Evaluation of Aquifer Performance and Water Supply Capabilities of Alluvial and Terrace Deposits of the North Fork of the Red River in Beckham, Greer, Kiowa and Jackson Counties, Oklahoma

By

Douglas C. Kent

OKLAHOMA STATE UNIVERSITY

Final Report

To

The Oklahoma Water Resources Board

October, 1980

EVALUATION OF AQUIFER PERFORMANCE AND WATER SUPPLY CAPABILITIES OF ALLUVIAL AND TERRACE DEPOSITS OF THE NORTH FORK OF THE RED RIVER IN BECKHAM, GREER, KIOWA AND JACKSON COUNTIES, OKLAHOMA

FINAL REPORT

Submitted
To

THE OKLAHOMA WATER RESOURCES BOARD

By
Douglas C. Kent
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Oklahoma State University

October, 1980

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

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ACKNOWLEDGMENTS

The cooperation and assistance of the personnel of the Oklahoma Water Resources Board is gratefully acknowledged.

Project Title: Evaluation of Aquifer Performance and Water Supply Capabilities of Alluvial and Terrace Deposits of the North Fork of the Red River in Beckham, Greer, Kiowa and Jackson Counties, Oklahoma

Principal Investigator: Douglas C. Kent, Professor, Department of Geology, Oklahoma State University

Institution Funded: Oklahoma State University

Summary: The objective of this research was to determine the maximum annual yield of fresh water that can be produced from the alluvium and terrace deposits of the North Fork of the Red River in Beckham, Greer, Kiowa and Jackson Counties, Oklahoma. The determination of maximum annual yield was based on criteria established by Oklahoma ground-water law (82 Oklahoma Statutes Supp. 1973, Paragraph 1020.1 et seq) using computer simulation of all prior appropriative and subsequent allocated pumping for twenty years (July 1, 1973 to July 1, 1993).

The total reach was subdivided into three subareas: Northern, Central and Southern sections. The combined maximum annual yield is 168,000 acre-feet proportioned as 0.92 acre-feet per acre over the combined area. This was based on the following parameters: (1) the total land area overlying the alluvium and terrace deposits in the main reaches of the North Fork is 343,000 acres (excluding surface water), (2) the amount of water in storage in the basin as of July 1, 1973 is 2,659,000 acre-feet based on criteria established by Oklahoma ground-water law (82 Oklahoma Statutes Supp. 1973, Paragraph 1020.1 et seq), (3) the potential amount of water in storage plus return flow over the twenty-year life of the basin is 4,137,000

acre-feet, (4) the estimated rate of net recharge from rainfall is 2.28 inches per year and the assumed irrigation return flow rate is 25 percent, and (5) the average initial transmissivity is 19,000 gallons per day per foot and average specific yield of the alluvium is 0.25. In addition, the predicted water table of July 1, 1993 indicates that the possibility of natural pollution within the alluvium is negligible along the main reach of the Red River and generally non-existent in other parts of the basin.

INTRODUCTION

The objective of the study was to determine the maximum annual yield of fresh water that can be produced from the alluvium and terrace deposits of the North Fork of the Red River in Beckham, Greer, Kiowa and Jackson Counties. Under 82 Oklahoma Statute Sections 1020.4 and 1020.5, enacted by the Oklahoma Legislature, the Oklahoma Water Resources Board is responsible for completing hydrologic surveys of each fresh ground-water basin or subbasin with 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.

The maximum annual yield of each fresh ground-water basin or sub-basin is based upon a minimum basin or subbasin life of 20 years from the effective date of the ground-water law (July 1, 1973). An annual allocation, in terms of acre-feet, is determined based on the maximum annual yield and is restricted to the aquifer area.

Previous Investigations

Portions of the North Fork alluvial and terrace deposits were mapped and briefly described in early studies of the bedrock geology of south-western Oklahoma (Gould, 1905, 1926; Sawyer, 1924; Gouin, 1927; Clifton, 1928). More detailed mapping of the alluvial deposits was undertaken by later investigators (Scott and Ham, 1957; Merritt, 1958; Murphey, 1958; Meinert, 1961; Johnson, 1963, 1969; Smith, 1964).

The first comprehensive study of the alluvial deposits of the North Fork basin was undertaken in 1951 by the US Geological Survey in cooperation with the Oklahoma Water Resources Board. In that year, the US Geological Survey initiated an exploratory drilling program in central Beckham County to determine the character of the alluvial sediments and to make an estimate of the total amount of water available from these deposits. In that same year, Shell Oil Company drilled a series of exploratory wells in the alluvium to find a reliable ground-water source for their refinery in eastern Beckham County. A report based on the results of these drilling programs plus an inventory of domestic and irrigation wells was published by the Oklahoma Water Resources Board (Burton, 1965). The report includes bedrock, water table elevation, and saturated thickness maps based on all available well data. The Oklahoma Water Resources Board also completed ground-water studies of Elk and Otter Creek Basins, which are tributaries of the North Fork (Hollowell, 1965).

A summary of the geology, soils, ground-and-surface-water availability and quality, as well as present and projected future water needs, was published by the Oklahoma Water Resources Board in "Appraisal of the Water and Related Land Resources of Oklahom, Region One" (1976). The Oklahoma Highway Department summarized the engineering properties of the soils, alluvial materials, and bedrock of southwestern Oklahoma (Oklahoma Highway Dept., 1969). The most up-to-date summary of the geology and water resources of southwestern Oklahoma was completed for the Clinton Quadrangle in 1976 (Carr and Bergman, 1976) and for the Lawton Quadrangle in 1977 (Havens, 1977) by the Oklahoma Geological Survey in cooperation with the US Geological Survey.

The present study consists of data processing for and calibration of an existing mathematical model to predict changes in the potentiometric head (water table) due to pumping. A finite-difference model (Trescott and Pinder, 1976) was used to simulate those changes in the North Fork alluvial aquifer. The model used in this study evolved from Pinder's original model (1970) which was designed to simulate changes in potentiometric head for two-dimensional aquifer problems, and from modifications made by Pinder (1969) and Trescott (1973). Further modifications and addition of a Print/Plot option (Witz, 1978) allow data and results to be selectively stored, and printed in map form.

In the present study, aquifer coefficients of permeability and specific yield are assigned to layered sediments described on drillers logs. This approach, based on work in the Washita River alluvium (Kent et al., 1973), was used successfully in a computer model simulation of the Tillman Terrace alluvium (Kent and Naney, 1978; Al-Sumait, 1978). A sensitivity analysis of the vertical variability of these aquifer properties, using a similar digital model, was completed by Loo (1972) and DeVries and Kent (1973).

Description of the Area

Location

The study is located in the southwestern Oklahoma counties of Beckham, Greer, Kiowa, and Jackson. It includes parts of T2N through T11N and R17W through R26W (Figure 1). It is bounded to the west by the Texas border and to the south by Tillman County, Oklahoma. The aquifer extends over an area of approximately 536 square miles.

