A COMPUTER GROUND-WATER MODEL FOR THE TILLMAN ALLUVIUM IN TILLMAN COUNTY, OKLAHOMA

By

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Bachelor of Science

Northern Arizona University

Flagstaff, Arizona

1970

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
December, 1978

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PREFACE

This study is concerned with the aquifer properties of the alluvial terrace and floodplain deposits in Tillman County, Oklahoma. The primary objective is to determine the maximum annual yield for the basin from July 1, 1973, to July 1, 1993. A computer model is used to determine the maximum annual yield based on pumpage prior to July 1, 1973, and subsequent allocated pumpage until July 1, 1993.

The author wishes to thank Dr. Douglas C. Kent, his thesis adviser, and Mr. James W. Naney, geologist with the Scientific and Educational Administration (SEA) of the U. S. Department of Agriculture, for providing the opportunity to participate in a cooperative research contract funded by the Oklahoma Water Resources Board (OWRB). Dr. Kent and Mr. Naney have been extremely helpful in directing all aspects of the research described in this thesis. Appreciation is also extended to Dr. Fred E. Witz, computer-system consultant, for his valuable assistance in the modifications of the U. S. Geological Survey ground-water model for applications to an alluvial aquifer and Oklahoma law. Gratitude is extended to the U. S. Geological Survey for providing the original version of the ground-water model, and to the Oklahoma Water Resources Board (OWRB) for providing funds in the contract for graduate research assistantships. Appreciation is also extended to the following staff members of the Oklahoma Water Resources Board (OWRB) for providing data and legal information required for the research: Mr. James Barnett, OWRB Director, Mr. J. A. Wood, Chief of Ground-Water Division, and Ms.

Ginia Wickersham, geologist, on the ground-water staff.

In particular, sincere appreciation is extended to my major adviser, Dr. Douglas C. Kent, for always being patient beyond limits, constantly fair beyond measure, and extremely helpful in directing my thesis research. Special appreciation is extended to Mr. James W. Naney and Dr. Gary F. Stewart, members of the thesis advisory committee, for their critique of this thesis.

The author expresses his sincere respect and gratitude to the Ministry of Electricity and Water of the State of Kuwait for sponsoring a program that made it possible for him to pursue graduate study at Oklahoma State University.

Finally, special gratitude is expressed to my wife, Azizah, and my children, Sabica, Aliya, Saud, and Dhuha, for their loving consideration and patience during the time of this study.

I dedicate this thesis to the memory of my beloved father and mother. May Allah rest them in His Paradise. Amen.

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CHAPTER I

ABSTRACT

The alluvial terrace and floodplain deposits in the western half of Tillman County are associated with the Red and North Fork of the Red River, and extend over an area of approximately 285 square miles. Ground water in these deposits supply about 850 wells for domestic and irrigation purposes. Cotton, wheat and alfalfa are the major irrigated crops.

A finite-differencing digital model was used to simulate well drawdown over a 20-year period between July 1, 1973, and July 1, 1993. A maximum annual yield was determined based on pumpage prior to 1973 and subsequent allocated pumpage at different trial rates. Calibration techniques were also compared. A pattern recharge of 2.87 inches was selected for optimum design. Computer input data include evapotranspiration and well rate at the surface; water level, land and bedrock elevations; specific yield, coefficient of storage and leakage rate of the river bed.

Computer output is used to show a rate of 1 acre foot per acre could be recommended as an allocation to each one-quarter section of the 285 square mile aquifer area. At this rate, only one-half of the aquifer area would go dry during the 20-year period. On this basis, 70,048 acre feet per year was established as the maximum annual yield. This annual discharge rate will yield a total volume of 1,400,967 acre

feet pumped from July 1, 1973, to July 1, 1993. The model results indicate that more than one half of the wells which belong to prior-appropriative right owners would go dry if annual allocation was permitted at the recommended rate. Only four percent of the prior-appropriative wells would go dry if annual allocation was not permitted.

CHAPTER II

INTRODUCTION

The Quaternary alluvial terrace and floodplain deposits along the Red River and the North Fork of the Red River in the western half of Tillman County comprise the major aquifer for the area. This aquifer supplies water for the municipalities of Frederick, Tipton, Davidson, and Manitou, as well as for domestic and irrigation uses in this area.

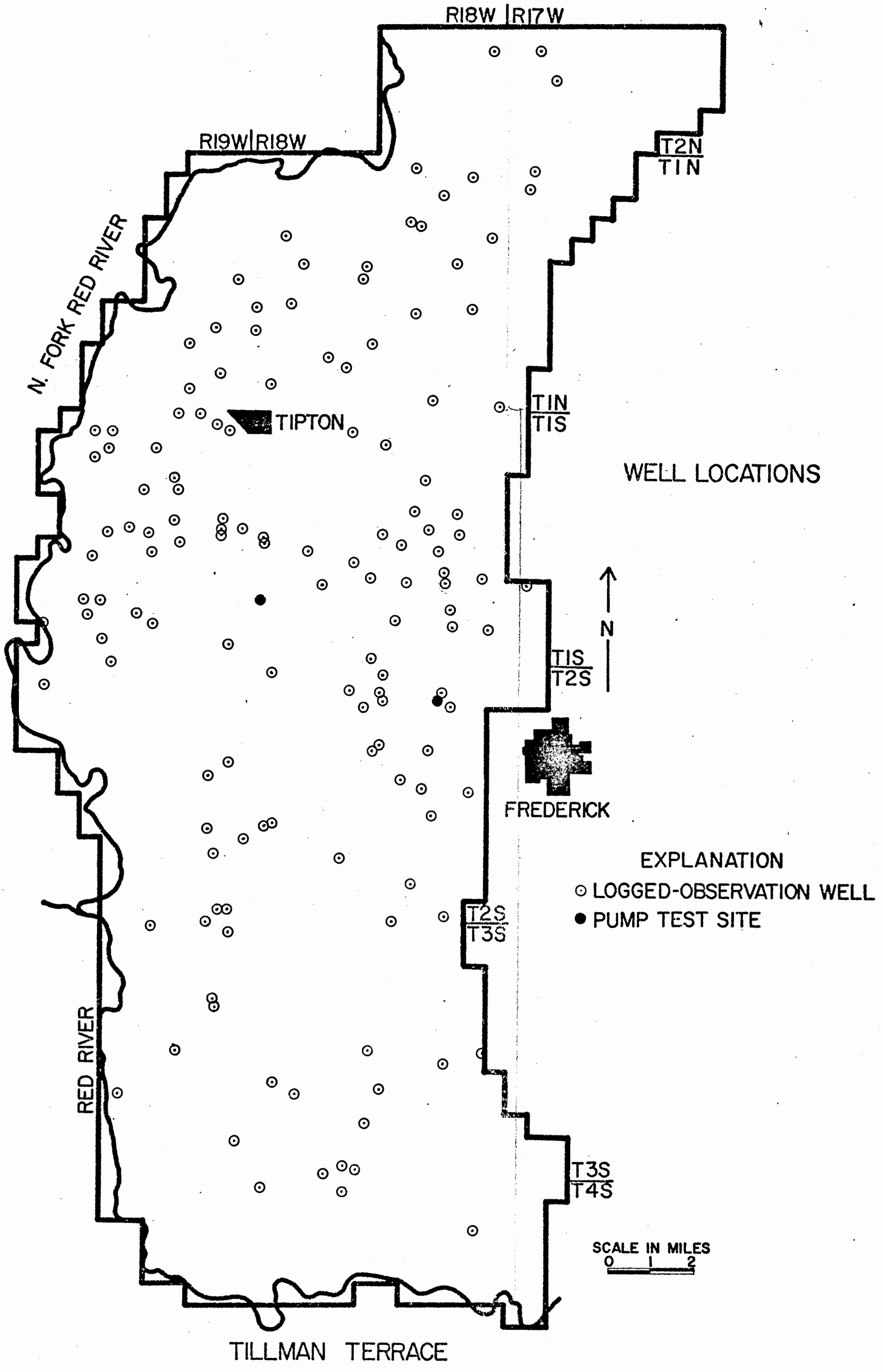
There are more than 800 water wells drilled in this area. Hydrogeologic information has been obtained from approximately 165 wells. The data collected from some of these wells include location, well elevations, water levels and total bedrock depth. A few pump tests have also been conducted. The locations of these wells are distributed throughout the area as shown in Figure 1.

The area has undergone extensive pumping during the last 20 years as a result of increasing irrigation development. Consequently, the water levels have been declining in some areas due to ground-water mining. In November, 1968, Tillman County was declared a critical ground-water area by the Oklahoma Water Resources Board.

Under Oklahoma Statute No.'s 82 § 1020.4 and 82 § 1020.5, the Oklahoma Water Resources Board is responsible for completing hydrologic surveys of each fresh ground-water basin or subbasin within the state of Oklahoma and for determining a maximum annual safe yield which will provide a 20-year minimum life for each basin or subbasin.

Oklahoma Statute No. 82 § 1020.5 states the following:

Figure 1. Well locations



WELL LOCATIONS

> After making the hydrologic survey, the Board shall make a determination of the maximum annual yield of fresh water to be produced from each ground-water basin or subbasin. Such determination must be based upon the following:
>
> 1. The total land area overlying the basin or subbasin;
> 2. The amount of water in storage in the basin or subbasin;
> 3. The rate of natural recharge to the basin or subbasin and total discharge from the basin or subbasin;
> 4. Transmissibility of the basin or subbasin; and
> 5. The possibility of pollution of the basin or subbasin from natural sources.
>
> The maximum annual yield of each fresh ground-water basin or subbasin shall be based upon a minimum basin or subbasin life of twenty (20) years from the effective date of this act. An annual allocation in terms of acre feet per acre per year is to be determined based on the maximum annual yield and used as a basis for issuing permits to owners whose land is located within the aquifer area.

Objectives

The objectives of this study are to utilize the available hydrological data of the area and determine the maximum annual yield and annual allocation of fresh ground water that can be produced from the alluvial floodplain and terrace deposits of the Red River and the North Fork of the Red River in Tillman County, Oklahoma for the 20-year period between July, 1973, and July, 1993. These objectives were achieved using the following methods:

1. Selection of hydrogeologic data including water levels and well data supplied by the Oklahoma Water Resources Board to be used as input data for the mathematical model.

2. Assignment of spatially distributed hydraulic properties to alluvial deposits based on available hydrogeological data.

3. Modification, calibration and validation of an existing mathematical model for predicting changes in an alluvial terrace and floodplain aquifer over a 20-year period.

Previous Work

The terrace deposits of the western part of Tillman County were briefly mentioned by Clifton (1929) as an area of Quaternary or recent exposures consisting of sands and alluvium. In November, 1944, a 24-hour aquifer test was conducted on the irrigation well at the Southwestern Cotton Substation near Tipton. In May, 1945, five test holes were drilled in search of a supplementary water supply for public use. Read and Schoft (1947) discussed the water level fluctuations observed between 1940 and 1947 in the irrigation well at the Southwest Cotton Substation. The Layne Western Company of Wichita, Kansas, drilled 40 test holes in the terrace deposits for the city of Frederick in 1948.

Barclays and Burton (1953) wrote a hydrological report on groundwater resources of the Tillman Terrace. This report was updated by the Oklahoma Water Resources Board which published a hydrologic atlas of Tillman County in 1974 (Wickersham, et al., 1974). This report describes the saturated thickness and the areal extent of irrigation associated with the terrace deposits.

Loo (1972) used a mathematical model to study the effect of vertical permeability variation on the Ogallala aquifer. DeVries and Kent (1973) used a digital model developed for the Texas High Plains in order to assess the sensitivity of the model to vertical variability of aquifer properties. Kent, et al. (1973) evaluated the coefficient of permeability and specific yield of the Washita River alluvium and determined that permeability and specific yield values could be assigned to layered sediments described on drillers' logs. This latter approach was subsequently used in this study.

The alluvial deposits are described as being discontinuous layers of clay, silt and sand which constitute an unconfined water-table aquifer. Bredhoeft and Pinder (1970) and Pinder (1970) designed a basic mathematical model to simulate two-dimensional aquifer problems. This model was used to simultaneously solve the finite-difference equations related to artesian and water-table conditions. Trescott (1973) and Prickett and Lonnquist (1971) added several problem options and input-output features. These features included the method of treating the storage coefficient and leakage in conjunction with evapotranspiration for combined artesian, water-table problems. This model has been modified several times by the U. S. Geological Survey. The 1974 version of this model was used in this study.

CHAPTER III

DESCRIPTION OF STUDY AREA

Location

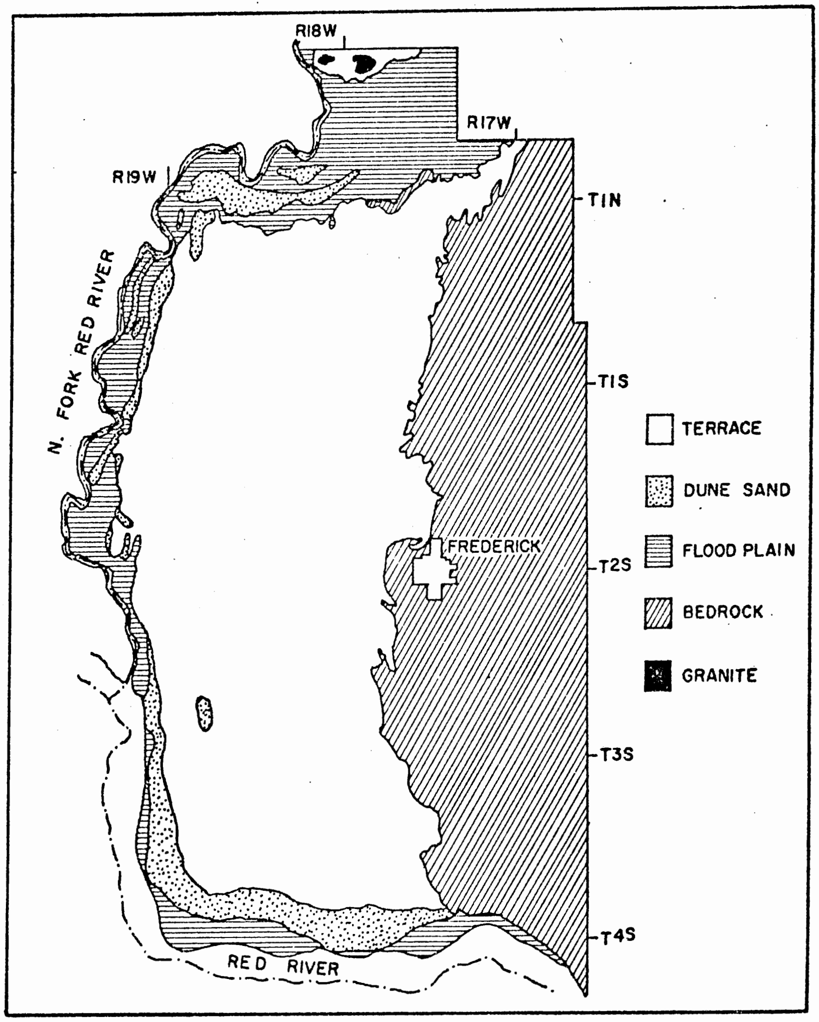
The study area is defined by the limits of the "Tillman Terrace" aquifer located in the western half of Tillman County in southwestern Oklahoma. It includes portions of T2N through T4S, and R17W through R19W as shown in Figure 1. It is bounded on the north by Kiowa County and on the south and west by an imaginary line extending north and south, passing just west of the city of Frederick. The aquifer extends over 285 square miles in Tillman County. Its maximum length from north to south is approximately 29 miles and its maximum width is about 13 miles.

Geology

The rocks exposed in the area range in age from Precambrian to Quaternary as shown in Figure 2. The oldest Paleozoic rocks were apparently deposited at the time when the area was relatively stable. Crustal deformation of the rocks occurred during the early Pennsylvanian resulting in the uplift of the Wichita Mountains. Sediments which might have been deposited between Permian and Quaternary times were eroded due to a long period of weathering and erosion.

The Precambrian granite is exposed at the surface in T2N, R18W, and is surrounded by the Quaternary sediments. The granite is believed to yield a very low quantity of water, except at the intersection of joints.

Figure 2. Geologic map


R18W
R17W
R19W
T1N
T1S
T2S
T3S
T4S
N. FORK RED RIVER
RED RIVER
FREDERICK
TERRACE
DUNE SAND
FLOOD PLAIN
BEDROCK
GRANITE

The Hennessey Formation of Permian age outcrops adjacent to and subcrops below the alluvial deposits. They are characterized by reddish-brown argillaceous siltstones intercalated with thin layers of gray and reddish-brown shale. The outcrop has a gentle regional dip to the southwest. The Hennessey Formation does not yield large quantities of water. Low to moderate yields might be obtained from lenticular sandstones.

The Quaternary sediments consist of alluvial and eolian sands which cover most of the area west of a low gradational escarpment formed by the contact between the alluvium and Hennessey shale (Figure 2). The contact trends north and south immediately west of the city of Frederick. The alluvium is predominately composed of terrace deposits. The terrace deposits consist of discontinuous layers of clay, sandy clay, sand and gravel. Generally the sand and gravel are not well sorted. These sediments vary in color from gray to brown and reddish brown. Scattered pebbles of quartz are found in the clay. The surface is gently undulated to flat, sloping gently westward to the North Fork of the Red River. Elevations range from 1,396 feet above mean sea level in the center of the area of the deposits to 1,131 feet above mean sea level in the southwest corner of the area.

The thickness of the terrace deposits vary from place to place due to irregularities of the underlying shale. Test drilling indicate that the average thickness of the terrace deposits is approximately 42 feet. These deposits thin northward to Kiowa County. Bedrock occurs at the surface in the south-central portion of the study area. Terrace gravels which overlie the bedrock in this area are shown in Figure 3. The terrace deposits are the major supply of ground water in the area. Wells

Figure 3. Hennessey shale and terrace alluvium. Terrace gravels typically occur on top of the Hennessey shale near the eastern edge of terrace alluvium in Sec. 34, T2S, R18W.

completed in these sediments may yield from 50 to 500 gpm and the average yield is 200 gpm. The average coefficient of permeability is 691 gpd/ft^2 and transmissivity ranges between 100 gpd/ft and 50,000 gpd/ft.

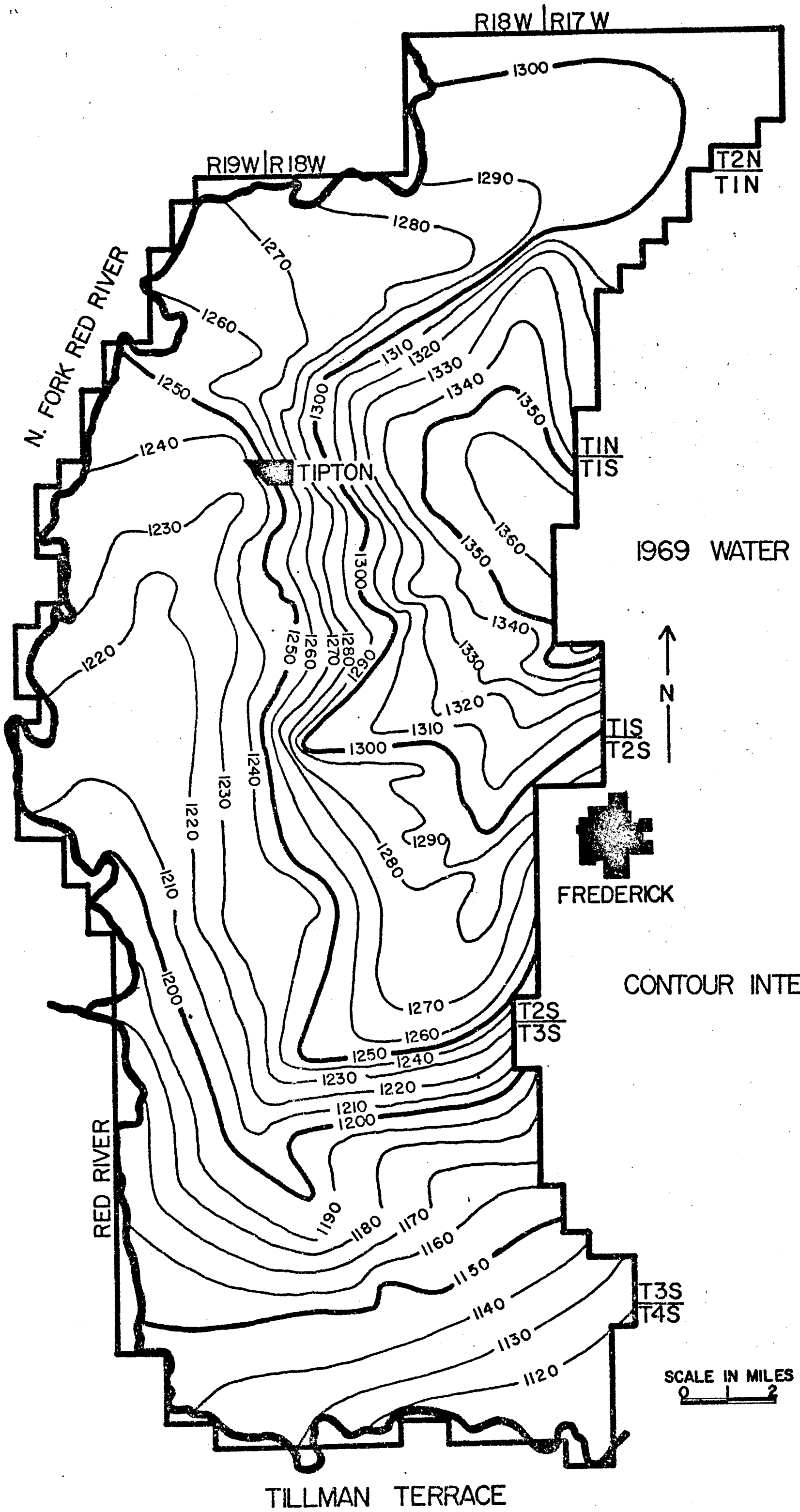
The floodplain alluvium ranges from less than one-half mile to one and one-half miles wide along most of the Red and North Fork of the Red River reaches. It is separated from the terrace deposits by a poorly defined topographic break. Its thickness varies from 27 feet to 47 feet, north to south, and averages 34 feet. The average well yield of the floodplain is 300 gpm. The average coefficient of permeability is 689 gpd/ft^2 and transmissivity ranges between 200 gpd/ft and 60,000 gpd/ft.

Eolian deposits discontinuously overlie the floodplain alluvium of the Red River and the east side of the North Fork of the Red River. The thickness ranges from 15 to 68 feet and generally occur above the water table. Being highly permeable, they serve an important role in allowing precipitation to infiltrate and recharge the floodplain portion of the aquifer.

Water Table

The terrace and alluvial deposits occur as an unconfined aquifer. A 1969 water table map is shown in Figure 4. The water table slopes at an average gradient of 18 feet per mile westward to the Red River forming an effluent stream condition. The North Fork of the Red River is generally influent with a gradient away from the river at 10 feet per mile. The water table slopes toward the Otter Creek tributary in the northern portion of the area.

Figure 4. 1969 Water-head elevations



1969 WATER HEAD ELEVATION

CONTOUR INTERVALS = 10 Ft.

Climate

The area is characterized by a semi-arid climate. The average annual temperature for the city of Frederick is 63.3°F. The average annual precipitation for the period of 1954 to 1974 is 24.95 inches. The highest precipitation occurs in May and the lowest in January. Precipitation data for the cities of Frederick and Tipton is shown in Table I for the period of 1954 to 1974.

Recharge

The sandy soil of western Tillman County has a high rate of infiltration. Presence of discontinuous layers of clay and caliche within the terrace deposits above the water table does not regionally prevent infiltration of precipitation to the zone of saturation but they will generally decrease it. Hydrologic studies by the Oklahoma Water Resources Board (1975) have used nine percent of precipitation as an estimate of net change recharge to the water table.

The average precipitation for the cities of Tipton and Frederick as computed from Table I is 24.45 inches. A recharge of 2.2 inches per year (6.6×10^{-9} feet per second) can be computed based on the percentage of nine percent and the 24.45 inches of rainfall. When this recharge is prorated over the 189,760 acres of the aquifer area, natural recharge is estimated to be 34,726 acre feet per year. Secondary recharge to the aquifer is the return flow from irrigation. A conservative percentage of 15 percent is estimated based on studies by the Oklahoma Water Resources Board (1975).

Evaporation and transpiration are important factors to be considered due to the shallow water table and semi-arid conditions. These two

TABLE I

PRECIPITATION DATA FOR THE CITIES OF TIPTON AND FREDERICK FROM 1954 TO 1974

Year	Frederick	Tipton
1974	28.43	27.34
1973	35.03	34.61
1972	26.24	22.77
1971	22.51	19.77
1970	18.37	13.18
1968	29.11	30.73
1966	19.27	17.69
1964	25.54	26.52
1962	31.48	29.07
1960	31.42	31.15
1958	23.12	22.69
1956	18.05	19.29
1954	15.82	16.45

factors have been combined together because of the difficulties in computing transpiration alone. In this study, evapotranspiration was considered as a part of net recharge and as evaporation occurring within the first one foot of the surface.

Irrigation

Farming is the major industry in this area. Cotton, wheat and alfalfa are the major crops. There is, however, small quantities of grain, grain sorghum, forage sorghum, oats and barley grown in the area. Pasture grasses are also grown for grazing during the fall, winter and spring months.

The irrigation period occurs predominantly in the months of June, July, August and September. The amount of irrigation differs from one crop to another. The water use for irrigation of different crop types in Tillman County are listed in Table II. The irrigation period as used in the model will include the months of June through September even though minor amounts of irrigation are applied during the early spring months.

TABLE II

1974 SURFACE AND GROUNDWATER USE FOR TILLMAN COUNTY (AFTER OKLAHOMA WATER RESOURCE BOARD, 1974)

	Ground Water		Surface Water	
Crop	Acres Irrigated	Water Use Acre-Feet	Acres Irrigated	Water Use Acre-Feet
Alfalfa	1,839	4,190	10	25
Grain Corn	33	26	0	0
Silage Corn	15	9	0	0
Cotton	6,140	4,904	0	0
Horticulture	46	42	0	0
Pasture	2,380	4,203	261	303
Peanuts	0	0	200	1,999
Wheat	3,718	2,325	50	22
Small Grain	447	322	20	13
Soybeans	21	54	0	0
Grain Sorghum	823	652	50	66
Forage Sorghum	591	820	35	46
Other Crops	260	241	52	17
TOTAL	16,313	17,788	678	2,491

MUNICIPAL AND INDUSTRIAL

Use		Water Use Acre-Feet		Water Use Acre-Feet
Municipal		1,306		0
Industrial		0		0
Recreation and Wildlife		0		0
Sec. Oil Rec.		0		0
Other M and I		0		0
TOTAL		1,306		0
TOTAL/SOURCE	16,313	19,094	678	2,491

COUNTY TOTAL ACRES IRRIGATED: 16,991 WATER USE (A.F.): 21,585

CHAPTER IV

METHODOLOGY

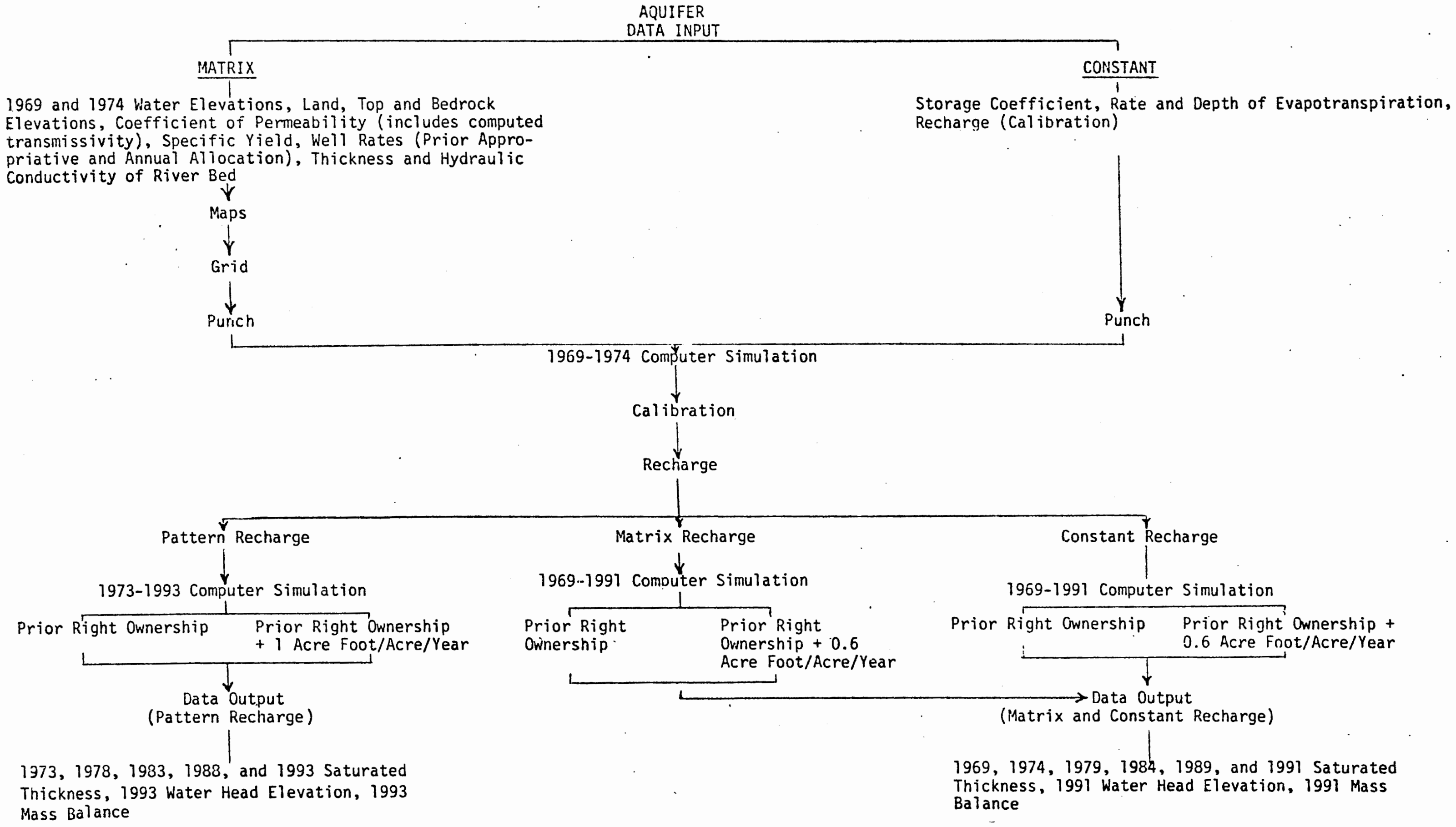
General

The hydrogeological data collected for the study area was analyzed and spatially distributed over the entire area. Steps employed to use the model for the desired results are summarized in Figure 5. The input data was divided into matrix and constant parameters. The matrix parameters included: water head elevations; land, top and bedrock elevations; coefficient of permeability; specific yield; river bed thickness and hydraulic conductivity; and well pumping rate. The constant parameters included storage coefficient of the river bed and rate and depth of evapotranspiration. Recharge rate was included in either category depending on the computer run used. These input data were transferred onto maps, gridded and punched on IBM cards.

A five-year computer simulation was performed for the period between 1969 and 1974 using the observed 1969 water-head elevations. This simulation was used to calibrate the model. Calibration was achieved by adjusting the recharge rate so that the simulated 1974 water-head elevations were within five feet of the observed 1974 water-head elevations. Three recharge versions were introduced: pattern recharge, calibration matrix recharge and constant recharge.

A 22-year computer simulation (1969 to 1991) was conducted using the calibration matrix and constant recharge versions. Two runs were made

Figure 5. Data input-out flow chart


AQUIFER
DATA INPUT
MATRIX
1969 and 1974 Water Elevations, Land, Top and Bedrock Elevations, Coefficient of Permeability (includes computed transmissivity), Specific Yield, Well Rates (Prior Appropriative and Annual Allocation), Thickness and Hydraulic Conductivity of River Bed
Maps
Grid
Punch
CONSTANT
Storage Coefficient, Rate and Depth of Evapotranspiration, Recharge (Calibration)
Punch
1969-1974 Computer Simulation
Calibration
Recharge
Pattern Recharge
1973-1993 Computer Simulation
Prior Right Ownership
Prior Right Ownership + 1 Acre Foot/Acre/Year
Data Output (Pattern Recharge)
1973, 1978, 1983, 1988, and 1993 Saturated Thickness, 1993 Water Head Elevation, 1993 Mass Balance
Matrix Recharge
1969-1991 Computer Simulation
Prior Right Ownership
Prior Right Ownership + 0.6 Acre Foot/Acre/Year
Constant Recharge
1969-1991 Computer Simulation
Prior Right Ownership
Prior Right Ownership + 0.6 Acre Foot/Acre/Year
Data Output (Matrix and Constant Recharge)
1969, 1974, 1979, 1984, 1989, and 1991 Saturated Thickness, 1991 Water Head Elevation, 1991 Mass Balance

for each version. Both runs were based on different pumping rates; one run uses the prior appropriative right ownership only and the other one incorporates both prior appropriative right ownership and the subsequent allocated pumping of 0.6 acre feet/acre/year. A final 20-year computer simulation was conducted for the 1973 to 1993 period using the pattern recharge version. Again, two runs were performed; one using prior appropriative right ownership only and the other run using prior appropriative right ownership and the subsequent allocated pumping of 1 acre feet/acre/year.

Data output from these versions were plotted using the computer printer. Data was plotted for each five-year interval of the total simulation period. Computed output data included transmissivity, saturated thickness, and water-head elevations.

Coefficient of Permeability

To determine the coefficient of permeability and transmissivity, well pump test data for the cities of Tipton and Frederick were analyzed using the Prickett-type (1965) curve method. The method is described in Tables III and IV and results are shown in Figures 6 and 7. The Tipton test resulted in a value of transmissivity of 17,054 gpd/ft and a coefficient of permeability of 352 gpd/ft^2 as shown in Table III. The transmissivity value obtained from the Frederick test is 21,015 gpd/ft and the coefficient of permeability was 350 gpd/ft^2 as shown in Table IV.

