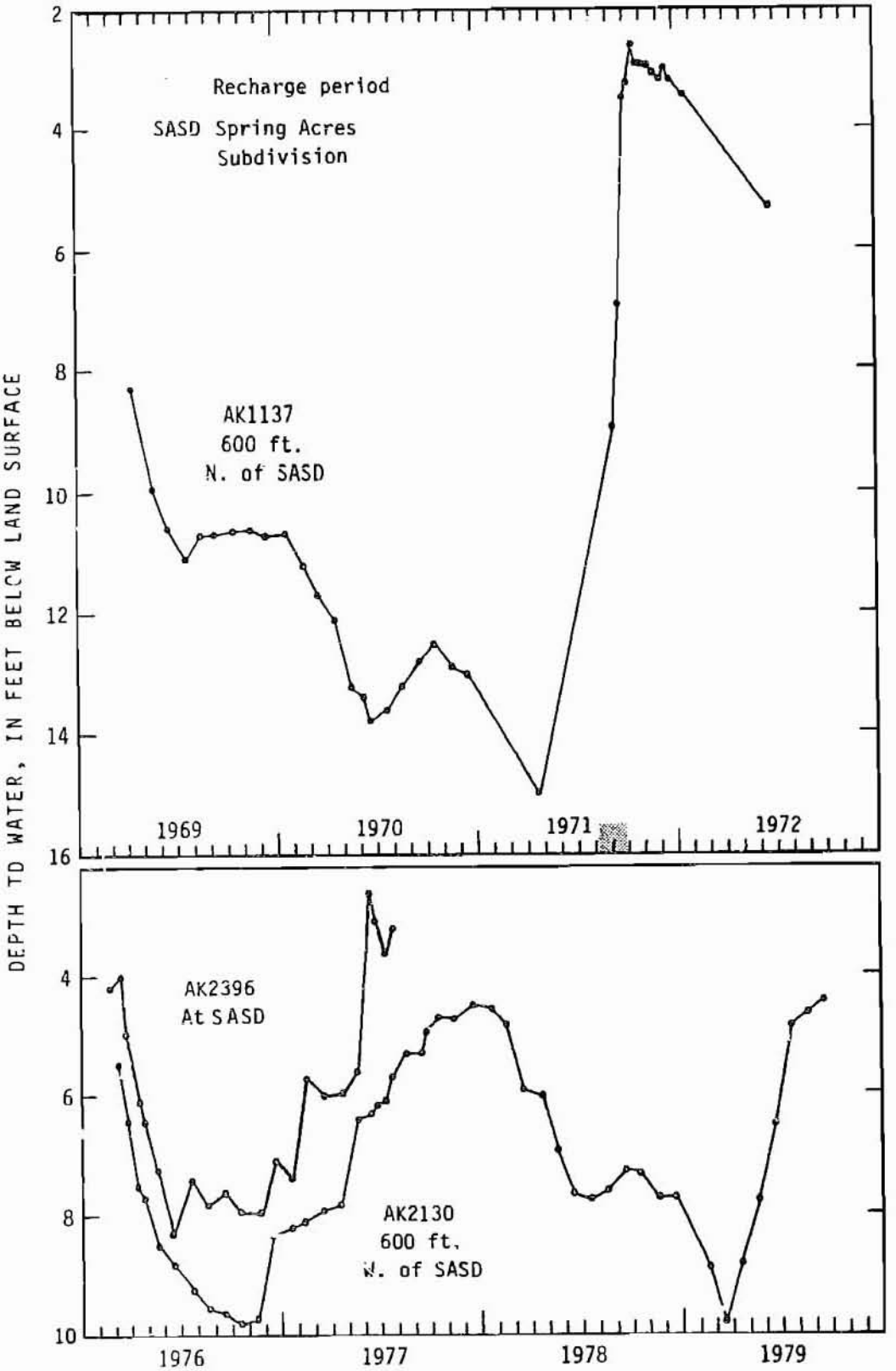


Figure 8.–Hydrographs of observation wells AK1137, AK2396, and AK2130.

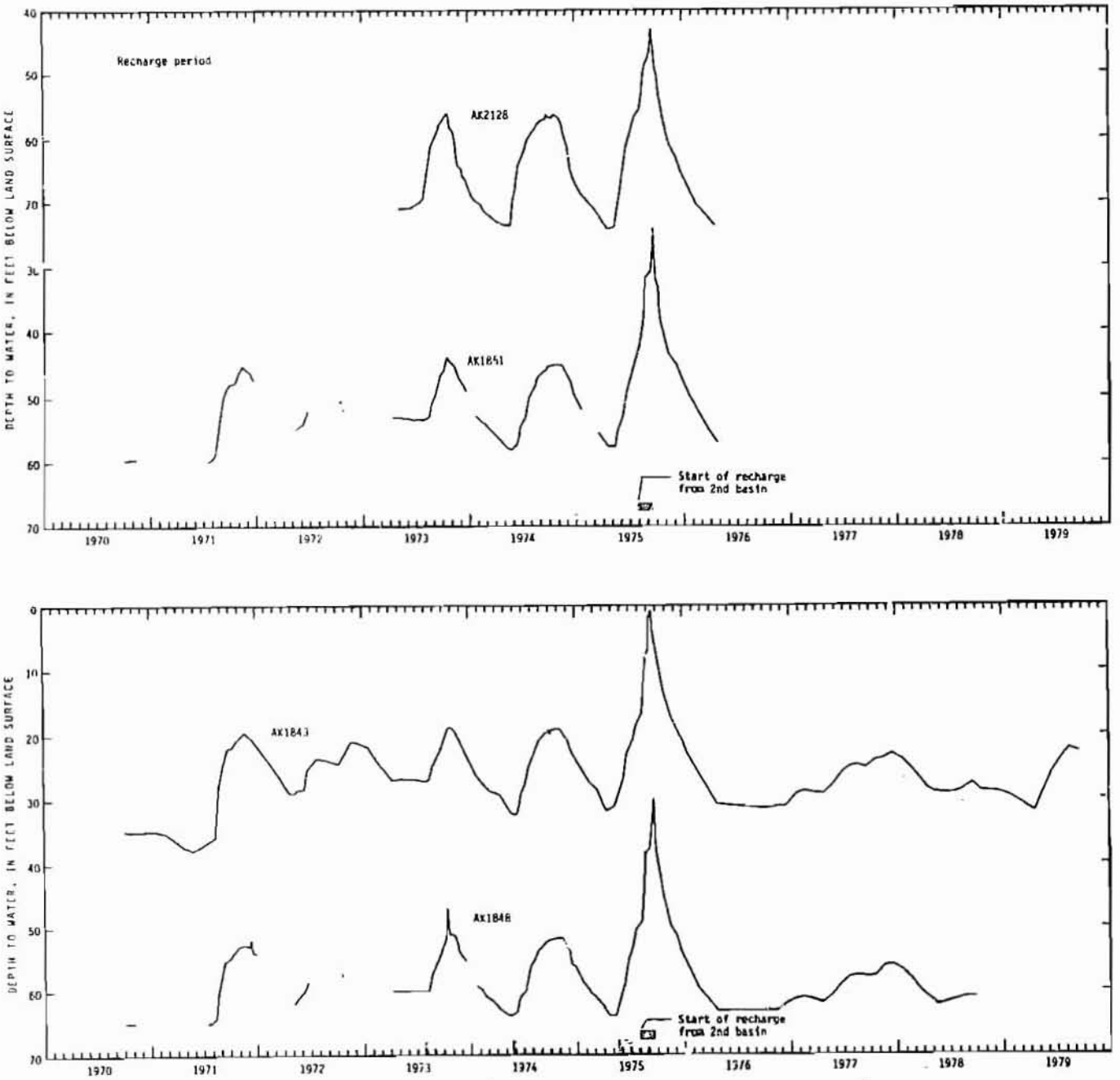


Figure 9.–Hydrographs of AK2128, AK1848, AK1851, and AK1843.

Water levels decline when discharge from the ground-water system exceeds recharge. Discharge from the ground-water system occurs naturally into the lower reaches of the streams in Anchorage and into the Knik and Turnagain Arms of Cook Inlet. Man-made discharge by ground-water pumping also occurs. Prior to pumping, recharge to the ground-water system in Anchorage equalled discharge on a long term basis, so that the long-term average yearly water level at a given location was nearly constant. Ground-water pumping has upset the natural equilibrium and resulted in declining water levels in both the artesian and unconfined aquifers. Pumping from either aquifer can lower water levels in the other, although there is a time lag between pumping in one aquifer and response in the other aquifer.

Water levels in the unconfined aquifer have been measured in the immediate vicinity of Spring Acres Subdivision in wells AK1137, and AK2130 (fig. 8). Observation well AK1138 is also in the vicinity of Spring Acres and has been measured for a longer period of time than the other wells, dating from 1969 to the present; unfortunately the screen of this well is set in silt and clay, and measurements are not indicative of the unconfined aquifer. Water-level measurements in well AK1137 began in April 1969 and were terminated in June 1972. Well AK2130 was installed as a replacement for AK1137. Measurements of water levels in well AK2130 began in February 1976 and continue to the present. These two wells are located approximately 600 ft north of Spring Acres Subdivision.

An observation well, AK2396, was constructed in the unconfined aquifer at Spring Acres Subdivision by the U.S. Geological Survey in 1976. Water-level measurements in this well began in February 1976 and terminated in July 1977 when the well was inadvertently destroyed.

The hydrographs of AK1137 and AK2130, figure 8, provide information on fluctuations of the water table near Spring Acres for a period of about 3 years prior to the recharge experiments and 4 years following the experiment. For the period of record, depth to the water table has ranged from 2.6 to 15.6 ft below land surface. An annual rise of water levels up to 12.4 ft was recorded. This particular rise is believed to be related to recharge to the ground-water system derived from the second largest flood of record, that occurred in Ship Creek on August 9, 1971. The 1971 artificial-recharge experiment was also being conducted during this time period, but the average rate of artificial recharge was insignificant compared to estimated rates of natural recharge from Ship Creek. Model analysis conducted during the course of this study indicated that the 1971 artificial-recharge experiments would not have induced a water-level rise at Spring Acres.

The hydrograph of AK2396 at Spring Acres shows the depth to water ranged from 2.6 ft to 8.6 ft for the 1½-year period of record. Average depth to water at Spring Acres was about 6 ft. Comparison of the hydrographs for AK2396 and AK2130 indicate that water levels at Spring Acres fluctuated in a manner similar to those some 600 ft to the north of the subdivision.

It is important to note, for the purposes of this study, that the depth to the water table approximately 600 ft from Spring Acres for the 3 years prior to the recharge experiments and the 4 years following the experiment was 15 ft or less. Of more importance, the water table was only 2.6 ft below land surface 600 ft north of Spring Acres in October 1971 and at Spring Acres in June 1977.

The only information on water levels in the immediate area of Spring Acres that is available for the period of the recharge experiments, 1973 to 1975, comes from five holes augered in March 1975 by a consultant for soil tests at Spring Acres Subdivision prior to construction. Data from these auger holes indicate that the depth to water was approximately 6-7 ft. The direction of water-level change at this time cannot be deduced from the available data.

Water Levels at the Artificial Recharge Site

Hydrographs from four of the piezometers installed as observation wells for the artificial-recharge experiment are shown in figure 9. Water-level measurements made in these wells over the time period shown in figure 9 are given in table 2. These wells, AK2128, AK1848, AK1851, and AK1843, are screened at varying depths in the unconfined aquifer. Figure 10 shows a geologic section through the area of the recharge basin along the line of the wells. Four observations pertinent to this study can be made from the hydrographs. First, the direction of water-level fluctuation was consistent from well to well. Second, for those years preceding and following the recharge experiments, seasonal changes in water levels were apparent in AK1843, with lows generally in the late spring and highs in late fall. Seasonal changes in water levels are also apparent in AK1848 following the experiments. Third, the amplitude of seasonal rises, unaffected by the artificial recharge, ranged from about 7 to 10 ft. Fourth, for those years unaffected by the 1973-75 artificial recharge and for which comparisons are possible (1971 and 1977), the amplitude of the observed rise was greatest in observation well AK1843, the farthest from the recharge basin. This is seen by comparing the rises measured in AK1848, AK1851, and AK1843 in 1971, and in AK1848 and AK1843 in 1977. For both years the greatest rise was recorded in AK1843, the farthest well from the recharge basin. The effect of the 1971 artificial recharge would have been to cause water levels nearest the recharge basin to rise the most, so that this recharge does not account for the observed variation in water level rises. The observed variation in this rise ranged from about 1.2 to 4 ft.

The high water levels in September 1975 (fig. 9) occurred after the water problems of July to August 1975 were encountered at Spring Acres Subdivision and are not considered further in this report.

Water-Level Rises After 58 and 80 Days of Artificial Recharge, 1974 and 1975

The altitude of the water level measured in piezometers AK2128, AK1848, AK1851, AK1843, and AK1044, following 58 and 80 days of recharge, are shown for 1974 and 1975 in figure 11. These times were chosen because they bracket the time period following the start of recharge on May 20, 1975, in which severe water problems were reported for Spring Acres Subdivision, late July-early August 1975. Water-level rises for the same time periods are shown in figures 12a and 12b. Both 1974 and 1975 rises were plotted and compared because artificial recharge rates in 1974 slightly exceeded recharge rates in 1975, table 1, for this time period, yet no water problems were reported in the Spring Acres Subdivision area in 1974. The rises shown in figures 12a and 12b have at least two components: (1) the rise induced by the recharge experiment, and (2) the natural annual rise.