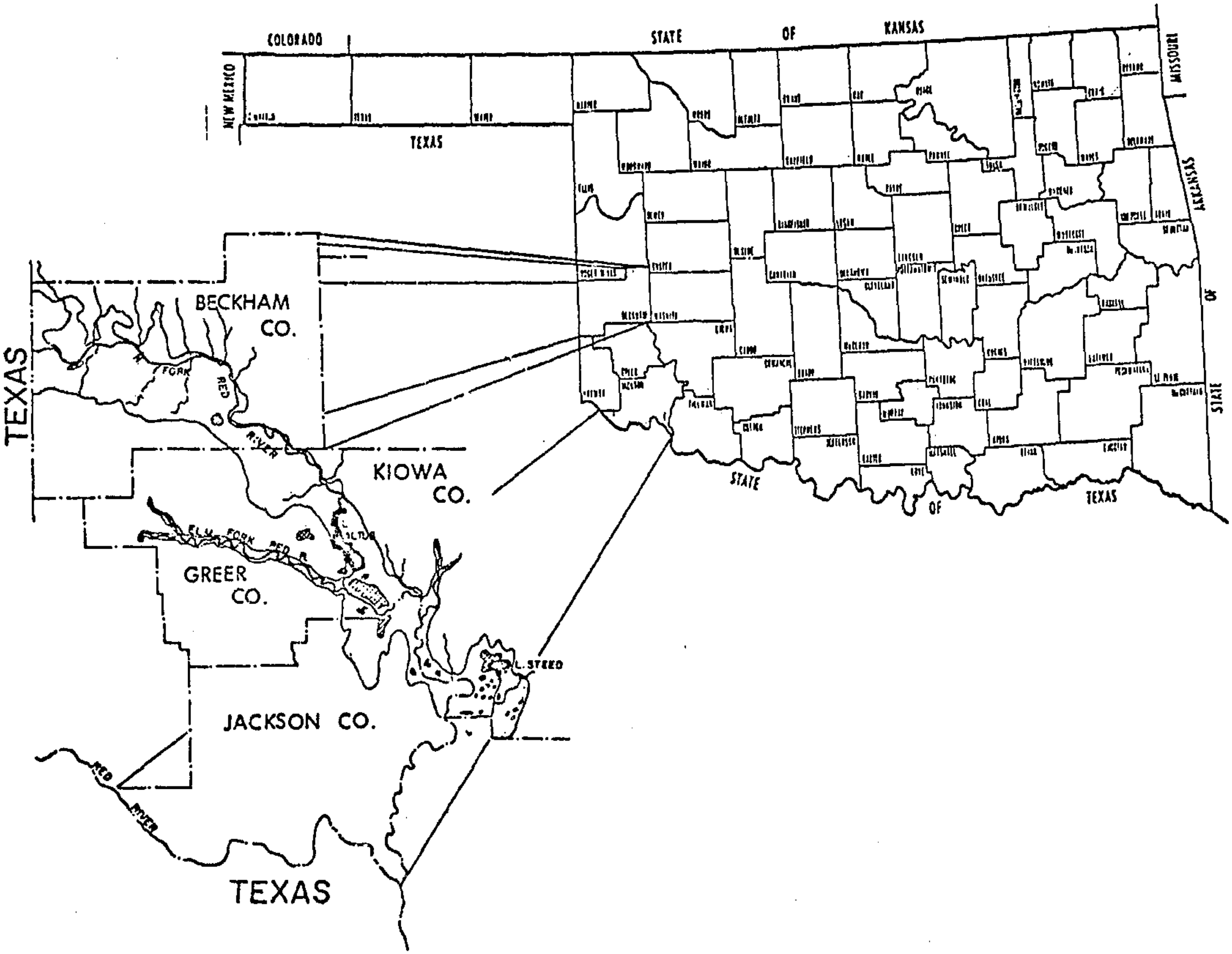

STATE OF KANSAS
COLORADO
NEW MEXICO
TEXAS
MISSOURI
ARKANSAS
STATE OF TEXAS
TEXAS
BECKHAM CO.
KIOWA CO.
GREER CO.
JACKSON CO.
L. STEED
TEXAS
RED RIVER

Figure 1

Climate

The area is characterized by a semi-arid climate. The average annual temperature at Lake Altus Dam is 63° F. Prevailing winds are from the southeast at 1 to 12 m.p.h.

The average annual precipitation is shown for several stations in Table 1. Annual and monthly precipitation amounts are also shown in Figures 2 and 3 for the period 1951-1978 at Sayre, Oklahoma. The average annual precipitation recorded at Sayre is 22.78 inches (Figure 2) in comparison to the overall average of 24.28 inches for all stations in the area (Table 1). The highest precipitation occurs in May and the lowest in January.

TABLE 1

WEIGHTED AVERAGE PRECIPITATION

Station	Average Precipitation	Area	Percentage of Area	Weighted Average
Shamrock	22.75 in/yr	42 mi^2	6.7%	1.52 in/yr
Erick	24.35	120	19.0	4.64
Sayre	22.78	91	14.4	3.2
Moravia	25.02	99	15.7	3.93
Mangum	25.27	19	3.0	0.76
Altus Dam	23.81	130	20.6	4.91
Altus	24.68	29	4.6	1.14
Roosevelt	26.12	19	3.0	0.79
Snyder	26.37	81	12.9	3.39
		630 mi^2	99.9%	24.28 in/yr