Problems arose because the limited available data from the 123 wells within the study area could not be used to directly furnish the coefficient of permeability and transmissivity for the entire area. Therefore, another method was used to generate the coefficient

TABLE III

PUMP TEST RESULT USING PRICKETT METHOD FOR SOUTHWESTERN SUBSTATION WELL, TIPTON

Early Match Point

$W(U_A, \frac{r}{D_t}) = 1.8$

$\frac{1}{U_A} = 14$

$U_A = 0.071$

$S = 2.2$ ft

$t = 100$ min

$$T = \frac{114.60}{S} W(U_A, \frac{r}{D_t}) = \frac{(114.6)(199)(1.8)}{2.2} = 17{,}627 \text{ gpd/ft}$$

$$S = \frac{TU_A t}{2693r^2} = \frac{(17{,}627)(.071)(100)}{(2693)(1600)} = .029$$

Late Match Point

$W(U_y, \frac{r}{D_t}) = 3.0$

$\frac{1}{U_y} = 10$

$U_y = 0.1$

$S = 3.6$ ft

$t = 1100$ min

$$T = \frac{114.6Q}{S} W(U_y, \frac{r}{D_t}) = \frac{(114.6)(188)(3)}{3.6} = 17{,}964 \text{ gpd/ft}$$

$$S_y = \frac{TU_y t}{2693r^2} = \frac{(17{,}954)(.1)(1100)}{(2693)(1600)} = 0.458$$

$K = \frac{T}{t}$ where t = thickness of aquifer $\frac{17{,}954}{51} = 352$ gpd/ft^2

TABLE IV

PUMP TEST RESULT USING PRICKETT METHOD FOR THE CITY OF FREDERICK

$W(U) = 0.62$

$\frac{1}{U_y} = 0.81$

$U_y = 1.23$

$Q = 210$ gpm

$S = 0.71$ ft

$t = 1450$ min

$r = 300$ ft

$$T = \frac{114.6Q}{S} W(U) = \frac{114.6\ (210)(0.62)}{(0.71)} = 21{,}015 \text{ gpd/ft} \quad (22{,}000)$$

$$S_y = \frac{TU_y t}{2693r^2} = \frac{(21{,}000)(1.23)(1450)}{2693(300^2)} = 0.155 \quad (.087)$$

$$K = \frac{T}{t} \text{ where } t = \text{thickness of aquifer} \quad \frac{21{,}015}{60} = 350 \text{ gpd/ft}^2$$

Figure 6. Water-table, fully penetrating, constant-discharge, time-drawdown type curves (modified after Prickett, 1965)

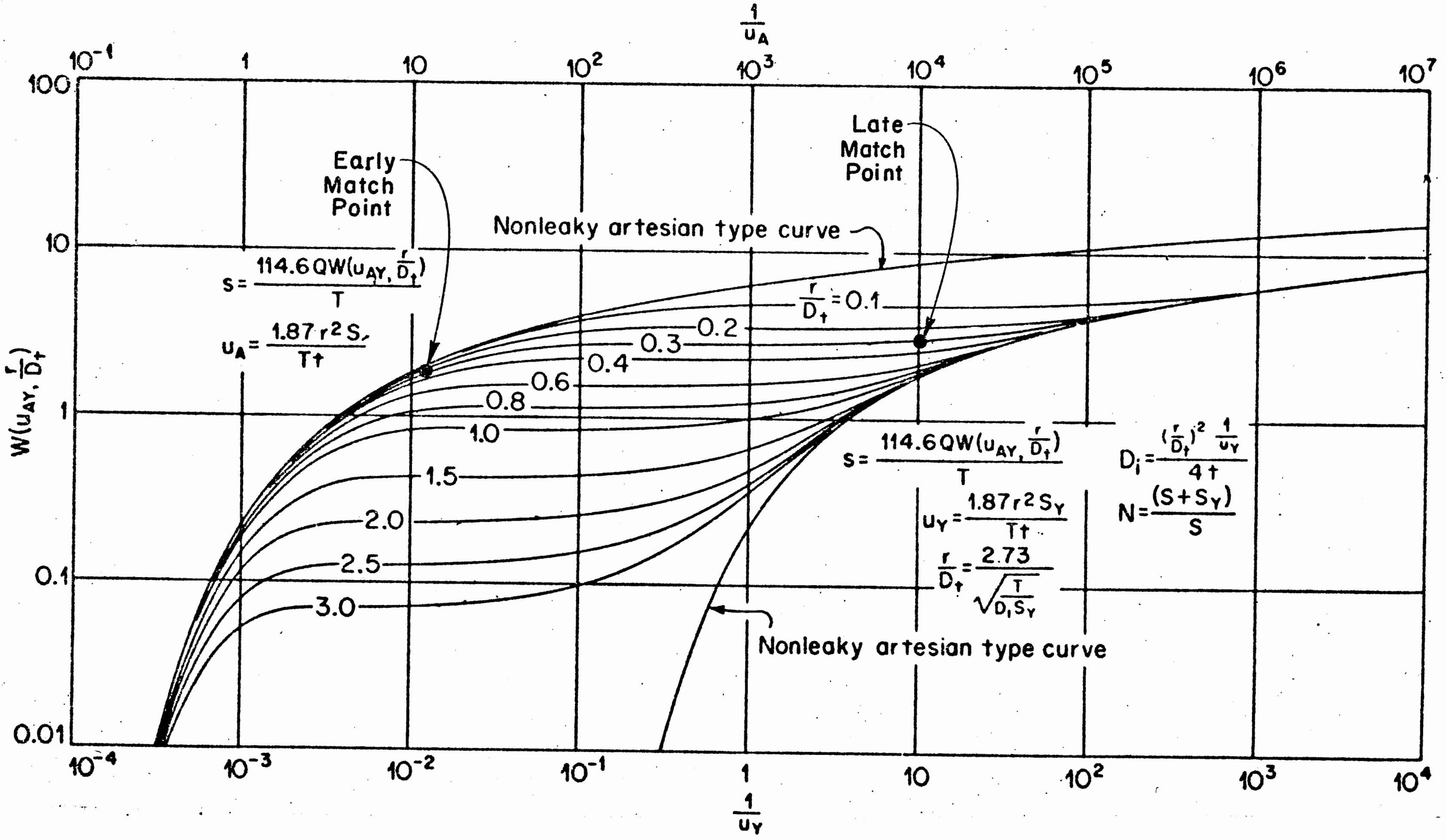
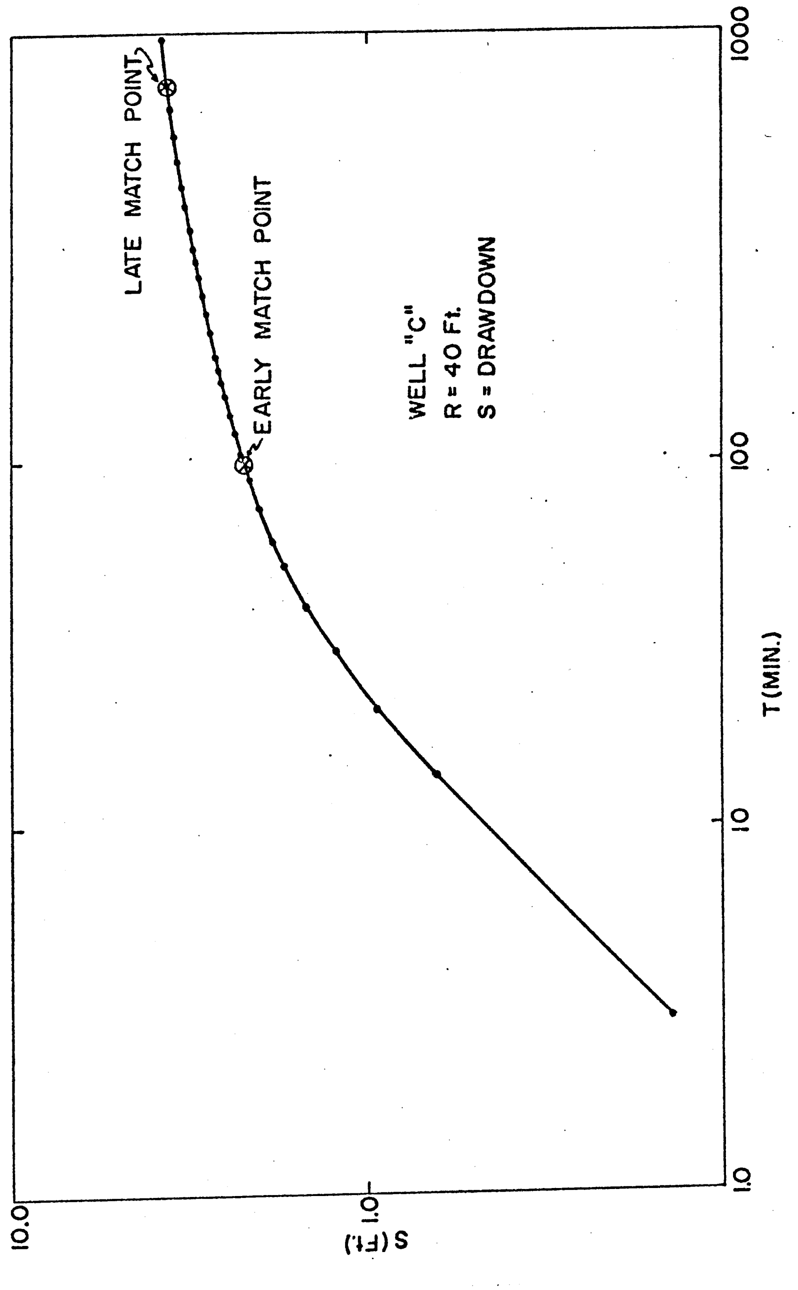
$\frac{1}{u_A}$
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^6
10^7
100
10
1
0.1
0.01
$W(u_{AY}, \frac{r}{D_t})$
Early Match Point
Late Match Point
Nonleaky artesian type curve
$s = \frac{114.6 Q W(u_{AY}, \frac{r}{D_t})}{T}$
$u_A = \frac{1.87 r^2 S}{Tt}$
$\frac{r}{D_t} = 0.1$
0.2
0.3
0.4
0.6
0.8
1.0
1.5
2.0
2.5
3.0
$s = \frac{114.6 Q W(u_{AY}, \frac{r}{D_t})}{T}$
$u_Y = \frac{1.87 r^2 S_Y}{Tt}$
$\frac{r}{D_t} = \frac{2.73}{\sqrt{\frac{T}{D_i S_Y}}}$
$D_i = \frac{(\frac{r}{D_t})^2 \frac{1}{u_Y}}{4t}$
$N = \frac{(S+S_Y)}{S}$
Nonleaky artesian type curve
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^2
10^3
10^4
$\frac{1}{u_Y}$

Figure 7. Pump test, time-drawdown graph for well "C" at Tipton, Oklahoma


LATE MATCH POINT
EARLY MATCH POINT
WELL "C"
R = 40 Ft.
S = DRAWDOWN
S (Ft.)
10.0
1.0
T (MIN.)
1.0
10
100
1000

of permeability and transmissivity for these wells and to distribute these values over the entire study area. Information related to thickness and lithology of the terrace deposits was obtained from driller's logs of 123 water wells. The driller's logs obtained from these wells describe the stratigraphic lithology contained in each well. The lithology is divided into four ranges: range one is associated with clay and silt; range two is very fine to fine sand; range three is fine to coarse sand; and range four is associated with coarse sand and gravel. A weighted average permeability was introduced by multiplying a weighting factor for the four ranges of size by the percentage of saturated thickness for each range and summing up the total for all the ranges. This method is described for the Tipton and Frederick pump test sites in Table V. The weighting factors for each range were obtained from the coefficient of permeability grain-size envelope developed by Kent _et al._ (1973) as shown in Figure 8. The ranges were chosen to represent various median grain sizes which correspond to the average coefficient of permeability for each range as shown in Figure 8. The values for permeabilities were converted from gpd/ft^2 to units of feet/second by using a multiple of 1.55×10^{-6}. The computed weighted average permeability values were compared with the coefficient of permeability derived from pump test analysis as shown in Table VI. Both methods produced similar results. This was considered to be justification for using the envelope in Figure 8 to determine an average permeability coefficient for each well. The computed average weighted permeability coefficients for the wells were used to generate a contour map to represent the distribution of permeability values at a scale of one-half inch per mile. The permeability map is shown in Figure 9. A one-quarter mile grid of the same scale was

TABLE V

WEIGHTED AVERAGE PERMEABILITY FOR THE CITIES OF TIPTON AND FREDERICK

Range	Coefficient of Permeability (GPD/FT^2)	Interval Thickness	% Thickness	Weighting of Permeability Coefficient (GPD/FT^2)
City of Tipton (Southwestern Cotton Substation)				
1	18	0	0.00	0.0
2	97	53	0.88	85.4
3	516	0	0.00	0.0
4	1,484	7	0.12	178.0
				263.4 gpd/ft^2
				($\overline{K}$) Average Weighted Permeability
City of Frederick				
1	18	0	0.00	0.0
2	97	34	0.66	64.0
3	516	3	0.07	36.1
4	1,484	14	0.27	400.7
				500.8 gpd/ft^2
				($\overline{K}$) Average Weighted Permeability

Figure 8. Relationship between hydraulic coefficient ranges, medium grain size and the coefficient of permeability

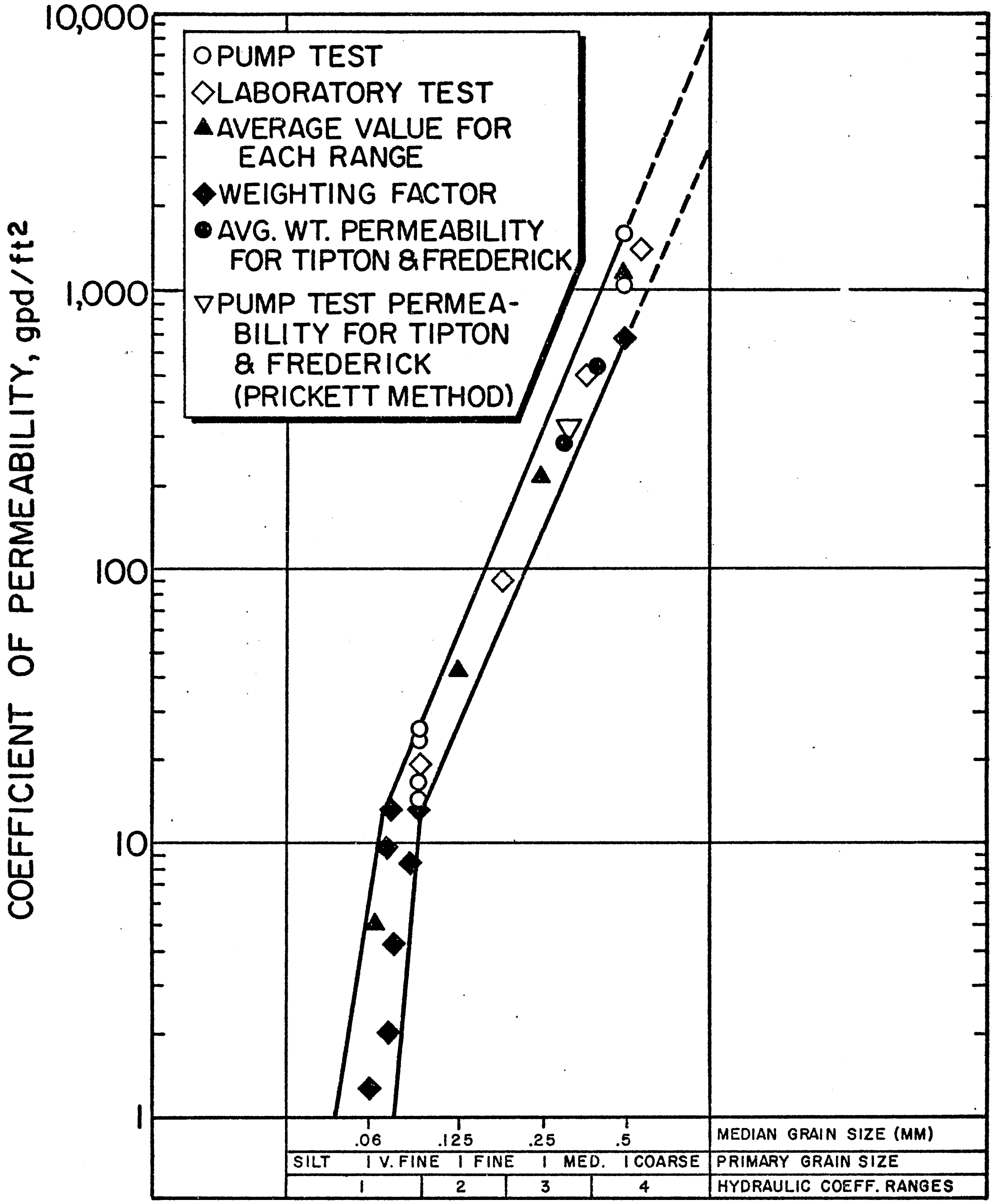
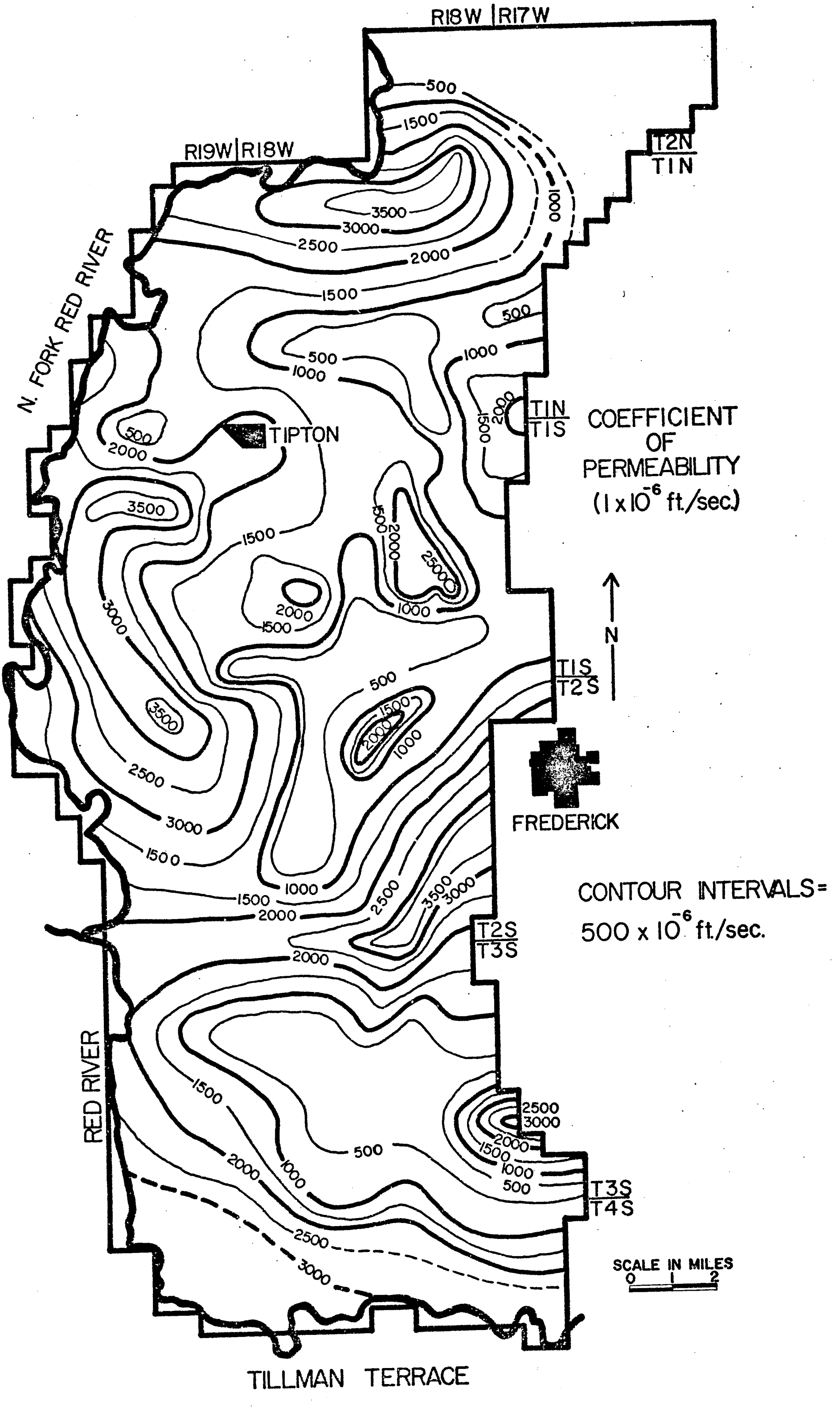

10,000
1,000
100
10
1
COEFFICIENT OF PERMEABILITY, gpd/ft2
○PUMP TEST
◇LABORATORY TEST
▲AVERAGE VALUE FOR EACH RANGE
◆WEIGHTING FACTOR
●AVG. WT. PERMEABILITY FOR TIPTON & FREDERICK
▽PUMP TEST PERMEABILITY FOR TIPTON & FREDERICK (PRICKETT METHOD)
.06
.125
.25
.5
MEDIAN GRAIN SIZE (MM)
SILT
V. FINE
FINE
MED.
COARSE
PRIMARY GRAIN SIZE
1
2
3
4
HYDRAULIC COEFF. RANGES

TABLE VI

COMPARISON OF COEFFICIENTS OF PERMEABILITY AND TRANSMISSIVITY AS DERIVED FROM PUMP TESTS AND DRILLER'S LOGS

	Tipton	Frederick
Computed Permeability from Pump Tests	352 gpd/ft^2	350 gpd/ft^2
Computed Weighted Average Permeability Using Envelope in Figure 8	500 gpd/ft^2	264 gpd/ft^2
Transmissivity from Pump Test	17,954 gpd/ft	21,015 gpd/ft
Computed Weighted Average Transmissivity Using Envelope in Figure 8	17,697 gpd/ft	15,840 gpd/ft

Figure 9. Coefficient of permeability map


R18W | R17W
R19W | R18W
T2N
T1N
T1N
T1S
T1S
T2S
T2S
T3S
T3S
T4S
N. FORK RED RIVER
RED RIVER
TIPTON
FREDERICK
TILLMAN TERRACE
COEFFICIENT
OF
PERMEABILITY
(1 x 10⁻⁶ ft./sec.)
N
CONTOUR INTERVALS =
500 x 10⁻⁶ ft./sec.
SCALE IN MILES
0 1 2
500
1000
1500
2000
2500
3000
3500

overlaid onto the contour map. Coefficient of permeability values were assigned to each node by a perimeter-averaging technique described by Griffen (1949). This technique involved averaging interpolated values at the center of each node face with the node center. The digitized permeability values are shown in Figure 10.

Specific Yield

Specific yield values were obtained for each range shown on the envelope in Figure 8. The graph in Figure 11 was used to provide a relationship between median grain size and specific yield. The dominant grain size scale shown in Figure 11 was considered to be equivalent to median grain size. The values for specific yield along with the corresponding permeability coefficients of the four ranges were plotted on a semi-logarithmic paper as shown in Figure 12. A parabolic relationship between permeability and specific yield was developed. Values of specific yield were assigned to each node by using the curve in Figure 11 and the average permeability coefficient determined for each node. The resulting specific yield contour map is shown in Figure 13 and the corresponding digitized version is shown in Figure 14.

Aquifer Boundaries

The water levels of these wells were obtained from the Water Resources Board (1976). The 1969 and 1974 water levels and their well locations were transferred onto a quarter-mile grid and contoured. These maps are shown in Figures 4 and 15. Interpolated head values at the center of each node were used for the computer matrix.

The Hennessey shale underlies the aquifer as an impermeable boundary.

Figure 10. Digitized computer input of permeability

```
                                      TILLMAN TERRACE AQUIFER
                                     PERMEABILITY (GPD/FT.SQ.)

           2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32   33   34   35

ROW  2 **********************************************************************************************************************************************************************
ROW  3 ******************************************************************************************  83. 146. 146. 146. 146. 146. 146. 146. 146. 146. 146. 146. 146. 146. 146. 146.
ROW  4 ******************************************************************************************  83. 187. 167. 167. 146. 146. 146. 146. 146. 146. 146. 146. 146. 146. 146. 146.
ROW  5 ****************************************************************************************** 333. 313. 313. 292. 229. 167. 146. 146. 146. 146. 146. 146. 146. 146. 146. 146.
ROW  6 ****************************************************************************************** 542. 563. 604. 646. 646. 500. 313. 167. 146. 146. 146. 146. 146. 146. 146.*****
ROW  7 ****************************************************************************************** 750. 730. 813. 959.1042. 834. 626. 396. 271. 146. 146. 146. 146.***************
ROW  8 *********************************************1084.1084.1084.1042.1042.1042.1042.1042.1042.1042. 959.1022.1313.1459.1042. 834. 613. 313. 158. 146. 146.********************
ROW  9 ****************************************1167.1167.1167.1167.1167.1230.1251.1335.1418.1439.1459.1459.1459.1480.1376.1146. 938. 730. 500. 167. 146. 146.********************
ROW 10 ****************************************1042.1042.1105.1126.1146.1272.1335.1397.1418.1439.1459.1464.1464.1459.1251.1022. 855. 688. 500. 229. 146.*************************
ROW 11 ***********************************  834.  834. 855. 876. 938.1022.1063.1126.1188.1209.1230.1230.1251.1251.1167.1063. 917. 750. 646. 500. 250.******************************
ROW 12 *********************************** 667. 667. 667. 688. 772. 792. 855. 938. 980.1022.1022.1022.1000. 988. 938. 834. 750. 709. 563. 417.***********************************
ROW 13 *********************************** 667. 667. 667. 667. 667. 667. 730. 742. 792. 813. 813. 813. 772. 730. 667. 646. 584. 521. 417.****************************************
ROW 14 *********************************** 667. 667. 667. 688. 667. 604. 563. 542. 584. 604. 563. 521. 480. 417. 417. 313. 271. 250. 167.****************************************
ROW 15 ************************* 980. 876. 834. 620. 600. 675. 563. 469. 300. 282. 229. 229. 187. 146. 125. 146. 292. 313. 187. 187. 209.****************************************
ROW 16 *************************1042.1042. 959. 825. 634. 667. 517. 434. 250. 150.  75.  75.  75.  83.  83. 146. 292. 313. 313. 333. 375.****************************************
ROW 17 ********************1342.1042.1042.1042. 920. 751. 584. 525. 511. 551. 500. 417. 301. 357. 357.  92. 146. 417. 563. 521. 521. 563.****************************************
ROW 18 ********************1342.1022. 938. 938. 920. 834. 730. 626. 686. 671. 584. 511. 534. 500. 469. 313. 125. 417. 667. 730. 792.*********************************************
ROW 19 ********************1322. 938. 688. 626. 657. 701. 743. 750. 876. 750. 663. 628. 555. 567. 507. 354.  83. 313. 584. 772. 917.*********************************************
ROW 20 ***************1084.1322. 813. 604. 563. 544. 550. 529.1022. 892. 876. 701. 588. 569. 550. 525. 417. 209. 333. 500. 688. 917.*********************************************
ROW 21 **********1042.1042.1384. 938. 896. 834. 750.1017.1067. 993. 993. 876. 803. 588. 586. 550. 563. 584. 438. 354. 505. 688. 730.*********************************************
ROW 22 ********** 980.1167.1167.1251.1251.1251.1032.1126.1067.1000. 774. 751. 701. 657. 540. 500. 563. 710. 513. 354. 505. 688. 688.*********************************************
ROW 23 ********** 980.1105.1334.1459.1459.1459.1459.1313. 845. 488. 563. 500. 667. 667. 534. 500. 750. 938. 417. 354. 396. 584.**************************************************
ROW 24 ***************1146.1376.1397.1417.1417.1459.1251. 834. 626. 563. 563. 619. 619. 507. 507. 657. 958. 521. 333. 313. 417.**************************************************
ROW 25 ***************1167.1334.1251.1105.1042.1042.1042. 750. 626. 626. 626. 626. 626. 563. 417. 626. 917. 626. 438. 292. 292.**************************************************
ROW 26 **********1084.1022.1334.1251. 959. 813. 834. 730. 626. 626. 646. 646. 646. 626. 417. 333. 626. 917. 917. 626. 354. 292.**************************************************
ROW 27 ***** 834.1000.1188.1334.1251.1022. 792. 629. 626. 626. 626. 667. 750. 771. 709. 417. 250. 688. 917. 917. 855. 375. 292.**************************************************
ROW 28 ***** 730. 938.1146.1334.1272.1105. 876. 709. 626. 626. 626. 688. 750. 834. 750. 417. 208. 417. 626. 626. 626. 417. 292. 292. 292.****************************************
ROW 29 ***** 626. 834.1105.1293.1334.1188.1000. 813. 604. 604. 604. 626. 626. 626. 584. 208.  83.  83. 187. 187. 187. 187. 292. 292. 292.****************************************
ROW 30 ********** 730. 959.1146.1334.1334.1146. 938. 709. 542. 417. 417. 417. 417. 313. 146.  83.  83.  83.  83. 125. 187. 292. 292. 292.****************************************
ROW 31 ***** 626. 626. 750.1346.1251.1334.1334.1042. 713. 521.  83.  83.  83.  83.  83.  83.  83.  83.  83. 213. 229. 250. 292. 417. 417.****************************************
ROW 32 ***** 626. 626. 742.1042.1167.1334.1376.1293.1042. 834. 626. 604. 521.  83.  83. 125. 208. 313. 396. 396. 292. 396. 417. 604. 626.****************************************
ROW 33 ***** 626. 521. 730. 938.1126.1272.1459.1459.1272.1146. 938. 750. 584.  83.  83. 313. 354. 626. 626. 417. 417. 438. 626. 730. 834.****************************************
ROW 34 ***** 626. 667. 730. 938.1128.1167.1334.1334.1334.1146. 938. 750. 542.  83. 208. 417. 834. 834. 417. 417. 417. 626.*******************************************************
ROW 35 ***** 626. 626. 730. 938. 980.1105.1146.1188.1251.1105. 938. 730. 521.  83. 208. 521. 834. 417. 417. 417. 626. 834.*******************************************************
ROW 36 *************** 626. 792. 855. 938.1042.1063.1105.1042. 896. 709. 417.  83. 208. 417. 417. 417. 417. 626. 834.1042.*******************************************************
ROW 37 *************** 626. 667. 792. 834. 917. 938. 980. 959. 834. 626. 313.  83. 208. 417. 417. 480. 688. 917.1042.1230.*******************************************************
ROW 38 ******************** 626. 627. 730. 792. 834. 896. 854. 750. 521. 208.  83. 146. 417. 480. 626. 917.1042.1251.1293.*******************************************************
ROW 39 ******************** 626. 626. 626. 667. 730. 730. 730. 629. 396.  83.  83.  83. 396. 604. 750.1000.1230.1459.1459.*******************************************************
ROW 40 ************************* 626. 626. 626. 626. 626. 626. 626. 313. 104.  83. 213. 438. 730. 938.1126.1418.1459.1397.*******************************************************
ROW 41 ************************* 709. 629. 626. 626. 626. 626. 626. 438. 417. 417. 417. 563. 876.1042.1230.1459.1355.1188.*******************************************************
ROW 42 ************************* 792. 771. 771. 771. 750. 730. 730. 709. 688. 629. 646. 730. 938.1146.1459.1334.1334.1022.*******************************************************
ROW 43 *************************1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1022.1042.1251.1397.1459.1126. 917.************************************************************
ROW 44 *************************1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1063.1146.1355.1459.1313. 938. 730.************************************************************
ROW 45 *************************1000.1000. 876. 834. 813. 750. 730. 688. 646. 688. 730. 834.1000.1042. 938. 730. 688.************************************************************
ROW 46 ************************* 834. 876. 792. 730. 626. 521. 480. 417. 417. 417. 417. 542. 730. 772. 626. 542. 521. 521.*******************************************************
ROW 47 ************************* 834. 834. 698. 480. 354. 208. 208. 208. 208. 208. 208. 417. 563. 438. 313. 354. 438. 438.*******************************************************
ROW 48 ************************* 917. 584. 626. 438. 313. 167.  83.  83.  83.  83.  83. 229. 371. 208.  83. 313. 354. 354.*******************************************************
ROW 49 ************************* 959. 854. 709. 500. 417. 313. 208. 167.  83.  83.  83.  83.  83.  83.  83. 167. 208. 208.*******************************************************
ROW 50 *************************1000. 876. 750. 688. 584. 500. 375. 292. 167.  83.  83.  83.  83.  83.  83. 167. 167. 208.*******************************************************
ROW 51 *************************1042. 938. 854. 730. 688. 626. 521. 417. 313. 167.  83.  83.  83.  83. 125. 167. 313. 626. 709.**************************************************
ROW 52 *************************1084.1042. 938. 834. 750. 667. 584. 500. 313. 167.  83.  83.  83.  83. 125. 167. 417. 834.1251.**************************************************
ROW 53 *************************1167.1126.1000. 938. 854. 771. 646. 521. 313. 208. 208. 208. 208. 208. 208. 208. 333. 834.1042.1042.*********************************************
ROW 54 *************************1251.1188.1126.1042.1000. 917. 834. 626. 417. 333. 292. 292. 313. 313. 250. 208. 208. 521. 626. 750. 750. 626.***********************************
ROW 55 *************************1251.1251.1251.1251.1167.1042.1000. 750. 459. 375. 354. 375. 417. 417. 417. 292. 208. 208. 313. 208. 208. 208.***********************************
ROW 56 *************************1251.1251.1251.1251.1251.1251.1167. 917. 750. 626. 521. 521. 580. 626. 584. 417. 375. 292. 208. 208. 208. 208.***********************************
ROW 57 *************************1251.1251.1251.1251.1251.1251.1251.1167.1042. 917. 834. 834. 834. 834. 834. 626. 417. 375. 375. 417. 417.****************************************
ROW 58 ***********************************1251.1251.1251.1251.1251.1251.1167.1084.1042.1042.1042.1042. 917. 834. 730. 626. 542. 626. 626.****************************************
ROW 59 ***********************************1251.1251.1251.1251.1251.1251.1251.1251.1167.1167.1146.1126.1084.1042.1042. 834. 834. 834. 834.****************************************
ROW 60 ***********************************1251.1251.1251.1251.1251.1251.1251.1251.1251.1251.1251.1251.1251.1251.1251.1042.1042.1042.1042.****************************************
ROW 61 *********************************************1251.1251.1251.1251.1251.1251.1251.1251.**********1251.1251.1251.1251.1251.1251.1042.****************************************
ROW 62 ************************************************************************************************************************1251.*********************************************

TILLMAN 20 YR. RUN  4/23/78  RECH=PATT, WELL=*36 .51 (407)
```

Figure 11. Grain size distribution of cored samples from the Tia Juana Basin, California (after Johnson, 1967)

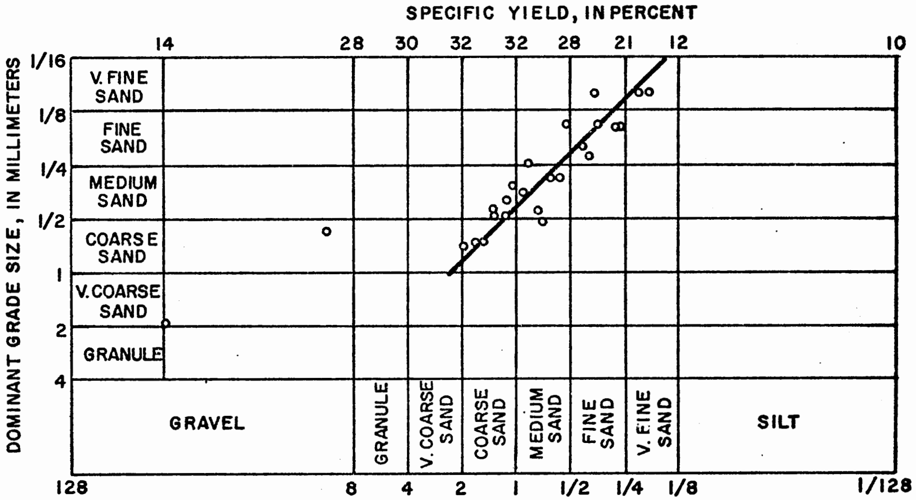

SPECIFIC YIELD, IN PERCENT
14
28
30
32
32
28
21
12
10
DOMINANT GRADE SIZE, IN MILLIMETERS
1/16
1/8
1/4
1/2
1
2
4
V. FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
GRANULE
GRAVEL
GRANULE
V. COARSE SAND
COARSE SAND
MEDIUM SAND
FINE SAND
V. FINE SAND
SILT
128
8
4
2
1
1/2
1/4
1/8
1/128

Figure 12. Relationship between specific yield and the coefficient of permeability

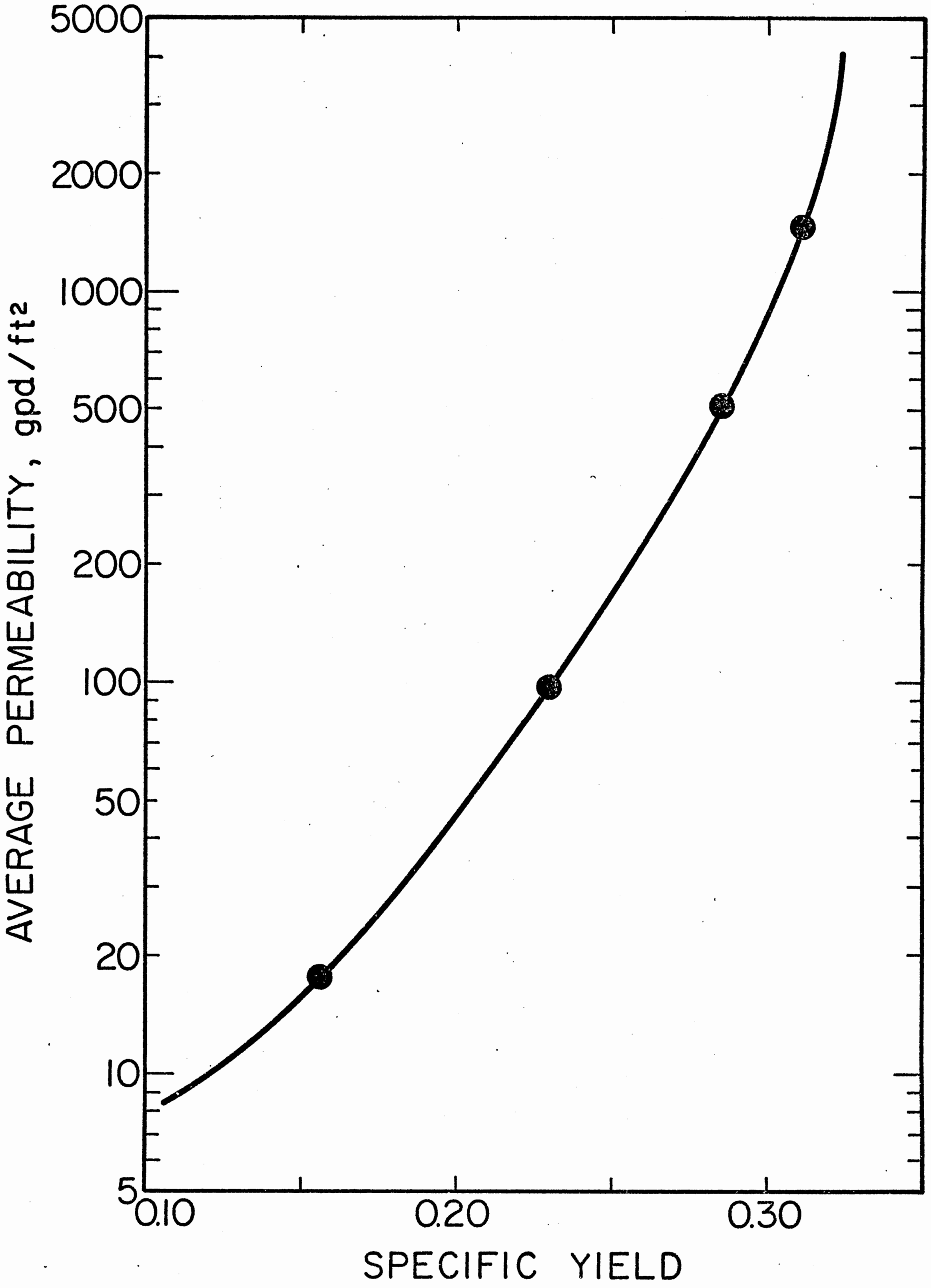
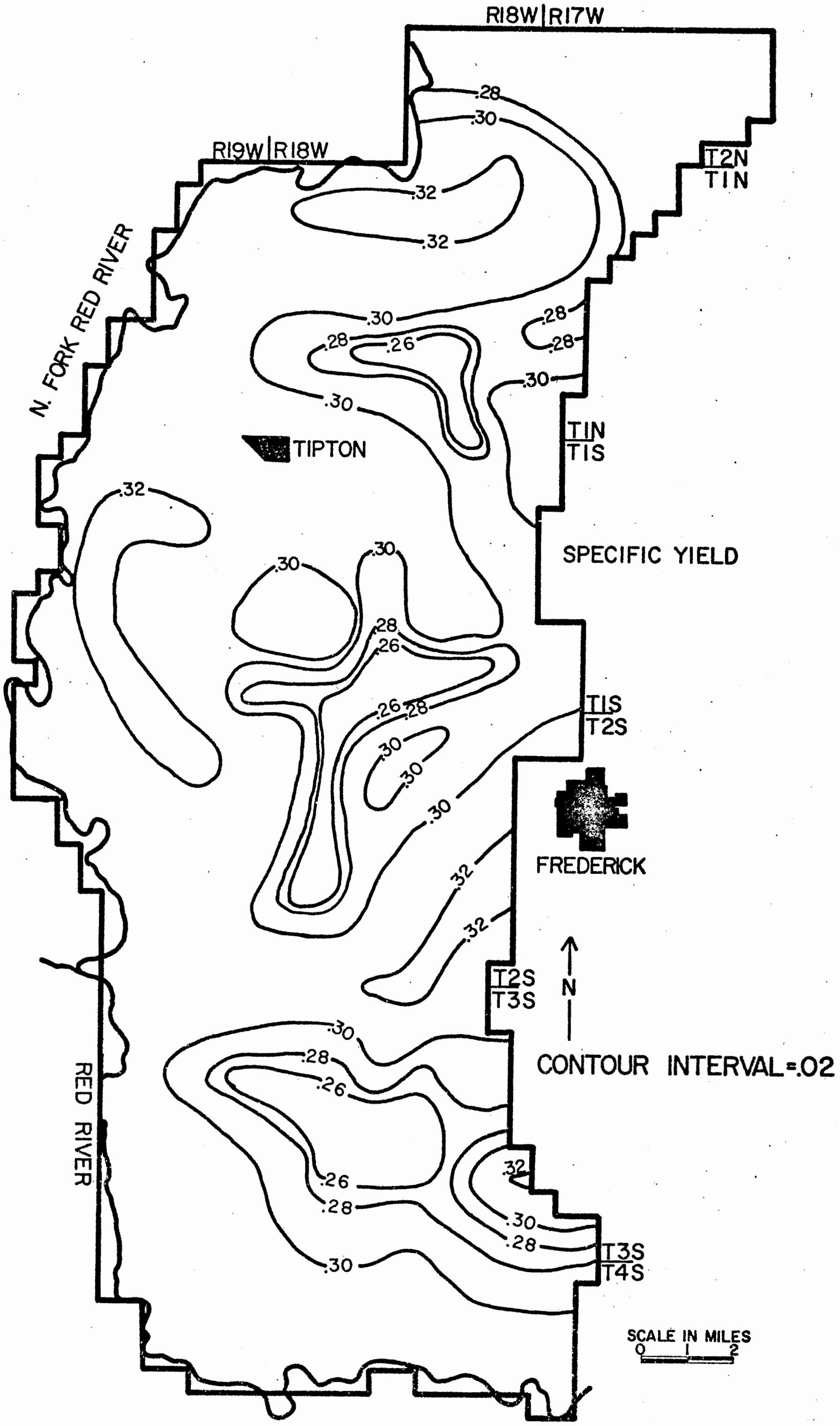