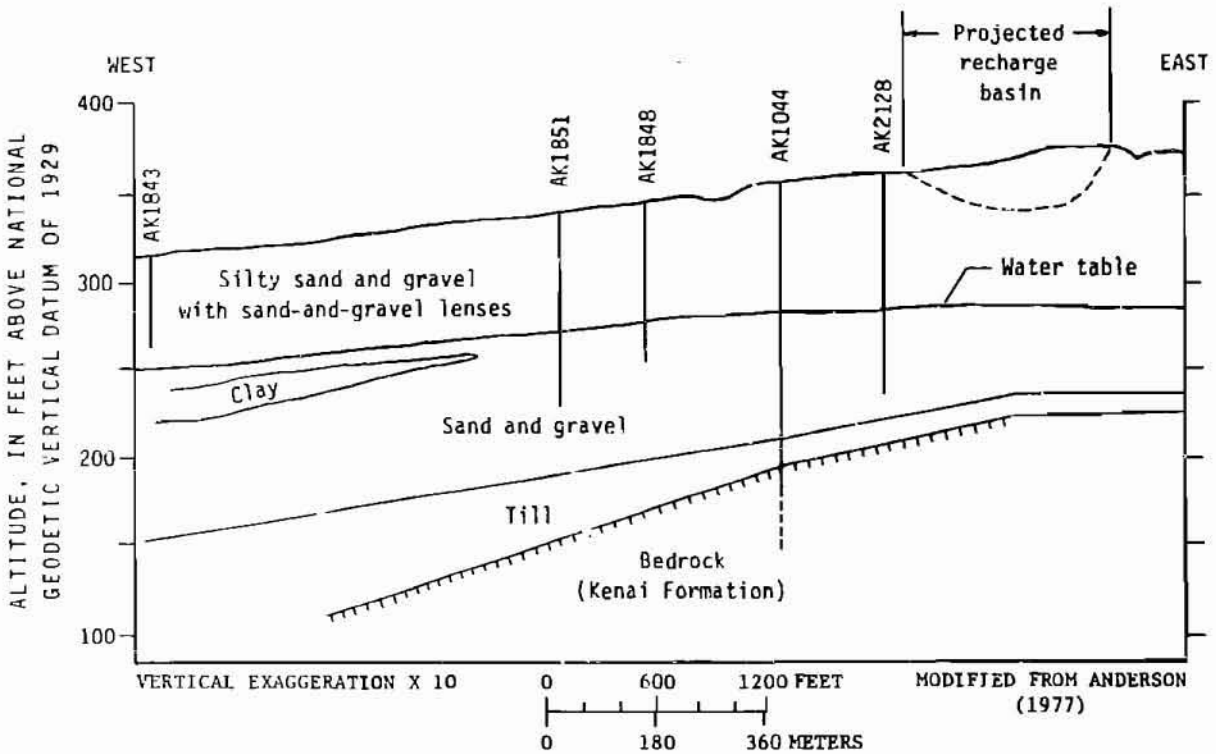


Figure 10.–Geologic section through recharge basin.

Table 2.--Depth to water in observation wells. Depth shown in feet below land surface datum.

Well no. AK2128		Well no. AK2128		Well no. AK2128		Well no. AK1851		Well no. AK1851	
Date	Water Level	Date	Water Level	Date	Water-Level	Date	Water-Level	Date	Water-Level
May 11, 1973	70.97	June 21, 1974	65.09	Dec. 18, 1974	64.69	Sept. 9, 1970	59.45	Oct. 20, 1971	47.15
May 17	70.83	June 24	64.39	Dec. 29	66.00	Oct. 2	59.42	Oct. 22	47.05
May 31	70.65	June 26	64.17	Jan. 21, 1975	68.41	Oct. 4	59.49	Oct. 26	46.79
June 7	70.87	June 28	63.82	Feb. 19	69.97	Oct. 5	59.43	Oct. 28	46.32
Aug. 1	68.99	July 1	63.22	March 5	70.91	Oct. 8	59.48	Nov. 1	46.02
Aug. 3	68.22	July 3	62.96	March 19	72.05	Oct. 9	59.34	Nov. 3	46.13
Aug. 5	67.52	July 5	62.64	April 21	73.95	Oct. 10	59.50	Nov. 5	45.94
Aug. 6	67.17	July 8	62.17	May 8	73.87	Oct. 12	59.44	Nov. 8	45.79
Aug. 10	65.18	July 10	61.93	May 23	71.06	Oct. 13	59.46	Nov. 12	45.86
Aug. 14	65.25	July 12	61.74	June 6	65.29	Oct. 14	59.41	Nov. 15	45.50
Aug. 17	64.39	July 15	61.19	June 20	61.16	Oct. 15	59.47	Nov. 19	45.80
Aug. 21	63.30	July 17	60.93	July 3	58.85	Oct. 16	59.44	Nov. 23	45.83
Aug. 23	62.86	July 20	60.68	July 18	56.88	Oct. 18	59.46	Nov. 26	45.74
Aug. 27	61.85	July 22	60.34	Aug. 5	55.57	Oct. 22	59.56	Nov. 29	45.76
Aug. 30	61.30	July 26	60.03	Aug. 15	54.92	Oct. 24	59.51	Dec. 8	46.27
Sept. 4	60.39	July 29	59.73	Aug. 18	53.12	Oct. 27	59.52	Dec. 15	46.27
Sept. 7	59.87	Aug. 2	59.27	Aug. 20	51.88	Oct. 30	59.47	Dec. 24	47.09
Sept. 11	59.61	Aug. 5	58.99	Aug. 22	49.83	Nov. 3	59.50	Dec. 30	47.31
Sept. 14	59.18	Aug. 9	58.82	Aug. 27	49.13	Nov. 6	59.51	May 16, 1972	55.38
Sept. 18	58.87	Aug. 12	58.58	Aug. 29	48.76	July 22, 1971	60.02	May 26	54.67
Sept. 26	57.87	Aug. 16	58.35	Sept. 2	48.19	July 30	59.86	June 1	54.33
Sept. 27	58.08	Aug. 19	58.03	Sept. 5	47.85	Aug. 3	59.78	June 13	53.51
Oct. 4	57.32	Aug. 22	57.83	Sept. 8	47.21	Aug. 15	59.04	June 27	52.12
Oct. 10	56.62	Aug. 26	57.83	Sept. 16	43.68	Aug. 18	58.17	Oct. 13	50.72
Oct. 17	56.22	Aug. 29	57.70	Sept. 19	42.94	Aug. 20	57.48	April 9, 1973	53.21
Oct. 24	56.80	Sept. 2	57.37	Sept. 23	46.03	Aug. 21	56.76	May 11	53.29
Oct. 31	58.16	Sept. 5	57.16	Sept. 26	47.42	Aug. 23	55.73	June 7	53.22
Nov. 1	58.35	Sept. 9	57.05	Sept. 30	48.96	Aug. 24	55.09	June 22	53.35
Nov. 2	58.50	Sept. 12	57.05	Oct. 4	50.62	Aug. 27	53.44	July 5	53.33
Nov. 5	58.80	Sept. 16	56.95	Oct. 14	53.50	Aug. 28	52.87	July 19	53.41
Nov. 7	59.30	Sept. 20	56.75	Oct. 31	58.02	Aug. 29	52.54	July 26	53.51
Nov. 14	60.67	Sept. 23	56.47	Nov. 18	61.07	Sept. 2	51.08	Aug. 1	53.55
Nov. 23	62.80	Sept. 27	56.63	Dec. 5	62.72	Sept. 5	50.47	Aug. 3	53.46
Nov. 28	63.97	Sept. 30	56.33	Dec. 22	64.80	Sept. 6	50.24	Aug. 7	53.33
Dec. 5	64.79	Oct. 3	57.03	Jan. 21, 1976	67.55	Sept. 8	49.96	Aug. 10	53.00
Dec. 12	65.71	Oct. 15	56.59	Feb. 26	70.13	Sept. 10	49.57	Aug. 14	52.77
Dec. 18	66.26	Oct. 21	56.47	March 26	71.92	Sept. 12	49.49	Aug. 17	52.40
Jan. 10, 1974	68.50	Oct. 29	56.43	April 23	73.45	Sept. 14	49.24	Aug. 21	52.31
Jan. 29	69.75	Nov. 4	56.77			Sept. 16	49.03	Aug. 23	51.59
Feb. 13	70.43	Nov. 11	57.02			Sept. 18	48.75	Aug. 27	51.04
Feb. 27	71.18	Nov. 13	56.86			Sept. 20	48.65	Aug. 30	50.90
March 13	71.82	Nov. 15	57.55			Sept. 22	48.55	Sept. 4	49.70
April 4	72.85	Nov. 18	57.88			Sept. 24	48.54	Sept. 7	49.16
May 1	73.45	Nov. 20	58.03			Sept. 26	48.38	Sept. 11	48.62
May 20	73.53	Nov. 22	58.50			Sept. 29	48.02	Sept. 14	48.18
June 7	69.12	Nov. 25	59.16			Oct. 4	48.03	Sept. 19	47.34
June 10	68.03	Nov. 27	59.40			Oct. 6	48.03	Sept. 26	46.60
June 12	67.40	Nov. 29	60.16			Oct. 8	47.85	Sept. 27	46.58
June 14	66.72	Dec. 2	60.52			Oct. 12	47.62	Oct. 4	46.04
June 17	66.04	Dec. 5	61.28			Oct. 14	47.72	Oct. 10	45.03
June 19	65.46	Dec. 11	63.11			Oct. 18	47.48	Oct. 17	44.30

Table 2.--Depth to water in observation wells. Depth shown in feet below land surface datum--Continued

Well no. AK1851		Well no. AK1851		Well no. AK1851		Well no. AK1843		Well no. AK1843	
Date	Water Level	Date	Water Level	Date	Water-Level	Date	Water-Level	Date	Water-Level
Oct. 24, 1973	44.30	Sept. 2, 1974	46.47	Sept. 1[illegible], 1975	23.91	Sept. 15, 1970	35.00	Sept. 20, 1971	22.73
Oct. 31	44.55	Sept. 5	46.26	Sept. 23	28.95	Oct. 2	34.90	Sept. 24	22.52
Nov. 7	44.95	Sept. 9	46.09	Sept. 26	30.36	Oct. 4	34.94	Sept. 26	22.25
Nov. 14	45.55	Sept. 12	45.97	Sept. 30	31.78	Oct. 5	34.90	Sept. 29	21.92
Nov. 28	47.02	Sept. 16	45.81	Oct. 4	33.29	Oct. 6	34.94	Oct. 4	21.95
Dec. 5	47.75	Sept. 20	45.65	Oct. 15	35.98	Oct. 7	34.85	Oct. 25	20.89
Dec. 12	48.35	Sept. 23	45.40	Oct. 27	38.83	Oct. 8	34.91	Nov. 23	19.94
Dec. 18	48.88	Sept. 27	45.40	Nov. 18	43.04	Oct. 9	34.86	Dec. 23	20.80
Jan. 29, 1974	52.55	Sept. 30	45.16	Dec. 5	44.73	Oct. 10	34.94	Jan. 22, 1972	22.44
Feb. 13	53.42	Oct. 3	45.27	Dec. 22	46.56	Oct. 12	34.92	Feb. 23	24.49
Feb. 27	54.15	Oct. 8	45.12	Jan. 21, 1976	49.49	Oct. 13	35.02	March 24	26.54
March 13	54.95	Oct. 11	45.00	Feb. 26	52.59	Oct. 14	34.87	April 14	28.13
April 5	56.41	Oct. 15	45.03	March 26	54.87	Oct. 15	34.92	April 25	28.92
May 1	57.45	Oct. 21	44.90	April 23	56.84	Oct. 16	34.90	May 16	28.98
May 7	57.56	Oct. 29	44.89			Oct. 18	34.90	May 24	28.69
May 9	57.68	Nov. 4	44.99			Oct. 22	34.91	May 26	28.55
May 20	57.88	Nov. 11	45.12			Oct. 24	34.93	June 13	28.40
May 28	57.99	Nov. 13	44.99			Oct. 27	34.96	June 27	26.08
June 5	57.64	Nov. 15	45.20			Oct. 30	34.90	July 10	24.32
June 7	57.55	Nov. 18	45.22			Nov. 3	35.00	July 25	23.45
June 10	57.25	Nov. 20	45.25			Nov. 6	34.99	Aug. 24	23.79
June 12	57.07	Nov. 22	45.47			Jan. 22, 1971	34.87	Oct. 13	24.52
June 14	56.83	Nov. 25	45.76			Feb. 22	35.60	Oct. 23	23.35
June 17	56.38	Nov. 27	45.80			March 25	36.55	Nov. 21	20.96
June 19	55.99	Nov. 29	46.26			April 22	37.39	Dec. 21	21.33
June 21	55.72	Dec. 5	46.83			May 14	37.74	Jan. 22, 1973	21.88
June 24	55.16	Dec. 11	47.47			May 17	37.76	Feb. 22	24.20
June 26	54.87	Dec. 18	48.29			May 25	37.75	March 22	25.76
June 28	54.51	Dec. 26	49.25			June 25	37.19	April 9	26.95
July 1	53.97	Jan 21, 1975	51.72			July 22	36.53	April 23	27.06
July 3	53.66	March 19	55.61			July 23	36.48	May 11	26.69
July 5	53.35	April 21	57.56			July 30	36.19	May 24	26.99
July 8	52.84	May 8	57.67			Aug. 3	36.01	May 31	27.00
July 10	52.55	May 23	55.60			Aug. 15	34.53	June 7	27.02
July 12	52.27	June 6	52.76			Aug. 18	33.69	June 21	27.07
July 15	51.77	June 20	49.07			Aug. 21	32.33	June 22	27.02
July 17	51.42	July 3	46.28			Aug. 24	30.71	July 5	27.20
July 19	[illegible].18	July 18	43.84			Aug. 26	29.47	July 19	27.28
July 22	50.67	Aug. 5	42.20			Aug. 27	28.83	July 26	27.39
July 26	50.12	Aug. 15	40.88			Aug. 28	28.16	Aug. 1	27.45
July 29	49.73	Aug. 18	39.00			Aug. 29	27.67	Aug. 3	27.36
Aug. 2	49.20	Aug. 20	36.06			Sept. 2	25.83	Aug. 7	27.32
Aug. 5	48.80	Aug. 22	34.60			Sept. 5	24.99	Aug. 10	27.10
Aug. 9	48.40	Aug. 25	33.00			Sept. 6	24.70	Aug. 14	26.80
Aug. 12	48.08	Aug. 27	32.84			Sept. 8	24.30	Aug. 17	26.48
Aug. 16	47.72	Aug. 29	31.84			Sept. 10	23.84	Aug. 21	25.96
Aug. 19	47.42	Sept. 2	31.05			Sept. 12	23.71	Aug. 23	25.72
Aug. 22	47.18	Sept. 5	30.84			Sept. 14	23.44	Aug. 27	25.14
Aug. 26	46.98	Sept. 8	29.56			Sept. 16	23.15	Aug. 30	24.69
Aug. 29	46.75	Sept. 15	25.05			Sept. 18	22.82	Sept. 4	23.90