ANNUAL PRECIPITATION AT SAYRE, OKLAHOMA 1951-1978

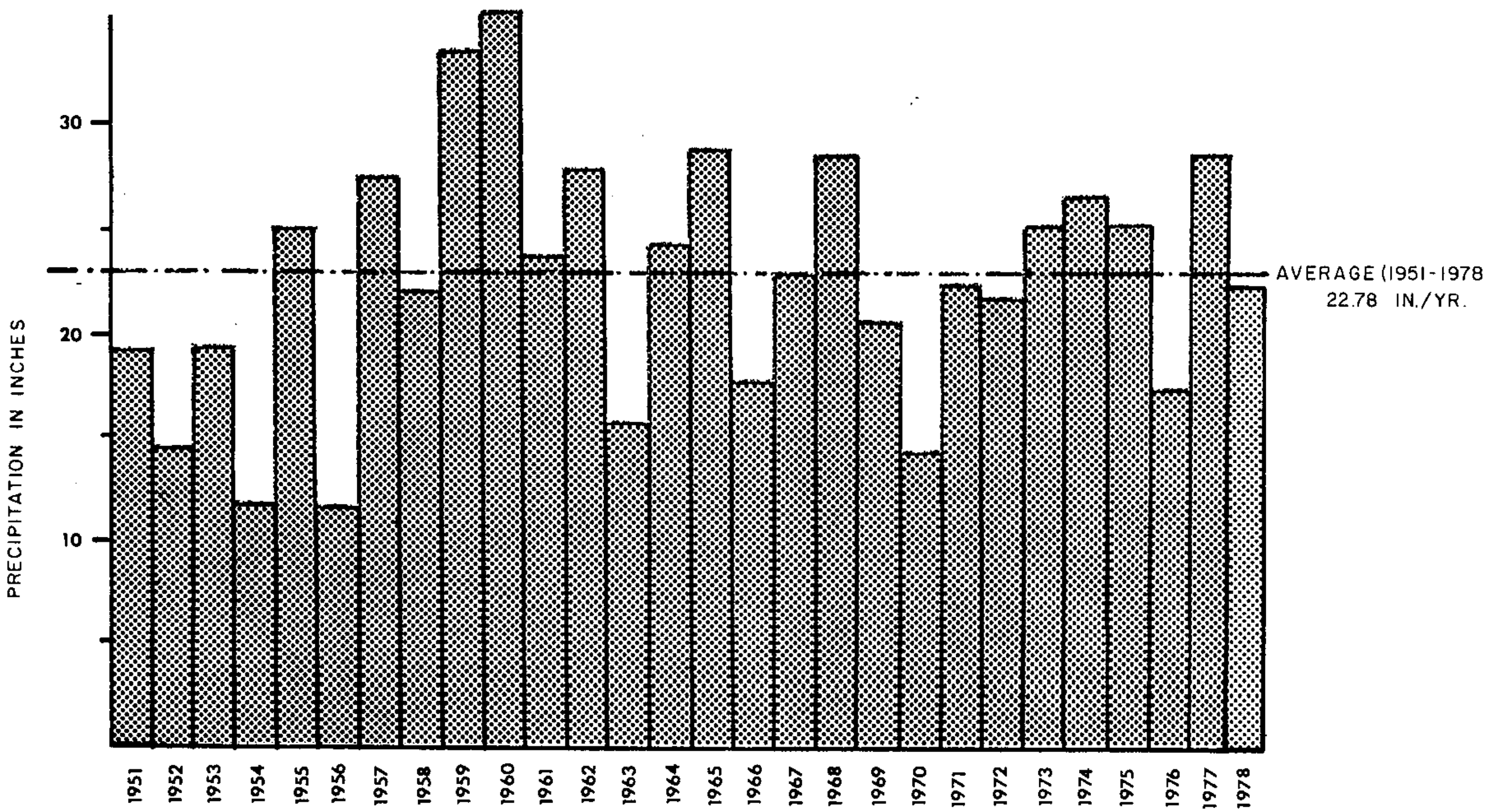


Figure 2

MONTHLY PRECIPITATION AT SAYRE, OKLAHOMA 1951-1978

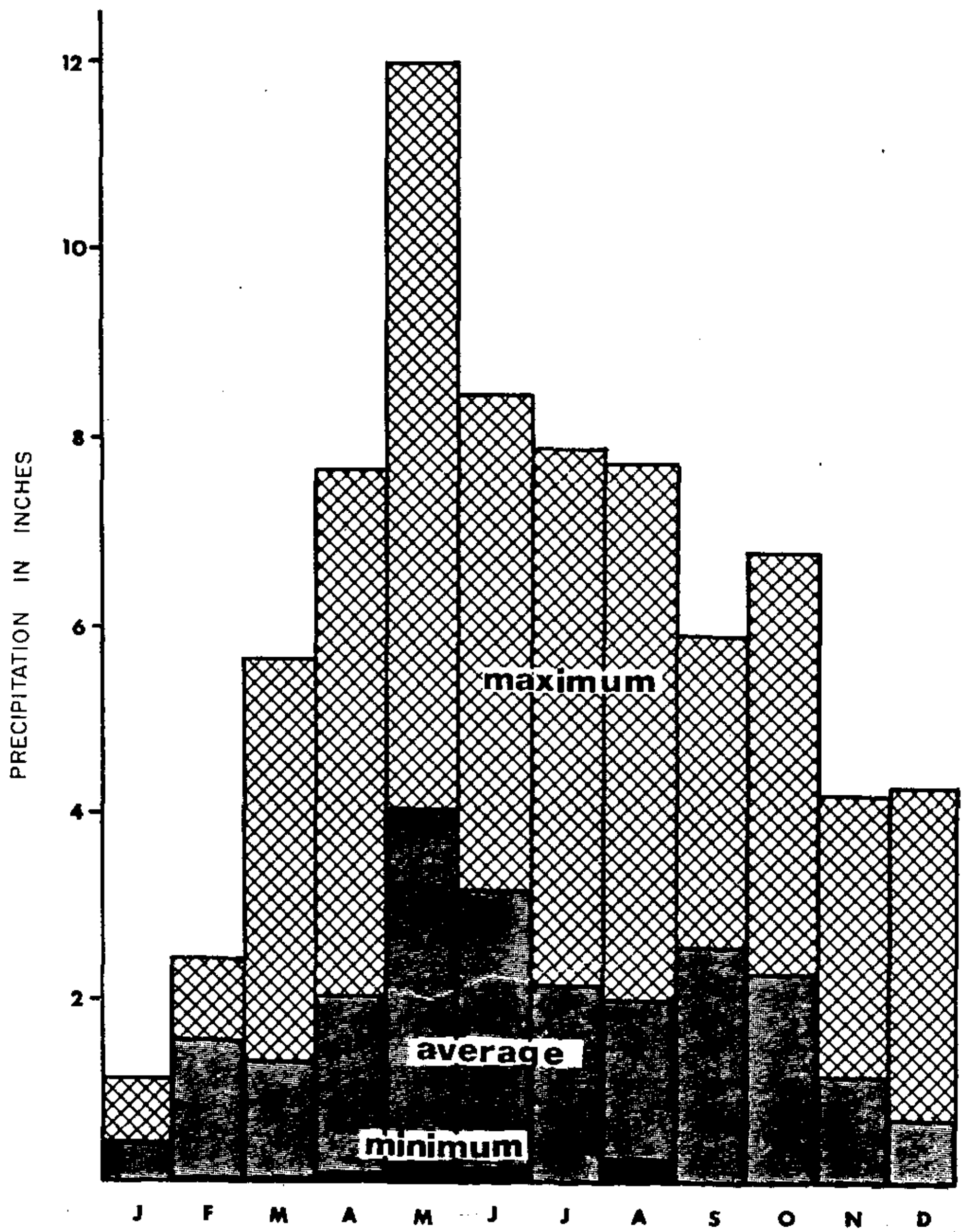


Figure 3

Geology

The rocks exposed within the study area range in age from Pre-cambrian to Quaternary (Figure 4). The oldest rocks found are the gabbros and granites associated with the Wichita Mountains which were apparently uplifted during Pennsylvanian time. These rocks are exposed as isolated barren hills ranging in height from a few feet to over a thousand feet above the surrounding plain. These units are highly fractured and, although springs are common at the intersection of joints, the total yield of water from these units is small.

Following the Wichita Uplift and removal of overlying early and middle Paleozoic units by erosion, formations were laid down during Permian time in a shallow sea which apparently advanced from the southwest. The oldest sediments found within the study are form the Wichita Formation. This formation consists of an Arkosis conglomerate (Post Oak Subunit) derived from the Pre-Cambrian outcrops and is usually found within six miles of these exposures. This unit grades into a red-brown shale containing deposits of salt, gypsum, anhydrite, and some dolomite. Exposures of the Wichita Formation are found in the south-eastern portion of the study area.

Overlying the Wichita Formation is the Hennessey Formation which is characterized by reddish-brown argillaceous shales and siltstones. This unit outcrops extensively over large portions of the southern part of the study area. The Hennessey Formation does not yield significant amounts of water although low to moderate yields can be obtained locally from isolated sandstone lenses.

The Flowerpot Formation overlies the Hennessey Formation and consists of a sandstone and a shale unit. The Duncan Sandstone subunit consists of

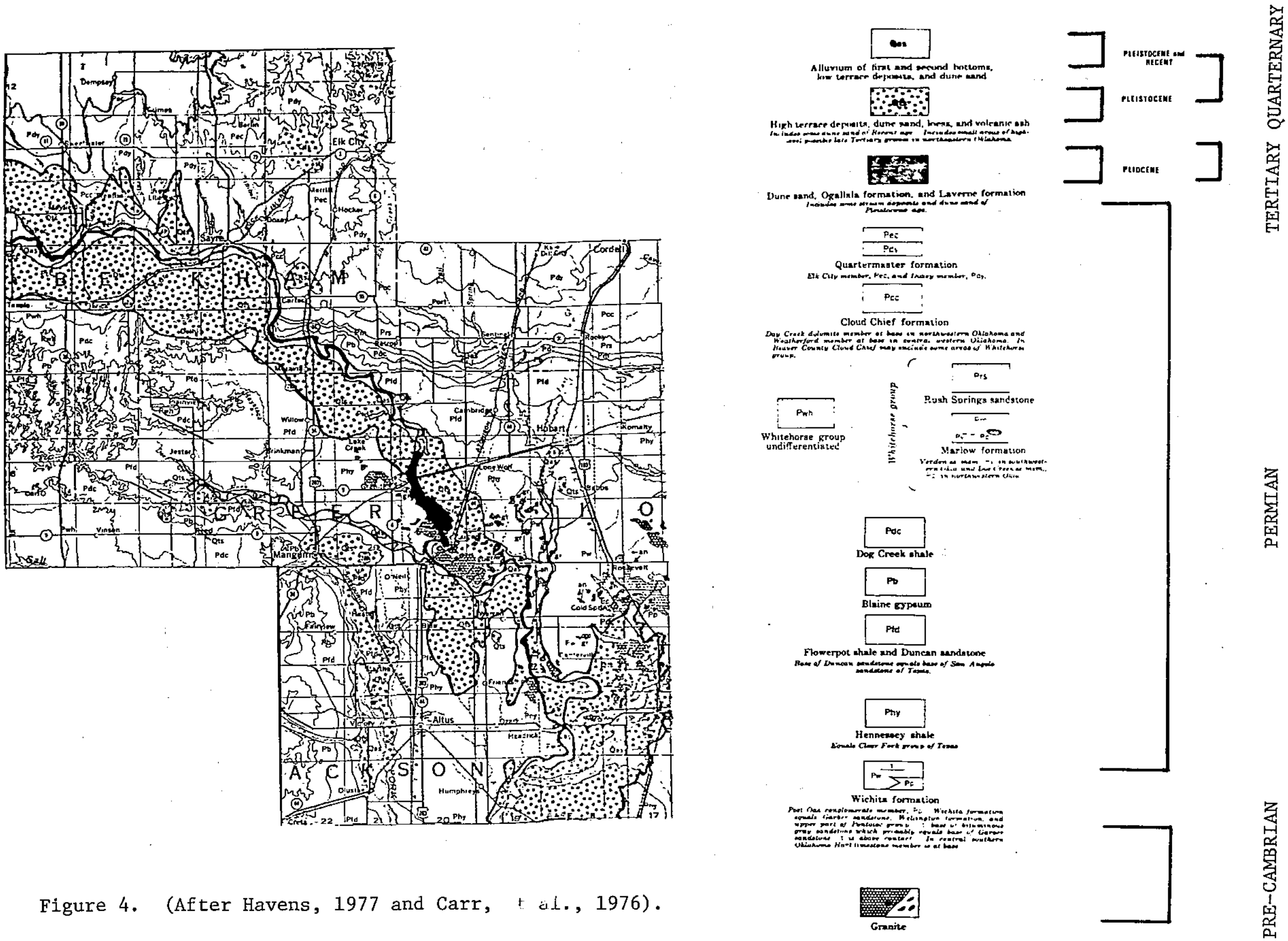


Figure 4. (After Havens, 1977 and Carr, et al., 1976).

a very fine-grained, silty lenticular sandstone interbedded with thick reddish-brown shales, which form the other subunit of the Flowerpot Formation. The shales increase in thickness westward and the sandstone pinches out near the center of the study area.

The Shale Subunit consists predominately of reddish-brown shale with minor amounts of thin, interbedded, greenish-gray shale, siltstone, gypsum, and dolomite and some large deposits of salt. The Flowerpot Formation outcrops in southern Beckham and northern Greer Counties. While some springs occur in these units along the Elm Fork of the Red River, the ground-water contribution from these units is small and of poor quality.

Overlying the Flowerpot Formation is the Blaine Formation. The Blaine Formation consists of cyclic shale and gypsum beds averaging 140 to 200 feet in thickness. Outcrops are found in southern Beckham and northern Greet Counties. This formation serves locally as an aquifer where solution channels in the gypsum beds are encountered. Only moderate groundwater yields of somewhat highly mineralized water are produced.

The Dog Creek Formation overlies the Blaine Formation and consists of salty, red-brown shales and some thin dolomites and gypsum. The Dog Creek Formation locally yields minor amounts of fair to poor quality water.

Upper Permain rocks occur predominately in the northern part of the project area. The Whitehorse Group consists primarily of a soft, reddish-orange, massive, locally crossbedded, very fine-grained to silty sandstone containing a few thin shales and gypsum layers. The group outcrops in southern Beckham County. Eastward from Beckham County, the strata of the Whitehorse Group can be distiguished as the Rush Springs and Marlow formations which are mapped separately throughout the rest of the Anadarko

Basin. The Rush Springs Sandstone is a good aquifer supplying moderate to large quantities of good quality water to wells. The Rush Springs Sandstone, however, probably makes only a minor contribution to the ground-water budget of the North Fork alluvial aquifer due to limited hydraulic continuity with that system.

The Rush Springs is overlain by the Cloud Chief Formation. The Cloud Chief is an orange-brown shale and siltstones containing some sandstone, dolomite and gypsum. Thicknesses of the formation are highly variable.

The division between the Cloud Chief Formation and the overlying Doxey Member of the Quartermaster Formation is defined primarily on the basis of color change. The Doxey is a red-brown, highly impermeable shale and siltstone. Both of these units outcrop extensively north of the study area.

The Elk City Sandstone, which is the youngest Permain formation in Oklahoma, outcrops north of the study area. It is a fine-grained, orange-brown sandstone which serves as a good acquifer but has no known hydraulic continuity with the North Fork alluvial aquifer.