5000
2000
1000
500
200
100
50
20
10
5
0.10
0.20
0.30
AVERAGE PERMEABILITY, gpd/ft²
SPECIFIC YIELD

Figure 13. Specific yield map



TILLMAN TERRACE

Figure 14. Digitized computer input of specific yield

```
                                                            TILLMAN TERRACE AQUIFER
                                                          SPECIFIC YIELD (PER CENT)

           2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32   33   34   35
ROW  2 ********************************************************************************************************************************************************************
ROW  3 ******************************************************************************************  25.  26.  26.  26.  26.  26.  26.  26.  26.  26.  26.  26.  26.  26.  26.  26.
ROW  4 ******************************************************************************************  25.  27.  27.  27.  26.  26.  26.  26.  26.  26.  26.  26.  26.  26.  26.  26.
ROW  5 ******************************************************************************************  29.  29.  29.  29.  28.  27.  26.  26.  26.  26.  26.  26.  26.  26.  26.  26.
ROW  6 ******************************************************************************************  30.  31.  31.  31.  31.  30.  29.  27.  26.  26.  26.  26.  26.  26.  26.*****
ROW  7 ******************************************************************************************  31.  31.  31.  31.  31.  31.  31.  30.  29.  26.  26.  26.  26.***************
ROW  8 *********************************************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  32.  32.  31.  31.  31.  29.  27.  26.  26.********************
ROW  9 ****************************************  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  31.  31.  30.  27.  26.  26.********************
ROW 10 ****************************************  31.  31.  31.  31.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  31.  31.  31.  30.  28.  26.*************************
ROW 11 ***********************************  31.  31.  31.  31.  31.  31.  31.  31.  32.  32.  32.  32.  32.  32.  32.  31.  31.  31.  31.  30.  28.******************************
ROW 12 ***********************************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  30.  30.***********************************
ROW 13 ***********************************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  30.  30.****************************************
ROW 14 ***********************************  31.  31.  31.  31.  31.  31.  31.  30.  31.  31.  31.  30.  30.  30.  30.  29.  29.  28.  27.****************************************
ROW 15 *************************  31.  31.  31.  31.  31.  31.  31.  30.  29.  29.  28.  28.  27.  26.  26.  26.  29.  29.  27.  27.  27.****************************************
ROW 16 *************************  31.  31.  31.  31.  31.  31.  30.  30.  28.  26.  24.  24.  24.  25.  25.  26.  29.  29.  29.  29.  30.****************************************
ROW 17 ********************  31.  31.  31.  31.  31.  31.  31.  30.  30.  30.  30.  31.  29.  29.  29.  25.  26.  31.  31.  30.  30.  31.****************************************
ROW 18 ********************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  30.  30.  30.  30.  29.  26.  31.  31.  31.  31.*********************************************
ROW 19 ********************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  30.  29.  25.  29.  31.  31.  31.*********************************************
ROW 20 ***************  31.  31.  31.  31.  31.  30.  30.  30.  31.  31.  31.  31.  31.  31.  31.  30.  30.  27.  29.  30.  31.  31.*********************************************
ROW 21 **********  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  30.  29.  30.  31.  31.*********************************************
ROW 22 **********  31.  32.  32.  32.  32.  32.  31.  32.  31.  31.  31.  31.  31.  31.  30.  30.  31.  31.  30.  29.  30.  31.  31.*********************************************
ROW 23 **********  31.  32.  32.  32.  32.  32.  32.  32.  31.  30.  31.  30.  31.  31.  30.  30.  31.  31.  30.  29.  30.  31.**************************************************
ROW 24 ***************  32.  32.  32.  32.  32.  32.  32.  31.  31.  31.  31.  31.  31.  30.  30.  31.  31.  30.  29.  29.  31.**************************************************
ROW 25 ***************  32.  32.  32.  32.  31.  31.  31.  31.  31.  31.  31.  31.  31.  30.  30.  31.  31.  31.  30.  29.  29.**************************************************
ROW 26 **********  31.  31.  32.  32.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  30.  29.  31.  31.  31.  31.  29.  29.**************************************************
ROW 27 *****  31.  31.  32.  32.  32.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  30.  28.  31.  31.  31.  31.  30.  29.**************************************************
ROW 28 *****  31.  31.  32.  32.  32.  32.  31.  31.  31.  31.  31.  31.  31.  31.  31.  30.  27.  30.  31.  31.  31.  30.  29.  29.  29.****************************************
ROW 29 *****  31.  31.  32.  32.  32.  32.  31.  31.  31.  31.  31.  31.  31.  31.  31.  27.  25.  25.  27.  27.  27.  27.  29.  29.  29.****************************************
ROW 30 **********  31.  31.  32.  32.  32.  32.  31.  31.  30.  30.  30.  30.  30.  29.  26.  25.  25.  25.  25.  26.  26.  29.  29.  29.****************************************
ROW 31 *****  31.  31.  31.  31.  32.  32.  32.  31.  31.  30.  25.  25.  25.  25.  25.  25.  25.  25.  25.  27.  28.  29.  29.  30.  30.****************************************
ROW 32 *****  31.  31.  31.  31.  32.  32.  32.  32.  31.  31.  31.  31.  30.  25.  25.  26.  27.  29.  30.  30.  29.  30.  30.  31.  31.****************************************
ROW 33 *****  31.  31.  31.  31.  32.  32.  32.  32.  32.  32.  31.  31.  31.  25.  25.  29.  29.  31.  31.  30.  30.  30.  31.  32.  31.****************************************
ROW 34 *****  31.  31.  31.  31.  31.  32.  32.  32.  32.  32.  31.  31.  30.  25.  27.  30.  31.  31.  30.  30.  30.  31.*******************************************************
ROW 35 *****  31.  31.  31.  31.  31.  31.  32.  32.  32.  31.  31.  31.  30.  25.  27.  30.  31.  25.  30.  30.  31.  31.*******************************************************
ROW 36 ***************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  30.  25.  27.  30.  30.  30.  30.  31.  31.  31.*******************************************************
ROW 37 ***************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  29.  25.  27.  30.  30.  30.  31.  31.  31.  32.*******************************************************
ROW 38 ********************  31.  31.  31.  31.  31.  31.  31.  31.  30.  27.  25.  27.  30.  30.  31.  31.  31.  32.  32.*******************************************************
ROW 39 ********************  31.  31.  31.  31.  31.  31.  31.  31.  30.  25.  25.  25.  30.  31.  31.  31.  31.  32.  32.*******************************************************
ROW 40 *************************  31.  31.  31.  31.  31.  31.  31.  29.  25.  25.  27.  30.  31.  31.  32.  31.  32.  32.*******************************************************
ROW 41 *************************  31.  31.  30.  31.  31.  31.  31.  30.  30.  30.  30.  31.  31.  31.  32.  31.  32.  32.*******************************************************
ROW 42 *************************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  32.  32.  31.  32.  31.*******************************************************
ROW 43 *************************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  32.  32.  32.  32.  31.************************************************************
ROW 44 *************************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  32.  32.  32.  32.  31.  31.************************************************************
ROW 45 *************************  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.  31.************************************************************
ROW 46 *************************  31.  31.  31.  31.  31.  30.  30.  30.  30.  30.  30.  30.  31.  31.  31.  30.  30.  30.*******************************************************
ROW 47 *************************  31.  31.  31.  30.  29.  27.  27.  27.  27.  27.  27.  30.  31.  30.  29.  29.  30.  30.*******************************************************
ROW 48 *************************  31.  31.  30.  29.  27.  25.  25.  25.  25.  25.  25.  28.  30.  27.  25.  29.  29.  29.*******************************************************
ROW 49 *************************  31.  31.  31.  30.  30.  29.  27.  27.  25.  25.  25.  25.  25.  25.  25.  27.  27.  27.*******************************************************
ROW 50 *************************  31.  31.  31.  31.  31.  30.  30.  29.  27.  25.  25.  25.  25.  25.  25.  27.  27.  27.*******************************************************
ROW 51 *************************  31.  31.  31.  31.  31.  31.  30.  30.  29.  27.  25.  25.  25.  25.  26.  27.  29.  31.  31.**************************************************
ROW 52 *************************  31.  31.  31.  31.  31.  31.  31.  31.  29.  27.  25.  25.  25.  25.  26.  27.  30.  31.  32.**************************************************
ROW 53 *************************  32.  32.  31.  31.  31.  31.  31.  30.  29.  27.  27.  27.  27.  27.  27.  27.  29.  31.  31.  31.*********************************************
ROW 54 *************************  32.  30.  30.  31.  31.  31.  31.  31.  30.  29.  29.  29.  29.  29.  28.  27.  27.  30.  31.  31.  31.  31.***********************************
ROW 55 *************************  32.  32.  32.  32.  32.  31.  31.  31.  30.  29.  29.  29.  30.  30.  30.  29.  27.  27.  29.  27.  27.  27.***********************************
ROW 56 *************************  32.  32.  32.  32.  32.  32.  32.  31.  31.  31.  30.  30.  30.  30.  30.  30.  29.  29.  27.  27.  27.  27.***********************************
ROW 57 *************************  32.  32.  32.  32.  32.  32.  32.  32.  31.  31.  31.  31.  31.  31.  31.  31.  30.  29.  29.  30.  30.****************************************
ROW 58 ***********************************  32.  32.  32.  32.  32.  32.  32.  32.  31.  31.  31.  31.  31.  31.  31.  31.  30.  31.  30.****************************************
ROW 59 ***********************************  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  31.  31.  31.  31.  31.  31.  31.****************************************
ROW 60 ***********************************  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  32.  31.  31.  31.  31.  31.  31.  31.****************************************
ROW 61 *********************************************  32.  32.  32.  32.  32.  32.  32.  32.**********  32.  32.  32.  32.  32.  32.  31.****************************************
ROW 62 ************************************************************************************************************************  32.*********************************************

TILLMAN 20 YR. RUN  4/23/78  RECH=PATT, WELL=*3C .51 (407)
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Figure 15. 1974 water-head elevations

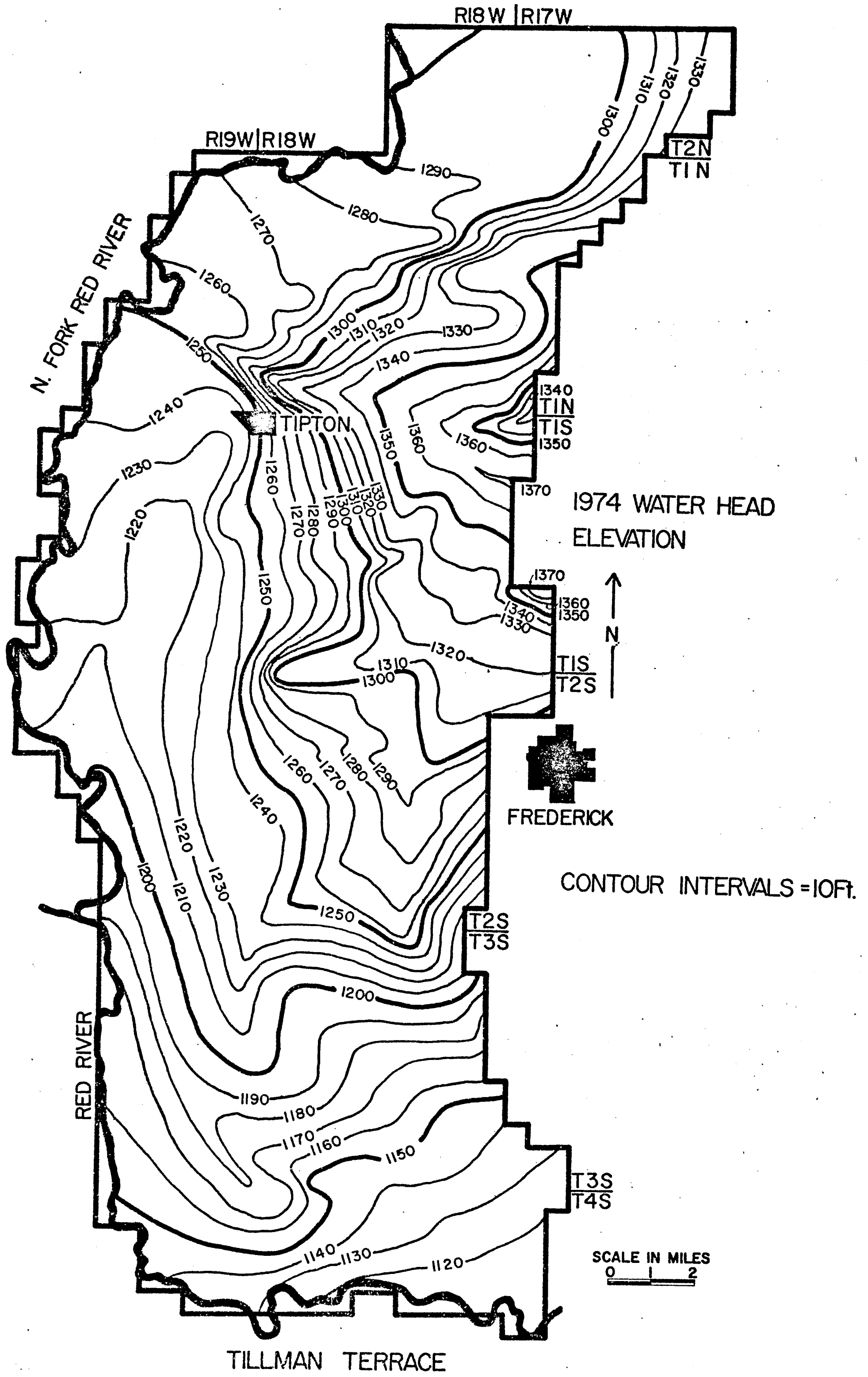

1974 WATER HEAD ELEVATION
CONTOUR INTERVALS = 10Ft.
R18W | R17W
R19W | R18W
T2N
T1N
T1S
T2S
T3S
T4S
N. FORK RED RIVER
RED RIVER
TIPTON
FREDERICK
TILLMAN TERRACE
N
SCALE IN MILES
0 1 2
1120
1130
1140
1150
1160
1170
1180
1190
1200
1210
1220
1230
1240
1250
1260
1270
1280
1290
1300
1310
1320
1330
1340
1350
1360
1370

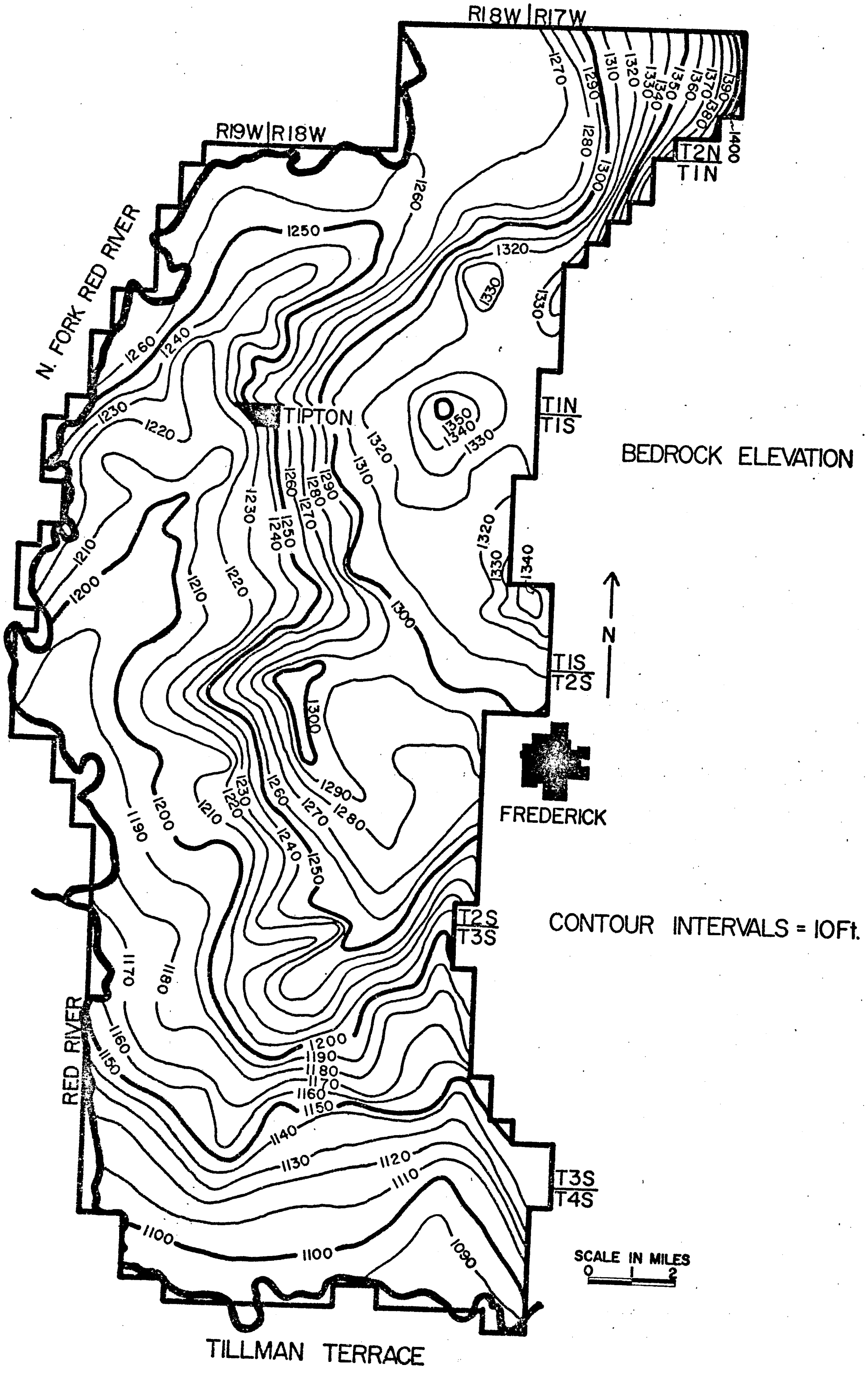
Figure 16 shows a representative Hennessey shale outcrop. It generally outcrops in the eastern half of Tillman County. The eastern boundary of the aquifer model was determined by using the topographic and geologic maps of Tillman County and verified by field investigation. The bedrock elevations for the study area under the terrace were obtained from the driller's logs. These data were contoured as subdatum elevations and assigned to the center of each node in the one-quarter mile grid. These data served as the lower boundary of the model. Contoured and digitized maps of the bedrock elevations are shown in Figures 17 and 18, respectively.

The Red River forms a discharge-recharge boundary at the southern and southwestern edge of the aquifer model. The North Fork of the Red River serves as a recharge boundary on the northwest side of the aquifer and as a discharge boundary on the north edge. The discharge-recharge relationship is time dependent to the configuration of the water table with respect to the river shown in Figures 4 and 15.

Land elevations were assigned to the quarter-mile grid by using a U. S. Geological topographic map. This information was used to establish a reference from which depth of evapotranspiration was measured. A printer output showing digitized values of "land" elevations is shown in Figure 19. The "top" elevation is a parameter incorporated in the program for denoting the top of a confined aquifer. A confined aquifer was assumed for the river boundary condition in the node. "Top" values, equivalent to two feet below land elevations, were used for all river nodes, whereas a value of 20,000 feet was applied to all other nodes. Other variables which were used in the computer program were thickness and hydraulic conductivity of the river bed. It was assumed that the

Figure 16. Hennessey shale with terrace alluvium gravels, Sec. 33, T2S, R18W

Figure 17. Bedrock elevation map



BEDROCK ELEVATION

CONTOUR INTERVALS = 10Ft.

Figure 18. Digitized computer output of bedrock elevation

```
                                                    TILLMAN TERRACE AQUIFER
                                                       BEDROCK ELEVATION

           2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32   33  34.  35

ROW  2 **********************************************************************************************************************************************************************
ROW  3 ******************************************************************************************1270.1270.1270.1265.1265.1265.1268.1275.1285.1305.1315.1327.1348.1357.1378.1398.
ROW  4 ******************************************************************************************1270.1270.1265.1265.1265.1265.1265.1270.1280.1298.1312.1325.1347.1356.1378.1396.
ROW  5 ******************************************************************************************1265.1265.1265.1265.1265.1265.1265.1270.1275.1292.1310.1329.1345.1368.1381.1400.
ROW  6 ******************************************************************************************1265.1265.1265.1265.1265.1265.1265.1270.1275.1289.1310.1333.1355.1377.1390.*****
ROW  7 ******************************************************************************************1270.1260.1265.1265.1265.1270.1270.1272.1278.1290.1315.1342.1375.***************
ROW    *********************************************1265.1265.1265.1265.1265.1265.1265.1266.1265.1260.1260.1265.1270.1270.1270.1275.1275.1280.1295.1320.1340.********************
ROW  9 ****************************************1265.1265.1263.1262.1265.1262.1262.1265.1263.1260.1258.1260.1270.1270.1275.1275.1277.1280.1285.1305.1336.1377.********************
ROW 10 ****************************************1263.1262.1258.1258.1257.1258.1260.1260.1260.1252.1260.1260.1270.1282.1285.1290.1290.1290.1299.1320.1352.*************************
ROW 11 ***********************************1260.1260.1260.1255.1252.1253.1252.1250.1248.1248.1250.1260.1269.1280.1290.1307.1307.1307.1310.1320.1335.******************************
ROW 12 ***********************************1258.1258.1255.1250.1247.1245.1240.1240.1240.1242.1250.1268.1270.1295.1315.1320.1320.1320.1325.1330.***********************************
ROW 13 ***********************************1256.1253.1251.1247.1240.1235.1230.1230.1238.1247.1255.1270.1285.1310.1325.1330.1330.1323.1330.****************************************
ROW 14 ***********************************1254.1251.1250.1242.1233.1225.1230.1240.1250.1257.1270.1285.1300.1305.1325.1330.1330.1328.1325.****************************************
ROW 15 *************************1246.1246.1246.1246.1245.1235.1230.1235.1251.1260.1270.1283.1295.1300.1310.1312.1320.1330.1330.1328.1325.****************************************
ROW 16 *************************1244.1244.1241.1240.1235.1225.1230.1235.1255.1270.1285.1295.1305.1310.1314.1320.1320.1330.1330.1326.1330.****************************************
ROW 17 ********************1241.1241.1238.1237.1230.1220.1230.1245.1244.1268.1275.1292.1303.1310.1315.1320.1320.1320.1327.1330.1330.1326.****************************************
ROW 18 ********************1239.1239.1238.1234.1227.1219.1229.1241.1255.1271.1282.1301.1311.1315.1317.1330.1335.1335.1330.1330.1324.*********************************************
ROW 19 ********************1238.1236.1235.1233.1223.1218.1228.1238.1265.1275.1290.1310.1320.1320.1320.1335.1350.1345.1340.1330.1324.*********************************************
ROW 20 ***************1235.1233.1230.1225.1225.1222.1216.1218.1230.1245.1260.1280.1300.1310.1320.1320.1335.1345.1345.1335.1330.1322.*********************************************
ROW 21 **********1233.1226.1225.1217.1217.1218.1220.1215.1215.1220.1240.1258.1275.1295.1310.1320.1320.1330.1340.1336.1325.1320.1320.*********************************************
ROW 22 **********1232.1223.1215.1210.1212.1213.1215.1210.1207.1220.1238.1257.1275.1295.1310.1315.1320.1330.1330.1330.1320.1320.1320.*********************************************
ROW 23 **********1252.1225.1215.1209.1207.1208.1208.1205.1210.1220.1235.1295.1275.1295.1300.1310.1320.1325.1325.1320.1320.1320.**************************************************
ROW 24 ***************1223.1217.1213.1205.1201.1200.1210.1217.1225.1235.1250.1270.1285.1295.1310.1320.1320.1320.1320.1320.1320.**************************************************
ROW 25 ***************1225.1215.1207.1203.1199.1203.1212.1220.1227.1235.1247.1266.1280.1295.1305.1310.1316.1319.1318.1320.1323.**************************************************
ROW 26 **********1225.1220.1210.1205.1200.1197.1200.1210.1220.1227.1235.1245.1260.1275.1295.1305.1318.1313.1316.1316.1320.1325.**************************************************
ROW 27 *****1223.1220.1215.1207.1200.1197.1197.1200.1213.1217.1225.1233.1240.1257.1270.1290.1299.1310.1313.1314.1320.1328.1330.**************************************************
ROW 28 *****1220.1215.1218.1200.1198.1196.1196.1200.1210.1215.1220.1225.1235.1245.1260.1275.1290.1300.1310.1310.1312.1320.1330.1338.1340.****************************************
ROW 29 *****1220.1210.1200.1197.1193.1195.1196.1200.1207.1213.1217.1225.1235.1245.1260.1270.1280.1290.1300.1310.1310.1320.1325.1338.1335.****************************************
ROW 30 **********1200.1195.1191.1192.1195.1197.1203.1208.1215.1220.1240.1255.1260.1275.1275.1280.1290.1295.1300.1310.1310.1315.1320.1322.****************************************
ROW 31 *****1207.1195.1190.1189.1195.1198.1203.1207.1215.1224.1240.1260.1275.1285.1290.1290.1290.1290.1295.1300.1305.1310.1318.1318.1310.****************************************
ROW 32 *****1200.1190.1187.1187.1195.1203.1208.1215.1222.1240.1260.1280.1290.1290.1290.1290.1290.1290.1290.1295.1300.1300.1300.1305.1305.****************************************
ROW 33 *****1192.1188.1185.1187.1195.1205.1215.1220.1235.1250.1265.1275.1290.1290.1290.1290.1290.1290.1290.1290.1294.1295.1300.1300.1300.****************************************
ROW 34 *****1187.1185.1182.1187.1195.1203.1210.1218.1225.1230.1245.1260.1280.1290.1290.1293.1290.1285.1285.1285.1286.1290.*******************************************************
ROW 35 *****1180.1180.1180.1185.1192.1200.1205.1208.1213.1220.1230.1250.1275.1290.1290.1290.1290.1280.1280.1280.1280.1285.*******************************************************
ROW 36 ***************1177.1183.1188.1194.1196.1203.1207.1209.1220.1245.1268.1290.1290.1293.1290.1280.1280.1279.1278.1280.*******************************************************
ROW 37 ***************1177.1180.1188.1191.1195.1203.1208.1215.1220.1240.1260.1275.1285.1290.1290.1283.1280.1278.1276.1274.*******************************************************
ROW 38 ********************1180.1185.1190.1195.1203.1209.1213.1220.1235.1250.1265.1270.1280.1290.1283.1280.1276.1272.1266.*******************************************************
ROW 39 ********************1177.1183.1198.1195.1201.1205.1207.1210.1225.1240.1250.1265.1270.1280.1280.1280.1275.1268.1260.*******************************************************
ROW 40 *************************1180.1185.1190.1198.1200.1200.1200.1212.1225.1240.1255.1260.1275.1280.1280.1272.1250.1245.*******************************************************
ROW 41 *************************1177.1182.1188.1192.1195.1196.1198.1210.1225.1240.1250.1260.1270.1275.1270.1250.1250.1233.*******************************************************
ROW 42 *************************1175.1180.1185.1187.1190.1192.1198.1215.1230.1240.1250.1260.1260.1270.1265.1250.1225.1225.*******************************************************
ROW 43 *************************1170.1175.1180.1182.1185.1190.1200.1220.1240.1245.1250.1260.1260.1260.1260.1235.1220.************************************************************
ROW 44 *************************1168.1172.1176.1179.1185.1195.1210.1230.1245.1247.1251.1256.1260.1255.1245.1220.1200.************************************************************
ROW 45 *************************1165.1169.1173.1177.1185.1200.1215.1235.1242.1245.1248.1245.1240.1235.1222.1210.1190.************************************************************
ROW 46 *************************1165.1169.1172.1180.1185.1200.1215.1230.1241.1242.1243.1238.1220.1213.1205.1197.1185.1192.*******************************************************
ROW 47 *************************1160.1167.1175.1180.1183.1196.1215.1225.1235.1241.1242.1230.1210.1195.1190.1185.1177.1185.*******************************************************
ROW 48 *************************1155.1165.1175.1180.1182.1185.1200.1215.1225.1230.1221.1215.1205.1185.1177.1175.1170.1180.*******************************************************
ROW 49 *************************1152.1160.1172.1175.1177.1177.1188.1200.1210.1210.1200.1198.1195.1185.1175.1170.1165.1175.*******************************************************
ROW 50 *************************1145.1155.1165.1170.1171.1173.1177.1188.1192.1190.1182.1182.1185.1180.1173.1165.1160.1165.*******************************************************
ROW 51 *************************1135.1145.1153.1160.1163.1163.1170.1175.1175.1165.1165.1165.1170.1173.1185.1160.1155.1157.1165.**************************************************
ROW 52 *************************1125.1130.1138.1145.1155.1158.1165.1168.1155.1147.1150.1145.1145.1158.1150.1150.1148.1140.1139.**************************************************
ROW 53 *************************1120.1120.1125.1135.1147.1153.1163.1160.1150.1140.1138.1136.1135.1133.1132.1130.1125.1125.1135.1146.*********************************************
ROW 54 *************************1116.1116.1121.1125.1138.1148.1155.1152.1138.1135.1133.1130.1125.1125.1122.1120.1115.1115.1120.1135.1143.1145.***********************************
ROW 55 *************************1112.1110.1115.1120.1125.1135.1140.1138.1130.1125.1122.1120.1118.1118.1115.1114.1114.1105.1117.1125.1140.1142.***********************************
ROW 56 *************************1107.1110.1110.1115.1120.1125.1125.1120.1118.1115.1115.1113.1113.1110.1110.1100.1098.1100.1105.1115.1137.1139.***********************************
ROW 57 *************************1103.1105.1105.1110.1115.1120.1115.1125.1110.1110.1110.1110.1110.1110.1100.1100.1090.1095.1100.1108.1125.****************************************
ROW 58 ***********************************1100.1100.1110.1110.1110.1110.1110.1105.1105.1104.1103.1130.1100.1090.1090.1090.1095.1100.1117.****************************************
ROW 59 ***********************************1095.1100.1100.1100.1100.1100.1100.1100.1100.1100.1100.1095.1090.1090.1090.1090.1090.1100.1105.****************************************
ROW 60 ***********************************1090.1095.1095.1100.1100.1100.1095.1100.1100.1100.1095.1090.1090.1090.1090.1090.1098.1090.1100.****************************************
ROW 61 *********************************************1090.1095.1095.1095.1095.1075.1095.1095.**********1090.1390.1090.1090.1098.1090.1095.****************************************
ROW 62 ************************************************************************************************************************1090.*********************************************