Table 2.--Depth to water in observation wells. Depth shown in feet below land surface datum--Continued

Well no. AK1843 Date	Water Level	Well no. AK1843 Date	Water Level	Well no. AK1843 Date	Water-Level	Well no. AK1843 Date	Water-Level	Well no. AK1848 Date	Water-Level
Sept. 7, 1973	23.40	July 29, 1974	24.08	July 3, 1975	20.70	March 16, 1978	26.86	Sept. 15, 1970	64.81
Sept. 11	22.80	Aug. 2	23.53	July 18	18.40	April 17	28.44	Oct. 2	64.82
Sept. 14	22.46	Aug. 5	23.15	Aug. 5	16.81	May 16	28.81	Oct. 3	64.84
Sept. 20	21.64	Aug. 9	22.76	Aug. 15	16.00	June 12	29.19	Oct. 4	64.88
Sept. 26	21.93	Aug. 12	22.42	Aug. 18	13.60	July 13	29.08	Oct. 5	64.83
Oct. 2	20.44	Aug. 16	22.05	Aug. 20	11.88	Aug. 15	28.61	Oct. 6	64.87
Oct. 10	19.39	Aug. 19	21.75	Aug. 22	10.80	Sept. 18	27.52	Oct. 7	64.84
Oct. 17	18.78	Aug. 22	21.51	Aug. 25	9.20	Oct. 19	28.78	Oct. 8	64.84
Oct. 24	18.70	Aug. 26	21.35	Aug. 27	8.45	Nov. 21	29.05	Oct. 9	64.76
Oct. 31	18.89	Aug. 29	21.11	Aug. 29	7.98	Dec. 22	29.25	Oct. 10	64.92
Nov. 7	19.30	Sept. 2	20.85	Sept. 2	7.23	Jan. 24, 1979	29.94	Oct. 11	64.84
Nov. 14	19.77	Sept. 5	20.63	Sept. 5	6.87	April 23	32.32	Oct. 12	64.86
Nov. 23	20.57	Sept. 9	20.45	Sept. 8	5.96	May 21	28.90	Oct. 13	64.39
Nov. 28	21.12	Sept. 12	20.35	Sept. 15	2.38	June 22	26.07	Oct. 14	64.85
Dec. 5	21.70	Sept. 16	20.23	Sept. 17	1.49	July 24	24.01	Oct. 15	64.88
Dec. 12	22.29	Sept. 20	20.05	Sept. 19	1.26	Aug. 23	22.46	Oct. 16	64.86
Dec. 18	22.78	Sept. 23	19.77	Sept. 22	4.19	Sept. 24	23.01	Oct. 18	64.88
Jan. 10, 1974	24.93	Sept. 27	19.30	Sept. 23	4.75	Oct. 23	23.65	Oct. 22	64.99
Jan. 29	26.32	Sept. 30	19.50	Sept. 26	5.91	Nov. 20	24.03	Oct. 24	64.95
Feb. 13	27.20	Oct. 3	19.68	Sept. 30	7.08	Dec. 19	23.91	Oct. 27	64.95
Feb. 27	27.95	Oct. 8	19.46	Oct. 4	8.42			Oct. 30	64.89
March 13	28.78	Oct. 11	19.33	Oct. 14	10.70			Nov. 3	64.90
April 5	29.32	Oct. 15	19.40	Oct. 27	13.32			Nov. 6	64.92
May 2	31.51	Oct. 21	19.22	Nov. 18	17.25			July 22, 1971	65.26
May 7	31.70	Oct. 29	19.25	Dec. 5	18.83			July 30	65.07
May 9	31.81	Nov. 4	19.38	Dec. 22	20.53			Aug. 3	64.99
May 20	32.16	Nov. 11	19.50	Jan. 21, 1976	23.27			Aug. 15	64.07
May 24	32.23	Nov. 13	19.19	Feb. 26	26.28			Aug. 18	63.07
May 28	32.27	Nov. 15	19.49	March 23	28.35			Aug. 20	62.48
June 5	32.12	Nov. 18	19.49	April 23	30.70			Aug. 21	61.89
June 10	31.84	Nov. 20	19.54	Sept. 21	31.58			Aug. 23	61.10
June 12	31.70	Nov. 22	19.71	Oct. 22	31.49			Aug. 24	60.62
June 14	31.48	Nov. 25	20.09	Nov. 22	31.35			Aug. 25	60.24
June 17	31.09	Nov. 27	19.96	Dec. 21	31.15			Aug. 27	59.28
June 19	30.76	Nov. 29	20.48	Jan. 21, 1977	29.18			Aug. 28	58.79
June 21	30.43	Dec. 2	20.57	Feb. 17	28.75			Aug. 29	58.53
June 24	29.82	Dec. 5	20.92	March 21	29.13			Aug. 30	58.04
June 26	29.52	Dec. 11	21.50	April 18	29.36			Aug. 31	57.88
June 28	29.10	Dec. 18	22.23	May 19	27.90			Sept. 1	57.62
July 1	28.55	Dec. 26	23.13	June 21	26.42			Sept. 2	57.32
July 3	28.20	Jan. 21, 1975	25.49	June 28	26.04			Sept. 3	57.16
July 5	27.85	Feb. 19	27.66	July 7	25.60			Sept. 4	57.03
July 8	27.32	March 5	28.57	July 22	24.97			Sept. 5	56.84
July 10	26.99	March 19	29.47	Aug. 18	24.72			Sept. 6	56.64
July 12	26.70	March 27	30.08	Sept. 19	25.14			Sept. 7	56.48
July 15	26.13	April 21	31.72	Oct. 19	24.09			Sept. 8	56.42
July 17	25.79	May 8	31.30	Nov. 22	23.53			Sept. 9	56.37
July 19	25.54	May 23	29.56	Dec. 23	23.07			Sept. 10	55.98
July 22	25.02	June 6	26.99	Jan. 19, 1978	23.87			Sept. 11	56.06
July 26	24.47	June 20	23.39	Feb. 15	25.27			Sept. 12	56.02

Table 2.--Depth to water in observation wells. Depth shown in feet below land surface datum--Continued

Well no. AK1848		Well no. AK1848		Well no. AK1848		Well no. AK1848		Well no. AK1848	
Date	Water Level	Date	Water Level	Date	Water-Level	Date	Water-Level	Date	Water-Level
Sept. 13, 1971	55.94	July 19, 1973	59.77	July 1, 1974	60.24	Feb. 19, 1975	60.50	July 22, 1977	57.68
Sept. 14	55.79	July 26	60.09	July 3	59.98	March 6	61.31	Aug. 18	57.49
Sept. 15	55.51	Aug. 1	60.11	July 5	59.70	March 19	62.01	Sept. 19	57.74
Sept. 16	55.63	Aug. 3	60.05	July 8	59.23	April 21	63.63	Oct. 20	57.52
Sept. 17	55.58	Aug. 7	59.88	July 10	58.99	May 8	63.67	Nov. 22	56.26
Sept. 18	55.38	Aug. 10	59.66	July 12	58.74	May 23	61.76	Dec. 23	55.88
Sept. 20	55.28	Aug. 14	59.36	July 15	58.24	June 6	59.20	Jan. 19, 1978	56.77
Sept. 21	55.16	Aug. 17	58.99	July 17	57.97	June 20	55.64	Feb. 15	58.19
Sept. 22	55.21	Aug. 21	58.51	July 19	57.75	July 3	52.90	March 16	59.77
Sept. 23	55.07	Aug. 23	58.20	July 22	57.25	July 18	50.52	April 17	61.04
Sept. 24	55.02	Aug. 27	57.65	July 26	56.73	Aug. 5	48.90	May 16	62.35
Sept. 26	54.96	Aug. 30	57.18	July 29	56.35	Aug. 15	47.31	June 12	61.62
Sept. 27	54.90	Sept. 4	56.36	Aug. 2	55.82	Aug. 18	45.06	July 13	61.48
Sept. 29	54.71	Sept. 7	55.60	Aug. 5	55.43	Aug. 20	42.24	Aug. 15	61.05
Oct. 4	54.75	Sept. 11	55.30	Aug. 9	55.04	Aug. 22	40.63	Sept. 18	61.10
Oct. 6	54.74	Sept. 14	54.86	Aug. 12	54.73	Aug. 25	39.36	Oct. 19	61.23
Oct. 8	53.58	Sept. 19	53.97	Aug. 16	54.39	Aug. 27	39.85		
Oct. 12	54.33	Sept. 26	53.33	Aug. 19	54.10	Aug. 29	38.17		
Oct. 14	54.42	Sept. 27	53.34	Aug. 22	53.85	Sept. 2	37.40		
Oct. 18	54.20	Oct. 4	52.54	Aug. 26	53.66	Sept. 5	37.25		
Oct. 20	53.89	Oct. 10	51.70	Aug. 29	53.44	Sept. 8	35.85		
Oct. 22	54.65	Oct. 17	46.90	Sept. 2	53.16	Sept. 15	31.07		
Oct. 26	53.47	Oct. 24	50.95	Sept. 5	52.95	Sept. 19	29.99		
Oct. 28	53.01	Oct. 31	51.22	Sept. 9	52.79	Sept. 23	35.44		
Nov. 1	53.68	Nov. 7	51.67	Sept. 12	52.66	Sept. 26	36.92		
Nov. 3	52.83	Nov. 14	52.30	Sept. 16	52.50	Sept. 30	38.38		
Nov. 5	52.53	Nov. 28	53.78	Sept. 20	52.36	Oct. 4	39.91		
Nov. 8	52.49	Dec. 5	54.48	Sept. 23	52.10	Oct. 15	42.68		
Nov. 12	52.55	Dec. 12	55.13	Sept. 27	52.10	Oct. 27	45.55		
Nov. 15	52.37	Jan. 29, 1974	59.25	Sept. 30	51.88	Nov. 18	49.82		
Nov. 19	52.51	Feb. 13	59.97	Oct. 3	51.98	Dec. 5	51.50		
Nov. 23	52.52	Feb. 27	60.75	Oct. 8	51.84	Dec. 22	53.36		
Nov. 26	52.45	March 13	61.46	Oct. 15	51.76	Jan. 21, 1976	56.31		
Nov. 29	52.50	April 5	62.66	Oct. 21	51.64	Feb. 26	59.33		
Dec. 8	53.01	May 1	63.49	Oct. 29	51.62	March 26	61.42		
Dec. 15	51.70	May 7	63.55	Nov. 4	51.72	April 23	63.06		
Dec. 24	53.82	May 9	63.66	Nov. 11	51.82	May 25	63.27		
Dec. 30	54.07	May 20	63.75	Nov. 13	51.64	June 21	62.94		
May 16, 1972	61.80	May 28	63.65	Nov. 15	51.95	July 23	62.88		
May 26	61.02	June 5	63.44	Nov. 18	51.97	Aug. 23	63.14		
June 1	60.73	June 7	63.32	Nov. 20	52.00	Sept. 23	63.29		
June 13	59.98	June 10	63.01	Nov. 22	52.22	Oct. 22	63.09		
June 27	58.63	June 12	62.85	Nov. 25	52.52	Nov. 22	63.18		
Oct. 13	57.43	June 14	62.62	Nov. 27	52.58	Dec. 21	62.34		
April 9, 1973	59.89	June 17	62.23	Nov. 29	53.02	Jan. 21, 1977	61.44		
May 11	59.94	June 19	61.88	Dec. 5	53.62	Feb. 17	61.18		
May 31	59.80	June 21	61.69	Dec. 11	54.24	March 21	61.55		
June 7	59.83	June 24	61.22	Dec. 18	55.08	April 18	61.75		
June 22	59.84	June 26	61.00	Dec. 26	56.02	May 19	60.67		
July 5	59.91	June 28	60.69	Jan. 21, 1975	58.45	June 21	59.09		