The Pliocene Ogallala formation outcrops in the northwestern corner of the study area. This formation is a partially indurated yellow-brown, fine-to-medium-grained quartz sand. The Ogallala is generally a very good aquifer but is believed to make only a small contribution to the North Fork water budget because it is relatively thin in this area and has limited hydraulic contact with the North Fork aquifer.

The Quaternary deposits found in the study area consist of alluvial and eolian sands associated with the North Fork of the Red River. These deposits consist of discontinuous layers of sand, silt, clay, and gravel derived from the Permian and Pre-Cambrian bedrock through which the river cuts. These sediments range from well to poorly sorted.

gently sloping generally toward the river. At some locations, particularly in the northern part of the area, several alluvial terrace levels may be observed but are partially obscured by wind blown sand. Elevations of these terraces range from approximately 1322 to 2200 feet above sea level with a maximum height of approximately 100 feet above the river bed. Test drilling indicates that the thickness of the alluvial deposits averages 40 feet and attains a maximum thickness exceeding 150 feet.

GROUND WATER

Simulation Procedure

A finite difference model developed by Trescott and Pinder has been used to satisfy the requirements of Oklahoma ground-water law. Initial ground-water levels, pumping rate, and transmissivity are primary variables used in the model of the aquifer. The model output consists of a mass balance and estimated volume of ground water in storage, as well as maps of predicted ground-water table elevations and saturated thicknesses at 5-year intervals throughout the 20-year minimum basin life. The total aquifer area is 536 square miles. Due to the areal extent and diversity of geologic features, the aquifer was subdivided into three subbasins referred to as the Northern, Central, and Southern sections as shown in Figure 5. The areal extent of the subbasins are: Northern, 252 square miles; Central, 165 square miles; and Southern, 119 square miles.

The model was applied to each of the subbasins. The approach used is shown by the flow diagram in Figure 6. The input data were divided into matrix and constant parameters (Figure 6). The matrix parameters include: water-table elevations; land, top, and bedrock elevations; river bed thickness and hydraulic conductivity; well pumping rate and recharge rate. These matrix parameters were collected for the study area, and mapped, contoured and digitized over each of the subareas. A grid spacing of one-half mile was used to establish a matrix. The storage coefficient of the river bed is a constant parameter and the

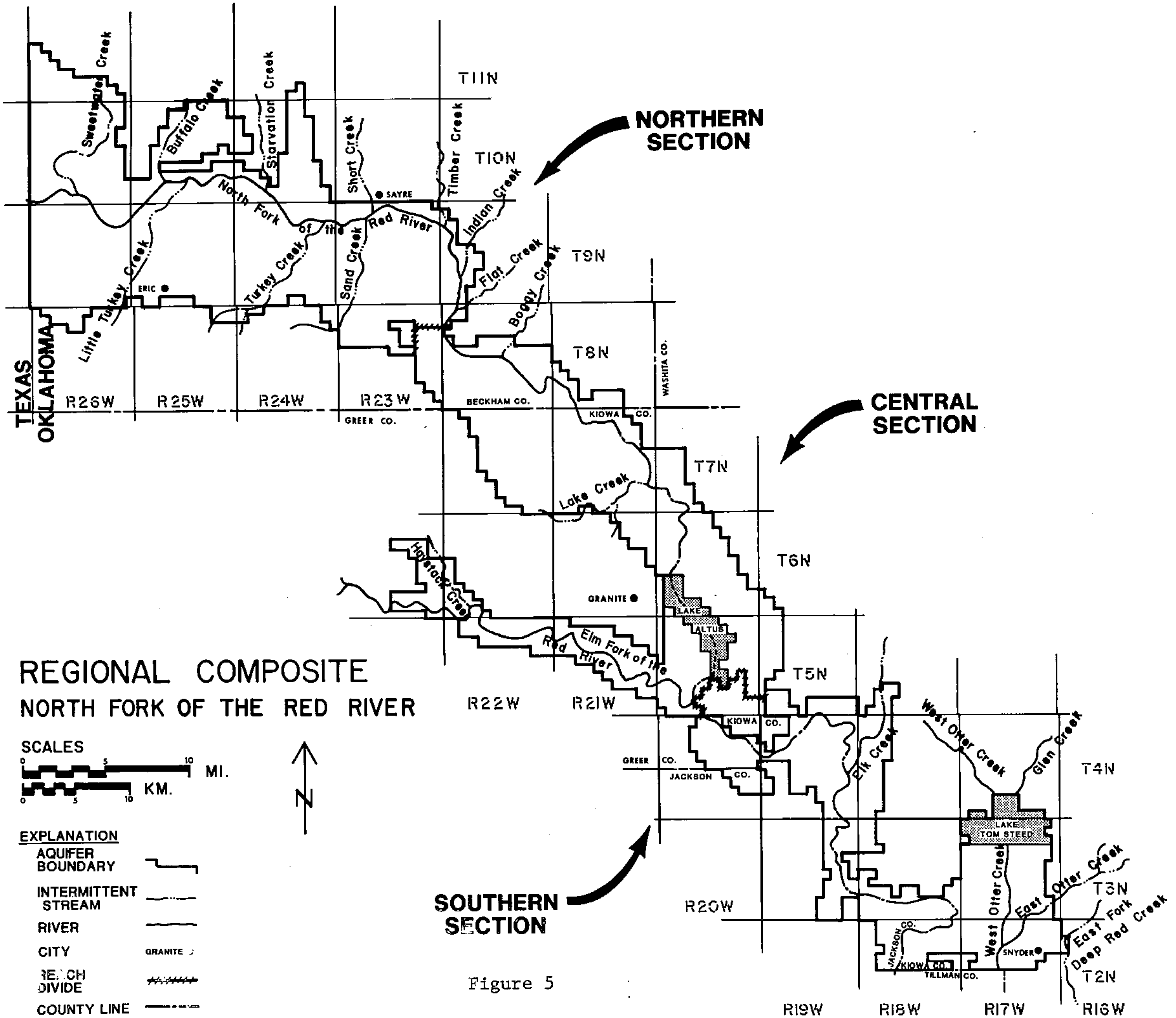

REGIONAL COMPOSITE
NORTH FORK OF THE RED RIVER
SCALES
0 5 10 MI.
0 5 10 KM.
EXPLANATION
AQUIFER BOUNDARY
INTERMITTENT STREAM
RIVER
CITY
COUNTY LINE
NORTHERN SECTION
CENTRAL SECTION
SOUTHERN SECTION
TEXAS
OKLAHOMA
T11N
T10N
T9N
T8N
T7N
T6N
T5N
T4N
T3N
T2N
R26W
R25W
R24W
R23W
R22W
R21W
R20W
R19W
R18W
R17W
R16W
Sweetwater Creek
Buffalo Creek
Starvation Creek
Short Creek
Timber Creek
Indian Creek
SAYRE
North Fork of the Red River
Turkey Creek
Sand Creek
Little Turkey Creek
ERIC
Flat Creek
Boggy Creek
BECKHAM CO.
GREER CO.
KIOWA CO.
WASHITA CO.
Lake Creek
Haystack Creek
GRANITE
LAKE ALTUS
Elm Fork of the Red River
JACKSON CO.
Elk Creek
West Otter Creek
Glen Creek
LAKE TOM STEED
West Otter Creek
East Otter Creek
East Fork Deep Red Creek
SNYDER
TILLMAN CO.