TILLMAN 20 YR. RUN  4/23/78  RECH=PATT, WELL=*36 .51 (407)
```

Figure 19. Printer output of digitized land elevations

LAND ELEVATION

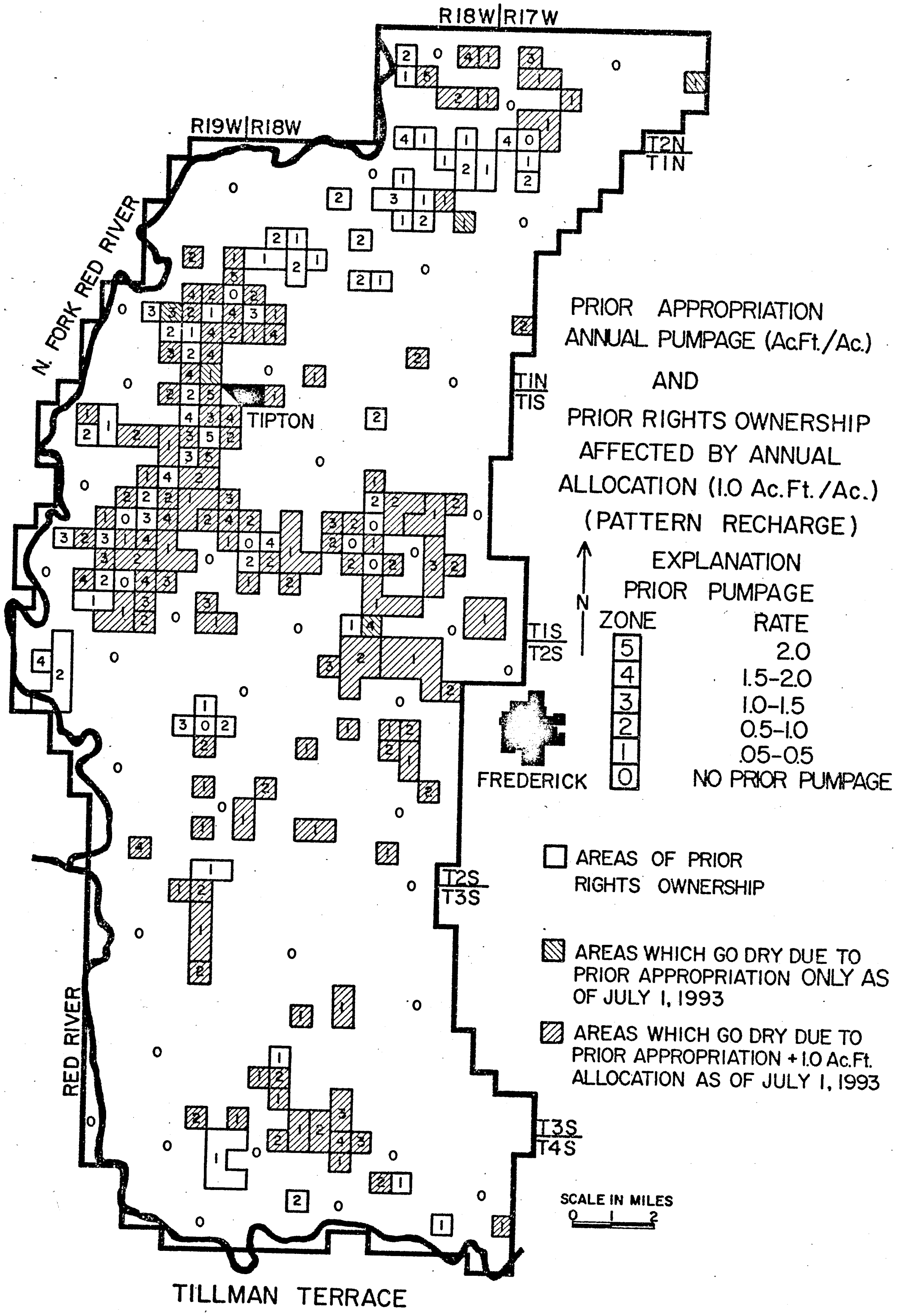
```
           2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32   33   34   35
ROW  2 **************************************************************************************************************************************************************************
ROW  3 ******************************************************************************************1303.1312.1315.1315.1315.1315.1315.1315.1318.1320.1330.1345.1355.1367.1385.1420.
ROW  4 ******************************************************************************************1301.1311.1311.1312.1313.1315.1316.1318.1325.1335.1350.1360.1368.1380.1390.1425.
ROW  5 ******************************************************************************************1298.1310.1310.1310.1310.1310.1312.1315.1320.1330.1332.1342.1375.1395.1418.1425.
ROW  6 ******************************************************************************************1296.1310.1310.1310.1310.1310.1312.1320.1340.1340.1350.1360.1375.1400.1420.*****
ROW  7 ******************************************************************************************1294.1308.1308.1308.1308.1310.1310.1315.1330.1345.1350.1365.1385.***************
ROW  8 *********************************************1275.1275.1275.1276.1278.1281.1284.1286.1288.1291.1306.1306.1306.1306.1306.1308.1325.1340.1360.1385.1400.********************
ROW  9 ****************************************1275.1275.1280.1295.1298.1290.1292.1290.1295.1298.1300.1300.1300.1305.1305.1325.1335.1350.1365.1385.1395.1400.********************
ROW 10 ****************************************1275.1275.1275.1285.1295.1300.1330.1300.1300.1300.1300.1300.1300.1305.1320.1350.1350.1355.1375.1385.1395.*************************
ROW 11 ***********************************1270.1270.1275.1275.1300.1285.1285.1285.1285.1285.1295.1300.1320.1325.1345.1350.1365.1375.1375.1380.1385.******************************
ROW 12 ***********************************1268.1272.1275.1275.1285.1295.1300.1295.1300.1300.1315.1325.1345.1365.1375.1376.1375.1374.1365.1360.***********************************
ROW 13 ***********************************1266.1272.1275.1275.1285.1295.1300.1295.1300.1300.1315.1325.1345.1365.1375.1376.1375.1374.1365.****************************************
ROW 14 ***********************************1264.1265.1275.1285.1290.1290.1300.1305.1305.1305.1310.1320.1325.1345.1355.1355.1365.1372.1363.****************************************
ROW 15 *************************1256.1256.1257.1264.1273.1285.1285.1290.1300.1300.1310.1315.1320.1325.1335.1345.1350.1355.1363.1365.1360.****************************************
ROW 16 *************************1254.1262.1275.1275.1275.1280.1285.1295.1300.1310.1320.1325.1335.1345.1350.1350.1350.1350.1350.1350.1356.****************************************
ROW 17 ********************1251.1251.1260.1277.1275.1275.1280.1285.1295.1310.1320.1325.1335.1350.1360.1357.1357.1357.1357.1357.1361.1361.****************************************
ROW 18 ********************1249.1256.1265.1278.1275.1275.1278.1288.1311.1313.1321.1331.1345.1355.1360.1365.1365.1373.1373.1370.1362.*********************************************
ROW 19 ********************1248.1255.1275.1275.1272.1274.1280.1295.1300.1310.1325.1345.1367.1370.1375.1370.1375.1375.1375.1375.1368.*********************************************
ROW 20 ***************1245.1243.1255.1265.1275.1270.1275.1270.1285.1300.1320.1335.1345.1355.1365.1375.1375.1375.1370.1370.1375.1375.*********************************************
ROW 21 **********1243.1239.1250.1250.1260.1265.1265.1265.1270.1282.1290.1325.1345.1348.1360.1360.1365.1365.1365.1370.1375.1375.1375.*********************************************
ROW 22 **********1242.1248.1248.1248.1255.1260.1260.1260.1265.1275.1290.1315.1340.1345.1355.1360.1360.1368.1370.1375.1375.1375.1378.*********************************************
ROW 23 **********1242.1235.1245.1246.1250.1255.1255.1260.1265.1275.1290.1305.1315.1330.1340.1355.1364.1370.1370.1372.1375.1375.**************************************************
ROW 24 ***************1235.1245.1245.1245.1250.1250.1255.1265.1275.1284.1295.1312.1323.1328.1345.1365.1370.1370.1372.1375.1375.**************************************************
ROW 25 ***************1235.1244.1245.1240.1245.1250.1255.1265.1275.1280.1294.1308.1312.1318.1335.1360.1368.1368.1375.1375.1375.**************************************************
ROW 26 **********1235.1232.1242.1242.1244.1248.1248.1253.1265.1274.1280.1290.1297.1305.1313.1330.1348.1360.1355.1365.1372.1375.**************************************************
ROW 27 *****1230.1230.1240.1240.1240.1240.1240.1245.1255.1270.1274.1278.1287.1295.1305.1313.1330.1350.1360.1365.1365.1368.1370.**************************************************
ROW 28 *****1230.1236.1237.1230.1230.1230.1240.1245.1255.1267.1268.1275.1280.1290.1305.1315.1330.1345.1355.1358.1362.1365.1370.1375.1366.****************************************
ROW 29 *****1230.1223.1237.1230.1225.1230.1235.1245.1251.1260.1265.1274.1280.1290.1305.1317.1320.1345.1350.1357.1362.1364.1368.1375.1375.****************************************
ROW 30 **********1221.1229.1225.1226.1228.1234.1240.1250.1264.1266.1276.1289.1302.1315.1324.1340.1345.1350.1354.1357.1358.1363.1365.1375.****************************************
ROW 31 *****1219.1220.1228.1225.1227.1228.1233.1236.1255.1274.1282.1288.1300.1308.1320.1330.1336.1342.1347.1352.1354.1355.1358.1360.1375.****************************************
ROW 32 *****1217.1222.1222.1222.1223.1224.1234.1245.1260.1277.1300.1311.1330.1330.1340.1350.1346.1347.1344.1345.1347.1349.1350.1355.1365.****************************************
ROW 33 *****1215.1222.1222.1222.1225.1225.1225.1230.1250.1271.1297.1314.1318.1330.1335.1352.1361.1355.1340.1342.1345.1345.1348.1345.1350.****************************************
ROW 34 *****1213.1220.1220.1220.1220.1224.1228.1246.1280.1305.1310.1324.1335.1345.1355.1354.1354.1340.1338.1340.1342.1320.*******************************************************
ROW 35 *****1211.1209.1207.1218.1219.1224.1228.1248.1270.1285.1287.1320.1335.1350.1350.1354.1354.1345.1335.1332.1335.1330.*******************************************************
ROW 36 ***************1205.1215.1220.1230.1250.1270.1275.1283.1290.1320.1335.1335.1340.1340.1342.1335.1330.1325.1300.1300.*******************************************************
ROW 37 ***************1203.1201.1208.1225.1229.1250.1263.1276.1275.1284.1315.1325.1327.1335.1333.1335.1335.1325.1290.1284.*******************************************************
ROW 38 ********************1199.1208.1214.1220.1250.1265.1265.1270.1278.1284.1300.1310.1324.1325.1325.1325.1320.1290.1276.*******************************************************
ROW 39 ********************1197.1195.1215.1215.1250.1265.1265.1265.1275.1280.1290.1315.1315.1317.1323.1320.1310.1288.1270.*******************************************************
ROW 40 *************************1193.1201.1215.1220.1262.1262.1265.1268.1275.1290.1300.1305.1308.1315.1315.1285.1280.1265.*******************************************************
ROW 41 *************************1191.1200.1215.1220.1252.1256.1264.1265.1275.1288.1295.1295.1305.1313.1300.1280.1275.1270.*******************************************************
ROW 42 *************************1189.1198.1213.1220.1245.1248.1256.1260.1275.1286.1288.1292.1300.1306.1295.1275.1265.1255.*******************************************************
ROW 43 *************************1186.1210.1212.1220.1235.1250.1260.1265.1284.1284.1284.1288.1300.1295.1275.1260.1255.************************************************************
ROW 44 *************************1181.1205.1210.1220.1235.1253.1260.1270.1285.1281.1282.1287.1290.1280.1260.1250.1240.************************************************************
ROW 45 *************************1178.1200.1212.1220.1230.1250.1260.1280.1280.1280.1281.1287.1285.1270.1240.1236.1225.************************************************************
ROW 46 *************************1175.1198.1215.1218.1225.1235.1270.1280.1270.1272.1280.1280.1260.1250.1220.1216.1211.1202.*******************************************************
ROW 47 *************************1171.1196.1215.1218.1220.1230.1270.1275.1260.1264.1270.1260.1240.1230.1214.1205.1201.1195.*******************************************************
ROW 48 *************************1169.1190.1212.1216.1215.1230.1260.1275.1256.1255.1255.1240.1221.1210.1205.1195.1191.1190.*******************************************************
ROW 49 *************************1167.1182.1210.1214.1214.1224.1250.1260.1250.1238.1232.1220.1210.1200.1195.1185.1181.1185.*******************************************************
ROW 50 *************************1165.1180.1208.1211.1213.1218.1230.1250.1240.1224.1222.1210.1204.1195.1185.1178.1170.1175.*******************************************************
ROW 51 *************************1163.1179.1208.1208.1209.1215.1221.1230.1235.1220.1211.1200.1195.1185.1185.1180.1172.1170.1175.**************************************************
ROW 52 *************************1161.1178.1220.1200.1200.1205.1208.1220.1224.1220.1208.1196.1190.1183.1185.1171.1168.1163.1162.**************************************************
ROW 53 *************************1158.1176.1200.1200.1195.1195.1204.1212.1214.1215.1205.1191.1183.1175.1174.1164.1160.1157.1154.1156.*********************************************
ROW 54 *************************1156.1190.1200.1200.1192.1190.1193.1197.1198.1198.1195.1185.1180.1172.1165.1160.1160.1156.1153.1150.1153.1155.***********************************
ROW 55 *************************1154.1185.1200.1200.1185.1187.1189.1194.1194.1190.1188.1180.1178.1174.1170.1161.1160.1156.1153.1150.1150.1152.***********************************
ROW 56 *************************1151.1163.1183.1190.1190.1183.1190.1190.1190.1190.1180.1178.1175.1172.1169.1163.1150.1150.1150.1150.1150.1149.***********************************
ROW 57 *************************1150.1148.1146.1185.1185.1185.1185.1185.1185.1185.1177.1175.1173.1171.1165.1160.1150.1150.1145.1141.1135.****************************************
ROW 58 ***********************************1144.1155.1165.1167.1167.1167.1165.1165.1170.1170.1175.1165.1155.1150.1150.1150.1150.1145.1135.****************************************
ROW 59 ***********************************1143.1153.1149.1146.1148.1149.1139.1136.1136.1150.1150.1150.1150.1150.1150.1150.1140.1130.1121.****************************************
ROW 60 ***********************************1141.1139.1137.1144.1141.1147.1134.1131.1127.1119.1117.1115.1113.1135.1135.1130.1128.1121.1121.****************************************
ROW 61 *********************************************1135.1134.1133.1131.1126.1123.1121.1120.**********1112.1110.1109.1108.1106.1104.1121.****************************************
ROW 62 **   *******************************************************************************************************************1101.*********************************************
TIL             IN  4/23/78  RECH-PATT, WELL=*3E .51 (407)
```

river bed consisted of silts and clays and thus served as a local aquitard to the underlying aquifer material. Therefore, the river and nodes were used to represent vertical seepage movements in either direction. Water-level elevations for the river nodes were also obtained from the topography map.

A value of 0.01 was placed at the outer edge of all aquifer boundaries on the water-head elevation matrix (STRT). The value actually represents the areas where transmissivity is equivalent to zero. The specific yield and bedrock elevation matricies were left blank outside of these same boundaries.

Pumping rates were entered as a variable in the model. Two matricies were used. One matrix included pump rates reportedly used prior to July 1, 1973. These were established by the Oklahoma Water Resources Board as prior appropriative right owners. Distribution of these rates is shown in Figure 20. A second matrix was used to enter a constant pumping rate which was assigned to all nodes other than those with prior appropriative rights. An example of this matrix is shown in Figure 21. Those prior appropriative pumping rates with less than the assigned constant value were automatically assigned the larger rate. All other prior appropriative pumping rates remained unchanged. Prior appropriative ownership rates were converted from acre feet per year for the number of permitted acres to acre feet per acre per year and cubic feet per second. The annual rate was restricted to a four-month pumping session between June 1, and October 1 (one-third year). This required the annual rate to be increased by three times for the shorter period. All pumpage rates include a net return flow of 15 percent of total pumpage.

Figure 20. Distribution of prior appropriative right ownership and corresponding pump rates (pattern recharge)



PRIOR APPROPRIATION ANNUAL PUMPAGE (Ac.Ft./Ac.)

AND

PRIOR RIGHTS OWNERSHIP AFFECTED BY ANNUAL ALLOCATION (1.0 Ac.Ft./Ac.)

(PATTERN RECHARGE)

EXPLANATION

PRIOR PUMPAGE

ZONE	RATE
5	2.0
4	1.5-2.0
3	1.0-1.5
2	0.5-1.0
1	.05-0.5
0	NO PRIOR PUMPAGE

☐ AREAS OF PRIOR RIGHTS OWNERSHIP

▩ AREAS WHICH GO DRY DUE TO PRIOR APPROPRIATION ONLY AS OF JULY 1, 1993

▨ AREAS WHICH GO DRY DUE TO PRIOR APPROPRIATION + 1.0 Ac.Ft. ALLOCATION AS OF JULY 1, 1993

TILLMAN TERRACE

Figure 21. Prior appropriative and allocated pumping rates

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                                             PRIOR APPROPRIATION AND ALLOCATION OF 0.96 ACRE FOOT
                                                        ANNUAL PUMPAGE (ACRE FEET)

           2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   25    26   27   28   29   30   31   32   33   34   35

ROW  2 ************************************************************************************************************************ **************************************************
ROW  3 ****************************************************************************************** 0.96 0.96 0.96 0.96 1.89 0.96  0.96 1.12 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96
ROW  4 ****************************************************************************************** 0.96 0.96 2.19 0.96 0.96 0.96  0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96
ROW  5 ****************************************************************************************** 0.96 0.96 0.96 1.00 0.96 0.96  0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96
ROW  6 ****************************************************************************************** 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96*****
ROW  7 ****************************************************************************************** 0.96 1.67 0.96 0.96 0.96 0.96  2.00 0.96 0.96 0.96 0.96 0.96 0.96***************
ROW  8 ********************************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96 0.96 0.96 0.96 0.96********************
ROW  9 **************************************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.00 0.96  0.96 0.96 0.96 0.96 0.96 0.96********************
ROW 10 **************************************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.17 1.17 0.96 0.96 0.96 0.96  0.96 0.96 0.96 0.96 0.96*************************
ROW 11 *********************************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96 0.96 0.96******************************
ROW 12 *********************************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.00 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96 0.96***********************************
ROW 13 *********************************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 14 *********************************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.03 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 15 ************************* 0.96 0.96 0.96 0.96 1.53 1.00 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 16 ************************* 0.96 0.96 1.10 1.25 0.96 0.96 1.56 1.09 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 17 ******************** 0.96 0.96 0.96 0.96 0.96 0.96 2.00 1.00 0.96 1.51 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 18 ******************** 0.96 0.96 0.96 0.96 1.05 0.96 1.87 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96*********************************************
ROW 19 ******************** 0.96 0.96 0.96 0.96 0.96 1.56 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96*********************************************
ROW 20 *************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 3.16 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96*********************************************
ROW 21 ********** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.94 1.09 1.54 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96*********************************************
ROW 22 ********** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.19 2.05 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96*********************************************
ROW 23 ********** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.08 2.31 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 **************************************************
ROW 24 *************** 0.96 0.96 0.96 0.96 0.96 1.72 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 **************************************************
ROW 25 *************** 0.96 0.96 0.96 1.00 0.96 0.96 0.96 0.96 1.05 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 **************************************************
ROW 26 ********** 0.96 0.96 0.96 0.96 0.96 1.13 2.00 0.96 0.96 1.62 0.96 0.96 0.96 0.96 1.11 0.96 0.96 0.96 0.96 0.96 0.96 0.96 **************************************************
ROW 27 ***** 0.96 0.96 1.04 1.00 1.25 0.96 1.80 0.96 0.96 0.96 0.96 0.96 1.64 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.31 0.96 0.96 **************************************************
ROW 28 ***** 0.96 0.96 0.96 0.96 1.12 0.96 0.96 0.96 0.96 0.96 0.96 0.97 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.95 1.43 0.96 0.96  0.96 0.96****************************************
ROW 29 ***** 0.96 0.96 0.96 2.00 0.96 0.96 1.87 1.16 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.27 0.96 0.96  0.96 0.96****************************************
ROW 30 ********** 0.96 0.96 0.96 0.96 0.96 1.24 0.96 0.96 1.33 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 31 ***** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.09 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 32 ***** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 33 ***** 0.96 2.00 1.30 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.37 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 34 ***** 0.96 0.96 1.00 0.95 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 35 ***** 0.96 1.00 1.00 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 36 *************** 0.96 0.96 0.96 0.96 0.96 0.96 1.19 0.96 1.00 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 37 *************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 38 ******************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 39 ******************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 40 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 41 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 42 ************************* 0.96 0.96 1.52 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 43 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96*********** **************************************************
ROW 44 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96*********** **************************************************
ROW 45 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96*********** **************************************************
ROW 46 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 47 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 48 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 49 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 50 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96****** **************************************************
ROW 51 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 **************************************************
ROW 52 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 **************************************************
ROW 53 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96*********************************************
ROW 54 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.19 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96 0.96***********************************
ROW 55 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.00 1.09 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96 0.96***********************************
ROW 56 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 1.54 1.05 0.96 0.96 0.96 0.96 0.96  0.96 0.96 0.96***********************************
ROW 57 ************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 58 *********************************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 59 *********************************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 60 *********************************** 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 61 ********************************************* 0.96 0.96 0.96 0.96 0.96 0.96 0.96 0.96********** 0.96 0.96 0.96 0.96 0.96  0.96 0.96****************************************
ROW 62 ************************************************************************************************************************  0.96*********************************************

TILLMAN 20 YR. RUN  4/23/76  RECH=PATT, WELL=03% .51 (407)
```

Simulation Period

The model was used to simulate pumping and corresponding water-level changes over a five- and twenty-year period. This is shown in the flow chart on Figure 5. The model was originally run between October 1, 1969, and October 1, 1974, in order to calibrate the model. The second period was changed to the interval between July 1, 1973, and July 1, 1993. The latter change was made because the Oklahoma Water Law No. 82 § 1020.5 requires that new allocations are to be assigned for a 20-year period between these two dates.

The five-year calibration period included only prior appropriative pumping. The 20-year simulation included two separate runs; one using prior appropriative pump rates only and a second using prior appropriative rates combined with constant rates assigned to all other nodes. The model was designed to automatically turn the pumping period on or off at the beginning and end of each pumping period, respectively, for either the five-year or twenty-year periods. Therefore, ten pumping periods (five periods with pumps on and five periods with pumps off) were used for the five-year calibration period and 40 pumping periods were employed for the 20-year simulation. Simulated withdrawal of water was designed to automatically cease if the water-head elevation dropped to an elevation within five feet of the bottom (bedrock). It was assumed that a submersible pump would be placed within the bottom five feet. Pumping would cease as the water head dropped within this interval because air would be drawn and, consequently, eliminate the lift capacity of the pump.

Data Input

The input data were digitized by punching values assigned to each node onto computer (IBM) cards. These data included other constant values punched as separate input data: QET--evapotranspiration rate; ETDIST--depth (1 foot) at which evapotranspiration ceases below land surface; ERR--error criteria for convergence of the mathematical solution (0.1 foot); ITMAX--maximum number of iterations per time step (50); NPER--number of the pumping perids; SSRIV--specific storage of river bottom; NUMT--number of time steps in pump period (assume time step of ten days); TMAX--number of days of the pumping periods; DELX--grid spacing in X-direction (2,640 feet); and DELY--grid spacing in Y-direction (2,640 feet); S--storage coefficient for river nodes only (2.0×10^{-8}); DIML--number of rows used in the model (63); and DIMW--number of columns (36). Other input cards were followed by variables entered as matricies: LAND--elevation of land surface; TOP--elevation of top of aquifer or the top of the bedrock; PERM--coefficient of permeability; SY--specific yield which ranges from 0.245 to 0.320; STRT--the 1969 water-table elevations; RATE--hydraulic conductivity of river bed; M--thickness of river bed; QRE--recharge used in calibration; and WELL--pump rates used when pumping is on. Complete listings of the data input is shown in the Appendix.

Calibration

Calibration was achieved by comparing the 1974 observed head (water table) elevations with the computed values from the five-year computer simulation between October 1, 1969, and October 1, 1974 (Figure 5, Flow Chart). Recharge (QRE) was adjusted in order to reduce the calibration error or residual values between observed and computed head elevations to ± five feet. Three approaches were used for calibration which included matrix, constant and pattern recharge. Where the matrix was used, recharge (QRE) was adjusted for each node. Matrix recharge values and the resulting calibration error are shown in Figures 22 and 23. In the constant recharge version, the mean of the matrix recharge values was used as a constant recharge for all nodes (7.5×10^{-9} feet per second). Pattern recharge included the mean of matrix recharge values which were selectively assigned to nodes. The pattern recharge concept was introduced to eliminate some errors in recharge that might have been introduced in the calibration recharge version. This approach involved the adjustment of the rate of recharge for the calibration matrix nodes in such a way that nodes with negative recharge values were replaced by 0 or positive recharge values. Although the residual error could not be restricted to within ± five feet, the resulting error distribution was indicative of areas where varying degrees of reliability could be assumed in the simulation results. This error distribution is shown in Figure 24. The error represents the total effect of inaccuracies which may be associated with the input parameters or the assumptions used. However, the mean value of all matrix recharge values was 2.87 inches per year as compared to 2.2 inches per year estimated by nine percent. The similarity between calculated and estimated recharge is indicative of a successful model calibration.

Some of the 1969 and 1974 water-head elevations located near the bedrock boundaries occurred below bedrock elevations. They were treated as a boundary condition for the model in the matrix and constant versions. Some of the nodes started dry and became wet after five years of pumping.

Figure 22. Recharge values in inch/year (matrix recharge version)

```
                                           TILLMAN TERRACE AQUIFER
                                        CALIBRATION (INCHES PER YEAR)

           2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32   33   34   35

ROW  2 ******************************************************************************************   0.   2.  -1.  -3.  -4.  -5.  -6.  -5.  -5.   0.   0.   0.   0.   0.   0.   0.
ROW  3 ******************************************************************************************   0.   2.  -0.  -2.  -8.  -4.  -5.  -2.  -5.   0.   0.   0.   0.   0.   0.   0.
ROW  4 ******************************************************************************************   0.   3.   3.   0.  -3.  -5.  -5.  -1.  -2.  -1.   0.   0.   0.   0.   0.   0.
ROW  5 ******************************************************************************************   0.   0.  -2.  -1.  -2.  -3.  -3.  -3.  -3.   0.   0.   0.   0.   0.   0.   0.
ROW  6 ******************************************************************************************   0.   0.  -0.   0.   1.  -0.  -1.   1.   3.   3.   0.   0.   0.   0.   0.*****
ROW  7 ******************************************************************************************   0.   1.   1.   1.   1.   1.   1.   0.   1.   6.   0.   0.   0.***************
ROW  8 *********************************************   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   3.   2.   2.   1.   0.   1.   1.   0.   1.   0.   0.********************
ROW  9 ****************************************   0.   0.   2.   2.   2.   4.   3.   2.   1.   1.   2.   2.   3.   2.   0.   0.   0.  -8.  -6.   1.   0.   0.********************
ROW 10 ****************************************   0.   5.   5.   0.   2.   3.   4.   2.   1.   1.   2.   4.   4.  10.   3. -10.   2.   5.  13.   9.   0.*************************
ROW 11 ***********************************   0.   0.   6.   5.   1.  -1.  -1.   0.   1.   1.   0.  -9. -11.   0.  10.   0.  -5.  26.  24.  16.   5.******************************
ROW 12 ***********************************   0.   5.   1.   2.   3.   0.   0.  -0.  -1.   0.  -7. -29.  -7.  -5.  -0. -14.  22.  25.  29.  18.***********************************
ROW 13 ***********************************   0.   1.  -0.   1.   0.  -0.  -1.   1.   1.  -2. -27.  14.  22.  32.  15.  12.  13.  17.  19.****************************************
ROW 14 ***********************************   0.   3.   1.  -1.   1.   1.  -2.  -4.  -1.   3.   3.   2.  14.   6.   6.   2.   0.  16.  13.****************************************
ROW 15 *************************   0.   0.   0.   1.   1.  -1.  -1.   3.  -3.  -8.   1.   3.   3.   2.  -2.  -7. -13.  -9.  -7.   5.  12.****************************************
ROW 16 *************************   0.   0.   2.   1.  12.   3. -12.  -4.   3.  -0.  -2.  -2.  -8.  -2.  -8. -10. -20. -13.  -5.   9.  28.****************************************
ROW 17 ********************   0.   0.   1.   2.   0.   0.  20.  19. -25.   0.  -9. -15. -11.  -9.   1.  -3.   4.   4.   4.   5.  17.  39.****************************************
ROW 18 ********************   0.   2.   1.   1.   0.   0.   0.  -0. 156.  27.  19.  26.   6.   9.   8.   2.   6.  14.  13.  19.  15.*********************************************
ROW 19 ********************   0.   2.   3.   2.   0.  -4. -19. -23.  -8.  38.  19.  28.  12.  10.  12.  11.   6.   3.   6.  12.  -5.*********************************************
ROW 20 ***************   0.   0.   5.   5.   3.   0.  -4.  -8. -25. -16. -15. -12.  32.   1.   8.  12.  10.   3.   2.  -7. -34. -38.*********************************************
ROW 21 **********   0.   0.  41.   6.   4.   3.   0.  -4.  -8. -11.  -9.  15. -14. -19.   0.   6.   6.  13.   6.   3.   4.   1.  -2.*********************************************
ROW 22 **********   0.   5.   5.   9.   2.  33.   0.  -4.  -8.   0.   0.   7.  -9.  -2.   2.   4.  11.  13.  10.   5.   4.  12.  22.*********************************************
ROW 23 **********   0.   0.   3.   2.  -1.  -1.  -2.  -3.  -2.   8.  -2.   1.  -2.  -3.  -9. -23.  31.   9.   4.   8.   5.  36.**************************************************
ROW 24 ***************   0.   2.  -1.  -3.  -4.  -5.   0.   6.   3.  -1.  -2.  -4.  -5.  -4. -12.  13.   4.   3.  -4.   8.   5.**************************************************
ROW 25 ***************   0.   4.  -1.  -2.  -4.  -5.  -2.   8.   1.  -3.  -5.  -3.  -2.  -4. -16.  13.   3.   3.  11.   2.  -9.**************************************************
ROW 26 **********   0.   0.   4.   1.  -1.  -4.  -3.  -6.  -3.  -2.  -2.   0.  -0.   3.  -2.   1. -10.   1.   5.   4.   1.   1.**************************************************
ROW 27 *****   0.   0.   4.   5.   4.   1.  -2.  -2.  -6.  -5.  -3.  -4.  -2.   2.  -2.  -2.   0.   0.   2.   2.   3.  -0.  -3.**************************************************
ROW 28 *****   0.  -2.   7.   6.   5.   1.  -1.  -1.  -4.  -5.  -5.  -4.  -3.  -7.  -1.  -3.   3.   4.   4.   3.   5.   1.   2.   7.  13.****************************************
ROW 29 *****   0.   0.   3.   5.   5.   2.   1.   0.  -2.  -6.  -6.  -5.  -6.  -4.  -4.  -6.   2.   4.   2.   5.   7.  -0.  -3.   5.   8.****************************************
ROW 30 **********   0.   2.   2.   2.   2.   2.  -1.  -1.  -0.  -6.  -4.  -2.  -1.  -2.  -3.  -0.   6.   4.   5.   1.   2.   6.   9.   6.****************************************
ROW 31 *****   0.   0.   4.  -2.   1.   3.   3.   2.   1.   1.  -2.  -3.   2.   4.   0.   2.   3.   7.   6.   0.   5.   3.   6.  13.  10.****************************************
ROW 32 *****   0.   3.   1. -38.  -1.   3.   2.   3.  14.   0.   0.   0.   6.   3.   3.   6.   6.   6.  -2.   3.   9.   6.   7.  15.   3.****************************************
ROW 33 *****   0.   4.   3.  -0.   0.   2.   5.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   8.   9.   7.   8.   2.   3.****************************************
ROW 34 *****   0.   2.  -1.  -2.   1.   1.   3.   2.   1.  -0.   4.   0.   0.   0.   0.   0.   0.  -2. -14.  13.  15.   8.*******************************************************
ROW 35 *****   0.   0.   0.  -0.   0.  -1.   2.   4.   2.   5.  11.   3.   0.   0.   0.   0.  -0.  -0.   3.   8.  10.   4.*******************************************************
ROW 36 ***************   0.  -2.  -7.   0.  -0. -15.   2.   2.  12.   3.   0.   0.   0.   0.   0.   3.  10.   7.   5.   0.*******************************************************
ROW 37 ***************   0.   0.   1.  -2.  -5.   0.   3.   5.   4.   2.   0.   0.   0.   0.   0.   8.   6.   2.  -7.   0.*******************************************************
ROW 38 ********************   0.   3. -11.   0.   2.   4.   4.   4.   1.   0.   0.   0.   0.   0.   0.  10.   3.  -0.  -3.*******************************************************
ROW 39 ********************   0.   0.   1.   1.   4.   6.   5.   3.   4.   0.   0.   0.   0.   0.   0.   0.   3.   0.   0.*******************************************************
ROW 40 *************************   0.   8.  -6.   6.   3.   3.   2.   4.  -3.  -1.  -1.   1.   0.   0.   0.   4.  -9. -16.*******************************************************
ROW 41 *************************   0.   1.  -9.  -6.   1.   5.   4.   2.  -4.   1.   5.   3.  -1.   0.   4.   3.  -3. -30.*******************************************************
ROW 42 *************************   0.  -5.   2.   2.   2.   4.   1.   2.   0.   2.  -3.  -7.  -3.   0.   4.  -0. -25. -37.*******************************************************
ROW 43 *************************   0.   0.   2.  -0.   3.   2.   5.  24.   0. -11.  -8.  -4.  -8.  -7.   1. -11. -30.************************************************************
ROW 44 *************************   0.  -2.  -0.  -1.   1.   3.   4.  -4.  -3.  -7.  -7.  -5.   0.   0.  35.  -8. -30.************************************************************
ROW 45 *************************   0.  -4.  -2.   0.   0.   4.  -1.  -3.  -3.   0.   0.   0.   0.   0.   7.  20. -23.************************************************************
ROW 46 *************************   0.  -1.   1.   2.   1.   2.   2.   0.   0.   0.   0.   0.   0.  -1.  -8.   4.   5.   5.*******************************************************
ROW 47 *************************   0.  -5.   0.   0.   7.   6.   0.   0.   0.   0.   0.   0.   0.  -5.  -2.  -1.   4.   0.*******************************************************
ROW 48 *************************   0.   0.   0.   0.   0.   6.   1.   0.   0.   0.   0.   0.   0.  -1.   1.   1.   3.   0.*******************************************************
ROW 49 *************************   0.   0.   0.   0.   7.   0.   6.   0.   0.   0.   0.   0.   0.   0.   5.  10.   4.   0.*******************************************************
ROW 50 *************************   0.   0.   0.   0.   0.  10.   5.   3.   1.   0.   3.   0.   0.   0.   0.   2.   2.   0.*******************************************************
ROW 51 *************************   0.   3.   0.   0.  10.   5.   6.   9.   5.   8.   3.   0.  -2.   0.   0.   0.  -1.  -1.   0.**************************************************
ROW 52 *************************   0.   3.   3.   6.  10.   6.  -6.  -1.   0.   3.   3.   1.   2.   1.   0.  -5.  -2.  -1.  -2.**************************************************
ROW 53 *************************   0.   3.   5.   6.  15.   8.   3.   0.   3.   2.   2.   1.   0.   3.   1.  -0.  -0.   0.  -0.   0.*********************************************
ROW 54 *************************   0.   3.   4.  10.  15.  29.  12.  -5.  -7.  -7.   1.  -7.   0.  -0.   1.   1.  -1.  -2.  -2.   0.   0.   0.***********************************
ROW 55 *************************   0.   3.   4.   6.  12.  32.  43.  30.  -2. -10.  -3.   3.   2.   1.   2.   1.   1.  -1.  -3.  -0.   0.   0.***********************************
ROW 56 *************************   0.   4.   6.   7.  10.  32.  40.  44.  42.  31.   6.   6.   5.   2.   2.   2.   2.   1.  -0.  -1.   0.   0.***********************************
ROW 57 *************************   0.   0.   0.   7.   7.  12.  19.  36.  50.  19.  11.   9.   8.   4.   4.   4.   2.   2.   2.   2.   0.****************************************
ROW 58 ***********************************   0.   7.   6.  13.  14.  36.  42.  14.  13.   9.   7.   6.  12.  10.   3.   4.   4.   2.   1.****************************************
ROW 59 ***********************************   0.   6.   7.   9.  10.  13. -38. -38.  11.   6.   7.   5.   6.   5.   2.   3.   4.   5.   4.****************************************
ROW 60 ***********************************   0.   0.   0.   7.  10.  39.   2.   8.   6.   0.   0.   0.   0.   7.   7.  14.  14.  14.  26.****************************************
ROW 61 *********************************************   0.   0.   0.   0.   0.   0.   0.   0.**********   0.   0.   0.   0.   0.   0.  42.****************************************
ROW 62 ************************************************************************************************************************   0.   0.****************************************
```