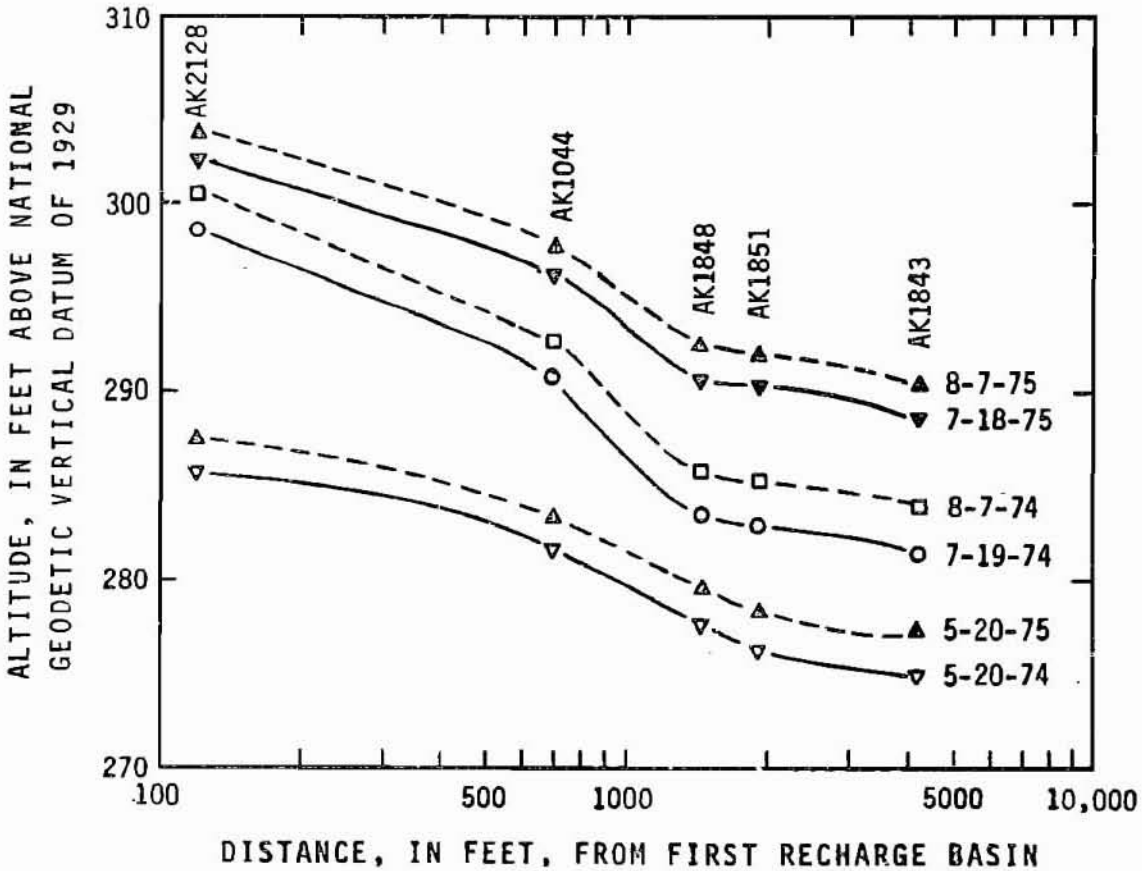


Figure 11.–Altitude of water levels at selected dates in the unconfined aquifer near the recharge basin.

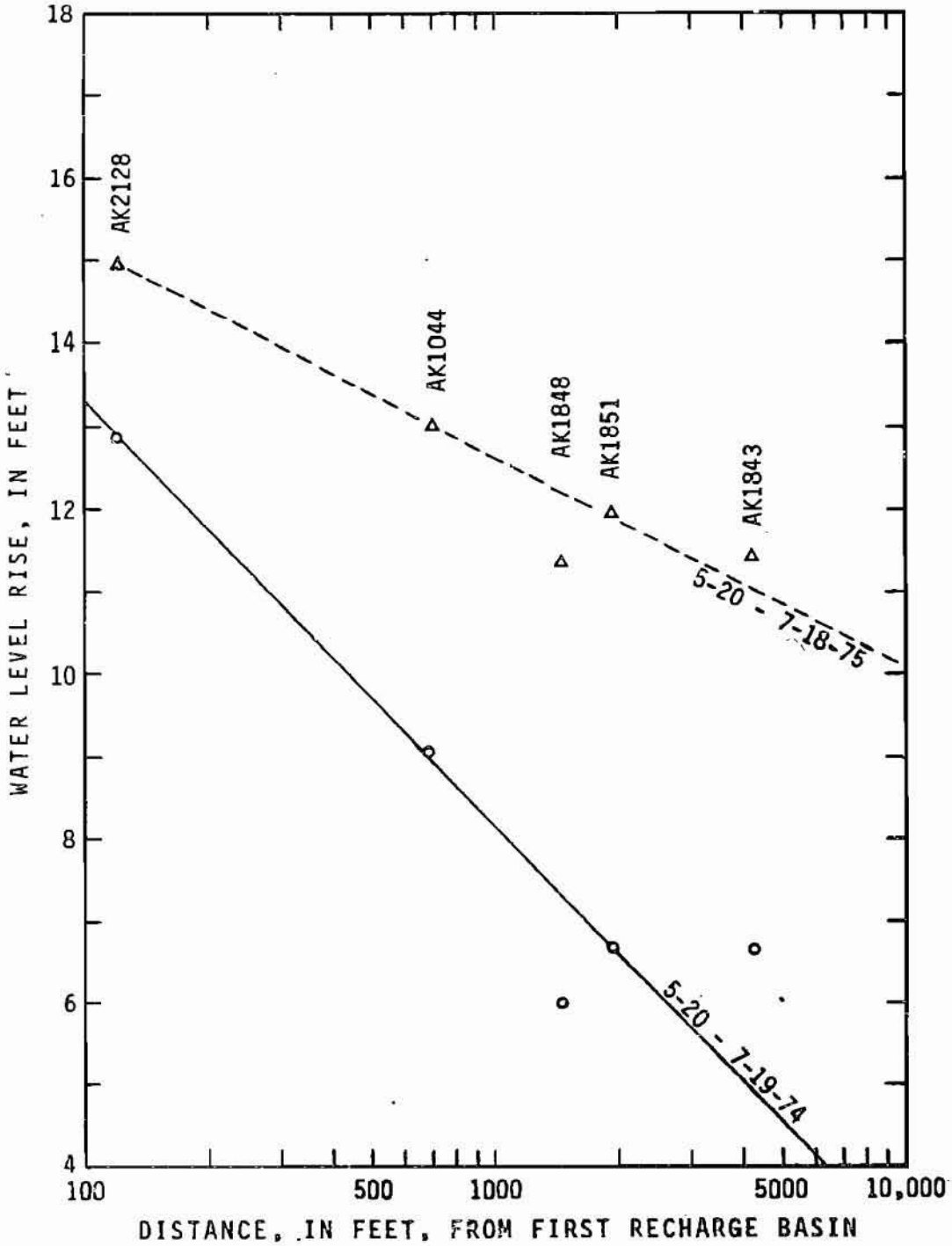


Figure 12a.--Water-level rise in observation wells in the unconfined aquifer, May 20 to July 19, 1974, and May 20 to July 18, 1975.

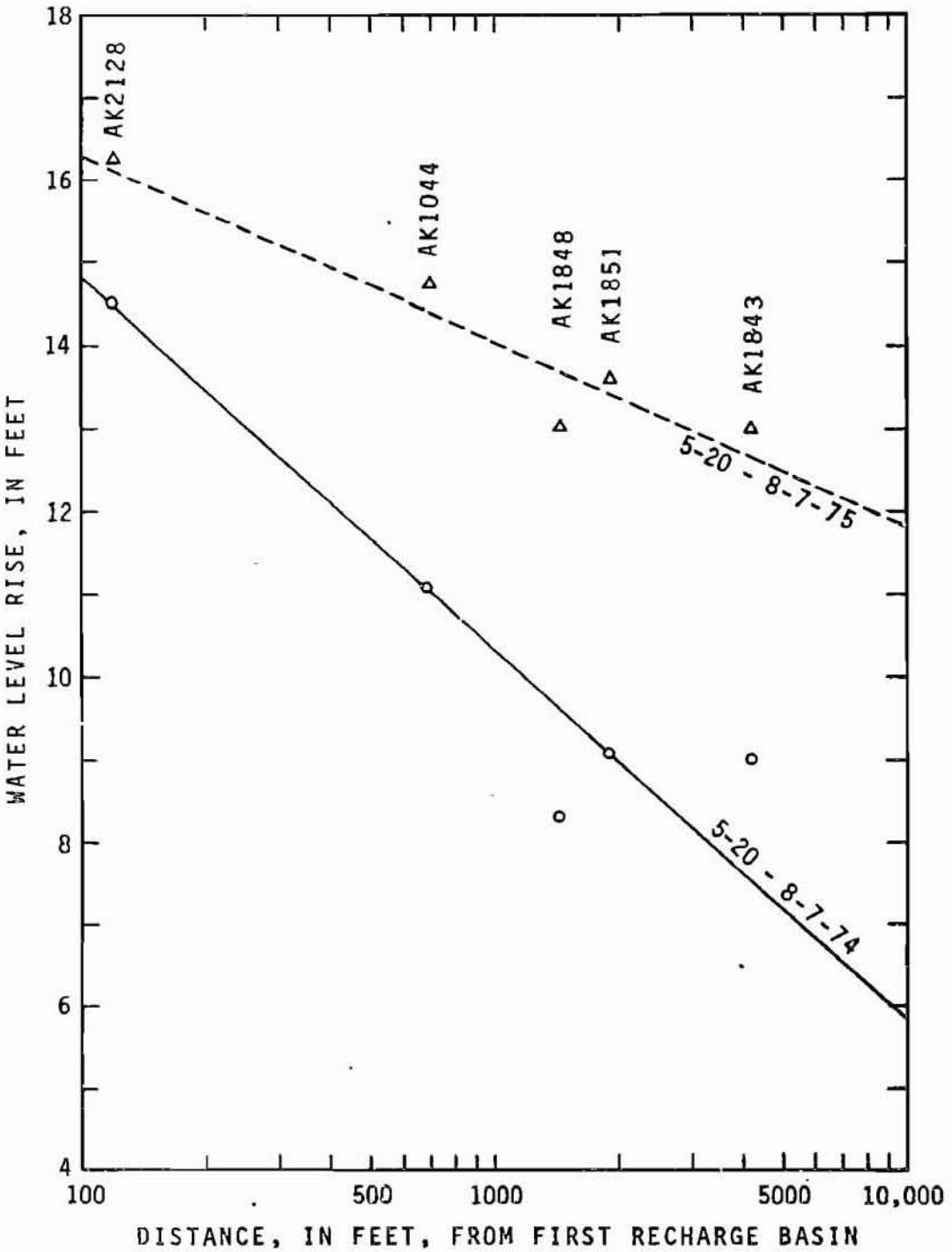


Figure 12b.--Water-level rise in the unconfined aquifer near the recharge basin, May 20 to August 7, 1974 and 1975.

Salient points indicated by the data presented in figures 11 and 12a and b are: (1) 1975 water levels were approximately 2.0 ft higher than those in 1974 at the start of artificial recharge; (2) for the same period of artificial recharge, 1975 water-level rises exceeded 1974 water-level rises; (3) the amount that 1975 water-level rises exceeded 1974 rises generally increased with distance from the recharge basin.

Because 1974 artificial-recharge rates slightly exceeded 1975 rates, one would expect 1974 water-level rises to be slightly greater than 1975 water-level rises, other things being equal. The fact that they are not greater suggests that natural recharge in 1975 was greater than in 1974, at least for the time period May 20 to August 7. Figure 13 shows discharge in Ship Creek for March through September for both 1974 and 1975. As indicated in the figure, 1975 discharge rates from May 20 through August 7 exceeded those of 1974 for the same time interval except for small periods of time. The 1975 discharge over the period was 30 percent greater than the 1974 discharge during this time period. Seepage from Ship Creek represents a major source of ground-water recharge in the vicinity of the artificial-recharge basins, and since the rate of this seepage is proportional to the flow in the creek it is clear that at least one component of recharge to the ground-water system was greater during May 20 to August 7, 1975, as compared with the same time period in 1974. Ground-water pumpage cannot account for the fact that 1975 water-level rises exceeded those in 1974, because pumpage from City well number 9, the well that would most likely affect this area, was greater in 1975 than in 1974. The increasing difference between 1974 and 1975 rises with distance from the recharge basin is a strong indication that natural recharge from streamflow, snowmelt, and precipitation is the dominant factor affecting ground-water levels in the vicinity of the development site.