Figure 5

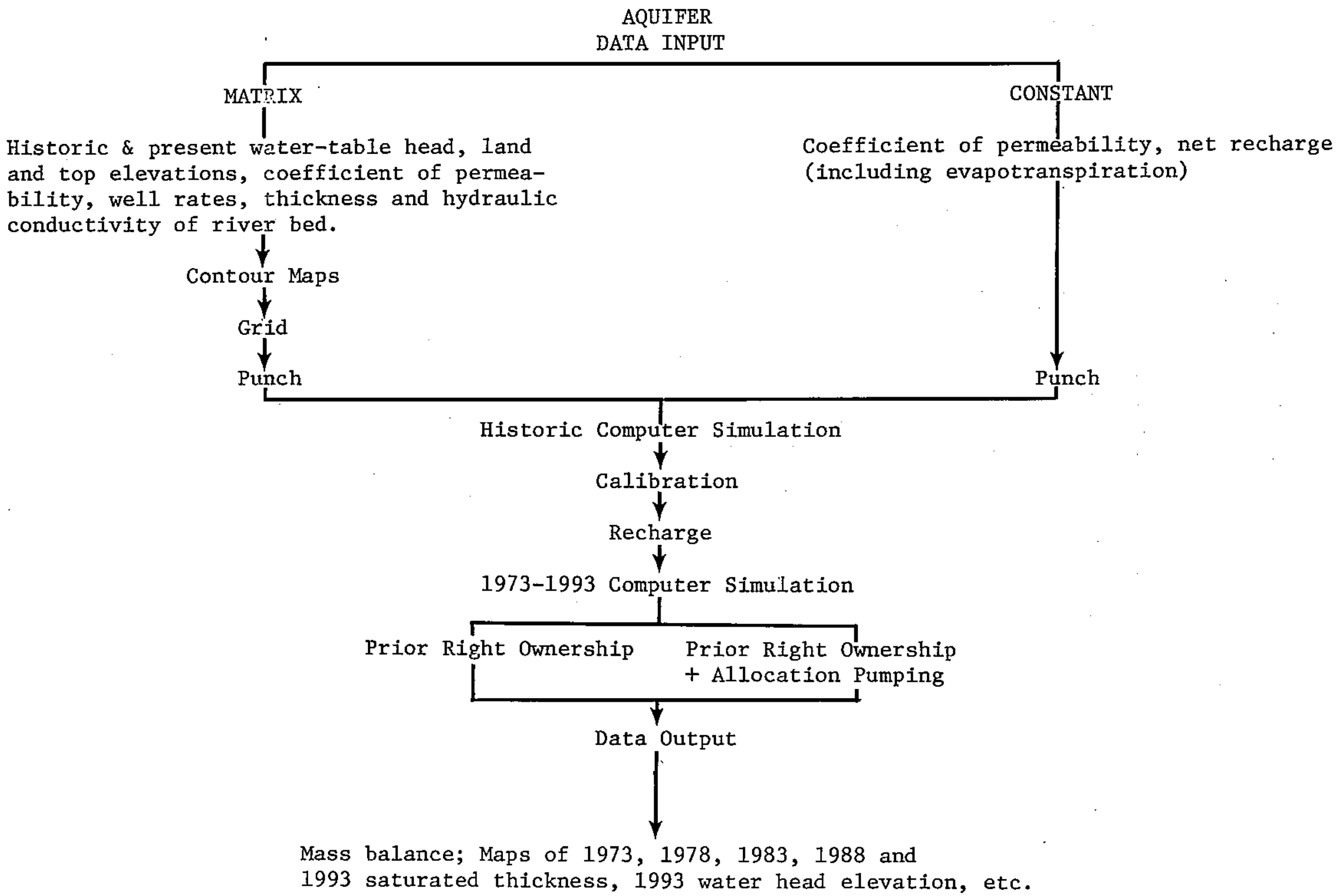

AQUIFER
DATA INPUT
MATRIX
CONSTANT
Historic & present water-table head, land and top elevations, coefficient of permeability, well rates, thickness and hydraulic conductivity of river bed.
Coefficient of permeability, net recharge (including evapotranspiration)
Contour Maps
Grid
Punch
Punch
Historic Computer Simulation
Calibration
Recharge
1973-1993 Computer Simulation
Prior Right Ownership
Prior Right Ownership + Allocation Pumping
Data Output
Mass balance; Maps of 1973, 1978, 1983, 1988 and 1993 saturated thickness, 1993 water head elevation, etc.

Figure 6

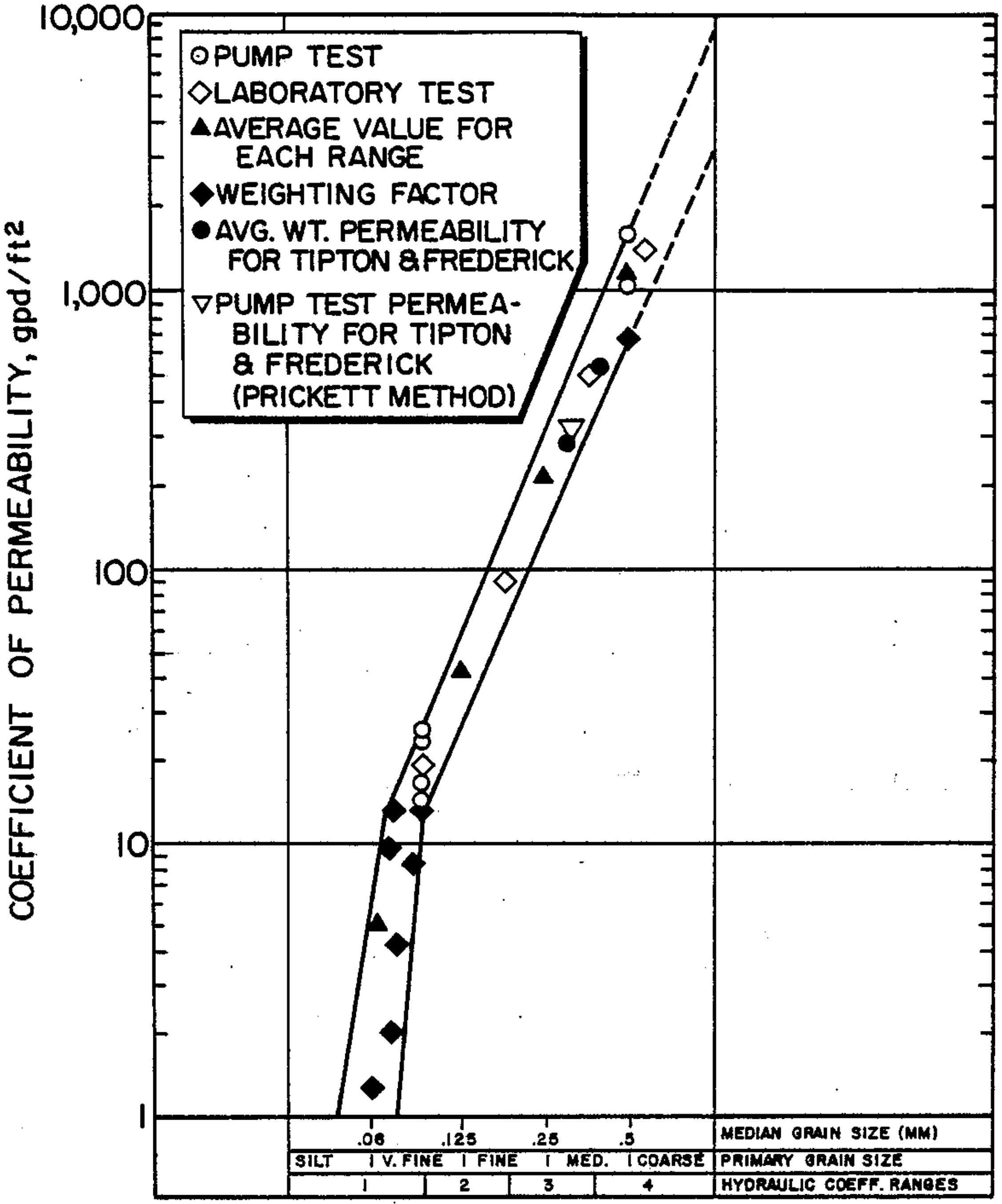
coefficient of permeability of the aquifer was considered variable or constant based on availability of data.

Coefficient of Permeability and Specific Yield

The hydraulic properties of the aquifer were needed as input in the model. This information cannot be obtained directly from driller's logs. A coefficient of permeability-grain size envelope shown in Figure 7 was developed by Kent et. al. (1973) and used to assign hydraulic properties (coefficient of permeability and specific yield) to lithologies described on the driller's logs. The permeability-grain size envelope was developed from research conducted in the Washita River alluvium and is based on field and laboratory permeability testing of alluvial materials.

Lithologies shown on driller's logs are assigned to one of four grain size ranges shown along the abscissa of the envelope. Each range has associated with it a permeability value corresponding to the median grain size of that range. An average weighted permeability for the stratigraphic section represented by each driller's log is obtained by multiplying the permeability of each range by the percentage of the total saturated thickness represented by that range and summing the total for all ranges. An example of this technique is shown in Table 2. Weighted average permeabilities were computed by this method for all wells within the area.

To supplement the permeability data and to verify computed values, a pump test was conducted during March 15 to 18, 1979. A 16-inch well, which was installed near the State Reformatory at Granite and located in T6N, R20W, section 28, NW ¼, was pumped continuously for 50 hours at a rate of 100 gallons per minute. One 4-inch observation well was



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

Figure 7

TABLE 2

WEIGHTED AVERAGE PERMEABILITY

REFORMATORY WELL FIELD

T.6N., R.20W., Sec. 28, N.W.¼

Range	Layer Coefficient of Permeability* (gpd/ft^2)	Saturated Interval Thickness (ft)	Percentage of Total Thicknes (%)	Permeability Coefficinet Times Percentage Thickness
1	10	12	33.3	3
2	100	0	0	0
3	515	0	0	0
4	1480	24	66.6	986
		36	99.9	
			Weighted Average	989 gpd/ft^2