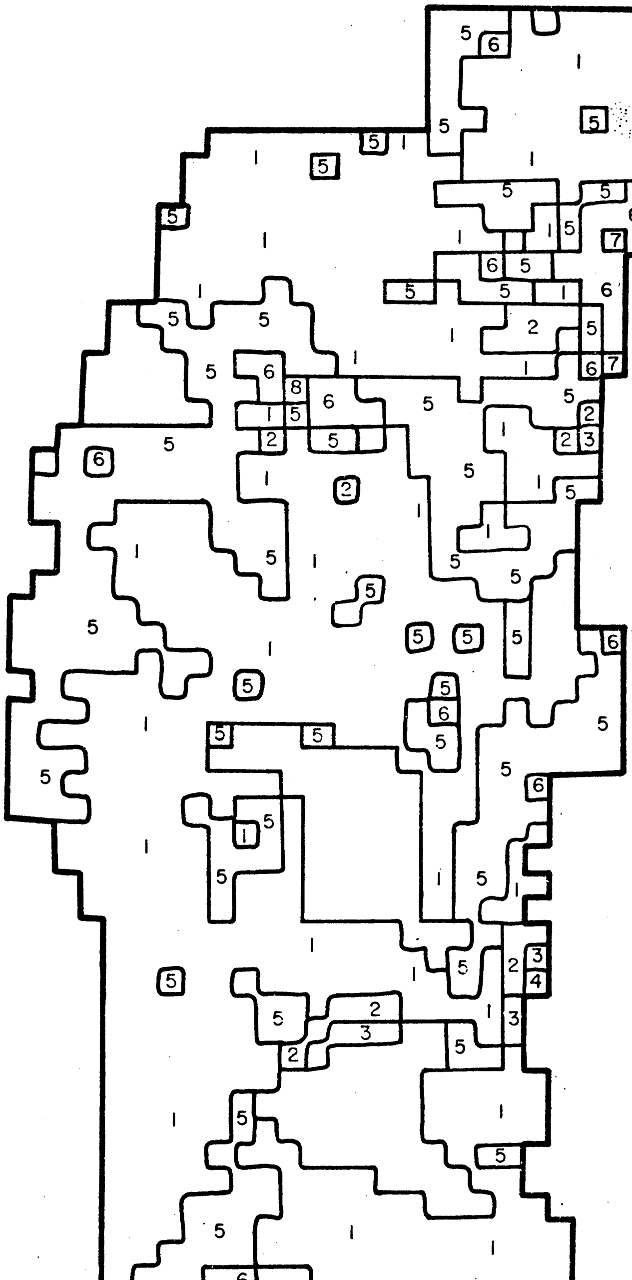
Figure 23. Calibration error--matrix recharge version (computed 1974 head elevations-observed 1974 head elevations)

```
                                                    TILLMAN TERRACE AQUIFER
                                         FOR 1975 OBSERVED SATURATED ABOVE FIVE FEET
                                                  CALIBRATION ERROR (1975)

          2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32   33   34   35

ROW  2 ***********************************************************************************************   2.   0.  -0.  -1.  -1.  -1.  -1.*****   5.   3.  -2.  -6. -16. -25. -28.
ROW  3 ***********************************************************************************************  -0.   0.  -0.  -3.  -2.  -1.  -3.  -1.***********************************
ROW  4 ***********************************************************************************************  -1.  -2.  -1.  -0.  -0.  -1.  -3.  -2.***********************************
ROW  5 ***********************************************************************************************   1.   2.   1.   0.  -0.  -0.  -0.   0.   2.******************************
ROW  6 ***********************************************************************************************   1.   1.   0.  -1.  -0.   0.  -2.  -2.  -1.******************************
ROW  7 ***********************************************************************************************   1.   0.  -0.  -1.  -1.  -1.  -0.  -4.  -3.******************************
ROW  8 ***********************************************************************************************  -1.  -0.  -1.  -1.   0.  -0.  -1.  -1.  -1.******************************
ROW  9 **************************************************   3.   1.  -0.  -2.  -0.   1.   1.   0.  -0.  -1.  -1.  -0.   0.   2.   2.  -1.  -4.  -8.******************************
ROW 10 *********************************************   2.   3.   3.   1.  -1.  -1.   0.   1.  -0.  -2.  -4.  -3.  -4.  -5.   2.  -0.  -3.  -6. -16.******************************
ROW 11 *********************************************   1.   2.   2.   3.   3.   3.   3.   2.   1.   1.   2.  -4.  -4.  -5.   1.   0.  -3. -11. -26.******************************
ROW 12 ****************************************   0.  -2.  -2.  -1.   1.   0.   1.   2.   2.   0.   2.  -0.***************   4.  -2.  -5. -15.***********************************
ROW 13 ****************************************   2.   2.   1.   0.   0.   1.  -1.  -2.   2.   3.  -5.  -0.  -0. -10.  -1.  -2.  -2.  -3.****************************************
ROW 14 ****************************************   3.   0.   2.  -0.  -1.   1.   3.   1.  -3.  -3.   3.  -1.  -1.  -3.   1.   1.  -1.  -8.****************************************
ROW 15 ****************************************   3.   1.   3.   2.  -3.   3.   3.  -1.  -2.  -1.   2.   2.  -1.  -2.**********   1.  -9.****************************************
ROW 16 ******************************   1.  -0.   2.  -4.   1.   4.   3.   1.   1.   0.  -1.  -1.  -1.  -5.  -1.  -3.*****  -2.   3.  -4.****************************************
ROW 17 ******************************   0.  -1.   0.   2.  -5.  -3.   3.   3.   3.   2.   3.   4.   2.   4.   2.   3.   5.   4.  -3.   2.****************************************
ROW 18 *************************   0.   0.  -0.  -0.   2.   2.   3.  -5.  -2.  -3.   0.   2.   0.   1.   4.   2.  -1.  -1.  -2.  -0.*********************************************
ROW 19 *************************   0.  -1.  -1.   0.   1.   3.   3.   3.  -4.  -5.   2.   1.  -1.   1.   0.  -0.   2.  -2.  -4.   4.*********************************************
ROW 20 *************************  -0.  -1.  -1.  -0.  -2.  -1.   4.   4.   3.   0.  -3.   5.   2.   1.   1.   2.   1.   3.  -3.   4.*********************************************
ROW 21 ********************  -2.   2.   1.   1.  -4.  -1.   3.   0.   1.   0.   3.  -5.   1.   2.   4.  -0.   2.   2.  -1.   1.   3.*********************************************
ROW 22 ***************  -1.   2.  -0.   3.  -2.  -2.   0.   2.   2.  -0.  -0.*****  -0.   1.   3.   2.   0.   0.   2.   2.  -1.  -1.*********************************************
ROW 23 ********************   1.   2.   4.   3.   1.  -0.  -2.  -5.  -0.  -3.  -2.*****  -3.   0.   0.   2.   4.  -0.   4.  -2.**************************************************
ROW 24 ********************   1.   3.   4.   4.   3.  -2.  -4.  -4.  -1.  -0.   0.   1.  -2.  -1.   1.   4.   3.   3.   1.   3.**************************************************
ROW 25 ********************  -2.   2.   2.   2.   3.   1.  -5.  -2.   0.   2.   1.  -1.   1.  -2.  -1.   3.   2.  -1.   3.   3.**************************************************
ROW 26 ********************  -2.   4.   1.   2.  -0.   3.   1.  -1.  -1.  -3.  -1.  -4.*****  -0.   4.   2.  -2.  -0.   3.   0.**************************************************
ROW 27 ***************  -2.  -2.  -2.  -0.   1.  -2.   1.   0.  -1.   0.  -1.  -4.  -1.*****   1.   1.   1.   1.   0.   2.   3.**************************************************
ROW 28 **********   4.  -4.  -3.  -3.   1.   1.  -2.  -1.   1.   1.   0.   0.   5.  -1.   2.  -1.  -1.  -1.   1.  -1.   1.   0.   0.  -2.****************************************
ROW 29 ***************   0.  -2.  -2.   0.  -1.  -2.  -0.   2.   1.   1.   3.   2.   2.   4.   2.   1.   1.  -0.  -0.   1.   2.   1.  -2.****************************************
ROW 30 ***************   0.   1.   0.   0.  -1.   1.  -0.  -3.   2.   0.   1.   1.   1.   1.   1.  -0.   1.   0.   1.  -0.  -2.  -1. -12.****************************************
ROW 31 ***************  -3.   2.   0.  -1.  -1.   0.   1.  -2.  -1.   1.   2.   1.   0.  -1.  -5.  -0.  -0.   2.  -0.   1.  -3.   4.  -8.****************************************
ROW 32 **********  -0.  -1.  -1.   0.  -2.   0.   1.  -1.***************   2.   1.   1.   0.  -2.   0.   4.   1.  -1.  -0.  -0.   4. -11.****************************************
ROW 33 **********  -2.  -3.  -1.  -0.  -0.   0.  -5.****************************************  -3.  -5.   3.  -0.  -1.  -1.   2. -18. -16.****************************************
ROW 34 **********  -0.   2.   2.  -0.   0.  -0.  -1.   1.   2.  -2.******************************  -2.   2.  -1.  -2.   0.*******************************************************
ROW 35 ********************   1.   1.   2.  -0.  -3.   0.  -1.  -2.  -2.*************************   1.  -0.  -0.  -0.   1.*******************************************************
ROW 36 ********************   3.   4.  -0.   0.   4.  -0.   2.  -2.  -1.*************************   0.  -1.   0.   5.  -7.*******************************************************
ROW 37 *************************   1.   2.   3.   1.  -1.  -1.  -0.  -0.*************************   2.  -0.   2.*****************************************************************
ROW 38 *************************   1.   3.   3.   2.  -1.  -0.  -0.   0.*************************  -5.   2.   0.*****************************************************************
ROW 39 ******************************   3.   3.   2.  -2.  -1.   1.  -1.*************************  -4.  -5.  -1.   1.************************************************************
ROW 40 ******************************   2.   3.   2.   1.   1.   1.  -2.   0.  -1.  -0.  -1.***************  -2.   2.************************************************************
ROW 41 ******************************   2.   2.   3.   2.  -1.  -1.   0.   4.  -0.  -4.  -2.**********  -3.  -2.*****************************************************************
ROW 42 ******************************   3.  -0.   1.   1.  -2.  -1.   1.   0.  -3.   1.*****   0.   0.  -2.  -2.  -2.************************************************************
ROW 43 ******************************   1.  -1.   2.  -1.   1.  -2.  -1.  -0.********************  -4.   0.  -3.*****************************************************************
ROW 44 ******************************   3.   1.   3.   2.  -1.  -2.***********************************  -2.  -2.   2.************************************************************
ROW 45 ******************************   4.   3.   1.   2.  -3.   2.***********************************   2.  -5.  -5.************************************************************
ROW 46 ******************************   1.  -0.  -1.   1.  -0.  -1.***********************************   2.   2.   1.  -0.*******************************************************
ROW 47 ***********************************  -0.  -0.   5.  -1.***********************************   1.   3.   2.   1.  -1.*******************************************************
ROW 48 ******************************   2.   1.  -1.  -1.  -1.   0.******************************  -4.  -0.  -1.   1.  -4.*******************************************************
ROW 49 ******************************   0.  -2.  -2.  -3.  -0.  -1.  -5.******************************  -2.   5.  -0.************************************************************
ROW 50 ******************************   0.  -0.  -2.  -0.  -3.  -0.   1.   1.  -5.  -0.********************   4.   2.************************************************************
ROW 51 ******************************  -1.   1.  -2.  -3.   1.  -1.  -1.  -1.  -0.   1.  -0.*************************************************************************************
ROW 52 ******************************  -0.   1.  -1.  -2.  -0.   5.   4.   2.   0.  -0.  -0.  -1.  -0.  -1.**********  -0.   0.**************************************************
ROW 53 ******************************   1.   0.   1.  -3.   1.   3.   3.  -1.  -1.  -1.  -1.   0.  -2.  -0.  -0.  -1.  -1.   2.**************************************************
ROW 54 ******************************   1.   2.  -1.  -2.  -1.  -0.   3.   1.   0.  -1.   3.   0.   1.  -0.  -0.   0.   1.   2.**************************************************
ROW 55 ******************************   1.   2.   3.   1.  -1.  -3.  -0.   2.   3.   1.  -0.   0.   1.   0.   0.  -0.   1.   2.  -2.*********************************************
ROW 56 ******************************  -1.  -1.   2.   2.  -1.  -3.  -4.  -3.  -2.   2.   0.   0.   2.   2.   1.   0.   0.   0.  -1.*********************************************
ROW 57 ****************************************  -0.   3.   2.   0.  -3.  -5.  -2.  -0.  -1.  -1.   1.   0.   0.   1.   1.   0.   0.*********************************************
ROW 58 ****************************************  -2.   2.   0.   1.  -2.  -4.  -1.  -1.  -1.   0.   0.  -2.  -2.   2.   0.   1.   3.   1.****************************************
ROW 59 ****************************************  -1.   0.   3.   2.   0.   4.   2.   0.   2.  -2.  -0.  -2.  -1.   2.   2.   2.   2.   3.****************************************
ROW 60 **************************************************   0.   1.  -5.   3.   2.   3.********************  -3.  -3.  -2.  -2.  -1.   3.****************************************
ROW 61 *****************************************************************************************************************************  -0.****************************************
ROW 62 **********************************************************************************************************************************************************************
```

Figure 24. Calibration error--pattern recharge version



PATTERN RECHARGE RESIDUAL (Ft)
COMPUTED—OBSERVED
OCTOBER 1, 1974 RESULTS

EXPLANATION

ZONE	RECHARGE (Ft)
4	>30'
3	21——30'
2	11——20'
1	0——10'
5	0——-10'
6	-11——-20'
7	-21——-30'
8	<-30'

This phenomenon occurs due to recharge from neighboring nodes along the hydraulic gradient. In some cases, where pumping automatically stops within five feet of the bottom, a node is recharged by neighboring nodes. Recharge from neighboring nodes was generally reoccurring because of changing gradients between nodes. Because the total drawdown (downward change in water-head elevation) was affected by recharge from adjacent nodes and the surface, it was difficult to determine surface recharge values to calibrate the model using the matrix version; therefore, permeability adjustments were needed for this calibration in some north-central portions of the study area.

A new formula was introduced to determine a surface recharge rate for the calibrations. The effects of lateral flow between nodes was considered by comparing the effects of drawdown in two or more adjacent nodes. Calculation of a new recharge rate is as follows:

(1) $\Delta Re_{New} = (DD_{N_1} * S_{Y_1} * C + DD_{N_2} * 0.01 * C)$

(2) $\Delta Re_{Old} = (DD_{N_1} * S_{Y_1} * C + DD_{N_2} * S_{Y_1} * C)$

Subtracting (2) from (1) we obtain:

$$\Delta Re_{New} - \Delta Re_{Old} = DD_{N_2} * (0.01 * C - S_{Y_1} * C)$$

$$= DD_{N_2} \; C \; (0.01 - S_{Y_1})$$

Re = Recharge; $DDN_{N_{1,2}}$ = Drawdown in nodes 1 and 2; S_Y = Specific Yield; The constant C is an emperical weighting factor.

Simulation - 20 years.

Two 20-year computer runs were made for each of the three calibration versions as shown in Figure 5 (Flow Chart). The two runs included simulation of prior appropriative right pumpage only and prior appropriative right pumpage in conjunction with allocations of 0.6 and 1.0 acre feet/acre/year, respectively.

The simulation period for the matrix and constant recharge versions was between October 1, 1969, and October 1, 1991. The third version was generated, using the pattern recharge approach, from July 1, 1973, to July 1, 1993. A new water-head matrix for July 1, 1973, was generated for the pattern recharge version after calibration was completed. This matrix is shown in Figure 25. An allocation of 0.6 acre feet/acre/year was used in the matrix and constant rechage runs while 1.0 acre feet/acre/year was used for the pattern recharge.

Model simulation was mathematically based on computations of change in storage and corresponding water-head elevations of each node. These changes were simultaneously computed in order to represent the effects of lateral flow to and from adjacent nodes. The volume of water in each node was computed using Darcy's Law to calculate lateral flow (Q) at each node face;

Where:

$$\pm Q_n = T_n I_n W_n$$

Q_n is the lateral flow of water into (+) or out (-) of the node at the n^{th} face; units in ft^3 per second.

T_n is the average coefficient of transmissivity of two adjacent nodes; units in ft^2 per second per foot.

I_n is the hydraulic gradient which was the difference in water-head elevations (feet) in two adjacent nodes divided by the distance (2,640 feet) between the two nodes.

W_n is the width (2,640 feet) of the common n^{th} node face.

Figure 25. 1973 generated water-head elevation

```
                                                  PRIOR APPROPRIATION
                                                  JULY 1, 1973 RESULTS
                                                  WATER HEAD ELEVATION

           2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32   33   34   35
ROW  2 **************************************************************************************************************************************************************************
ROW  3 ******************************************************************************************1302.1299.1300.1308.1294.1299.1300.1296.1300.1310.1320.1331.1344.1360.1373.1392.
ROW  4 ******************************************************************************************1300.1298.1291.1299.1298.1298.1299.1299.1297.1299.1317.1330.1350.1359.1381.1397.
ROW  5 ******************************************************************************************1297.1297.1295.1295.1295.1295.1296.1297.1298.1301.1315.1333.1349.1370.1384.1402.
ROW  6 ******************************************************************************************1295.1295.1294.1295.1295.1295.1295.1297.1298.1299.1315.1337.1358.1380.1392.*****
ROW  7 ******************************************************************************************1293.1291.1293.1294.1294.1295.1292.1296.1297.1303.1319.1346.1377.***************
ROW  8 *********************************************1271.1272.1273.1275.1277.1280.1283.1285.1287.1290.1290.1291.1293.1294.1295.1296.1297.1299.1303.1324.1362.********************
ROW  9 ****************************************1268.1270.1274.1275.1277.1279.1281.1283.1284.1286.1287.1288.1290.1292.1294.1297.1298.1297.1299.1310.1339.1379.********************
ROW 10 ****************************************1267.1271.1273.1275.1274.1278.1280.1282.1283.1284.1285.1286.1288.1292.1298.1302.1305.1304.1306.1324.1355.*************************
ROW 11 ***********************************1264.1265.1270.1272.1273.1274.1276.1279.1281.1283.1285.1285.1286.1289.1297.1310.1314.1316.1315.1323.1338.******************************
ROW 12 ***********************************1262.1266.1267.1269.1271.1273.1275.1278.1281.1284.1285.1288.1291.1298.1317.1326.1328.1328.1328.1331.***********************************
ROW 13 ***********************************1260.1263.1263.1266.1267.1271.1274.1278.1282.1285.1289.1294.1301.1315.1329.1336.1337.1334.1334.****************************************
ROW 14 ***********************************1258.1261.1261.1261.1260.1269.1274.1279.1284.1290.1294.1303.1314.1326.1336.1342.1342.1335.1330.****************************************
ROW 15 *************************1250.1253.1256.1257.1253.1258.1262.1268.1276.1284.1293.1302.1312.1320.1326.1333.1340.1343.1340.1335.1330.****************************************
ROW 16 *************************1248.1251.1249.1249.1253.1257.1261.1270.1282.1293.1305.1313.1325.1331.1336.1342.1347.1347.1342.1336.1334.****************************************
ROW 17 ********************1245.1246.1249.1249.1247.1249.1252.1262.1274.1286.1302.1316.1329.1338.1344.1348.1352.1353.1352.1348.1339.1331.****************************************
ROW 18 ********************1243.1246.1247.1247.1244.1245.1249.1262.1276.1290.1305.1321.1334.1343.1348.1353.1354.1357.1355.1352.1350.*********************************************
ROW 19 ********************1242.1244.1244.1244.1242.1240.1245.1257.1272.1288.1303.1320.1335.1344.1350.1355.1363.1362.1358.1355.1353.*********************************************
ROW 20 ***************1239.1240.1240.1240.1239.1236.1235.1236.1252.1265.1280.1296.1316.1331.1343.1349.1355.1362.1363.1359.1357.1355.*********************************************
ROW 21 **********1237.1238.1236.1235.1235.1234.1233.1231.1236.1246.1260.1276.1290.1309.1328.1340.1347.1353.1359.1362.1361.1360.1358.*********************************************
ROW 22 **********1236.1236.1233.1232.1230.1230.1230.1230.1234.1245.1258.1272.1285.1303.1322.1336.1344.1350.1356.1360.1361.1361.1360.*********************************************
ROW 23 **********1235.1234.1232.1230.1228.1227.1227.1229.1233.1246.1257.1271.1283.1300.1316.1329.1340.1346.1352.1357.1360.1361.**************************************************
ROW 24 ***************1233.1231.1228.1226.1225.1225.1229.1235.1247.1257.1269.1283.1298.1311.1324.1334.1341.1347.1352.1357.1360.**************************************************
ROW 25 ***************1232.1228.1225.1223.1222.1223.1228.1235.1244.1256.1268.1281.1295.1308.1321.1330.1335.1340.1346.1351.1355.**************************************************
ROW 26 **********1230.1231.1226.1223.1221.1219.1220.1227.1234.1241.1254.1266.1278.1290.1300.1313.1327.1333.1338.1342.1349.1353.**************************************************
ROW 27 *****1227.1228.1223.1221.1219.1219.1217.1221.1227.1235.1243.1254.1263.1275.1286.1297.1314.1325.1331.1335.1336.1342.1348.**************************************************
ROW 28 *****1225.1224.1222.1220.1218.1218.1216.1222.1227.1236.1246.1255.1266.1276.1286.1297.1310.1323.1328.1332.1331.1337.1347.1351.1353.****************************************
ROW 29 *****1224.1222.1220.1217.1217.1218.1217.1221.1228.1237.1247.1258.1269.1279.1289.1300.1315.1321.1327.1330.1324.1331.1335.1336.1340.****************************************
ROW 30 **********1220.1219.1217.1217.1218.1218.1222.1229.1236.1248.1261.1275.1285.1296.1306.1313.1318.1321.1324.1325.1327.1325.1325.1326.****************************************
ROW 31 *****1218.1219.1217.1216.1217.1218.1219.1224.1230.1237.1249.1276.1294.1302.1308.1312.1309.1299.1314.1316.1319.1321.1318.1315.1315.****************************************
ROW 32 *****1216.1215.1214.1214.1215.1218.1220.1225.1232.1243.1263.1283.1297.1300.1301.1331.1296.1296.1304.1309.1312.1313.1311.1309.1309.****************************************
ROW 33 *****1214.1209.1210.1212.1214.1217.1220.1225.1237.1251.1267.1278.1293.1295.1295.1295.1295.1296.1301.1306.1308.1307.1306.1305.1305.****************************************
ROW 34 *****1212.1210.1208.1210.1213.1216.1220.1226.1233.1239.1250.1264.1283.1295.1295.1294.1295.1295.1299.1303.1302.1296.*******************************************************
ROW 35 *****1210.1208.1206.1208.1210.1214.1219.1225.1231.1237.1243.1255.1277.1294.1295.1294.1294.1294.1297.1298.1296.1292.*******************************************************
ROW 36 ***************1204.1205.1208.1213.1218.1224.1229.1235.1239.1250.1271.1294.1294.1294.1294.1293.1291.1290.1290.1286.*******************************************************
ROW 37 ***************1202.1200.1206.1210.1216.1223.1229.1234.1239.1247.1263.1280.1289.1293.1294.1289.1286.1284.1282.1279.*******************************************************
ROW 38 ********************1198.1203.1208.1216.1223.1229.1234.1238.1243.1254.1270.1275.1284.1292.1287.1284.1282.1277.1271.*******************************************************
ROW 39 ********************1196.1194.1205.1214.1222.1229.1233.1237.1241.1245.1256.1270.1275.1284.1284.1284.1280.1273.1268.*******************************************************
ROW 40 *************************1192.1200.1210.1219.1227.1232.1236.1240.1245.1251.1261.1273.1279.1283.1282.1275.1266.1264.*******************************************************
ROW 41 *************************1190.1198.1206.1215.1224.1230.1235.1241.1248.1257.1263.1270.1272.1278.1274.1267.1262.1260.*******************************************************
ROW 42 *************************1188.1194.1201.1212.1221.1228.1234.1241.1249.1256.1261.1267.1270.1273.1269.1260.1256.1254.*******************************************************
ROW 43 *************************1185.1193.1201.1209.1218.1225.1231.1239.1249.1255.1260.1265.1268.1267.1262.1251.1249.************************************************************
ROW 44 *************************1180.1189.1198.1206.1214.1221.1229.1238.1248.1254.1258.1263.1262.1258.1248.1241.1238.************************************************************
ROW 45 *************************1177.1186.1194.1204.1212.1219.1227.1238.1245.1250.1253.1251.1244.1238.1232.1230.1224.************************************************************
ROW 46 *************************1174.1182.1191.1200.1208.1216.1226.1234.1244.1247.1247.1241.1227.1219.1218.1215.1210.1199.*******************************************************
ROW 47 *************************1170.1176.1187.1197.1204.1210.1220.1230.1239.1245.1245.1233.1215.1208.1205.1201.1200.1192.*******************************************************
ROW 48 *************************1168.1175.1185.1194.1201.1203.1214.1220.1230.1234.1225.1219.1209.1188.1192.1190.1189.1185.*******************************************************
ROW 49 *************************1166.1173.1182.1191.1197.1201.1206.1205.1214.1214.1205.1203.1200.1190.1181.1176.1177.1179.*******************************************************
ROW 50 *************************1164.1171.1178.1186.1191.1196.1199.1202.1203.1196.1190.1188.1190.1185.1178.1172.1169.1170.*******************************************************
ROW 51 *************************1162.1167.1173.1179.1185.[illegible].1193.1196.1196.1193.1189.1184.1176.1178.1170.1165.1160.1158.1167.**************************************************
ROW 52 *************************1160.1164.1168.1172.1178.1182.1186.1188.1188.1185.1182.1176.1172.1169.1164.1157.1153.1149.1149.**************************************************
ROW 53 *************************1157.1161.1163.1167.1170.1175.1178.1180.1178.1174.1172.1168.1164.1161.1158.1152.1148.1147.1146.1148.*********************************************
ROW 54 *************************1155.1158.1160.1161.1163.1166.1168.1168.1167.1164.1163.1158.1153.1153.1153.1150.1145.1143.1142.1141.1146.1149.***********************************
ROW 55 *************************1153.1154.1156.1157.1158.1158.1159.1158.1157.1155.1152.1148.1145.1147.1146.1145.1142.1139.1137.1132.1144.1146.***********************************
ROW 56 *************************1150.1151.1151.1152.1153.1153.1152.1151.1150.1148.1146.1142.1139.1139.1140.1139.1137.1135.1132.1129.1141.1143.***********************************
ROW 57 *************************1149.1147.1145.1148.1149.1148.1147.1147.1145.1144.1141.1139.1136.1135.1134.1133.1132.1130.1128.1127.1129.****************************************
ROW 58 ***********************************1143.1144.1145.1144.1143.1142.1141.1139.1137.1134.1132.1130.1128.1127.1127.1126.1124.1123.1123.****************************************
ROW 59 ***********************************1142.1142.1141.1140.1140.1138.1136.1134.1131.1128.1126.1123.1122.1122.1122.1121.1120.1119.1119.****************************************
ROW 60 ***********************************1140.1138.1136.1137.1136.1134.1131.1129.1125.1118.1116.1114.1112.1116.1116.1115.1114.1114.1114.****************************************
ROW 61 *********************************************1134.1133.1132.1130.1125.1122.1120.1119.**********1110.1109.1108.1107.[illegible].[illegible].1106.****************************************
ROW 62 ************************************************************************************************************************1100.*********************************************

TILL                  WELLS * 3, PATT RECH, PP (403)
```

Transmissivity is calculated in the model by multiplying the value of permeability by the saturated thickness of each node. The distribution of transmissivity values is shown in Figure 26. The net flow into or out of each node is the algebraic sum of the lateral flows determined for the node faces as well as outflow due to pumpage and evapotranspiration and inflow due to surface recharge (calibration).

The computed values for inflow and outflow are summarized as a mass balance in Tables VII, VIII and IX. A conceptual input-output model is shown in Figure 27 to represent the relationship between parameters used in the mass balance. The mass-balance tables are computed for each model time step. A model time step of ten days was used for each set of computer calculations of head change. The head change was computed by using the following relationship:

Where:

$$\pm \Delta H_n = (Q_{net,\ n,\ t=1} - Q_{net,n,\ t=2})\ Sy$$

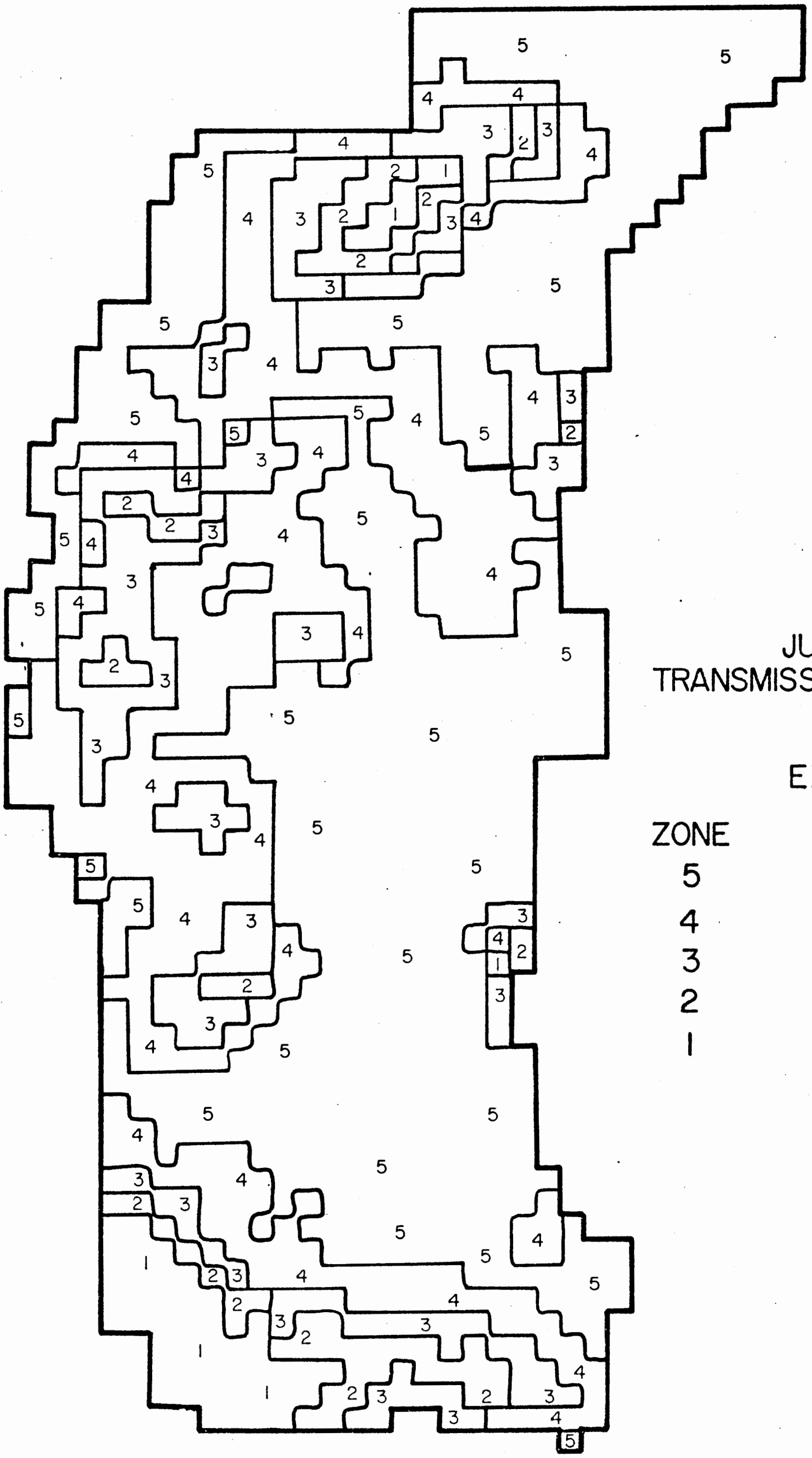
ΔH_n = change in water-head elevation (drop = - and rise = +); units are in feet.

$Q_{net,n,\ t=1,2}$ = net flow into or from each n^{th} node as computed at the end of consecutive time steps (t); units are in cubic feet.

Sy = Specific Yield; unitless.

The above relationship was used in sets of simultaneous equations for all nodes during each model time step. Subsequently, a relaxation procedure was used to adjust the resulting head elevations (former head $\pm \Delta H_n$) to within a model error of 0.1 foot.

Figure 26. Transmissivity distribution map



JULY 1, 1973
TRANSMISSIVITY (100 GPD/Ft.)

EXPLANATION

ZONE	T (100 GPD/Ft.)
5	0 — 100
4	101 — 200
3	201 — 300
2	301 — 400
1	>400

TABLE VII

PRIOR APPROPRIATION ONLY, OCTOBER 1, 1974 - OCTOBER 1, 1991 CONSTANT RECHARGE

	Average Annual Acre Ft		Total Acre Ft	
	In	Out	In	Out
Pumping	0	-16,737	0	-267,799
Leakage	724	- 8,227	11,580	-131,630
Constant Flux	91	- 68	1,458	- 1,083
Evapotranspiration	0	- 3,091	0	- 49,462
Recharge	34,481	0	551,701	0
Return Flow	2,511	0	40,170	0
TOTAL	37,807	-28,123	604,909	-449,973
Net Storage Change	+9,684		+154,936	

TABLE VIII

PRIOR APPROPRIATION, JULY 1, 1973 - JULY 1, 1993
PATTERN RECHARGE

	Average Annual Acre Ft		Total Acre Ft	
	In	Out	In	Out
Pumpage	0	-23,923	0	-478,453
Leakage	1,114	- 8,465	22,285	-169,299
Constant Flux	91	- 68	1,823	- 1,354
Evapotranspiration	0	- 5,799	0	-115,981
Recharge	45,760	0	939,310	0
Return Flow	3,588	0	71,768	0
TOTAL	50,553	-38,255	1,011,078	-765,087
Net Storage Change	+12,298		+245,991	

TABLE IX

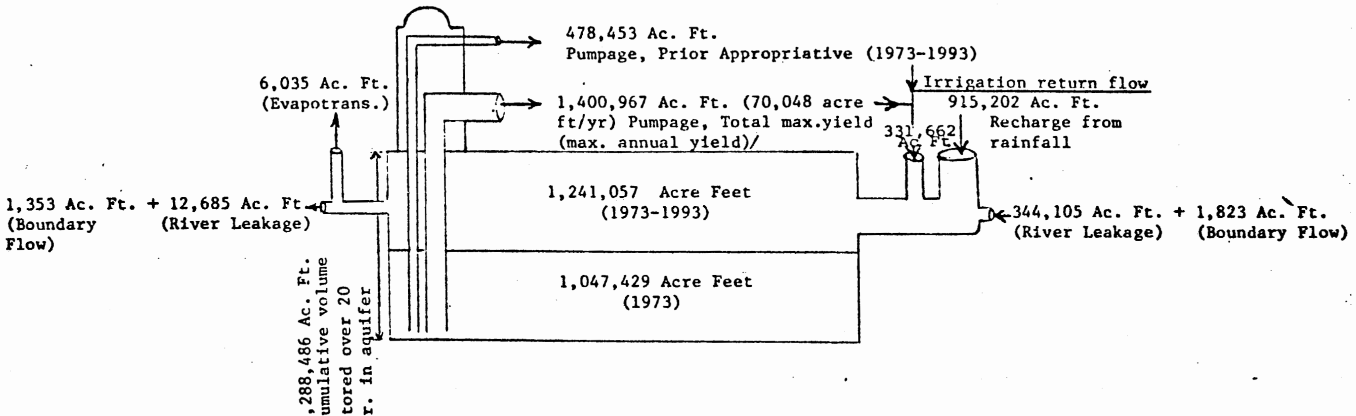
TILLMAN TERRACE MASS BALANCE, PRIOR APPROPRIATIVE + 1.0 ACRE FT/ACRE ALLOCATION JULY 1, 1973 - JULY 1, 1993 (PATTERN RECHARGE)

	Average Annual Acre Ft		Total Acre Ft	
	In	Out	In	Out
Pumpage	0	-93,971	0	-1,879,420
Leakage	17,205	- 634	344,105	- 12,685
Constant Flux	91	- 68	1,823	- 1,350
Evapotranspiration	0	- 302	0	- 6,035
Recharge	45,760	0	915,202	0
Return Flow	17,096	0	281,913	0
TOTAL	77,153	-94,975	1,543,043	-1,899,490
Net Storage Change	-17,822		-356,447	

Figure 27. Mass balance distribution

MASS BALANCE DISTRIBUTION

TILLMAN TERRACE



Recovery Factor (Total Maximum Yield)

$\frac{1,400,967}{2,288,486} = 61.2\%$ of cumulative volume is pumped over 20 years at a rate of 1 acre ft/acre/yr. (Less Prior Appropriative)

Recovery Factor (Prior Appropriative Only)

$\frac{478,453}{2,288,486} = 20.9\%$ of cumulative volume is pumped over 20 years by prior appropriative owners.

CHAPTER V

RESULTS

Calculated saturated thickness for the three versions were compared for October 1, 1991, (matrix and constant recharge) and July 1, 1993, (pattern recharge). The resulting saturated thicknesses were subdivided into ranges as shown in Figures 28, 29, 30, 31, 32 and 33. The nodes which fall in zone 6 (saturated thickness range from 0 to 5.49 feet) are considered dry because of the assumed pump position at the bottom of the well.

The percentage of the total nodes (1,186) are calculated for each version. They are listed in Table VII. As expected, the percent of dry nodes is directly proportional to the additional allocations.

Results shown in Table X indicate that the constant and calibration matrix versions yielded similar results. However, the prior appropriative run, using pattern recharge, did reduce the dry area by 14 percent to 21 percent. This suggests that the pattern recharge calibration procedure produces optimistic results. A 24 percent to 25 percent increase in dry area is caused by the one acre foot per acre allocation as compared to the constant and matrix versions using 0.6 acre feet per acre annual allocation. Although the constant and matrix recharge simulation runs were terminated on October 1, 1991, instead of July 1, 1993, test runs indicate that only a small difference in results would be produced by extending the simulation time to July 1, 1993.