MODEL DESIGN

A three-layer finite-difference model that utilizes the digital program of Trescott (1975) and Trescott and Larson (1976) to simulate unsteady three-dimensional ground-water flow was constructed to determine the change in water levels in the artesian and unconfined aquifers at Spring Acres Subdivision caused by artificially induced recharge. Throughout most of the model area, layer 1 represents the artesian aquifer, layer 2 the clay unit, and layer 3 the unconfined aquifer. In the part of the model area where the clay unit is missing, the entire section is unconfined, and each model layer represents one-third of the thickness of the composite unconfined section. The model simulates lateral flow within each layer of the section and vertical movement of water between layers.

Model construction was accomplished by designing a finite-difference grid (fig. 14) of the study area and assigning average values for transmissivity, storage coefficient, and vertical hydraulic conductivity for each layer to each rectangular area in the finite-difference grid. Initial values of transmissivity assigned to the part of layer 1 representing the artesian aquifer were determined from figure 4. Initial values of transmissivity assigned to the part of layer 2 representing the semipermeable clay unit were obtained by multiplying the average thickness of the clay (fig. 3) by the average vertical hydraulic conductivity of the clay for that area (fig. 5). This value of transmissivity would result in a low value for transmissivity of the clay unit, but since lateral flow through this material is insignificant no accuracy in model-predictive ability was sacrificed.

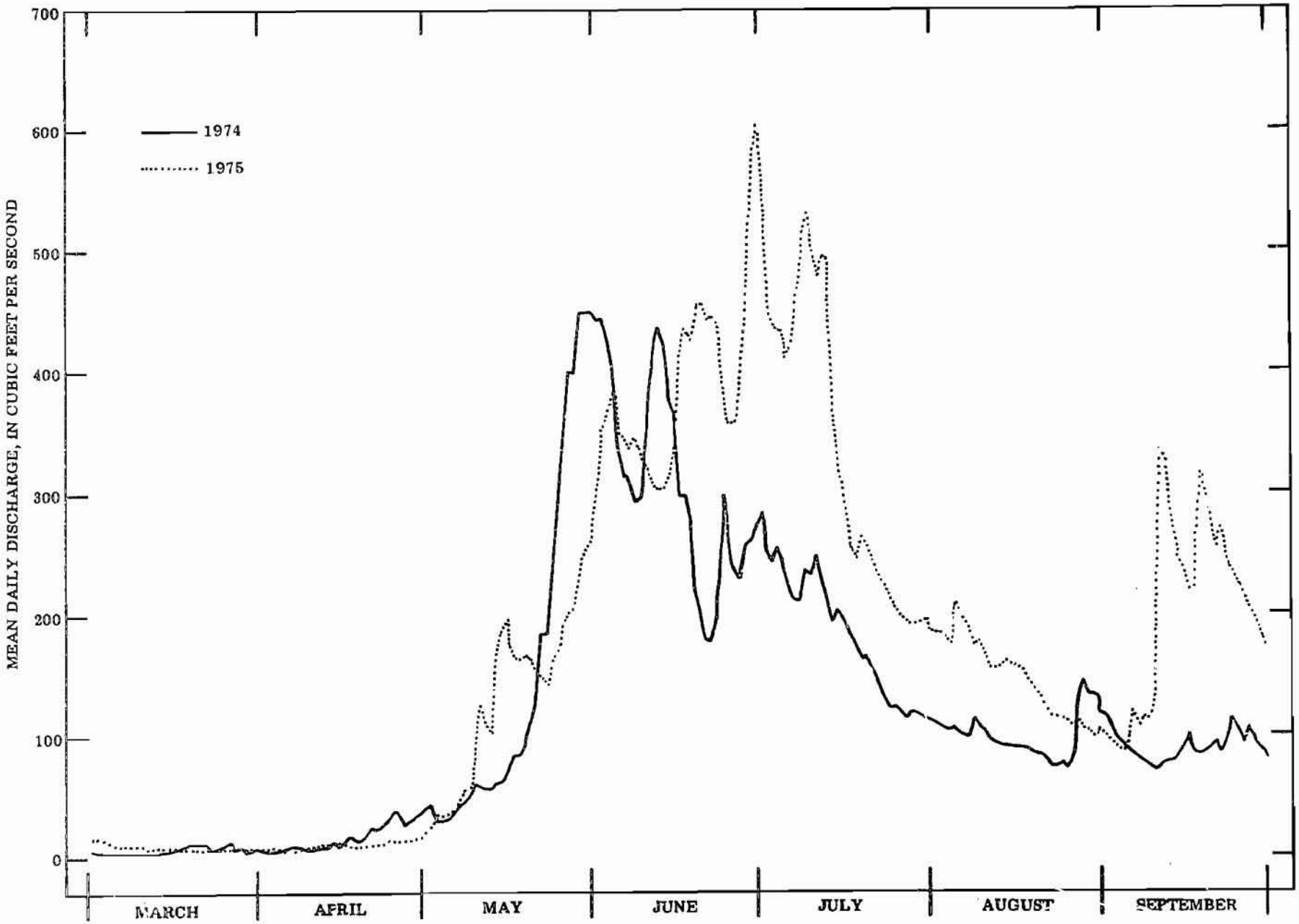


Figure 13.--Mean daily discharge of Ship Creek, March - September, 1974 and 1975.

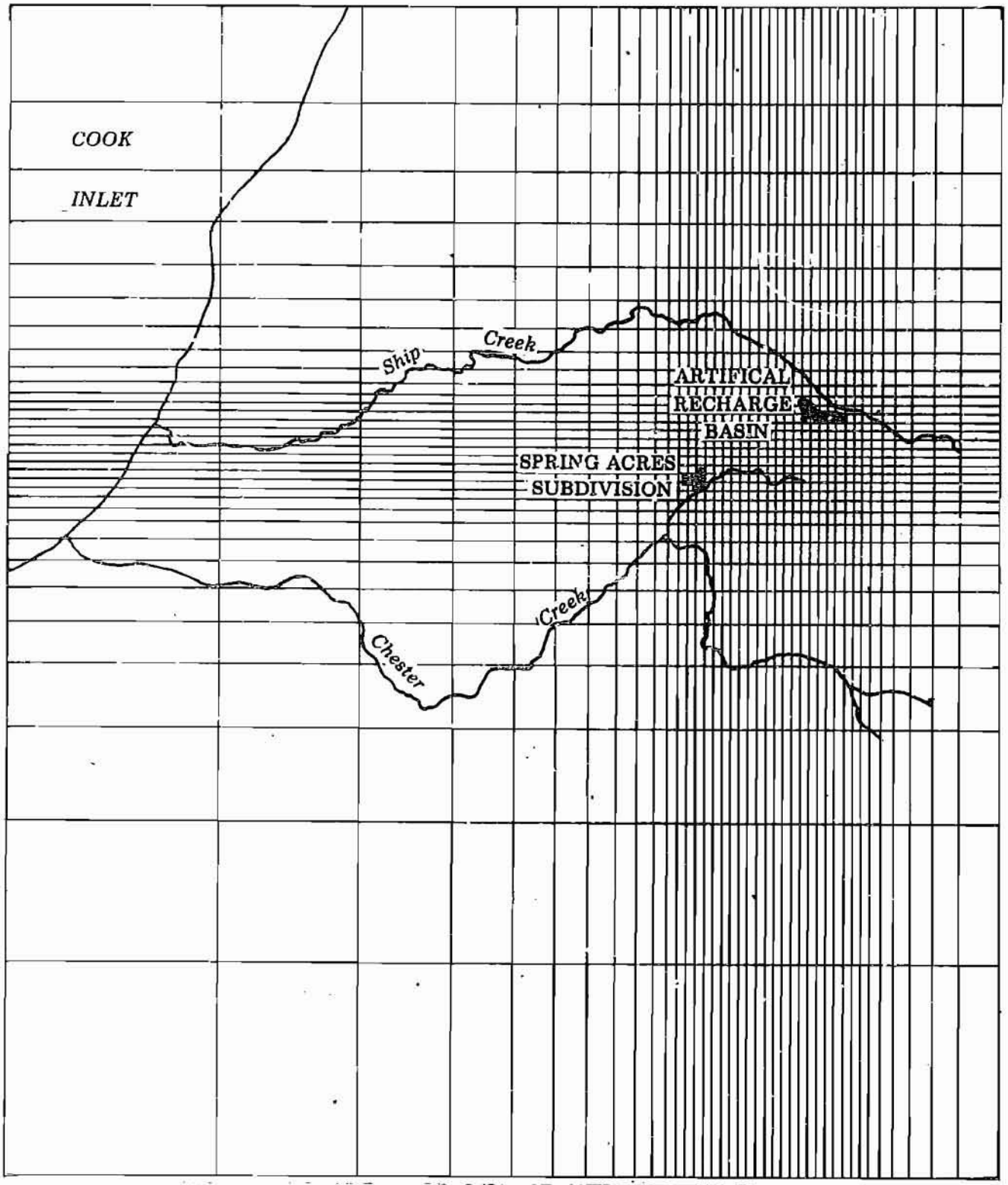


Figure 14.–Finite-difference grid used in model construction.

The major objective in modeling the clay unit was to permit vertical movement of water between the artesian and unconfined aquifers and permit head to change in the clay unit. A value of 10^{-5} per foot was simulated for the specific storage of the part of the model representing the clay unit.

Transmissivity for the part of the unconfined aquifer that is underlain by the clay unit was calculated by multiplying its saturated thickness by a value for lateral hydraulic conductivity of 225 ft/day. As mentioned previously, in the part of the model where the clay unit is not present, each model layer represented one-third of the thickness of the composite unconfined aquifer. For purposes of the model-calibration procedure to be discussed later, the value of lateral hydraulic conductivity assigned to each of these layers was 68 ft/day. As will be discussed subsequently, these values were adjusted progressively upward during model calibration.

A storage coefficient of 10^{-4} was used through layer 1 and for the part of layer 2 representing the middle one-third of the composite aquifer. A constant value of 0.15 was assigned for the storage coefficient of layer 3.

Values for the vertical hydraulic conductivity of the clay unit used in the model are shown in figure 5. In the remaining part of the model, the vertical hydraulic conductivity of the unconfined and artesian aquifers were initially simulated at 1.4 ft/day.

MODEL CALIBRATION

The model was calibrated to water-level rises measured in AK2128, AK1848, AK1851, AK1843, and AK1044 after the first 80 days of artificial recharge in 1974 and 1975. This time period was selected because it includes the period of immediate interest in 1975 and is still sufficiently long to permit model calibration. The only stress simulated by the model was the artificial recharge from the first basin. No natural recharge or discharge was simulated. The model boundaries were extended sufficiently so that head changes caused by the artificial recharge were negligible at the boundaries, or the aquifer system terminated at natural impermeable boundaries. No-flow conditions were specified around the model perimeter for all layers. Because the only stress applied to the model was artificial recharge from the first basin, water-level changes indicated by the model reflect only changes resulting from the artificial-recharge experiments.

The total time period simulated during model calibration extended from initiation of 1973 recharge through August 7, 1975. Only recharge from the first basin was simulated during the calibration procedure. Recharge from the second basin, which started August 14, 1975, was not simulated because the severe water problems at Spring Acres Subdivision occurred before the start of this recharge. Recharge in 1971 from the ½-acre basin was not simulated because it was reasonable to assume that no residual effects of this recharge on ground-water levels at the recharge basins existed in 1973. On the basis of the water-level response in observation wells near the recharge basin and the sustained infiltration rates, a 2-day travel time was estimated for the movement of water from the recharge basin through the unsaturated zone to the water table.

Although the geometry and hydraulic characteristics of the unconsolidated deposits were available from previous work, it was still necessary to refine values for the lateral and vertical hydraulic conductivity of the unconfined aquifer because of the range reported for these values. As discussed, water levels in the area of the recharge basin rose during the two calibration periods. This rise should have at least two components: (1) at least part of the seasonal rise resulting from natural recharge, and (2) the rise induced by the artificial-recharge experiments. As a result, model-predicted water-level rises should be less than those observed. The model was therefore calibrated by adjusting values of lateral and vertical hydraulic conductivity assigned to the unconfined aquifer not underlain by clay in a series of model experiments until model-predicted water-level rises were less than the observed rises and the difference between these rises increased by several feet from AK2128 to AK1843. The latter criterion was used to be consistent with observed data. All possible combinations of the extreme values reported for lateral and vertical hydraulic conductivity were simulated in a series of model experiments, and model-predicted water-level rises for each experiment were compared to the observed water levels.

The reported values for the lateral hydraulic conductivity of the unconfined aquifer at the recharge basin ranged from 68 ft/day to 225 ft/day. The estimated values for vertical hydraulic conductivity of the unconfined aquifer at this site ranged from 1.4 ft/day to a maximum of 1/10 the value for the lateral hydraulic conductivity, or 22.5 ft/day. The first calibration experiment used the lowest values reported for lateral hydraulic conductivity and estimated for vertical hydraulic conductivity of the unconfined layer; the second experiment used the lowest value of lateral hydraulic conductivity and highest value of vertical hydraulic conductivity reported or estimated; the third experiment used the highest value of lateral hydraulic conductivity and lowest value of vertical hydraulic conductivity reported or estimated; and the fourth experiment used the highest values of lateral hydraulic conductivity and vertical hydraulic conductivity reported and estimated.