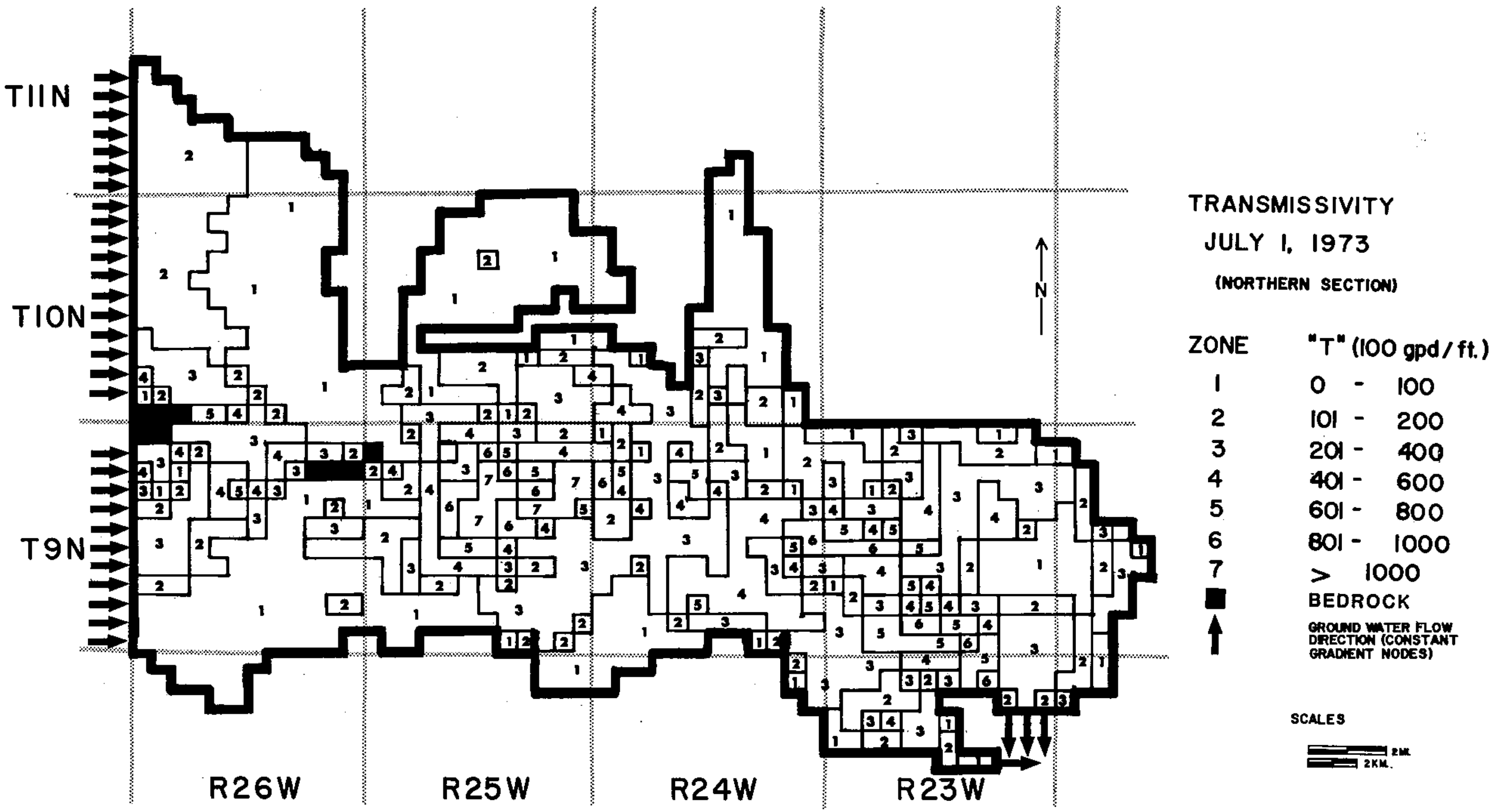
*Permeability coefficients derived from Figure 7.

installed at 75 feet from the pumped well. Drawdowns measured during the pump test are shown in Appendix B.

The results of the pump test were analyzed using various methods including the Jacob method and the non-artesian type curve method developed by Prickett (1965). Graphs used for the Jacob and Prickett method are shown in Appendix B. These techniques were designed for pump tests conducted under varying ground-water conditions including consideration of delayed drainage due to gravity.

The transmissivity values obtained from the Reformatory pump test are shown in Appendix B for both methods used. Permeability coefficients of between 735 and 975 gallons per day per foot squared are obtained when the transmissivities are divided by the 36 feet of saturated thickness. These values compare favorably to the weighted average of 989 gallons per day per foot squared (see Table 2) using the permeability envelope in Figure 7 for the samples obtained from the same well. The favorable correlation was considered to be justification for using the permeability-grain size envelope to determine an average permeability for each driller's log. The distribution of initial transmissivity values used in the model for the three subareas are represented in Figures 8, 9, and 10.

Specific yield values were computed automatically in the model. The graph shown in Figure 11 (after Johnson, 1967) was used to provide a relationship between median grain size and specific yield. The dominant grain sizes in Figure 11 were considered to be equivalent to the median grain sizes of the permeability envelope. The values of specific yield along with the corresponding permeability coefficients of the four ranges were plotted on semi-logarithmic paper to produce the relationship shown in Figure 12. This curve was programed into the model.



TRANSMISSIVITY
JULY 1, 1973
(NORTHERN SECTION)
ZONE
"T" (100 gpd/ft.)
1 0 - 100
2 101 - 200
3 201 - 400
4 401 - 600
5 601 - 800
6 801 - 1000
7 > 1000
BEDROCK
GROUND WATER FLOW DIRECTION (CONSTANT GRADIENT NODES)
SCALES
2MI.
2KM.
N
T11N
T10N
T9N
R26W
R25W
R24W
R23W

Figure 8

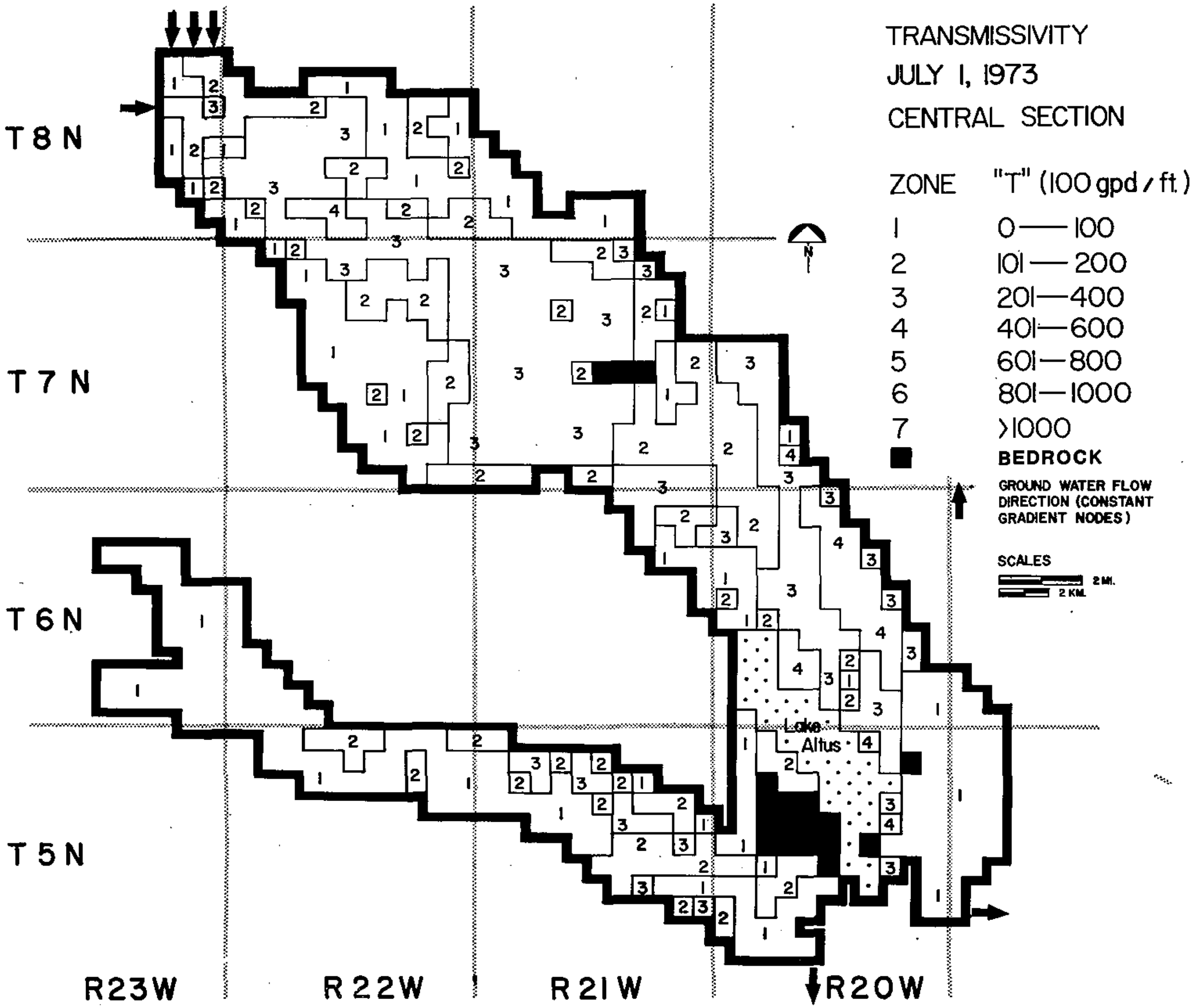

TRANSMISSIVITY
JULY 1, 1973
CENTRAL SECTION
ZONE "T" (100 gpd / ft.)
1 0 — 100
2 101 — 200
3 201 — 400
4 401 — 600
5 601 — 800
6 801 — 1000
7 >1000
BEDROCK
GROUND WATER FLOW DIRECTION (CONSTANT GRADIENT NODES)
SCALES
2 MI.
2 KM.
N
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
Lake Altus