Figure 28. 1991 calculated saturated thickness prior rights only (matrix recharge)

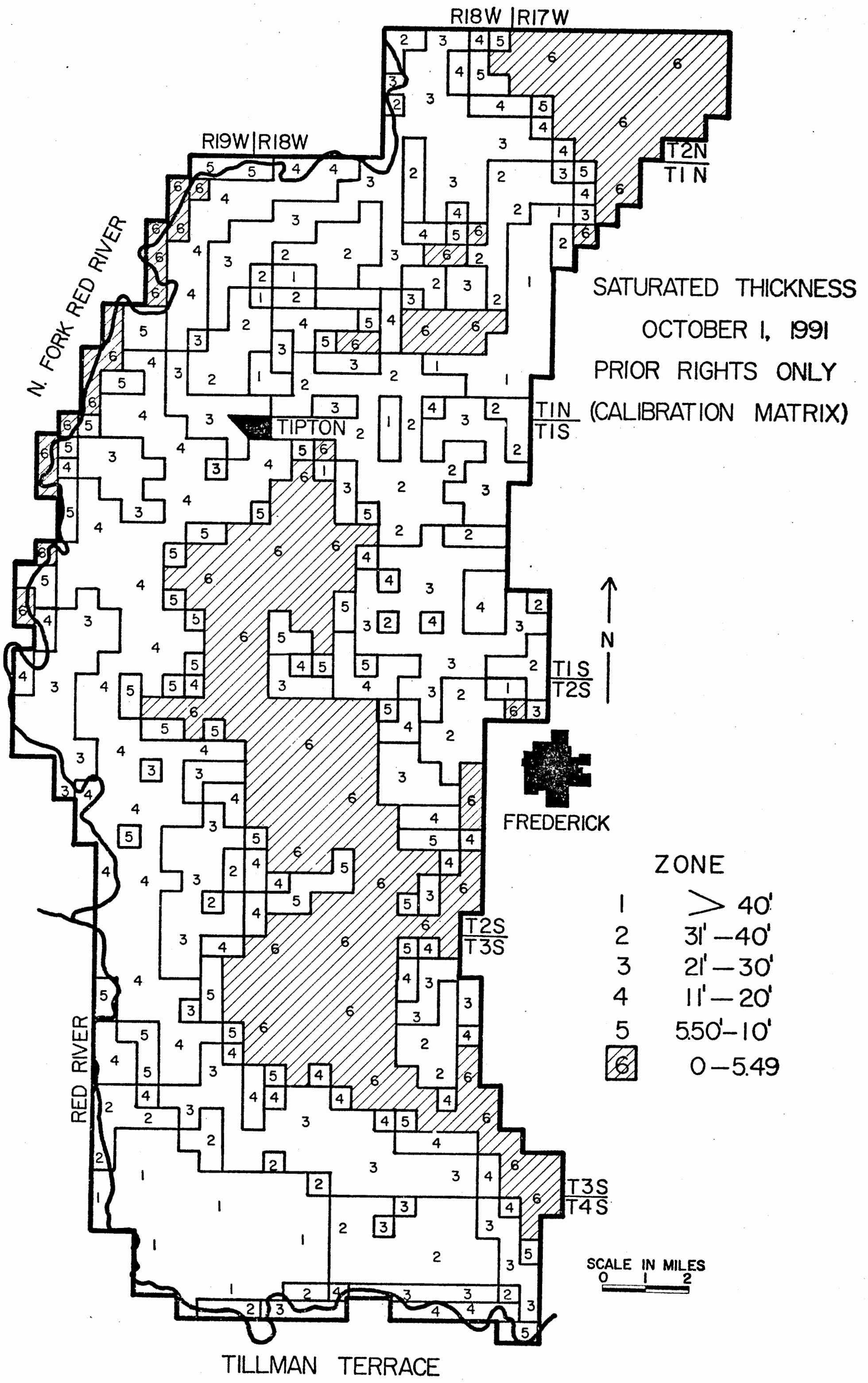

SATURATED THICKNESS
OCTOBER 1, 1991
PRIOR RIGHTS ONLY
(CALIBRATION MATRIX)
R18W | R17W
R19W | R18W
T2N
T1N
N. FORK RED RIVER
TIPTON
T1N
T1S
T1S
T2S
N
FREDERICK
T2S
T3S
RED RIVER
T3S
T4S
SCALE IN MILES
0 1 2
TILLMAN TERRACE
ZONE
1 > 40'
2 31'—40'
3 21'—30'
4 11'—20'
5 5.50'—10'
6 0—5.49

Figure 29. 1991 calculated saturated thickness--prior rights plus 0.6 acre ft/acre annual allocation (matrix recharge)

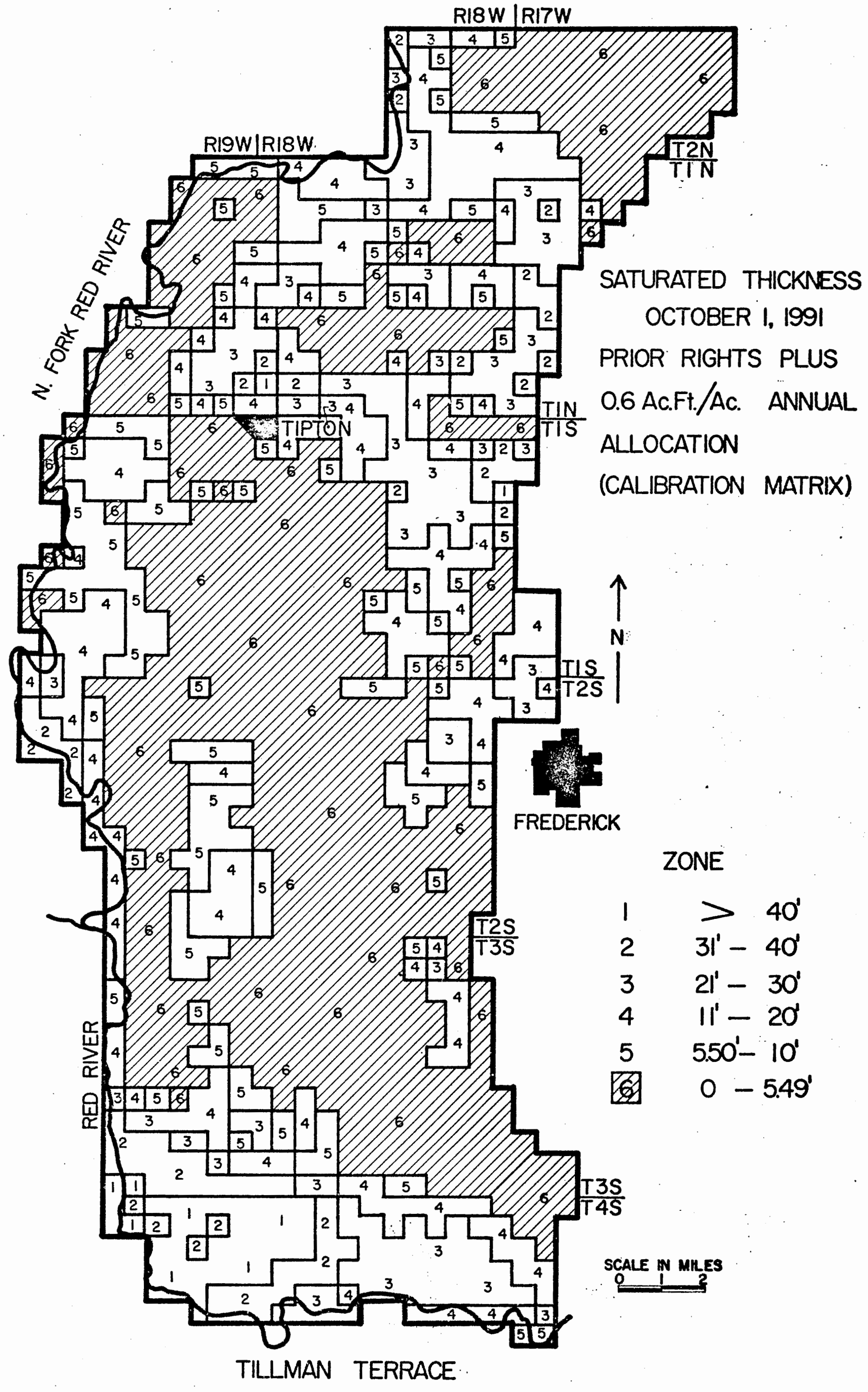
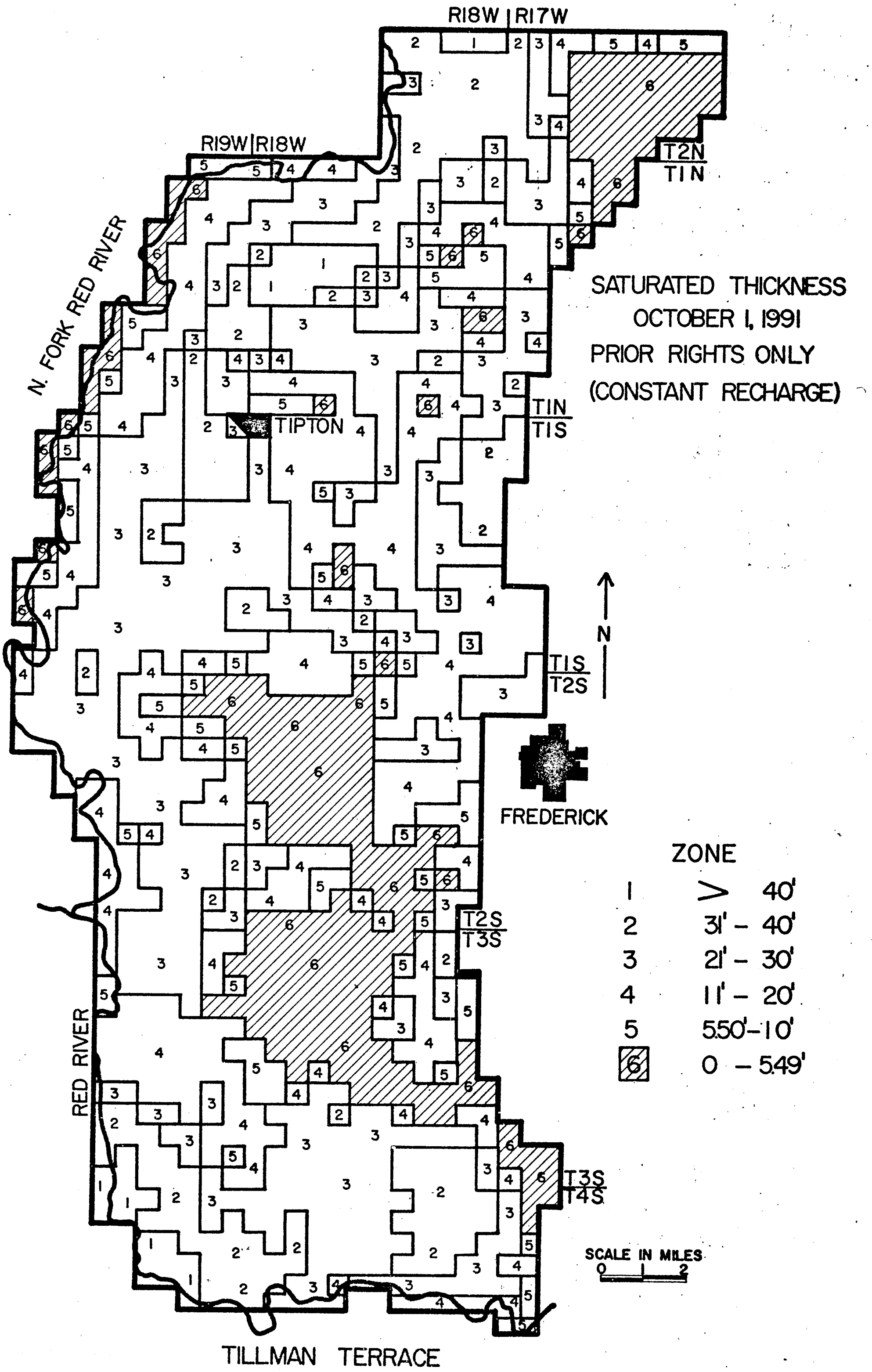
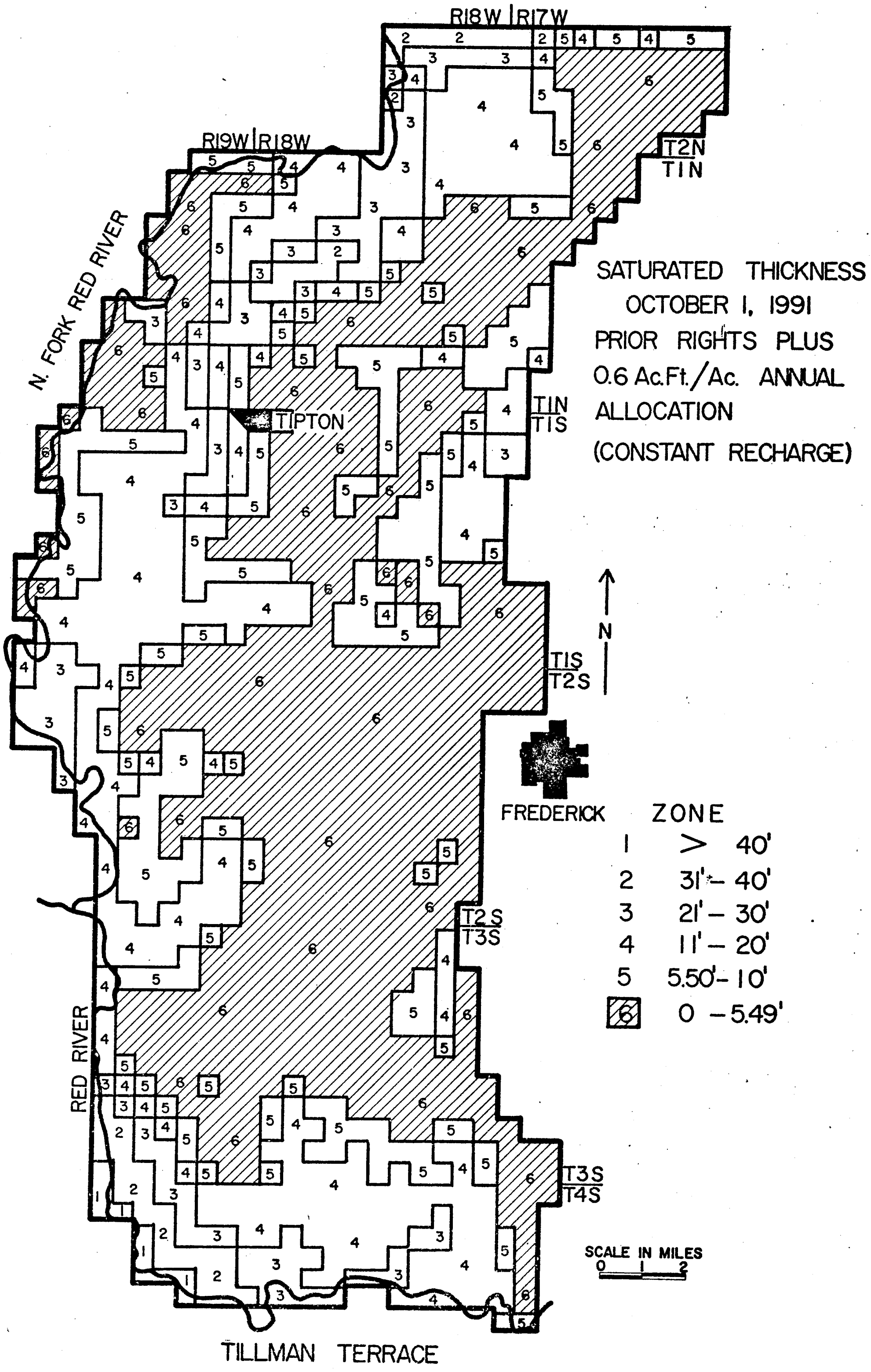

SATURATED THICKNESS
OCTOBER 1, 1991
PRIOR RIGHTS PLUS
0.6 Ac.Ft./Ac. ANNUAL
ALLOCATION
(CALIBRATION MATRIX)
R18W | R17W
R19W | R18W
T2N
T1N
N. FORK RED RIVER
TIPTON
T1N
T1S
T1S
T2S
N
FREDERICK
ZONE
1 > 40'
2 31' – 40'
3 21' – 30'
4 11' – 20'
5 5.50' – 10'
6 0 – 5.49'
T2S
T3S
RED RIVER
T3S
T4S
SCALE IN MILES
0 1 2
TILLMAN TERRACE

Figure 30. 1991 calculated saturated thickness--prior rights only (constant recharge)



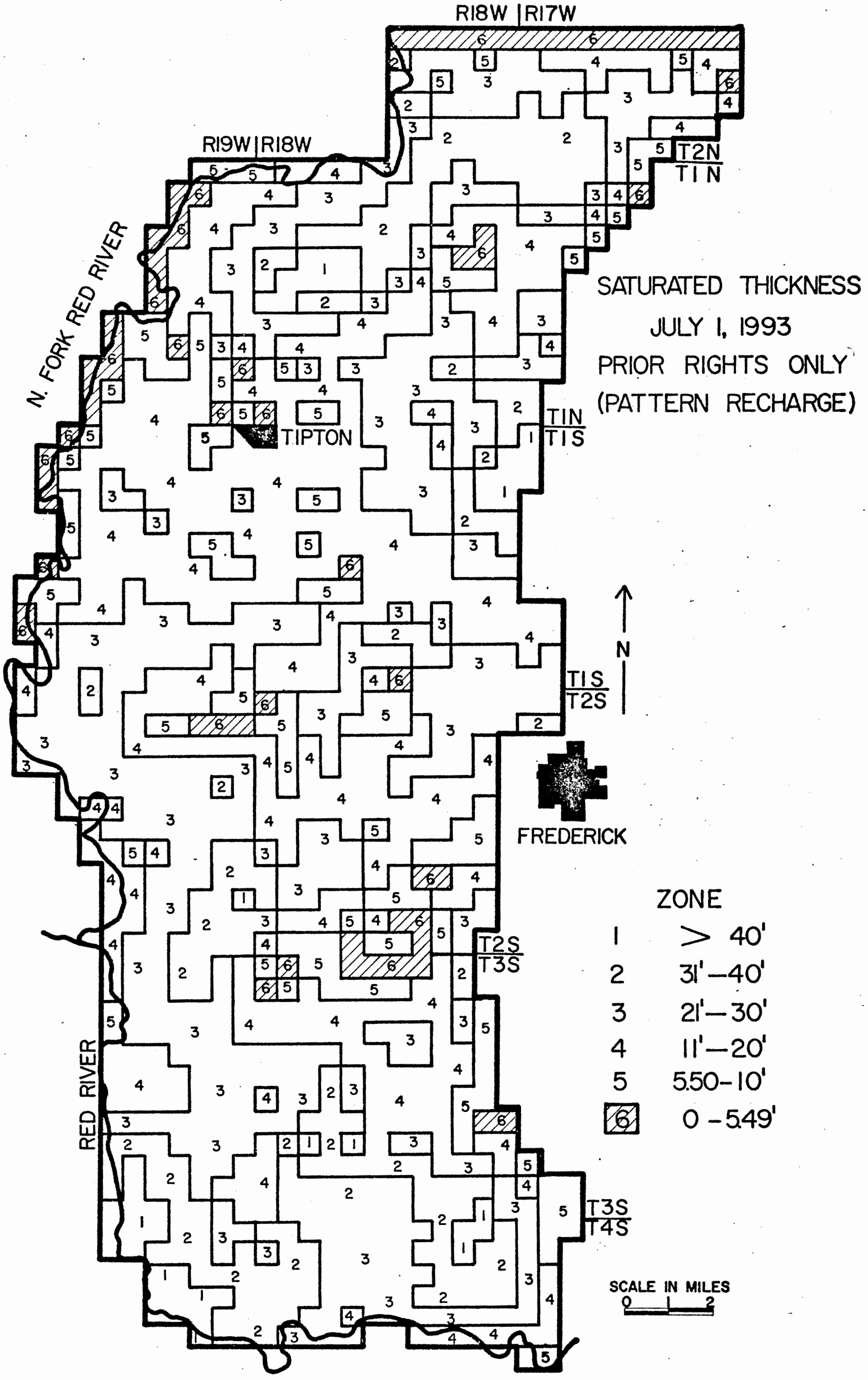
SATURATED THICKNESS
OCTOBER 1, 1991
PRIOR RIGHTS ONLY
(CONSTANT RECHARGE)

Figure 31. 1991 calculated saturated thickness--prior rights plus 0.6 acre ft/acre annual allocation (constant recharge)



SATURATED THICKNESS
OCTOBER 1, 1991
PRIOR RIGHTS PLUS
0.6 Ac.Ft./Ac. ANNUAL
ALLOCATION
(CONSTANT RECHARGE)

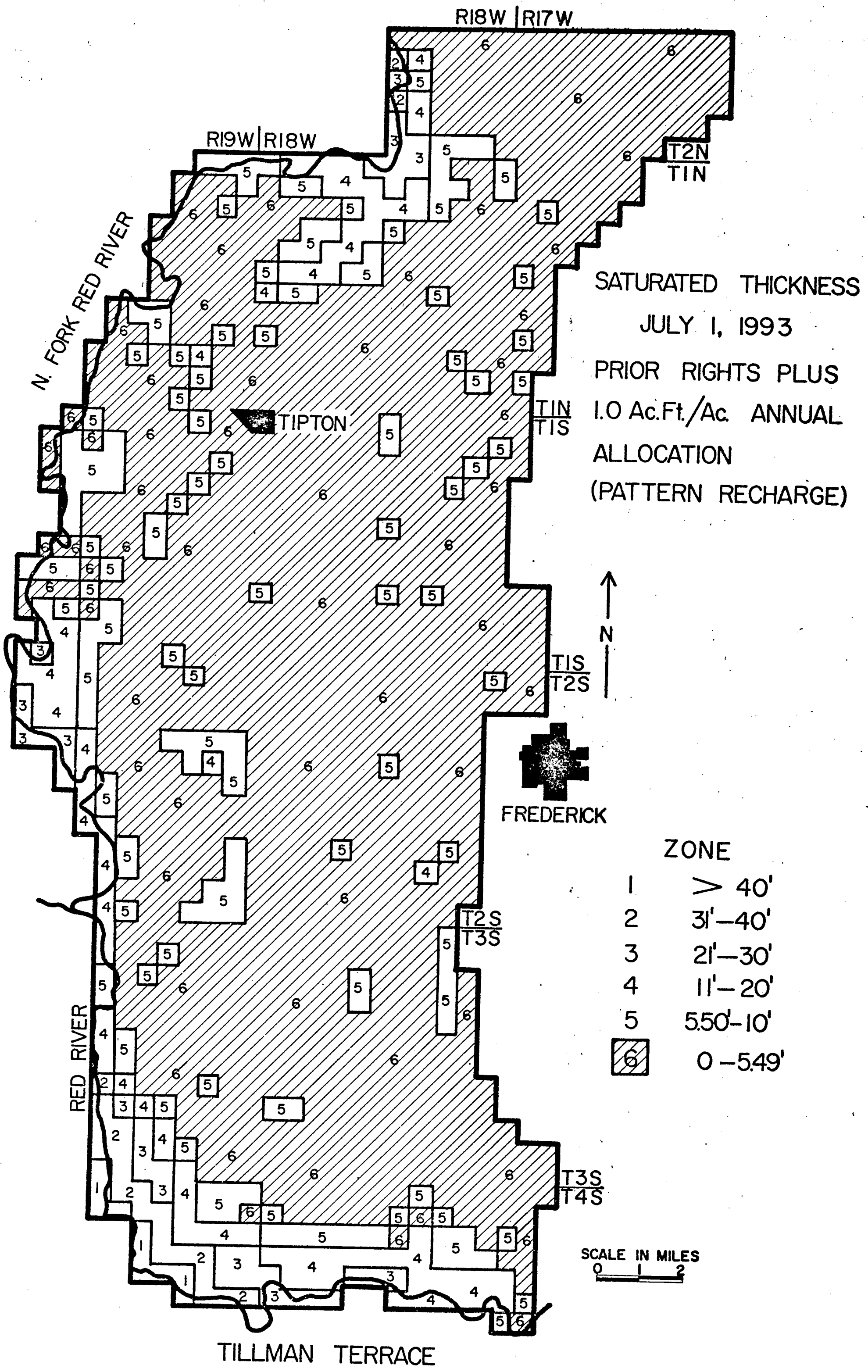
Figure 32. 1993 calculated saturated thickness--prior rights only (pattern recharge)



SATURATED THICKNESS
JULY 1, 1993
PRIOR RIGHTS ONLY
(PATTERN RECHARGE)

TILLMAN TERRACE

Figure 33. 1993 calculated saturated thickness--prior rights plus 1.0 acre ft/acre annual allocation (pattern recharge)



SATURATED THICKNESS
JULY 1, 1993
PRIOR RIGHTS PLUS
1.0 Ac.Ft./Ac. ANNUAL
ALLOCATION
(PATTERN RECHARGE)

TABLE X

COMPARISON OF CALCULATED SATURATED THICKNESS AND DRY NODE PERCENTAGES FOR THREE RECHARGE VERSIONS OF COMPUTER SIMULATION

OCTOBER 1, 1991--CALCULATED SATURATED THICKNESS, % DRY NODES FOR (0-5.49) FT SATURATED THICKNESS INTERVALS		
1	Constant Recharge, Prior Appropriation	$\frac{211}{1186} = 18\%$
2	Constant Recharge, Prior Appropriation + 0.6 acre ft/acre/year	$\frac{574}{1186} = 48\%$
3	Calibration Matrix, Prior Appropriation	$\frac{301}{1186} = 25\%$
4	Calibration Matrix, Prior Appropriation + 0.6 acre ft/acre/year	$\frac{580}{1186} = 49\%$
JULY 1, 1993--CALCULATED SATURATED THICKNESS, % DRY NODES FOR (0-5.49) FT SATURATED THICKNESS INTERVALS		
5	Pattern Recharge, Prior Appropriation	$\frac{44}{1186} = 4\%$
6	Pattern Recharge, Prior Appropriation + 1 acre ft/acre/year*	$\frac{861}{1186} = 73\%$

* % dry nodes for (0-5.01) ft saturated thickness intervals = 50%

The pattern recharge version was selected as the version to represent the final results (Figure 33). These results show that the areas in the northeast corner, along the North Fork of the Red River, became dry due to subsequent allocated pumping. The average saturated thickness for the year 1973 was 18.4 feet as compared with the remaining 7.1 feet of saturated thickness in 1993 as inferred from the pattern recharge version in Figure 33. Computed initial and final areas and volumes of water which were determined from the pattern recharge version are shown in Table XI.

Maximum annual yield was determined by adjusting the amount of allocated pumpage which would cause 50 percent of the nodes to go dry by the end of the simulation period (pattern recharge version). Several simulation runs were made to obtain the 50 percent dry area. This is shown graphically in Figure 34. The maximum annual yield was determined to be 70,048 acre feet per year using a pumping allocation of 1 acre foot/acre/year. This value was produced by dividing the total pumpage (1993) by the period of simulation of 20 years. A 20-year sequence of areas which became dry are shown in Figures 35, 36, 37, 38 and 39 for the pattern recharge version. The final depth (1993) to the water table is shown in Figure 40. Dry nodes were found in the central and northcentral part of the study area and in areas which are closer to the bedrock boundary. The areas along the river generally remained wet with little change in saturated thickness and transmissivity. Recharge from the river to the nearby nodes contributed to the recharge of the area. Few of the appropriated right owners would go dry during the 20-year period; however, additional allocation was permitted and more of their wells went dry as expected. Figures 41, 42 and 43 indicate the areas where prior

TABLE XI

INITIAL MASS DATA
JULY 1, 1973

SATURATED THICKNESS RANGE (FEET)	% AREA	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	SPECIFIC YIELD	STORED WATER (AC.FT.)
0-10	26.3	49,920	5.1	.3	77,066
10-20	29.9	56,800	15.6	.3	265,371
20-30	28.8	54,560	24.6	.3	401,874
30-40	12.1	23,040	33.8	.3	233,571
40-50	2.8	5,280	42.4	.3	67,146
50-60	0.1	160	50.0	.3	2,400
TOTALS	100.0	189,760	18.4 (AVE.)		1,047,429

MASS DATA FROM SIMULATION RUN USING PATTERN RECHARGE
JULY 1, 1993
1.0 AC.FT./AC./YR.
AND/OR PRIOR APPROPRIATION

0-10	86.7	164,640	4.9	.3	242,140
10-20	7.5	14,240	14.4	.3	61,629
20-30	3.2	6,080	25.0	.3	45,614
30-40	1.7	3,200	35.3	.3	33,877
40-50	0.8	1,600	43.9	.3	21.073
50-60	-	-	-		-
	100.0	189,760			404,332

Figure 34. Cumulative percentage of dry area using the pattern recharge version

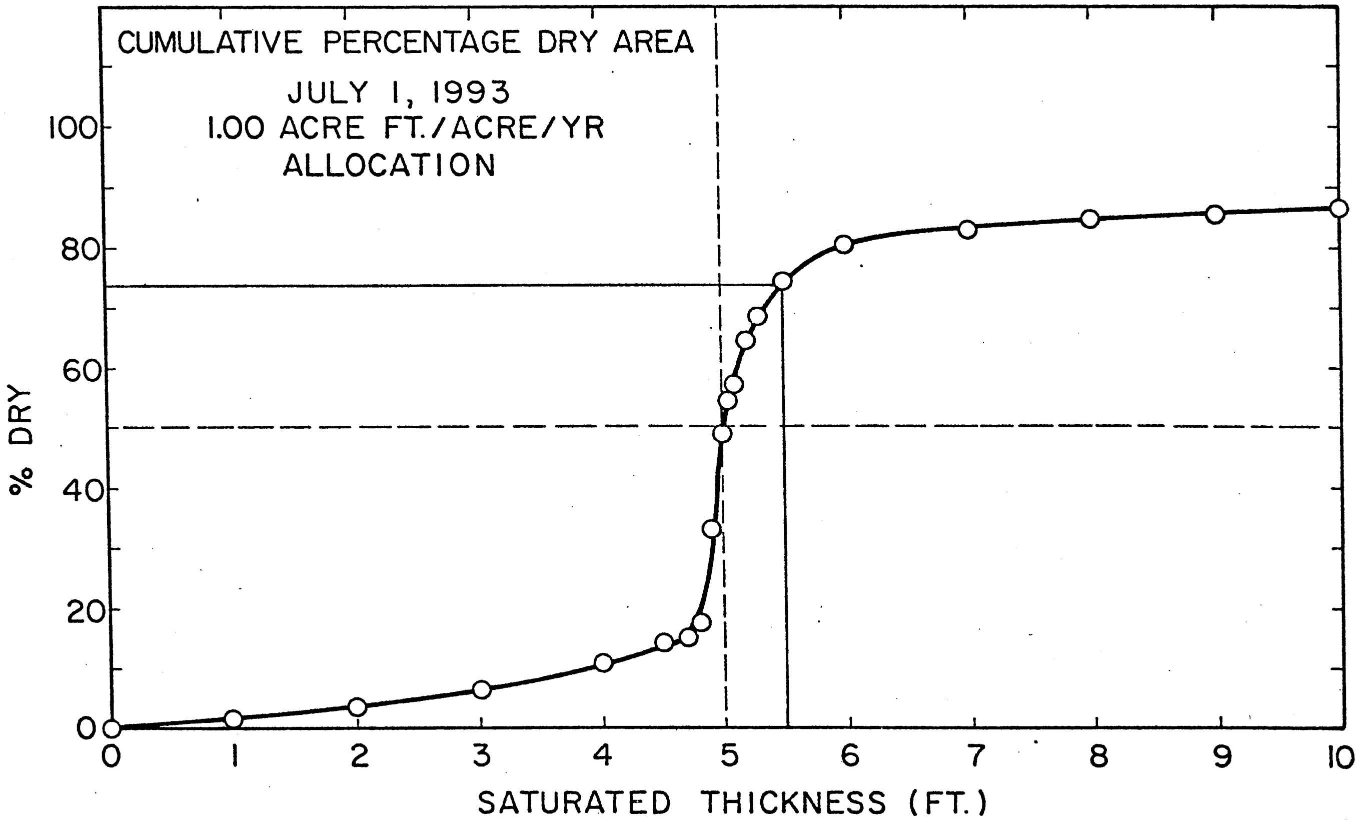

CUMULATIVE PERCENTAGE DRY AREA
JULY 1, 1993
1.00 ACRE FT./ACRE/YR
ALLOCATION
% DRY
0
20
40
60
80
100
0
1
2
3
4
5
6
7
8
9
10
SATURATED THICKNESS (FT.)