The first two experiments produced unacceptable results, in that model-predicted water-level rises were far in excess of those observed. The third experiment produced an acceptable match between model-predicted and observed water-level rises (fig. 15a&b). The lateral and vertical hydraulic conductivity of the unconfined aquifer simulated in this experiment were 225 and 1.4 ft/day. This model is hereinafter referred to as model A. The fourth experiment resulted in an unacceptable match between observed and model-predicted water-level rises, but the results also indicated that an acceptable match could be obtained by progressively increasing the transmissivity of the unconfined aquifer. Transmissivity was therefore increased until an acceptable match between model-predicted and observed water-level rises was obtained (fig. 16a&b). The value of transmissivity for the composite aquifer not underlain by the clay unit was identified as 16,900 ft^2/day. This value corresponds to a lateral hydraulic conductivity of the composite aquifer of 338 ft/day. The vertical hydraulic conductivity simulated in this experiment was 34 ft/day. This model is hereinafter referred to as model B.

Because each observation well was screened at a different depth in the unconfined aquifer, recorded water-level rises in these wells must be compared to the model-predicted water-level rises for the respective depth for each well. Observa-

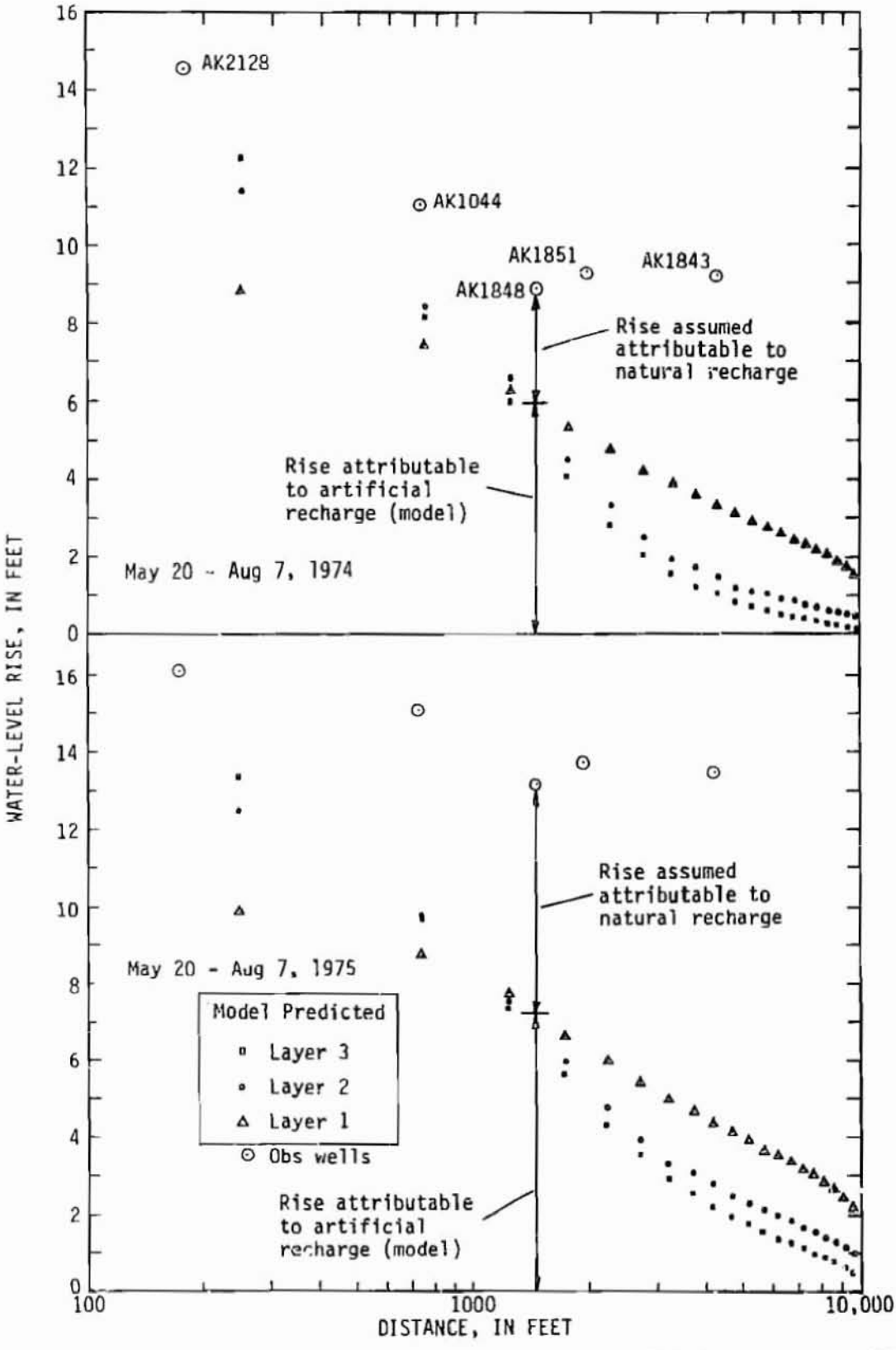


Figure 15a & b.--Model-predicted vs. observed water-level rises, 1974 and 1975 - Model A.

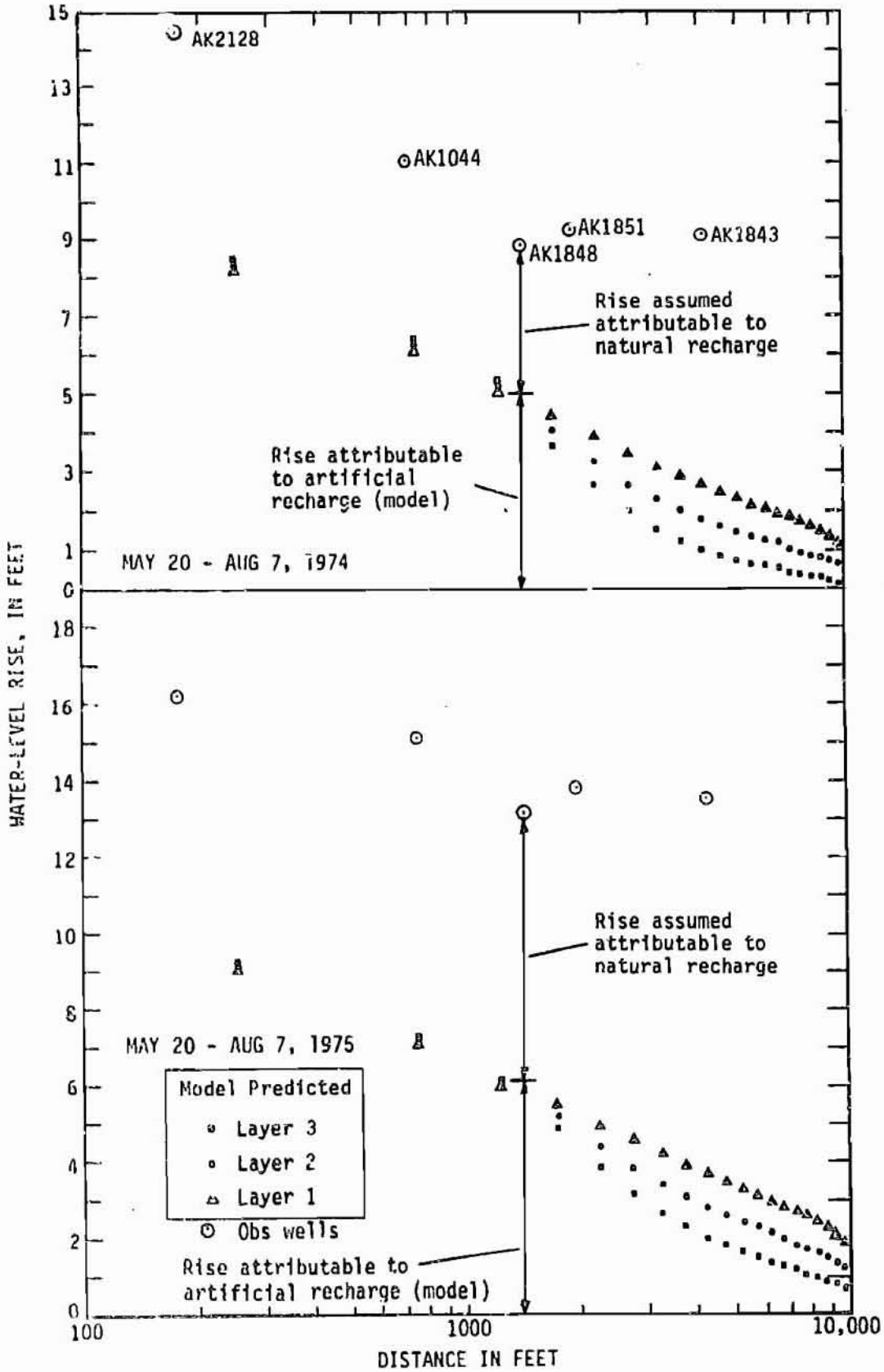


Figure 16a & b.–Model-predicted vs. observed water-level rises, 1974 and 1975 - Model B.

tion wells AK2128 and AK1044 are screened in layer 1; observation well AK1851 is screened in layer 2, and observation wells AK1848 and AK1843 are screened in layer 3.

In model A, observed water-level rises exceeded model-predicted rises by an average 5.0 and 7.8 ft along the line of observation wells for 1974 and 1975, respectively. In model B, the observed rises exceeded the model-predicted rises by an average 5.4 and 8.3 ft. These additional rises are consistent with the amplitude of seasonal rises observed in AK1843 in 1972, 1977, and 1979, and in AK1848 in 1977. The fact that the difference between model-predicted and observed water-level rises was greater in 1975 as compared with 1974 is consistent with data presented in figure 12b. As indicated in this figure, 1975 water-level rises exceeded those in 1974.

The modeling technique did not simulate changes in transmissivity of the unconfined aquifer that occurred because of an increase in the saturated thickness of the aquifer due to artificial recharge. The increase in saturated thickness, and therefore transmissivity, ranged from 23 percent of that simulated 250 ft from the edge of the recharge pit to 2 percent at observation well AK1843 for the calibrated simulations. These increases resulted in model-predicted water-level rises ranging from approximately 1.2 ft too high for the 23-percent increase in transmissivity to less than 0.1 ft difference for the 2-percent increase. Model-predicted water-level rises were adjusted accordingly.

MODEL PREDICTIONS

A major objective of this study was to determine the effect of the artificial-recharge experiments on water levels at Spring Acres Subdivision, particularly with regard to induced water-level rises in the unconfined aquifer at the subdivision during the period May 20 to August 7, 1975. The intermittent nature of the artificial-recharge experiments caused water levels in the area of the recharge basins to rise and fall, with the timing and magnitude of these changes dependent upon, among other things, the rate of artificial recharge, the distance from the recharge basins, and the hydraulic properties of the ground-water system. Two model experiments simulating different hydraulic characteristics of the unconfined aquifer gave acceptable matches between observed and model-predicted water-level rises between May 20 and August 7, 1974 and 1975. Both models (A and B) were used to examine the effect of the artificial-recharge experiments on water levels at Spring Acres Subdivision, beginning with the start of recharge in 1973 and lasting through August 7, 1975. The results of these two experiments are shown in figures 17 and 18.

As indicated in these figures, the models predicted a water-level rise in the unconfined aquifer of 1.1 ft at Spring Acres Subdivision from the start of recharge in 1973 through August 7, 1975. Differences between water-level rises predicted by the two model experiments are small for any given time and for the total time. Of major significance for the purpose of this study is the incremental rise predicted by the models for the unconfined aquifer at Spring Acres Subdivision between May 20 and August 7, 1975. Both models indicate that this rise would have been 0.2 ft.