Figure 9

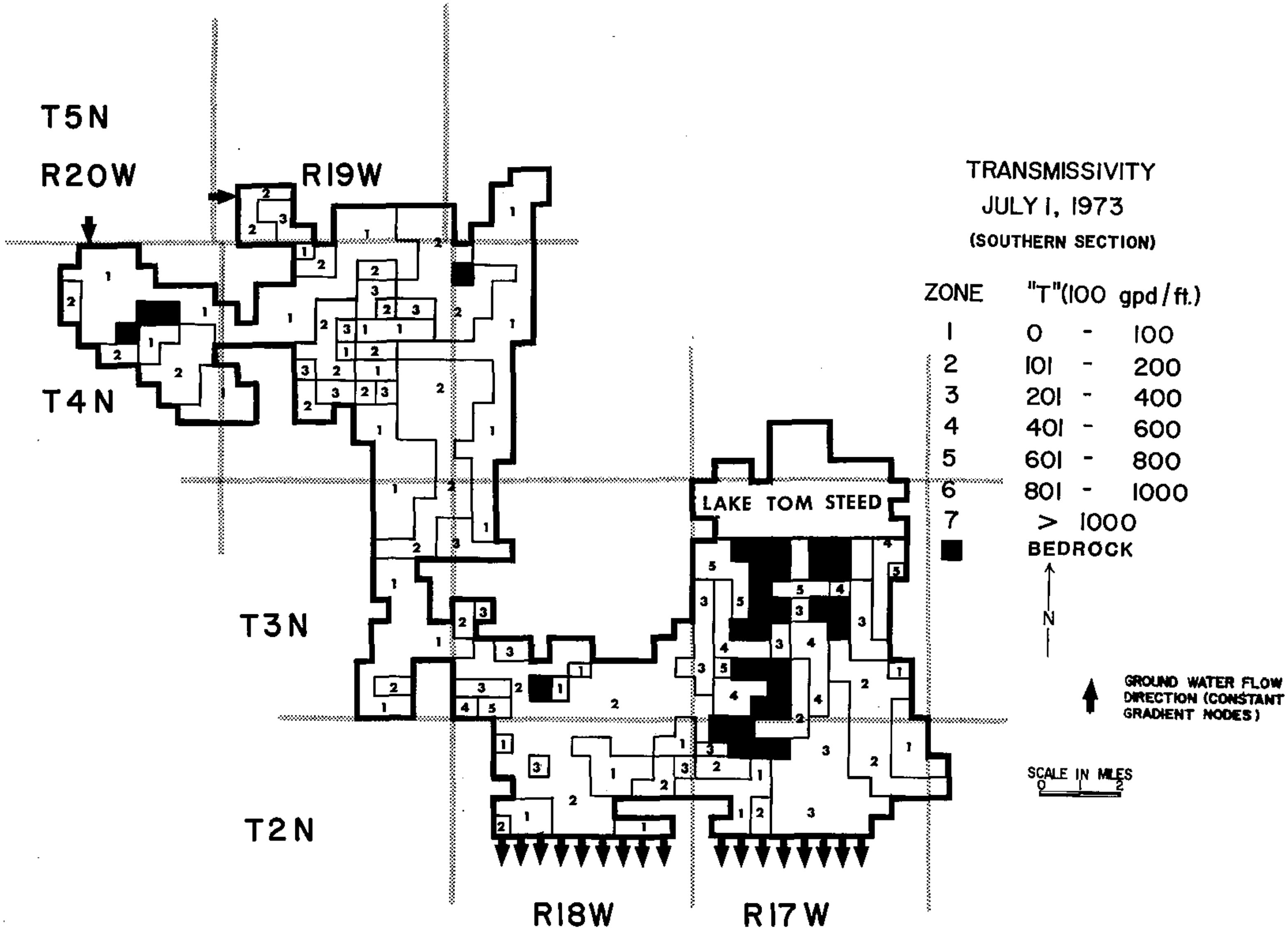

T5N
R20W
R19W
T4N
T3N
T2N
R18W
R17W
LAKE TOM STEED
TRANSMISSIVITY
JULY 1, 1973
(SOUTHERN SECTION)
ZONE "T"(100 gpd/ft.)
1 0 - 100
2 101 - 200
3 201 - 400
4 401 - 600
5 601 - 800
6 801 - 1000
7 > 1000
BEDROCK
N
GROUND WATER FLOW DIRECTION (CONSTANT GRADIENT NODES)
SCALE IN MILES
0 1 2

Figure 10

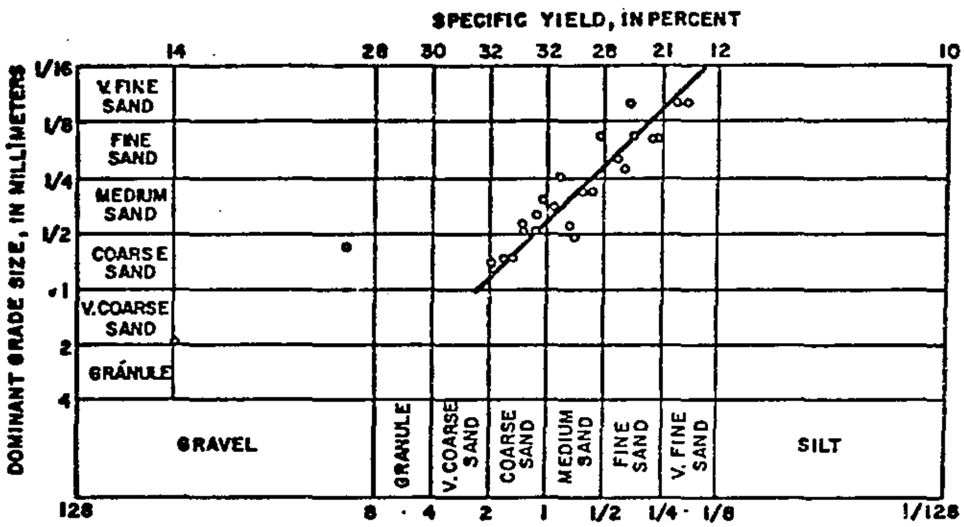

SPECIFIC YIELD, IN PERCENT
14
28
30
32
32
28
21
12
10
DOMINANT GRADE SIZE, IN MILLIMETERS
1/16
1/8
1/4
1/2
1
2
4
V. FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
GRANULE
GRAVEL
GRANULE
V. COARSE SAND
COARSE SAND
MEDIUM SAND
FINE SAND
V. FINE SAND
SILT
128
8
4
2
1
1/2
1/4
1/8
1/128

Figure 11

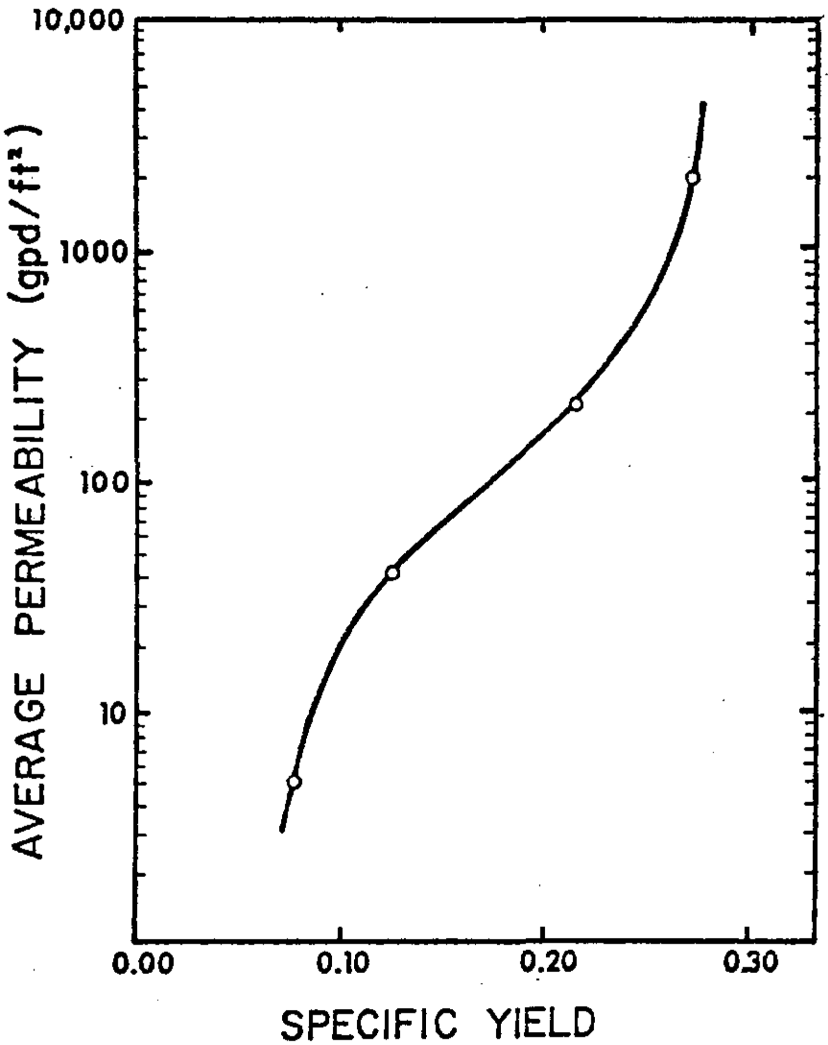

10,000
1000
100
10
AVERAGE PERMEABILITY (gpd/ft²)
0.00
0.10
0.20
0.30
SPECIFIC YIELD

Figure 12

Values of specific yield were automatically assigned to each node using the corresponding permeability value of each node.

Bedrock and Historic Water-Table Elevations

Records of bedrock as well as past and present water table depths were made available by the Oklahoma Water Resources Board. These records are based on driller's logs and field measurements by the Oklahoma Water Resources Board personnel. Depths to water and bedrock were subtracted from surface elevations, derived from the US Geological Survey topographic maps, to obtain water table and bedrock elevations. These elevations were plotted on base maps and contoured. Aquifer boundaries were determined from the US Geological Survey and the Oklahoma Geological Survey hydrologic atlases (Carr and Bergman, 1976; Havens, 1977) and field checked during this investigation. For modeling purposes, the bedrock surface at the base of the alluvium was considered to be an impermeable boundary with no net water gain to or loss from the alluvial deposits to/or from this source.