Figure 35. Dry areas in 1973

PRIOR RIGHTS + 1.00 Ac Ft/Ac/Yr
SATURATED THICKNESS

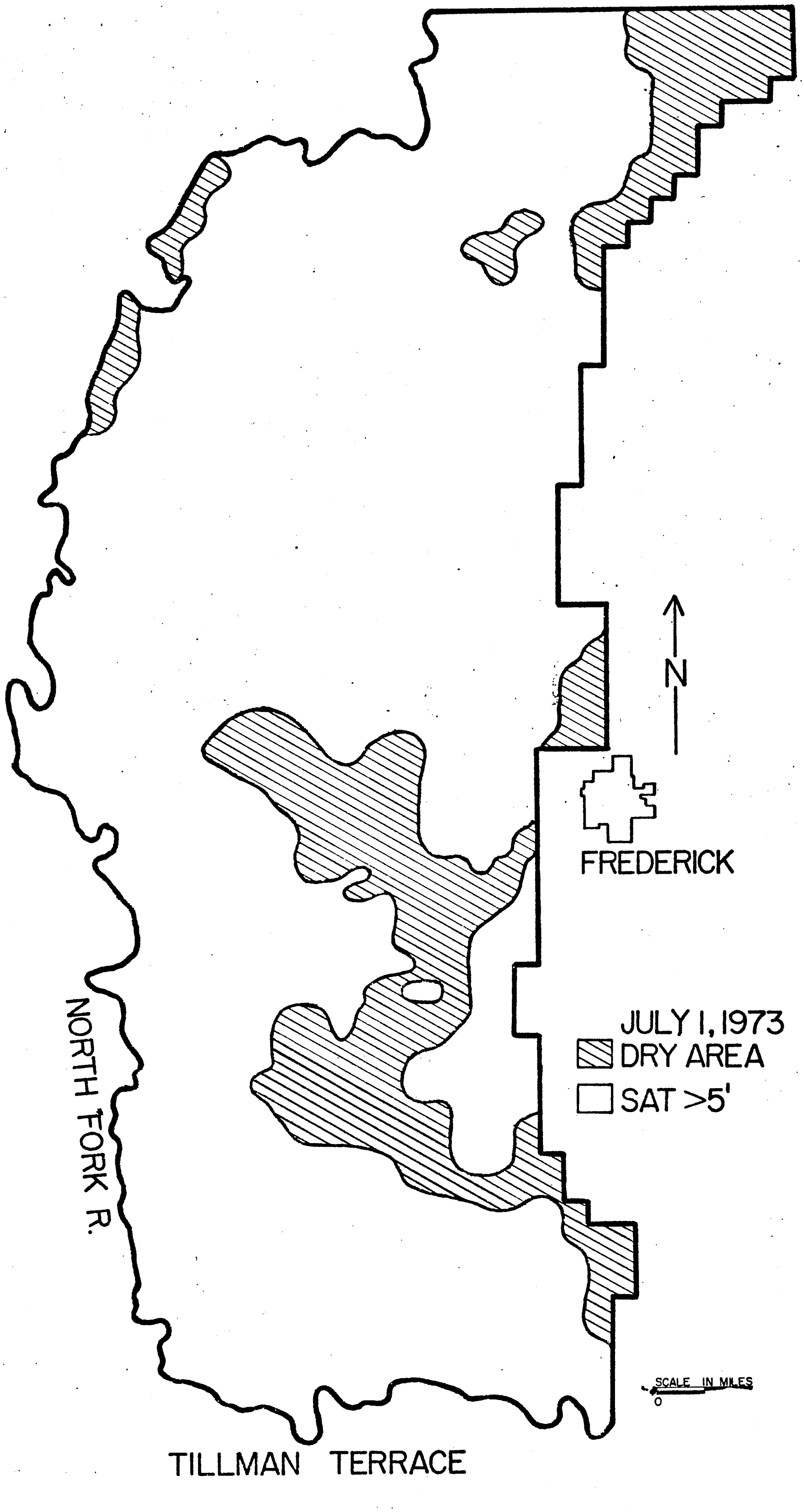


Figure 36. Dry areas in 1978

PRIOR RIGHTS + 1.00 AcFt/Ac/Yr
SATURATED THICKNESS

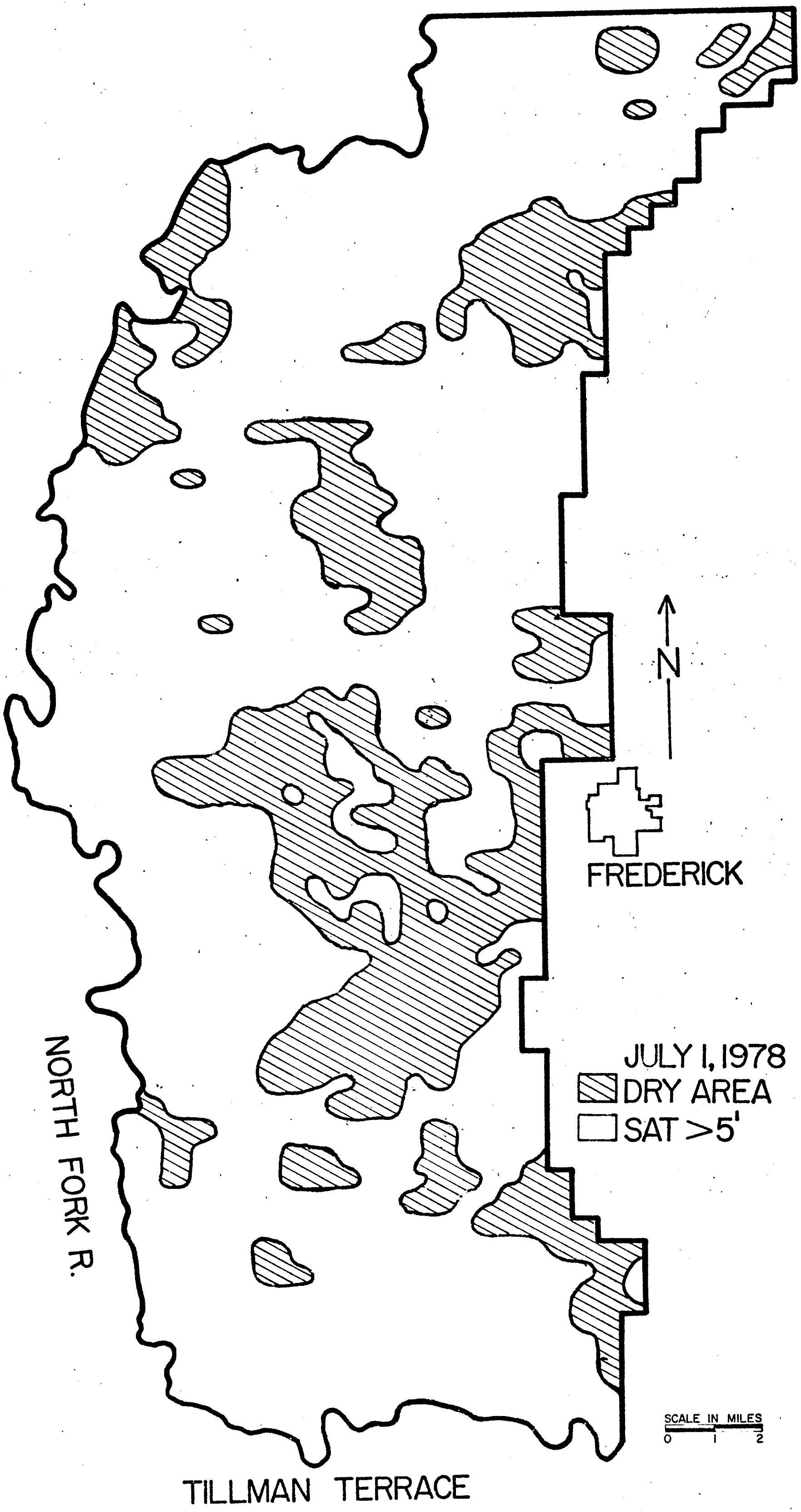


Figure 37. Dry areas in 1983

PRIOR RIGHTS + 1.00 AcFt/Ac/Yr
SATURATED THICKNESS

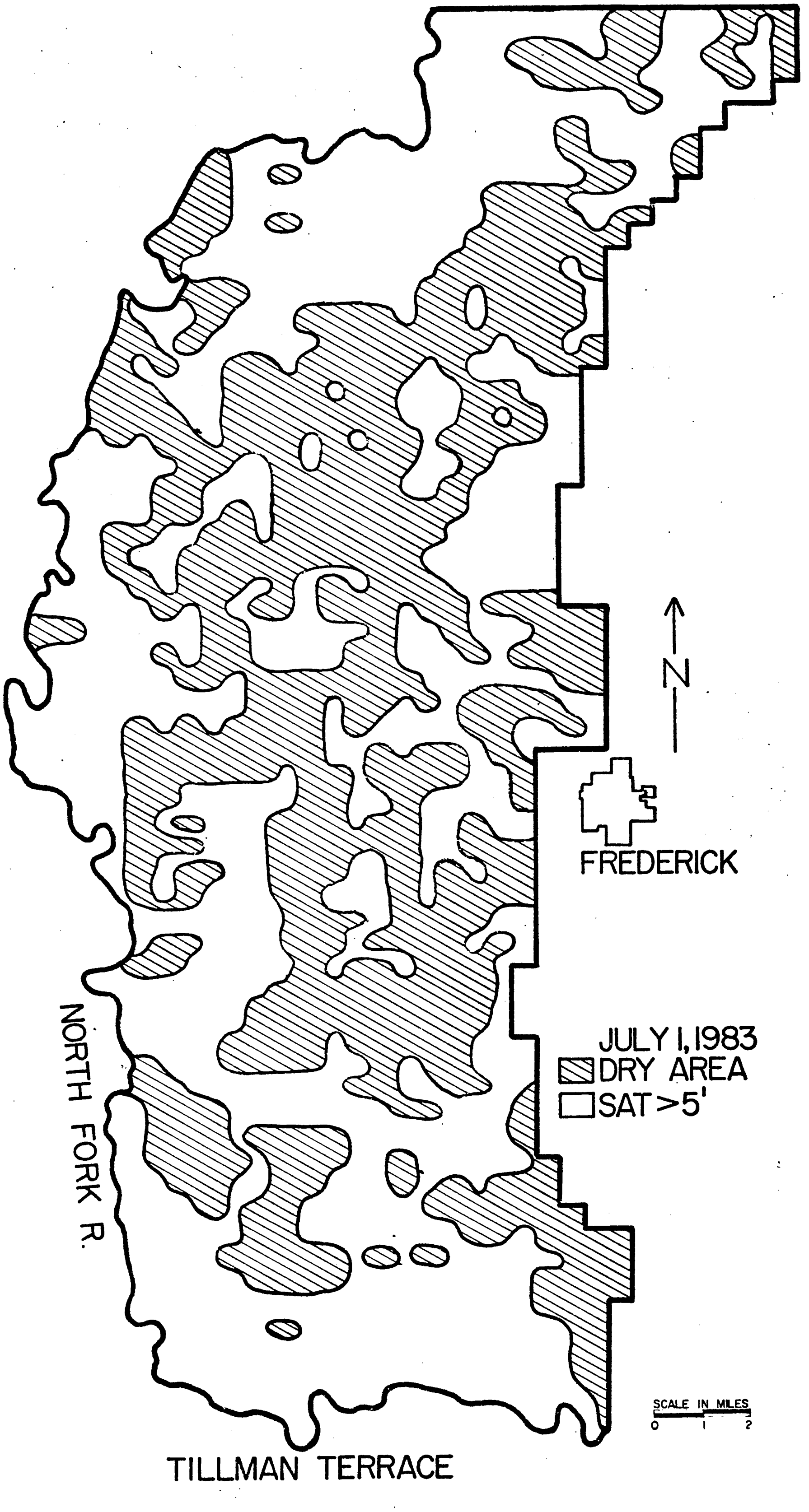


Figure 38. Dry areas in 1988

PRIOR RIGHTS + 1.00 Ac Ft/Ac/Yr
SATURATED THICKNESS

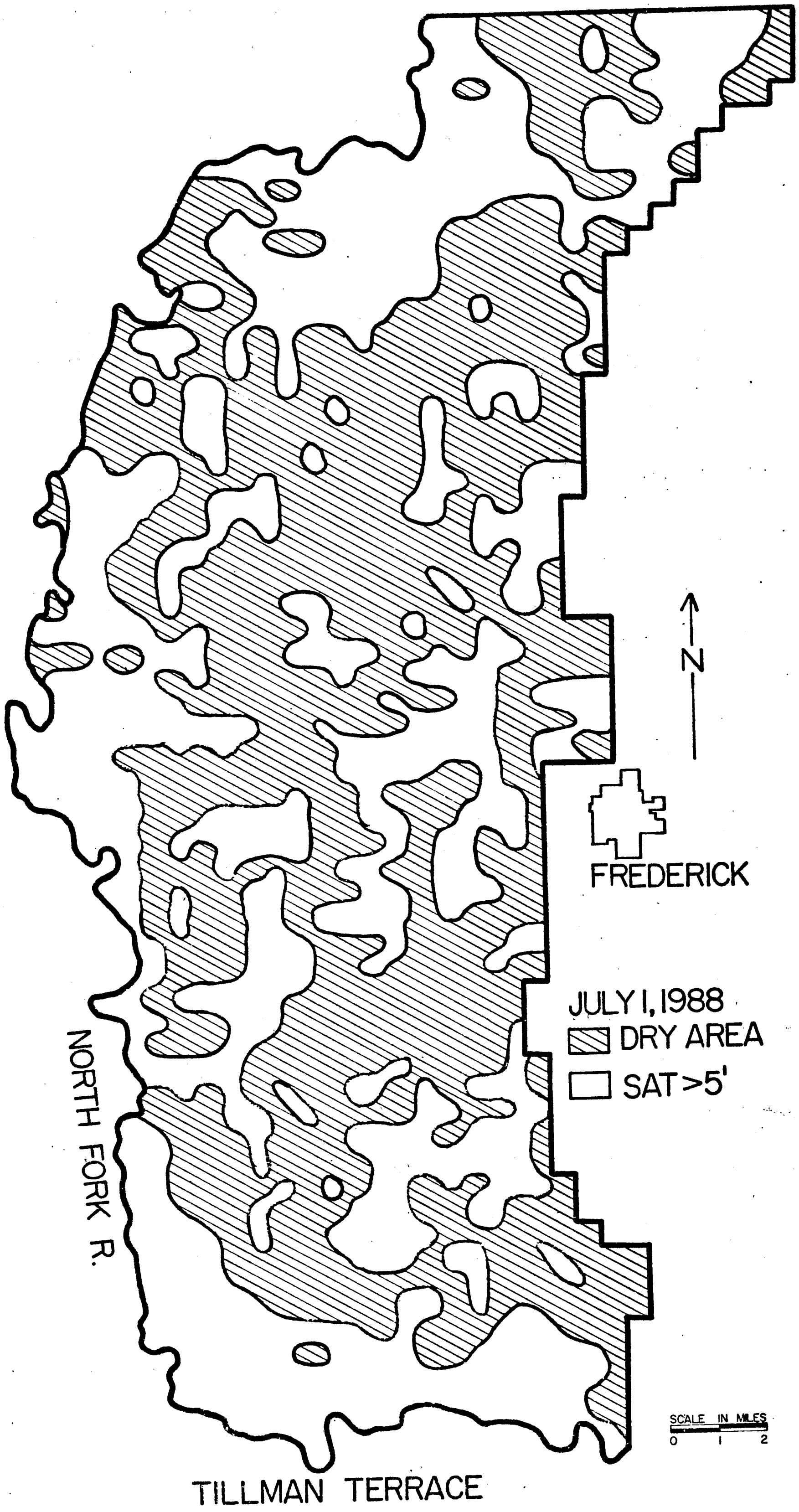


Figure 39. Dry areas in 1993

PRIOR RIGHTS + 1.00 Ac Ft/Ac/Yr
SATURATED THICKNESS

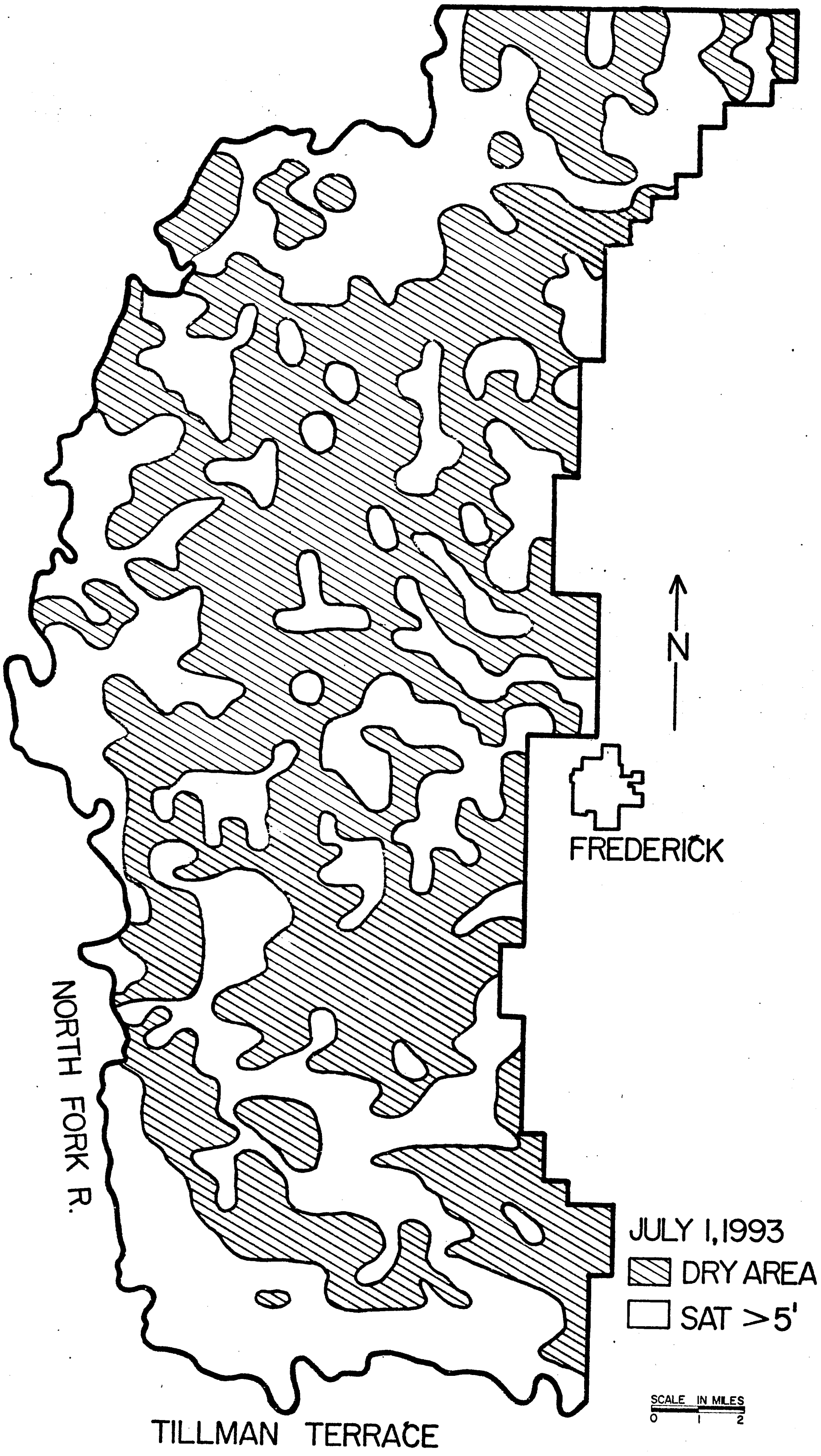
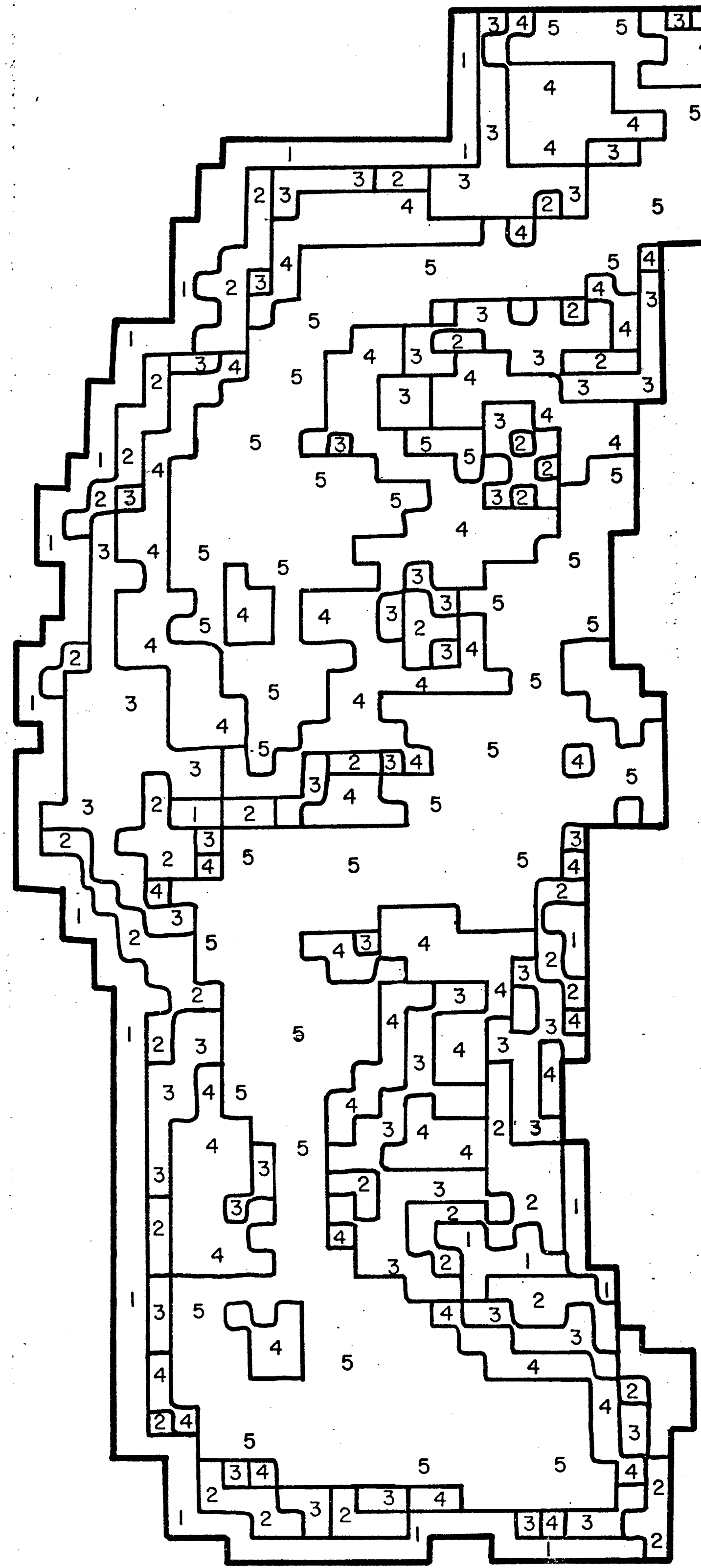


Figure 40. 1993 water depth from the surface



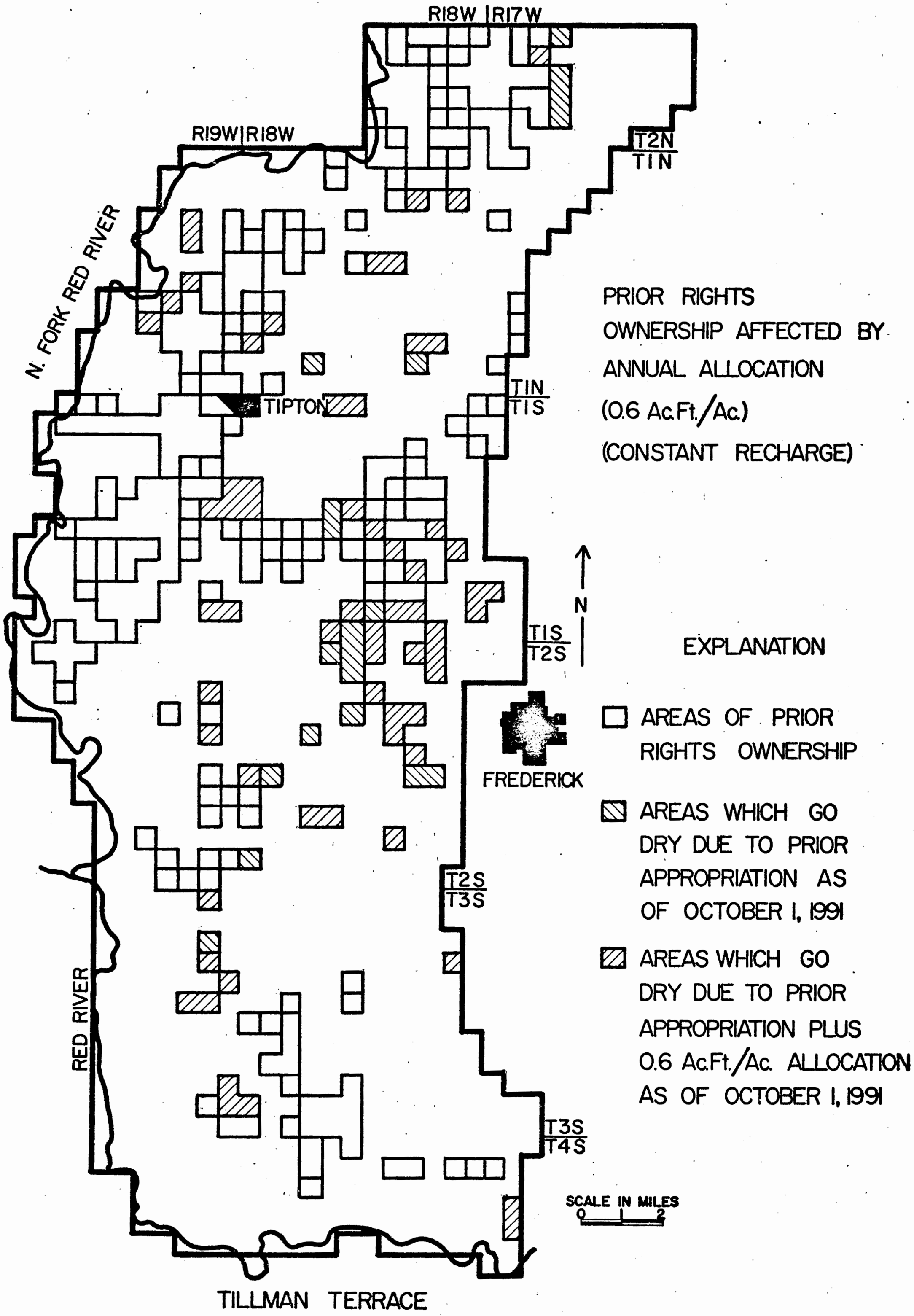
PRIOR APPROPRIATION AND ALLOCATION OF 1.00 ACRE FOOT

JULY 1, 1993 RESULTS

WATER DEPTH EXPLANATION

ZONE	DEPTH (Ft.)
5	>40'
4	31—40'
3	21—30'
2	11—20'
1	0—10'

Figure 41. Prior rights affected by annual allocation of 0.6 acre ft/acre (constant recharge)



PRIOR RIGHTS OWNERSHIP AFFECTED BY ANNUAL ALLOCATION (0.6 Ac.Ft./Ac.) (CONSTANT RECHARGE)

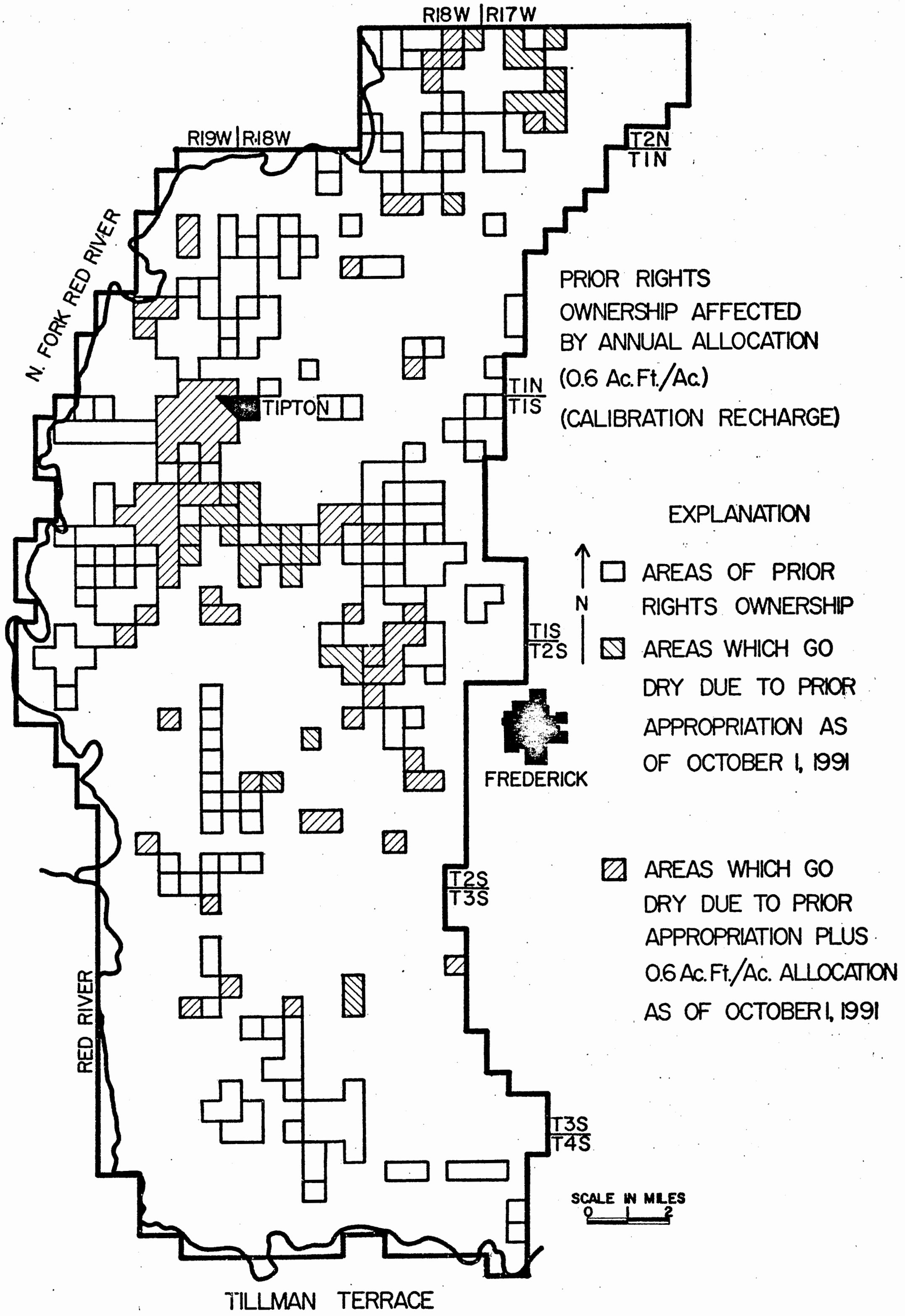
EXPLANATION

☐ AREAS OF PRIOR RIGHTS OWNERSHIP

▧ AREAS WHICH GO DRY DUE TO PRIOR APPROPRIATION AS OF OCTOBER 1, 1991

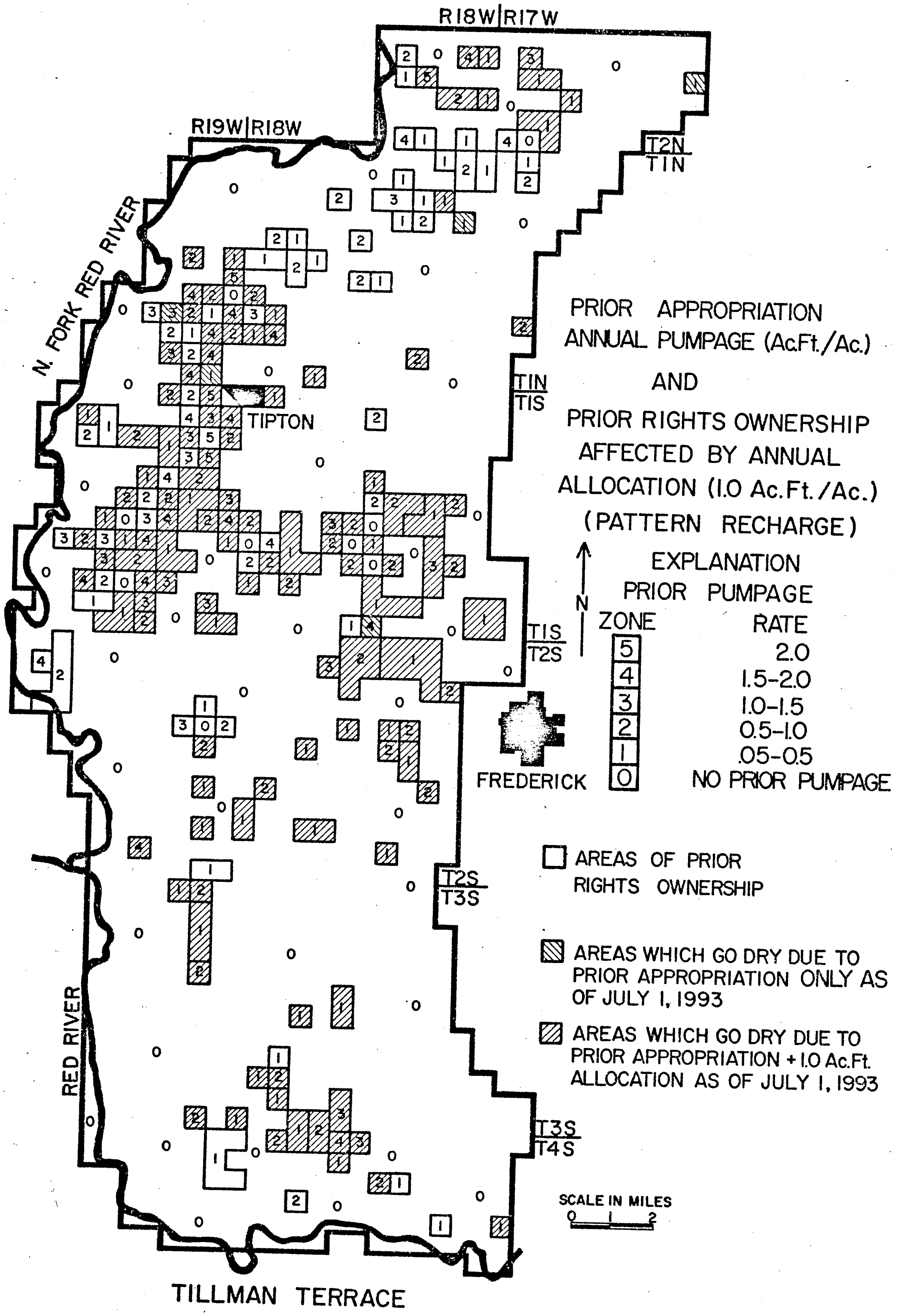
▨ AREAS WHICH GO DRY DUE TO PRIOR APPROPRIATION PLUS 0.6 Ac.Ft./Ac. ALLOCATION AS OF OCTOBER 1, 1991

Figure 42. Prior rights affected by annual allocation of 0.6 acre ft/acre (matrix recharge)



PRIOR RIGHTS OWNERSHIP AFFECTED BY ANNUAL ALLOCATION (0.6 Ac.Ft./Ac.) (CALIBRATION RECHARGE)

Figure 43. Prior rights affected by annual allocation of 1.0 acre ft/acre (pattern recharge)


R18W|R17W
R19W|R18W
T2N
T1N
T1N
T1S
T1S
T2S
T2S
T3S
T3S
T4S
N. FORK RED RIVER
RED RIVER
TIPTON
FREDERICK
TILLMAN TERRACE
PRIOR APPROPRIATION ANNUAL PUMPAGE (Ac.Ft./Ac.)
AND
PRIOR RIGHTS OWNERSHIP AFFECTED BY ANNUAL ALLOCATION (1.0 Ac.Ft./Ac.)
(PATTERN RECHARGE)
N
EXPLANATION
PRIOR PUMPAGE
ZONE
RATE
5 2.0
4 1.5-2.0
3 1.0-1.5
2 0.5-1.0
1 .05-0.5
0 NO PRIOR PUMPAGE
AREAS OF PRIOR RIGHTS OWNERSHIP
AREAS WHICH GO DRY DUE TO PRIOR APPROPRIATION ONLY AS OF JULY 1, 1993
AREAS WHICH GO DRY DUE TO PRIOR APPROPRIATION + 1.0 Ac.Ft. ALLOCATION AS OF JULY 1, 1993
SCALE IN MILES
0 1 2

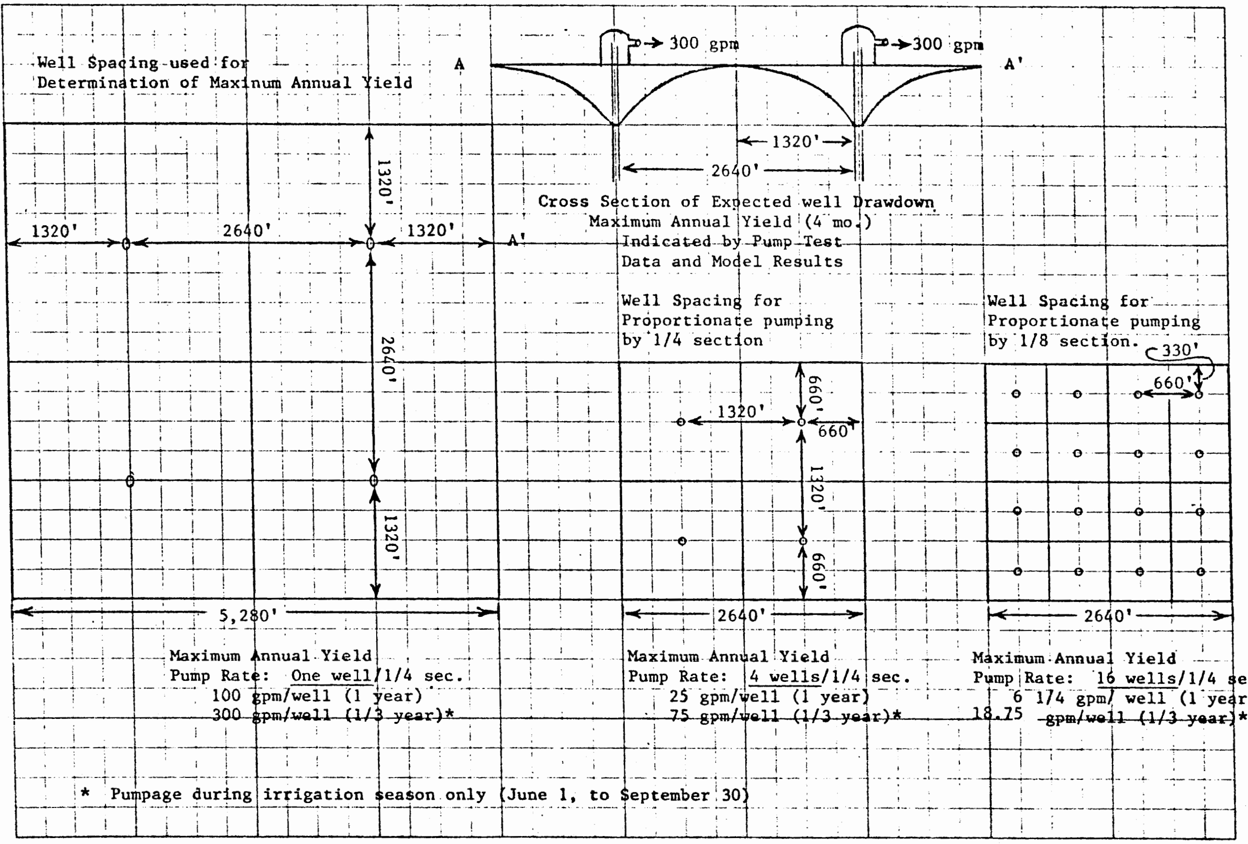
appropriative owners would go dry due to additional allocations. Approximately 31 percent, 33 percent and 69 percent of the prior appropriative owners would be adversely affected according to constant, matrix and pattern simulation runs, respectively.

A well spacing of one-half mile was determined using the pump test results and subsequent model simulation using the pattern recharge option. This is shown in Figure 44. A rate of one acre foot/acre/year was applied to a single well within each one-quarter section of a square mile (160 acres) and a 2,640 foot spacing between wells. The pump rate was equivalent to a continuous pumping of 100 gpm for one year or 300 gpm continuous pumping for four months during the irrigation season. Smaller spacings and pumping rates are recommended when more than one well is used in a single quarter section.

Simulated water-head elevations for 1973 and 1993 are shown in Figures 45 and 46. Comparison between 1969 head elevations and simulated head elevations indicate a significant decline in water level. Assessment of the predicted 1993 saturated thickness maps in Figure 33, and the water-head elevation maps, indicate that the possibility of pollution from high salt ($CaSO_4$) concentrations in the river exist within one and one-half miles of the North Fork of the Red River tributary and the Red River. This would result from an influent condition (gradient away from river) created by pumpage near the rivers where effluent conditions (gradient toward the river) currently exist.