Model-predicted water-level rises for the artesian aquifer at Spring Acres Subdivision are also shown in the figures. Again, differences between water-level

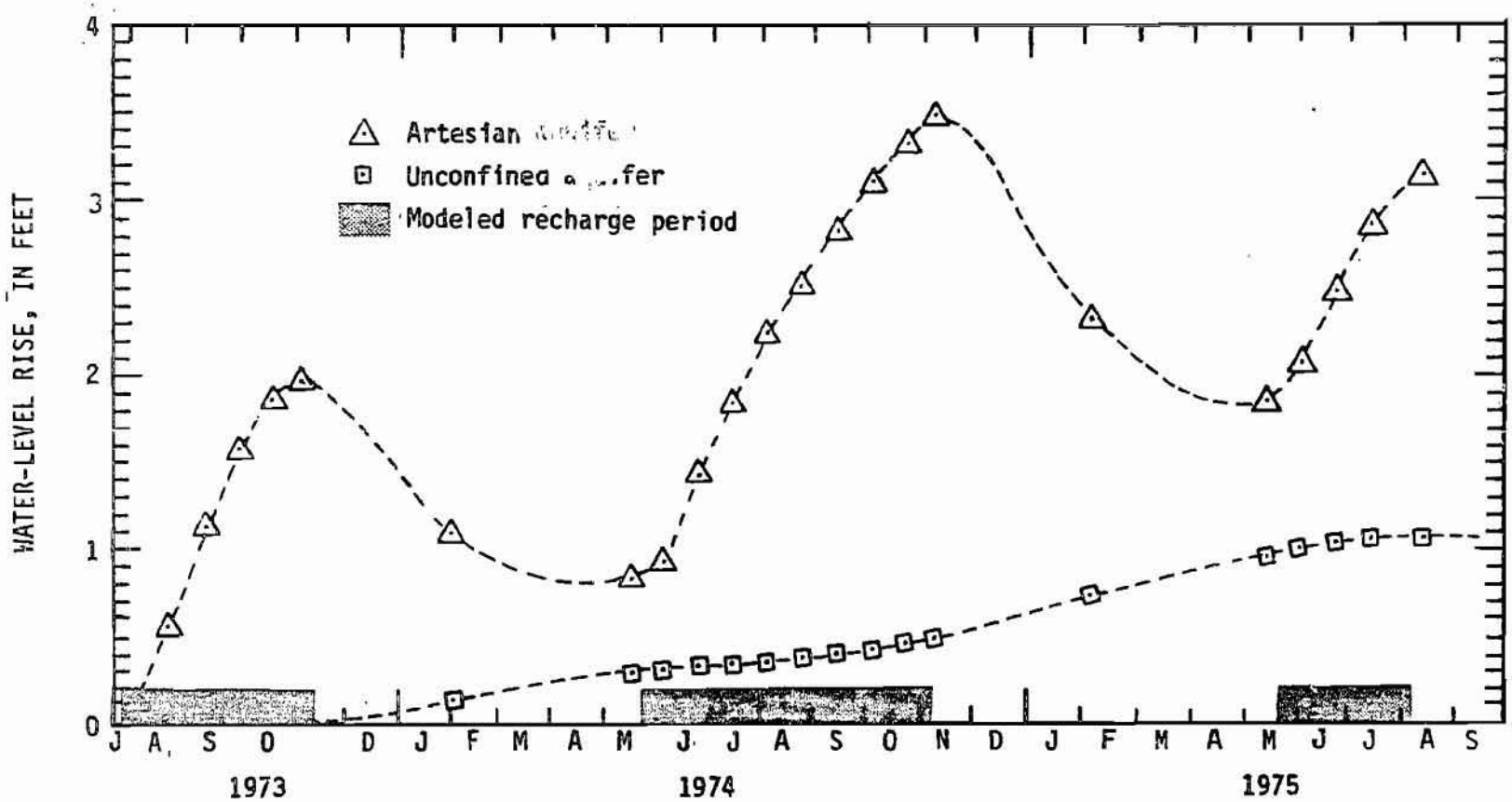


Figure 17.–Model-predicted water-level rises at Spring Acres Subdivision, Model A.

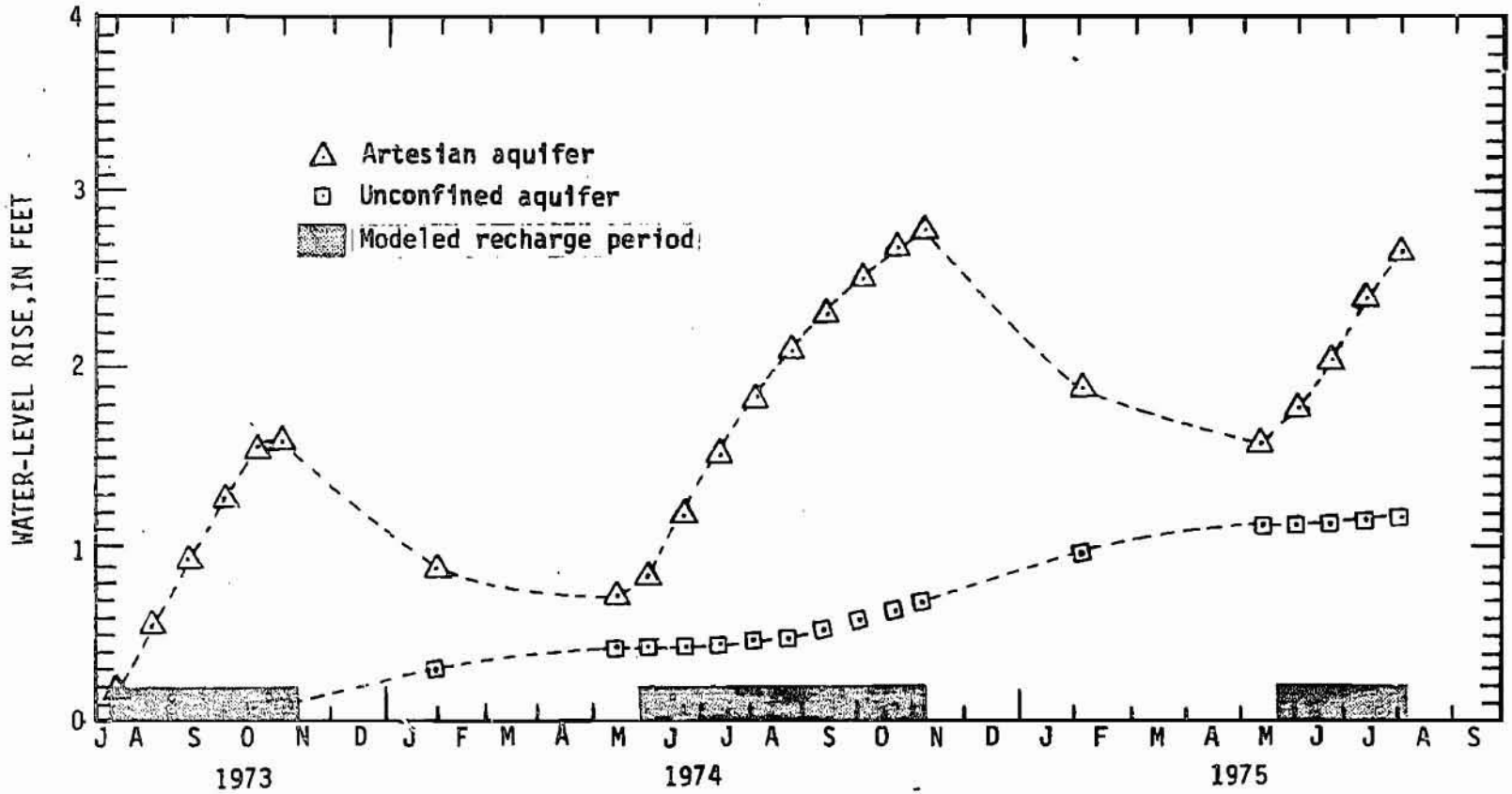


Figure 18.–Model-predicted water-level rises at Spring Acres Subdivision, Model B.

changes predicted by the two models are small. The models predicted water-level rises of as much as 3.5 ft during the course of the recharge experiments and indicated a rise of 3.2 ft on August 7, 1975. The predicted water-level rise in the artesian aquifer from May 20 to August 7, 1975, was 1.3 ft.

The areal water-level rises predicted by the two model experiments for August 7, 1975, for the unconfined and artesian aquifers are shown in figures 19 through 22. As the figures show, water levels rose in nearly concentric rings around the recharge basin. Maximum rises of 25 ft were predicted immediately under the recharge basins.

Figures 19 and 20 show the areal water-level rise induced by the artificial-recharge experiments for model A for the unconfined and artesian aquifer. Figures 21 and 22 show the induced rises for these aquifers for model B. Water-level rises of 5 ft and 1 ft in the unconfined aquifer were predicted approximately 2,000 and 8,000 ft from the recharge basin by both models. Similar water-level rises in the artesian aquifer were predicted by both models at approximately 3,000 ft and 12,000-30,000 ft depending on direction from the recharge basin.

SUMMARY AND CONCLUSIONS

A subdivision developer encountered water while digging trenches associated with developing property at Spring Acres Subdivision, Anchorage, Alaska, during the summer of 1975. He reported encountering water at a depth of about 8 ft in June 1975 and also reported a rise in water level to approximately land surface by early August. Neither incident was expected by the developer. The U.S. Geological Survey and the Municipality of Anchorage conducted an artificial-recharge experiment approximately 9,000 ft northeast of Spring Acres Subdivision from May 20 through September 19, 1975. Recharge experiments were also conducted in 1971, 1973, and 1974. The proximity of the 1975 recharge experiment to the subdivision caused speculation on the possible connection between the artificially recharged water and the water problems encountered by the developer.

The effect of the recharge experiment on water levels at Spring Acres Subdivision was evaluated by (1) examining the natural water-level fluctuation in the area, and (2) simulating, with a digital model, the water-level rises caused by the recharge experiment.

Water-level data collected by the U.S. Geological Survey at various observation wells in the Anchorage area since the mid-1950's indicate that water levels fluctuate seasonally. Annual lows occur in the spring, and annual highs occur in late summer-early winter. Water-level measurements in and near the Spring Acres Subdivision for a 3-year period prior to the 1973-1975 recharge experiments and a 4-year period following the experiments showed seasonal rises of 2 to 12.4 ft. A depth to water below land surface of 2.6 ft was measured 600 ft from Spring Acres Subdivision in 1971 and in the subdivision in 1977. Average depth to water in the area was 7.0 ft from early 1976 to September 1979. No observation-well data are available in or near Spring Acres Subdivision for the 1973-75 period. Water-level data collected from auger holes in March 1975 by a consulting firm for the contractor indicated a depth to water of 6-7 ft below land surface at Spring Acres Subdivision.

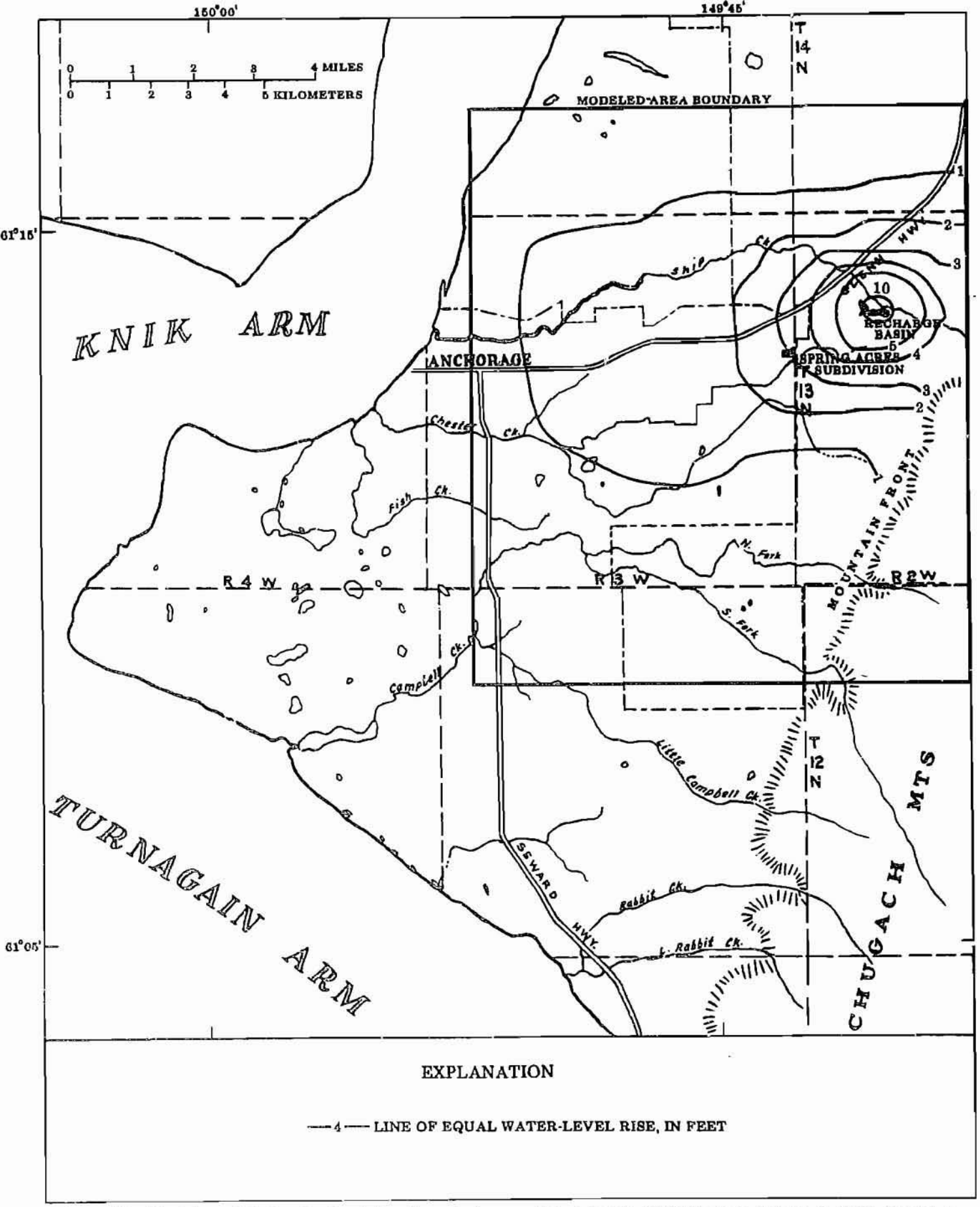


Figure 19.–Model-predicted water-level rises for artesian aquifer, July 19, 1973 through August 7, 1975, Model A.