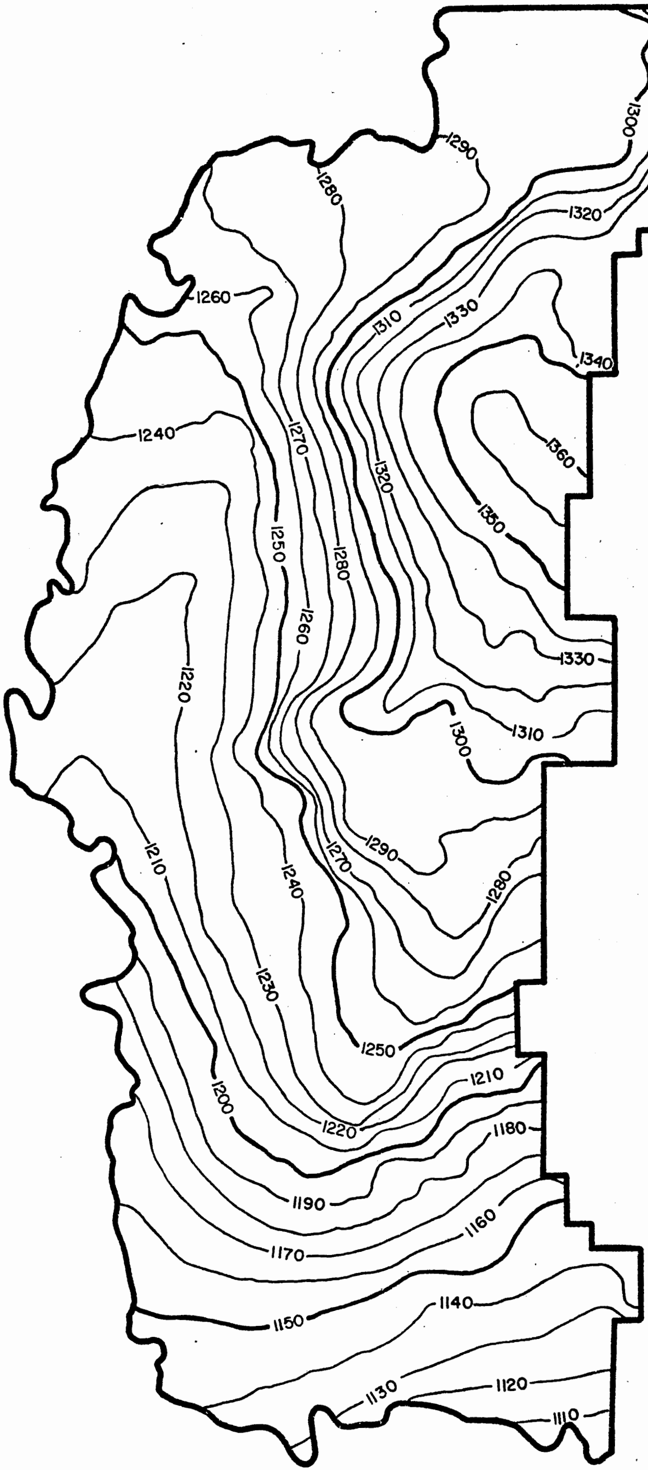
Figure 44. Recommended well spacing for maximum annual yield

RECOMMENDED WELL SPACING FOR MAXIMUM ANNUAL YIELD
TILLMAN TERRACE



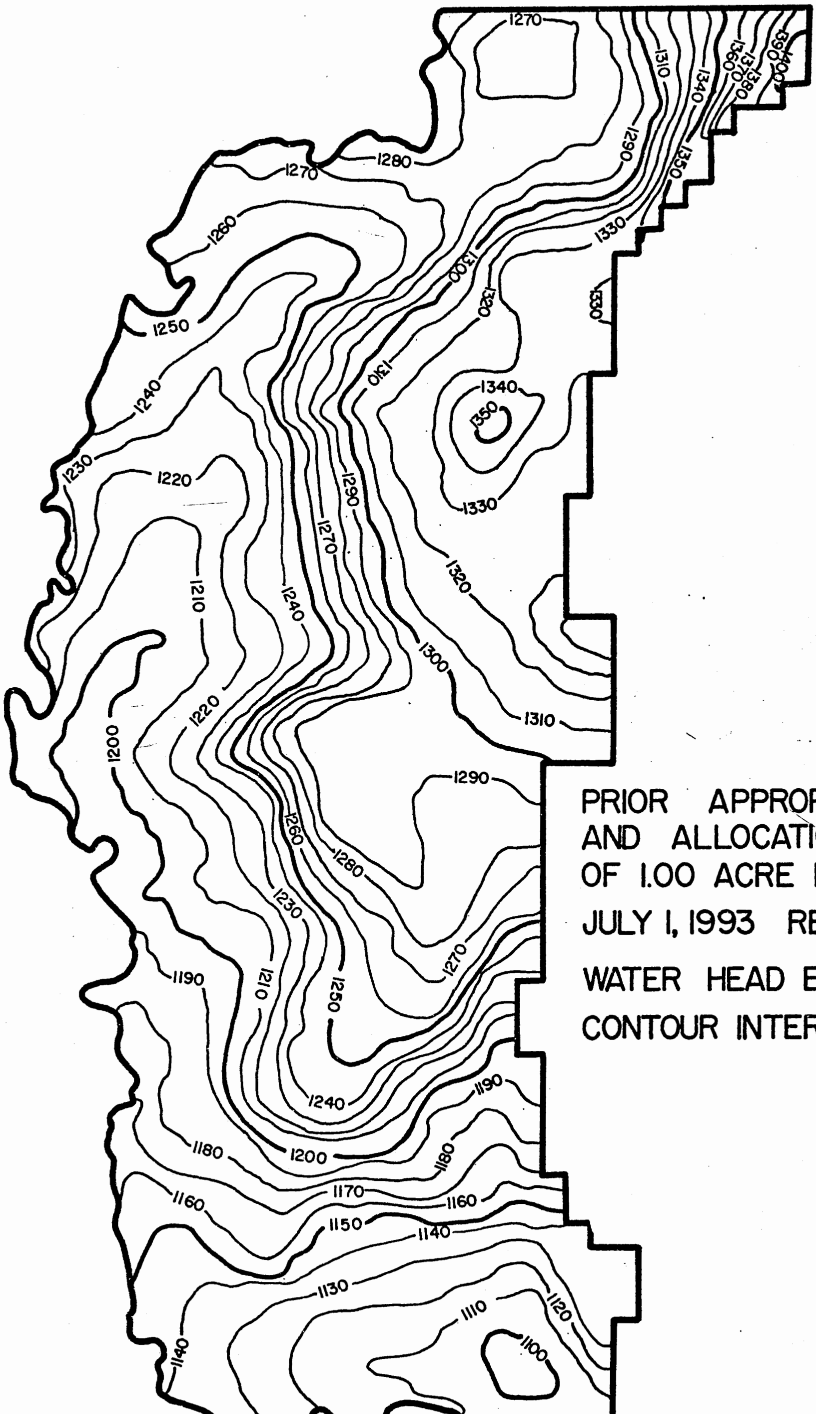
* Pumpage during irrigation season only (June 1, to September 30)

Figure 45. 1973 water-head elevations



JULY 1, 1973
WATER HEAD ELEVATION
CONTOUR INTERVAL = 10'

Figure 46. 1993 simulated water-head elevations (pattern recharge only)



PRIOR APPROPRIATION
AND ALLOCATION
OF 1.00 ACRE FOOT
JULY 1, 1993 RESULTS
WATER HEAD ELEVATION
CONTOUR INTERVALS = 10'

CHAPTER IV

SUMMARY AND CONCLUSIONS

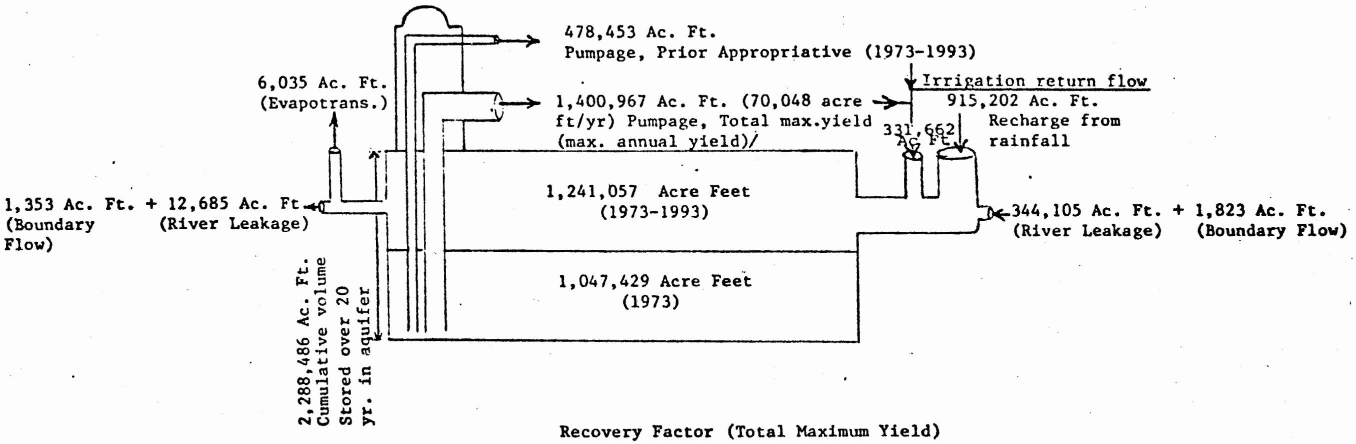
Computer simulation is an effective tool for determining the maximum annual yield for the ground-water basin (aquifer) in the western half of Tillman County. The prior appropriative right owners and those who are allocated one acre foot/acre/year between July 1, 1973, and July 1, 1993, can use a total rate of 70,048 acre feet per year. The mass balance is summarized in Figure 47. A total volume of 1,400,967 acre feet represents the cumulative amount of water pumped from storage at a discharge rate of one acre foot per acre during a 20-year period. A cumulative volume of 478,453 acre feet is pumped by the prior appropriative owners during the same period. A cumulative volume of 2,288,486 acre feet is stored over the 20-year period. A ground-water storage of approximately 1,047,429 acre feet is computed to have existed in 1973. The computations are shown in Table XI. An additional 1,241,057 acre feet was accumulated due to recharge, especially during the non-pumping periods (8 months per year), as well as to river leakage and boundary flow from the north edge of Tillman County. A recovery factor of 81 percent of cumulative aquifer storage is also computed in Figure 47. This percentage represents the amount of ground water pumped from cumulative ground-water storage as of July 1, 1993. The recommended well spacing and corresponding pump rates are shown in Figure 48.

The reliability of the output results of the model, however

Figure 47. Mass balance distribution and recovery factor for maximum annual yield (pattern recharge version)

MASS BALANCE DISTRIBUTION

TILLMAN TERRACE



Recovery Factor (Total Maximum Yield)

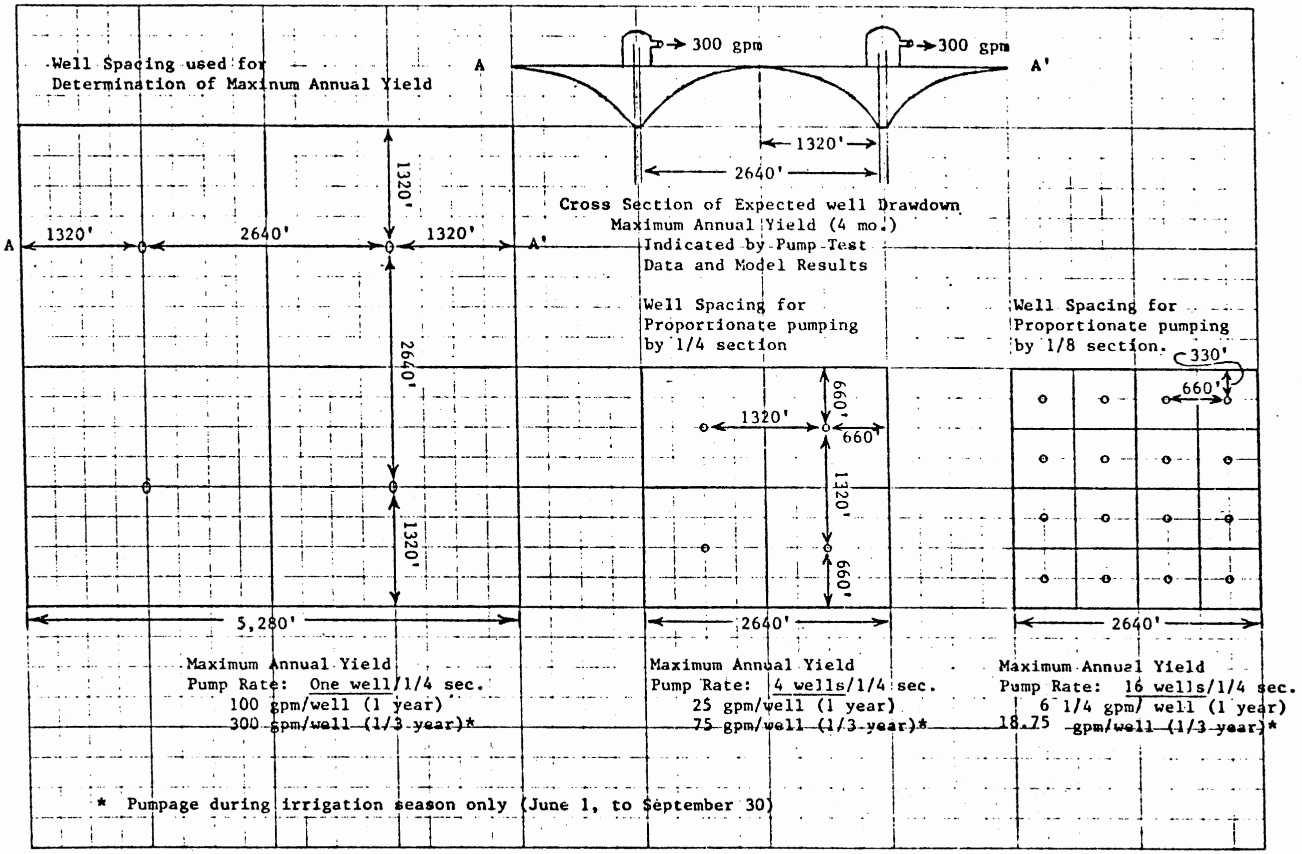
$\frac{1,400,967}{2,288,486} = 61.2\%$ of cumulative volume is pumped over 20 years at a rate of 1 acre ft/acre/yr. (Less Prior Appropriative)

Recovery Factor (Prior Appropriative Only)

$\frac{478,453}{2,288,486} = 20.9\%$ of cumulative volume is pumped over 20 years by prior appropriative owners.

Figure 48. Recommended well spacing for maximum annual yield

RECOMMENDED WELL SPACING FOR MAXIMUM ANNUAL YIELD
TILLMAN TERRACE



* Pumpage during irrigation season only (June 1, to September 30)

sophisticated, can only be as good as the data input upon which they are based. It is, therefore, essential in the modelling process to devote considerable care to the collection, interpretation and validation of these data.

In conclusion, the principal parameters from which the maximum yield was determined are:

(1) The total land area is 189,760 acres overlying the terrace and floodplain deposits in the aquifer (basin);

(2) The volume of water in storage in the aquifer as of July 1, 1973, is 1,047,429 acre feet; the cumulative volume of water in storage for 20 years is 2,570,399 acre feet;

(3) The estimated rate of natural recharge is 2.87 inches per year based on calibration results;

(4) The average specific yield for the basin is 0.30; and

(5) An average transmissivity (1973) is 13,230 gpd/ft.

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Wickersham, Ginia, 1976, Basic Data Report on Ground-Water Levels in Western Tillman County, Oklahoma, 1944-1975, Publ. 73.

APPENDIX

COMPUTER LISTING OF DATA INPUT FOR GROUND-WATER MODEL (PATTERN RECHARGE VERSION)

```
//GWMDL EXEC PGM=LOADER,
// PARM='SIZE=600K',REGION=600K
/*JOBPARM K=0 NO PAGING
/*JOBPARM F=9001,N=2                                                    1=N MRAPBOJ*/
//SYSLIB DD DISP=SHR,DSN=SYS1.FORTLIB
//SYSLOUT DD SYSOUT=A
//SYSLIN DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(GWMDL26)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(MNPROG26)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(DATAI26)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(COMPUT25)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(COEF25)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(CHECKI25)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(PRNTAI)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(BLDATA25)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(PLTXI)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(PLTEI)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(PLTTI)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(PLTAI)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(PLTUI)
// DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(PLTFI)
//FT06F001 DD SYSOUT=A
//FT08F001 DD SYSOUT=A,DCB=RECFM=UA
//FT51F001 DD SYSOUT=A,DCB=RECFM=UA
//FT52F001 DD SYSOUT=A,DCB=RECFM=UA
//FT60F001 DD SYSOUT=A,DCB=RECFM=UA
//FT90F001 DD DISP=SHR,
// DSN=OSU.ACT11236.AQUIFER1(PLTDF)
//FT22F001 DD DISP=OLD,                    INPUT DATA FILE FOR CONTINUATION
// DSN=TEMP.ACT11236.FILE1
//FT20F001 DD DISP=(NEW,CATLG),            OUTPUT DATA FILE
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=2480),
```

```
// UNIT=3350,VOL=SER=SYSRS2,
// SPACE=(TRK,(10,10),RLSE),
// DSN=TEMP.ACT11236.FILE2
//FT50F001 DD *
   90         30   30   10
TEXT           1   72
FILE TITLE - DESCRIBE RUN HERE
START                2
UNIT           4   22    1   52                              INPUT FILE
OPENR          2   20   20                                   READ HEADER
LIMITR               7                                       JUNE 1, 1973
READ          25   25                                        READ SAT
FUNCTION       5        25    5                              PHI = SAT + BOTTOM
FUNCTION       1    3   25    5                              STRT
UNIT           5             52 1.                           STD FILE OUTPUT
UNIT           5         1                                   PRINT OUTPUT LOG
OPENW          1   20    1
WRITE          4                                             ISUR(STRT)
WRITE          5                                             BOTTOM
WRITE          6                                             TOP
WRITE          7                                             LAND
WRITE          8                                             RIVER
WRITE         10                                             S
WRITE         11                                             SY
WRITE         12                                             PERM
WRITE         13                                             TRANS
WRITE         16                                             RATE(RIVER PERM)


WRITE         18                                             ORE (RECH)
WRITE         19                                             WELLD
FUNCTION      -5              5                              SAT
WRITE
BEGIN                                                        ADD WELLS HERE
PERIOD         8    8                                        1973, JUNE 1
STEPP          3    3                                        JULY 1
COMPARE       -2   21   19    4 0.      -1.        20000.    COPY WELLS(NOT CF)
COMPARE       -2   21   21   21 .55     0.         .55       NEW RATE IF < OLD
COMPARE       -1   21        12                              BLANK BORDER
```

```
COMPARE      -2   19   21     4 0.       -1.       20000.    REPLACE WELLS
COMPARE      -2   20   21     4 0.       -1.       20000.    REPLACE WELLS
WRITE        19                                              WELLD
END
BEGIN
PERIOD        8   48   40                                    1973, 1993
DEPTH         3
STEPP         0    0    3                                    EACH MONTH
FUNCTION     -5              5                               SAT
WRITE
STEPP         3    3                                         JULY 1 ONLY
WRITE        13                                              TRANS
END
BEGIN
PERIOD       18   38   10                                    1978, 1983, 1988
STEPP         3    3                                         JULY 1
FUNCTION     -5              5                               SAT
WRITE
WRITE        13                                              TRANS
END
BEGIN
DEPTH         2                                              END OF PERIOD
BEGIN
PERIOD        7   47   40                                    1973, 1993 JUNE 1
FUNCTION     -5              5                               SAT
WRITE
END
BEGIN
PERIOD       10        10                                    1974, 1979, 1984 ...
FUNCTION     -5              5                               SAT
WRITE
END
BEGIN
PERIOD       46   46                                         OCT 1, 1992
FUNCTION     -5              5                               SAT
WRITE
END
PERIOD       48                                              1993
CLOSE
STOP          1
END
EOD                3
//FT05F001 DD *
    1         1    8    2   50   51
TILLMAN TERRACE,1/4 SQUARE MILE GRID,REAL DATA,1977
```

```
TIME STEP = 10 DAYS
WATERTAB
LEAKAGE
CONVERT
EVAPOTRANSPIRATION
RECHARGE
CHECK
NO PUNCH
NUMERIC
HEAD
NO CONTO
    1
        99        63        36      9999         5      .005        1.        50
     1E-10        0. 1000.E-10        1.        1.        1.        0.


STRT               1         1         1         1
       .01       .01       .01       .01       .01       .01       .01       .01
       .01       .01       .01       .01       .01       .01       .01       .01
       .01       .01       .01       .01       .01       .01       .01       .01
       .01       .01       .01       .01       .01       .01       .01       .01
       .01       .01       .01       .01
       .01       .01       .01       .01       .01       .01       .01       .01




       .01       .01       .01       .01       .01       .01       .01       .01
       .01       .01       .01     21304     21304     21304     21304     21304
     21303     21302     21302     21302     21302     21302     21303     21304
     21304     21305     21307       .01
       .01       .01       .01       .01       .01       .01       .01       .01
       .01       .01       .01       .01       .01       .01       .01       .01
       .01       .01       .01      1302      1302      1302      1302      1302
      1301      1300      1300      1300      1300      1300      1301      1302
      1302      1303      1305       .01
       .01       .01       .01       .01       .01       .01       .01       .01
       .01       .01       .01       .01       .01       .01       .01       .01
       .01       .01       .01      1300      1300      1300      1300      1299
```

ETC.

```
S               2E-8                   1
PERM            1E-6         1         2          1        1
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
                                                                           0 226
 226 226 226 226 226 226 226 226 226 226 226 226 226 226 226   0
                                                                           0 129
 226 226 226 226 226 226 226 226 226 226 226 226 226 226 226   0
                                                                           0 129
 290 258 258 226 226 226 226 226 226 226 226 226 226 226 226   0
                                                                           0 516




 484 484 452 355 258 226 226 226 226 226 226 226 226 226 226   0
                                                                           0 839
 871 93510001000 774 484 258 226 226 226 226 226 226 226   0
                                                                           01161
11291258148416131290 968 613 419 226 226 226 226   0
                                       0167716771677161316131613161316131613
14841581203222581613129O 948 484 245 226 226   0
                                   018061806180618061806190319352065219422262258
2258225822902129177414521129 774 258 226 226   0
                                   016131613171017421774196820652161219422262258
2265226522581935158113231065 774 355 226   0
                               0129012901323135514521581164517421839187119031903
1935193518061645141911611000 774 387   0
                               0103210321032106511941226132314521516158115811581
154815291452129011611097 871 645   0
                               0103210321032103210321032112911481226125812581258
1194112910321000 903 806 645   0
                               010321032103210651032 935 871 839 903 935 871 806
 742 645 645 484 419 387 258   0
                       0151613551290 959 9291045 871 725 464 436 355 355 290 226
 194 226 452 484 290 290 323   0
                       01613161214841277 9811032 800 671 387 232 116 116 116 129
 129 226 452 484 484 516 581   0
                   0161316131612161214231162 903 813 790 852 774 645 465 552 552
 142 226 645 871 806 806 871   0
                   01613158114521452142312901129 96810611038 903 790 826 774 725
                                      ETC.
```

```
BOTTOM             1         1         1         1

                                                                            1270
127012701265126512651270127812921307131913291340135013681386
                                                                            1270
127012701265126512651265127512851305131513271340135713701390
                                                                            1270
127012651265126512651265127012801298131213251347135613781396
                                                                            1265
126512651265126512651265127012751292131013291345136813811400
                                                                            1265
12651265126512651265126512701275128913101333135513771390
                                                                            1270
126012651265126512701270127212781290131513421375
                                        1265126512651265126512651265126612651260
1260126512701270127012751275128012951320 1360
                                    12651265126312621265126212621263126312601258
1260127012701275127512771280128513051336 1377
                                    12631262125812581257125812601260126012521260
1260127012821285129012901290129913201352
                                1260126012601255125212531252125012481248125 01260
126912801290130713071307131013201335
                                125812581255125012471245124012401240124212501260
12701295131513201320132013251330
                                125612531251124712401235123012301238124712551270
1285131013251330133013231330
                                125412511250124212331225123012401250125712701285
1300130513251330133013281325
                        12461246124612461245123512301235125112601270128012951300
1310131213201330133013281325
                        12441244124112401235122512301235125512701285129513051310
1314132013201330133013261330
                    124112411238123712301220123012451244126812751292130313101315
1320132013201327133013301326
                    123912391238123412271219122912411255127112821301131113151317
133013351335133013301324
                    123812361235123312231218122812381265127512901310132013201320
133513501345134013301324
                1235123312301225122512221216121812301245126012801300131013201320
133513451345133513301322
            12331228122512171217121812201215121512201240125812751295131013201320
133013401336132513201320
```

ETC.

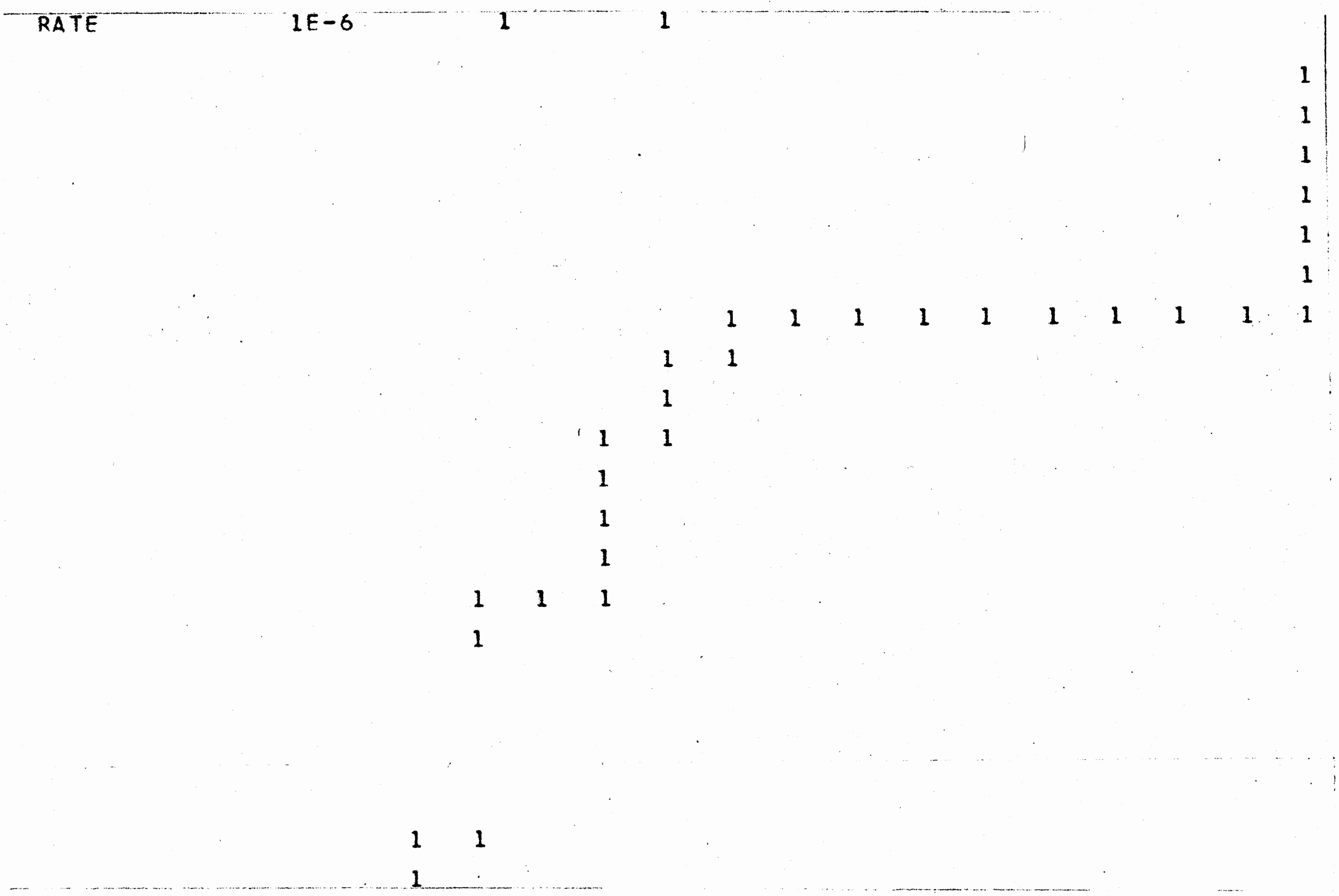
```
SY                 1         1         0

                                                                            .265
.265.265.265.265.265.265.265.265.265.265.265.265.265.265.265
                                                                            .245
.265.265.265.265.265.265.265.265.265.265.265.265.265.265.265
                                                                            .245
.275.270.270.265.265.265.265.265.265.265.265.265.265.265.265
                                                                            .290
.290.290.285.280.270.265.265.265.265.265.265.265.265.265.265
                                                                            .300
.305.305.305.305.300.290.270.265.265.265.265.265.265.265
                                                                            .305
.305.310.315.315.310.305.295.285.265.265.265.265
                                        .315.315.315.315.315.315.315.315.315.315
.315.315.320.320.315.310.305.290.270.265.265
                                    .320.320.320.320.320.320.320.320.320.320.320
.320.320.320.320.320.315.310.300.270.265.265
                                    .315.315.315.315.320.320.320.320.320.320.320
.320.320.320.320.315.310.305.300.280.265
                                .310.310.310.315.315.315.315.315.320.320.320.320
.320.320.320.315.315.310.305.300.280
                                .305.305.305.305.310.310.310.315.315.315.315.315
.315.315.315.310.310.305.300.295
                                .305.305.305.305.305.305.310.310.310.310.310.310
.310.310.305.305.305.300.295
                                .305.305.305.305.305.305.305.300.305.305.305.300
.300.295.295.290.285.280.270
                        .315.315.310.305.305.305.305.300.285.285.280.280.275.265
.260.265.285.290.275.275.275
                        .315.315.315.310.305.305.300.295.280.265.240.240.240.245
.245.265.285.290.290.290.295
                    .315.315.315.315.315.310.305.300.300.300.300.305.285.290.290
.250.265.305.305.300.300.305
                    .315.315.315.315.315.310.305.305.305.305.305.300.300.300.300
.290.260.305.305.310.310
                    .315.315.305.305.305.305.310.310.315.310.305.305.305.305.300
.290.245.290.305.310.315
                .315.315.310.305.305.300.300.300.315.315.315.305.305.305.305.300
.295.275.290.300.310.315
            .315.315.315.315.315.310.310.315.315.315.315.315.310.305.305.305.305
.305.295.290.300.310.310
            .315.320.320.320.320.320.315.320.315.315.310.310.305.305.300.300.305
.310.300.290.300.310.310
                                       ETC.
```

```
 TOP               1       1       1
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    1302    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    1300    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    1298    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    1295    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    1293    9999    9999    9999    9999



        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    1291    9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
        9999    9999    9999    9999
        9999    9999    9999    9999    9999    9999    9999    9999
                                ETC.
```



ETC.

```
RIVER                                  1         1
M                -1         0
LAND              1         1         1
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00  21310.00   1313.00   1317.00   1317.00   1317.00
   1317.00   1317.00   1317.00   1318.00   1320.00   1329.00   1339.00   1355.00
   1360.00   1378.00   1396.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00  21303.00   1312.00   1315.00   1315.00   1315.00
   1315.00   1315.00   1315.00   1318.00   1320.00   1330.00   1345.00   1355.00
   1367.00   1385.00   1420.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00  21301.00   1311.00   1311.00   1312.00   1313.00
   1315.00   1316.00   1318.00   1325.00   1335.00   1350.00   1360.00   1368.00
   1380.00   1390.00   1425.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00  21298.00   1310.00   1310.00   1310.00   1310.00
   1310.00   1312.00   1315.00   1320.00   1330.00   1332.00   1362.00   1375.00
   1395.00   1418.00   1425.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00  21296.00   1310.00   1310.00   1310.00   1310.00
   1310.00   1312.00   1320.00   1340.00   1340.00   1350.00   1360.00   1375.00
   1400.00   1420.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00  21294.00   1308.00   1308.00   1308.00   1308.00
   1310.00   1310.00   1315.00   1330.00   1345.00   1350.00   1365.00   1385.00
   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00  21275.00  21275.00  21275.00  21276.00  21278.00  21281.00
  21284.00  21286.00  21288.00  21291.00   1306.00   1306.00   1306.00   1306.00
   1306.00   1308.00   1325.00   1340.00   1360.00   1385.00   1400.00   9999.00
   9999.00   9999.00   9999.00   9999.00
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00  21275.00  21275.00   1280.00   1295.00   1298.00   1290.00   1292.00
```

ETC.

```
QRF              110E-10               1           0            1
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.     0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.     0.   0.   0.   0.
    1.   0.   0.   0.   0.   0.   0.   0.   1.   1.   1.   1.   1.   1.   1.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.     0.   0.   0.   0.
    1.   0.   0.   1.   0.   0.   1.   0.   1.   1.   1.   1.   1.   1.   1.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.     0.   0.   0.   0.
    1.   1.   1.   0.   0.   0.   1.   0.   0.   1.   1.   1.   1.   1.   1.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.     0.   0.   0.   0.
    1.   0.   1.   1.   0.   0.   0.   0.   1.   1.   1.   1.   1.   1.   1.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.     0.   0.   0.   0.
    1.   0.   1.   1.   0.   0.   1.   1.   0.   1.   1.   1.   1.   1.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.     0.   0.   0.   0.
    1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.     0.   0.   0.   0.
    1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   1.   1.   1.   1.   1.     1.   1.   1.   1.
    1.   1.   1.   1.   1.   0.   0.   0.   1.   1.   1.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   1.   1.   1.   1.   1.   1.     1.   1.   1.   1.
    1.   1.   1.   1.   0.   1.   1.   1.   1.   1.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   1.   1.   1.   0.   0.   1.     1.   1.   1.   0.
    0.   1.   1.   1.   0.   1.   1.   1.   1.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   1.   1.   1.   1.   1.   1.   1.     0.   1.   1.   0.
    0.   0.   1.   0.   1.   1.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   1.   1.   1.   1.   1.   0.   1.     1.   0.   0.   1.
    1.   1.   1.   1.   1.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   1.   1.   0.   1.   1.   0.   1.     0.   1.   1.   1.
    1.   1.   1.   1.   1.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   0.   0.   1.   1.   1.   0.   1.   0.   0.     1.   1.   1.   1.
    0.   0.   0.   0.   0.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   1.   1.   1.   1.   1.   0.   1.   1.   0.     0.   0.   0.   0.
    0.   0.   0.   0.   0.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   0.   1.   1.   1.   1.   1.   1.   0.   1.   0.     0.   0.   0.   1.
    0.   1.   1.   1.   1.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   1.   1.   1.   1.   1.   1.   0.   1.   1.   1.     1.   1.   1.   1.
    1.   1.   1.   1.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   1.   1.   1.   1.   1.   0.   0.   0.   1.   1.     1.   1.   1.   1.
    1.   1.   1.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   0.   1.   1.   1.   1.   1.   1.   0.   0.   0.   0.     1.   0.   1.   1.
    1.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   0.   1.   1.   1.   1.   1.   1.   0.   0.   0.   1.   0.     0.   1.   1.   1.
    1.   1.   1.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
    0.   0.   0.   0.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   0.     0.   1.   1.   1.
    1.   1.   1.   1.   1.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

                                   ETC,
```

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WELL      -.00357117         1         0         1              .0001
                                                                             145
 154 154 176 176 172 145 109  45.089.089.089.089.089.089.089
 150         303  31     179
  80 350                  43  40                          80
         160 100  50               27
                          60  51
 267  53      38     320      76                             320
          55  86  40      60
  80         160  40     110
                                                                     100     187
 188  70  66




  70  90      50
                                                          92  50         160
                                          92      75  25  25 140  59
                                                 634         120         160  54
                                         245 160     140
                                 176 200 100  70 250 174  30
                         142
                                     142  75 320 160  60 242
                             101
                                     170 150 300
      88                 106
```

ETC.

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DELX             2640
DELY             2640
WELL     1   0      0  240 9999    1. 240.     0    0   -1   -1          24
WELL     2   1      0  120 9999    1. 240.     0    1   -1   -1          12
WELL     3   2      0  240 9999    1. 240.     0    0   -1   -1          24
WELL     4   3      0  120 9999    1. 240.     0    1   -1   -1          12
WELL     5   4      0  240 9999    1. 240.     0    0   -1   -1          24
WELL     6   5      0  120 9999    1. 240.     0    1   -1   -1          12
WELL     7   6      0  240 9999    1. 240.     0    0   -1   -1          24
WELL     8   7      0  120 9999    1. 240.     0    1   -1   -1           3
WELL     9   8      0  240 9999    1. 240.     0    0   -1   -1          24
WELL    10   9      0  120 9999    1. 240.     0    1   -1   -1          99
WELL    11  10      0  240 9999    1. 240.     0    0   -1   -1
WELL    12  11      0  120 9999    1. 240.     0    1   -1   -1
WELL    13  12      0  240 9999    1. 240.     0    0   -1   -1
WELL    14  13      0  120 9999    1. 240.     0    1   -1   -1
WELL    15  14      0  240 9999    1. 240.     0    0   -1   -1
WELL    16  15      0  120 9999    1. 240.     0    1   -1   -1
WELL    17  16      0  240 9999    1. 240.     0    0   -1   -1
WELL    18  17      0  120 9999    1. 240.     0    1   -1   -1
WELL    19  18      0  240 9999    1. 240.     0    0   -1   -1
WELL    20  19      0  120 9999    1. 240.     0    1   -1   -1
WELL    21  20      0  240 9999    1. 240.     0    0   -1   -1
WELL    22  21      0  120 9999    1. 240.     0    1   -1   -1
WELL    23  22      0  240 9999    1. 240.     0    0   -1   -1
WELL    24  23      0  120 9999    1. 240.     0    1   -1   -1
WELL    25  24      0  240 9999    1. 240.     0    0   -1   -1
WELL    26  25      0  120 9999    1. 240.     0    1   -1   -1
WELL    27  26      0  240 9999    1. 240.     0    0   -1   -1
WELL    28  27      0  120 9999    1. 240.     0    1   -1   -1
WELL    29  28      0  240 9999    1. 240.     0    0   -1   -1
WELL    30  29      0  120 9999    1. 240.     0    1   -1   -1
WELL    31  30      0  240 9999    1. 240.     0    0   -1   -1
WELL    32  31      0  120 9999    1. 240.     0    1   -1   -1
WELL    33  32      0  240 9999    1. 240.     0    0   -1   -1
WELL    34  33      0  120 9999    1. 240.     0    1   -1   -1
WELL    35  34      0  240 9999    1. 240.     0    0   -1   -1
WELL    36  35      0  120 9999    1. 240.     0    1   -1   -1
WELL    37  36      0  240 9999    1. 240.     0    0   -1   -1
WELL    38  37      0  120 9999    1. 240.     0    1   -1   -1
WELL    39  38      0  240 9999    1. 240.     0    0   -1   -1
WELL    40  39      0  120 9999    1. 240.     0    1   -1   -1
WELL    41  40      0  240 9999    1. 240.     0    0   -1   -1
WELL    42  41      0  120 9999    1. 240.     0    1   -1   -1
```

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WELL     43    42     0  240 9999   1. 240.    0    0   -1    -1
WELL     44    43     0  120 9999   1. 240.    0    1   -1    -1
WELL     45    44     0  240 9999   1. 240.    0    0   -1    -1
WELL     46    45     0  120 9999   1. 240.    0    1   -1    -1
WELL     47    46     0  240 9999   1. 240.    0    0   -1    -1
WELL     48    47     0  120 9999   1. 240.    0    1   -1    -1         3
//
//
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END OF INPUT DATA

VITA 2

Abdulaziz Jasem Al-Sumait

Candidate for the Degree of

Master of Science

Thesis: A COMPUTER GROUND-WATER MODEL FOR THE TILLMAN ALLUVIUM IN TILLMAN COUNTY, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Kuwait, March 2, 1946, the son of Mr. Jasem Mohammad Al-Sumait.

Education: Graduated from Shuaikh Secondary School in June, 1964; received Bachelor of Science degree from Northern Arizona University, Flagstaff, Arizona, in May, 1970, with a major in Geology; completed requirements for the Master of Science degree at Oklahoma State University in December, 1978.

Professional Experience: Employed in the Ministry of Electricity and Ground-Water Department in Kuwait as a geologist between 1970 and 1972, and again from 1973 to 1975; attended six-month course in hydrology in Padova, Italy, from January, 1973, to June, 1973.