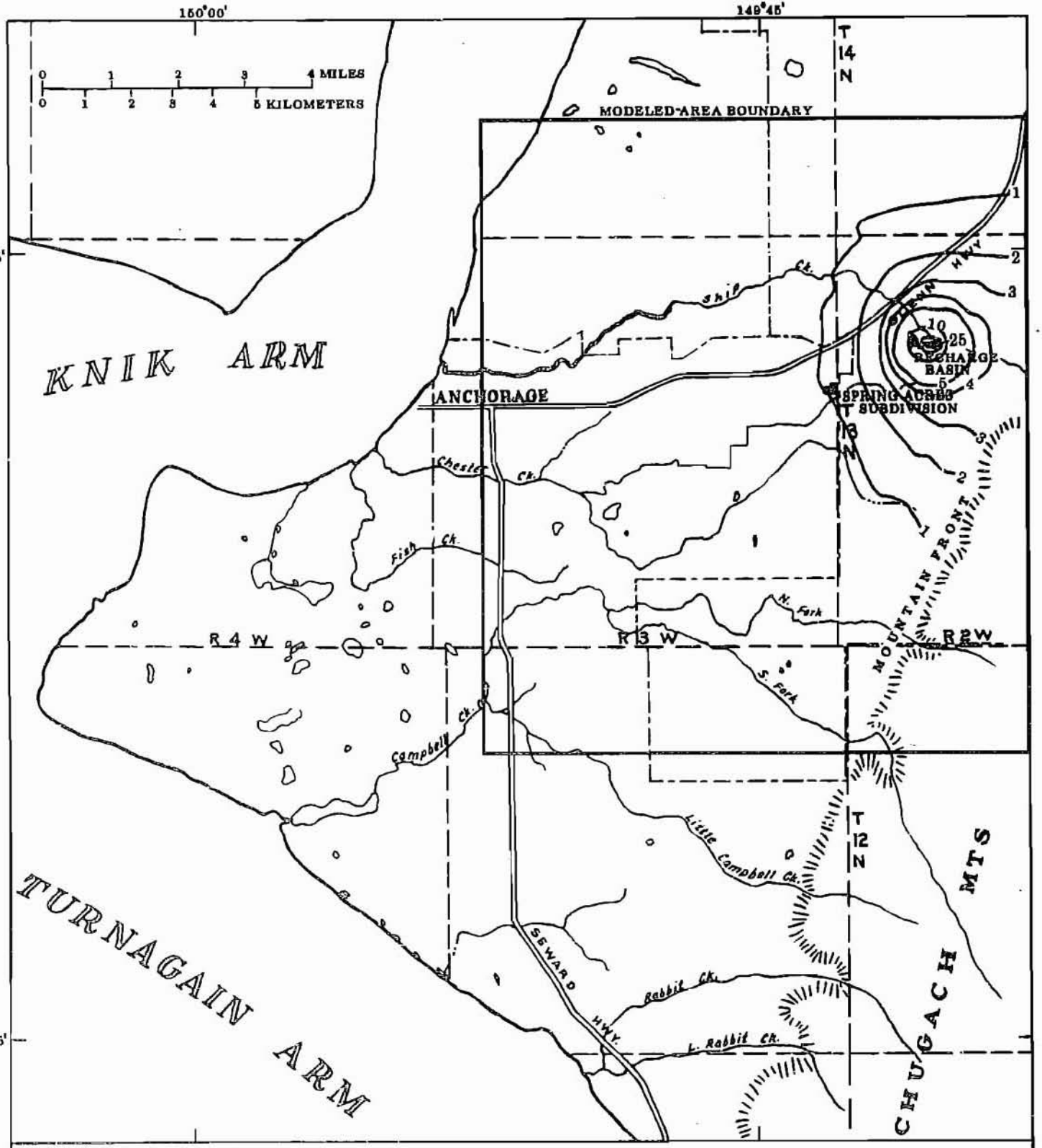


Figure 20.--Model-predicted water-level rises for unconfined aquifer, July 19, 1973 through August 7, 1975, Model A.

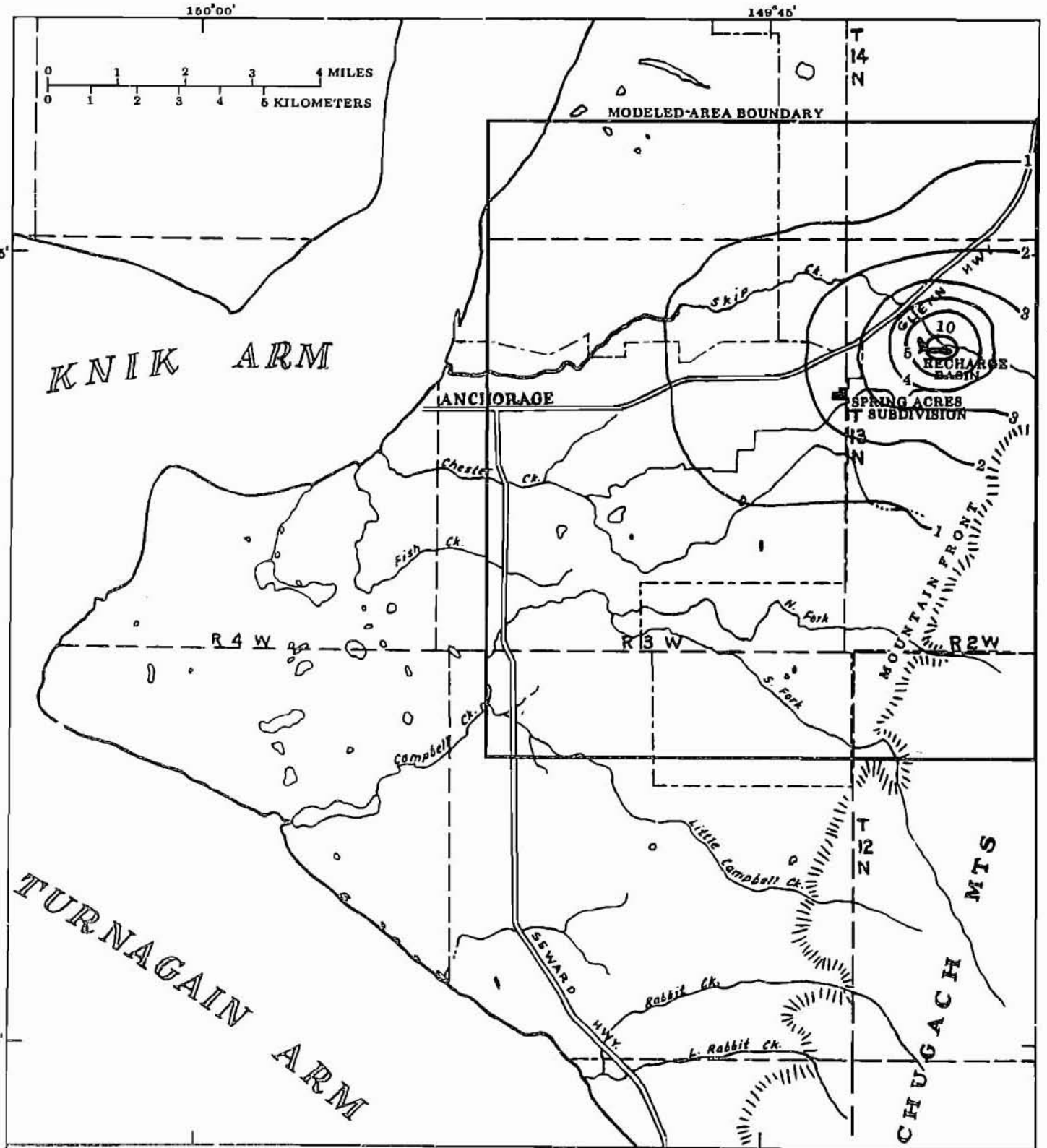
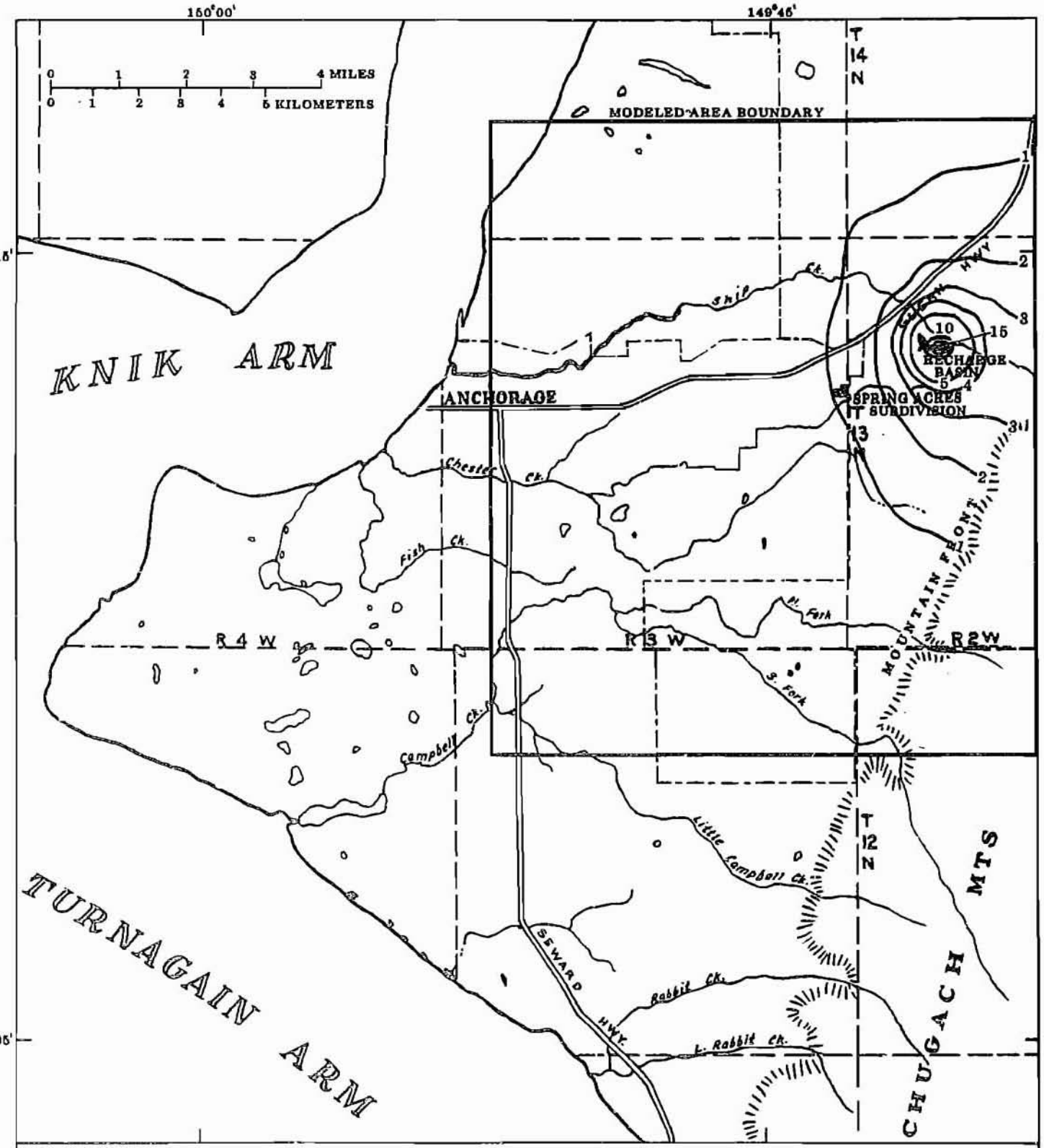


Figure 21.–Model-predicted water-level rises for artesian aquifer, July 19, 1973 through August 7, 1975, Model B.



EXPLANATION

—4— LINE OF EQUAL WATER-LEVEL RISE, IN FEET

Figure 22.–Model-predicted water-level rises for unconfined aquifer, July 19, 1973 through August 7, 1975, Model B.

Information on the geologic setting and hydraulic characteristics of the ground-water system determined during previous studies in the area was used, along with data generated for this study, to construct two digital-computer models of the ground-water system. Special emphasis was placed on the area of the recharge basins. The models were used to estimate the effect of the artificial-recharge experiments on the ground-water system, particularly Spring Acres Subdivision.

The models varied in the values of lateral and vertical hydraulic conductivity used to simulate the unconfined aquifer. Both models indicated a rise of approximately 0.2 ft in water levels in the unconfined aquifer at Spring Acres Subdivision from May 20 to August 7, 1975. The models indicated a water-level rise for the artesian aquifer at the subdivision of 1.3 ft during the same period. Total rises of 1.1 ft and 3.2 ft were predicted for the unconfined and artesian aquifers, respectively, at Spring Acres Subdivision from July 16, 1973, to August 7, 1975, as a result of the artificial recharge.

The calibration procedure indicated that water levels in the area of the recharge basin rose an average of 7.8 to 8.3 ft from May 2 to August 7, 1975, because of factors other than the recharge experiment. This rise is within the range of rises recorded in the area (7-10 ft) during years prior to and following the recharge experiment and are considered for the most part to be attributable to seasonal recharge.

REFERENCES

Anderson, G. S., 1977, Artificial recharge experiments on the Ship Creek alluvial fan, Anchorage Alaska: U.S. Geological Survey Water-Resources Investigations 77-38, 39 p.

Trescott, P. C., 1975, Documentation of finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Open-File Report 75-438, 102 p.

Trescott, P. C., and Larson, S. P., 1976, Document of finite-difference model for simulation of three-dimensional ground-water flow; Supplement: U.S. Geological Survey Open-File Report 76-591, 21 p.

Waller, R. M., 1964, Hydrology and the effects of increased ground-water pumping in the Anchorage area, Alaska: U.S. Geological Survey Water-Supply Paper 1779-D, 37 p.

Weeks, J. B., 1970, The relationship between surface water and ground water in Ship Creek near Anchorage, Alaska: U.S. Geological Survey Professional Paper 700-B, p. B224-B226.