Several large areas occur within the region for which no water table and bedrock information was available. A seismic survey of those areas was undertaken to fill "gaps" in these data. A 12-channel refraction seismograph recorder produced by Electronics System Division of Houston, Texas (Model ER-75-12) was used in the study. Seismic shot locations are shown on maps in Figures 13, 14, and 15.

Water table and bedrock depths are subtracted from surface elevations, plotted on corresponding base maps, and used in conjunction with well data to produce bedrock and water table contour maps of the area (Figures 13 to 20).

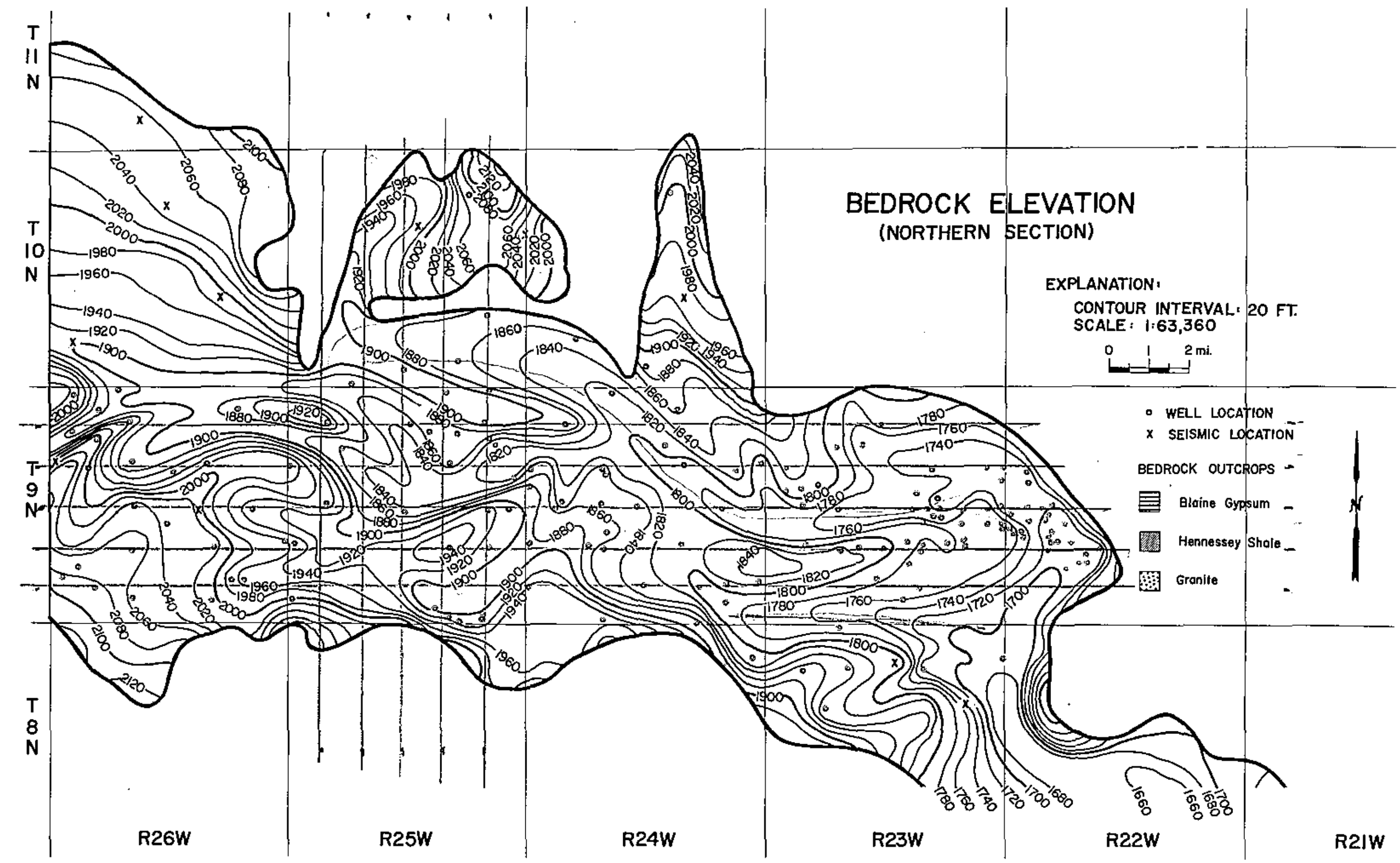

BEDROCK ELEVATION
(NORTHERN SECTION)
EXPLANATION:
CONTOUR INTERVAL: 20 FT.
SCALE: 1:63,360
0 1 2 mi.
WELL LOCATION
X SEISMIC LOCATION
BEDROCK OUTCROPS
Blaine Gypsum
Hennessey Shale
Granite
T 11 N
T 10 N
T 9 N
T 8 N
R26W
R25W
R24W
R23W
R22W
R21W

Figure 13

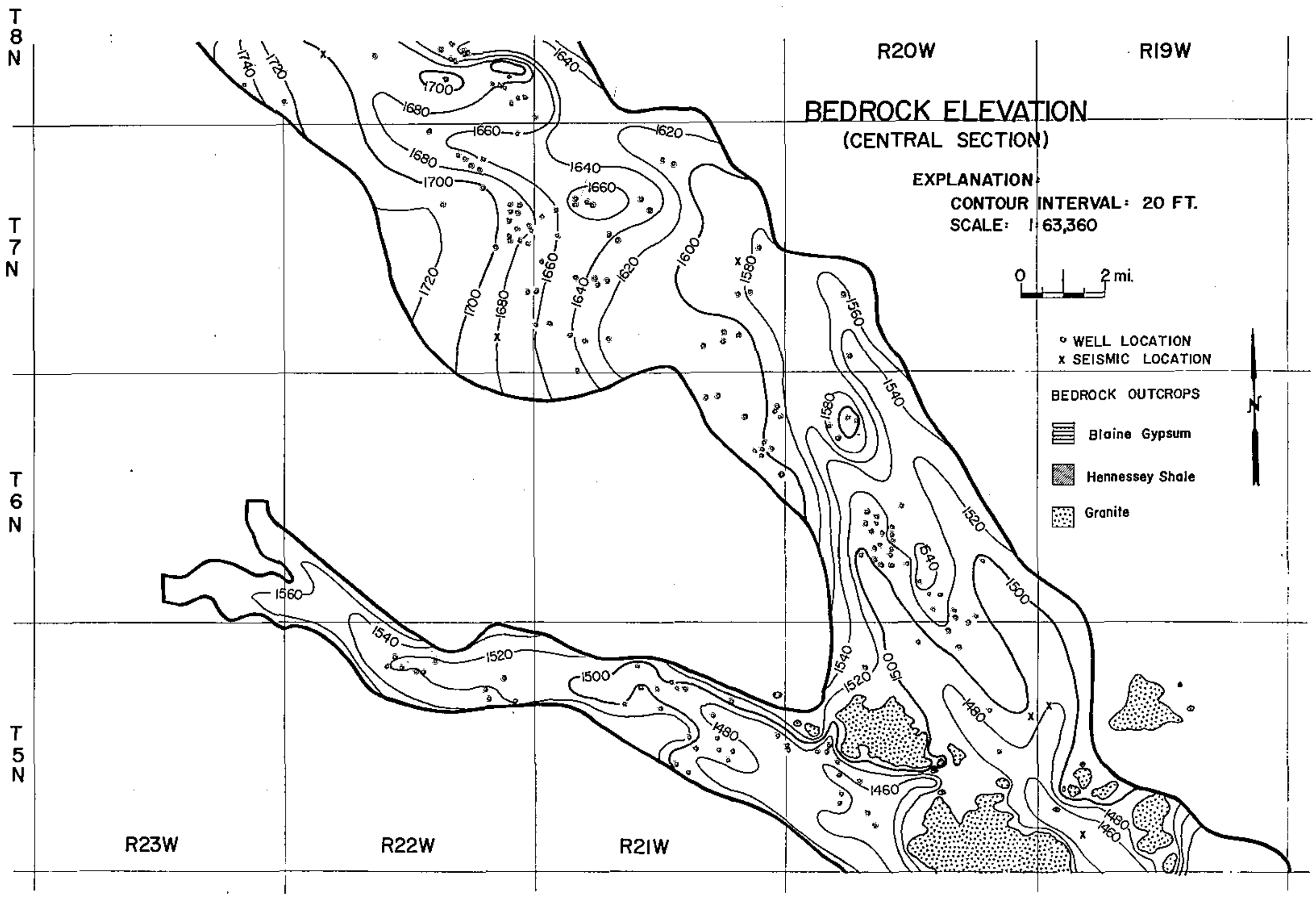

BEDROCK ELEVATION
(CENTRAL SECTION)
EXPLANATION:
CONTOUR INTERVAL: 20 FT.
SCALE: 1:63,360
0 2 mi.
WELL LOCATION
x SEISMIC LOCATION
BEDROCK OUTCROPS
Blaine Gypsum
Hennessey Shale
Granite
N
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W
1740
1720
1700
1680
1660
1640
1620
1600
1580
1560
1540
1520
1500
1480
1460

Figure 14

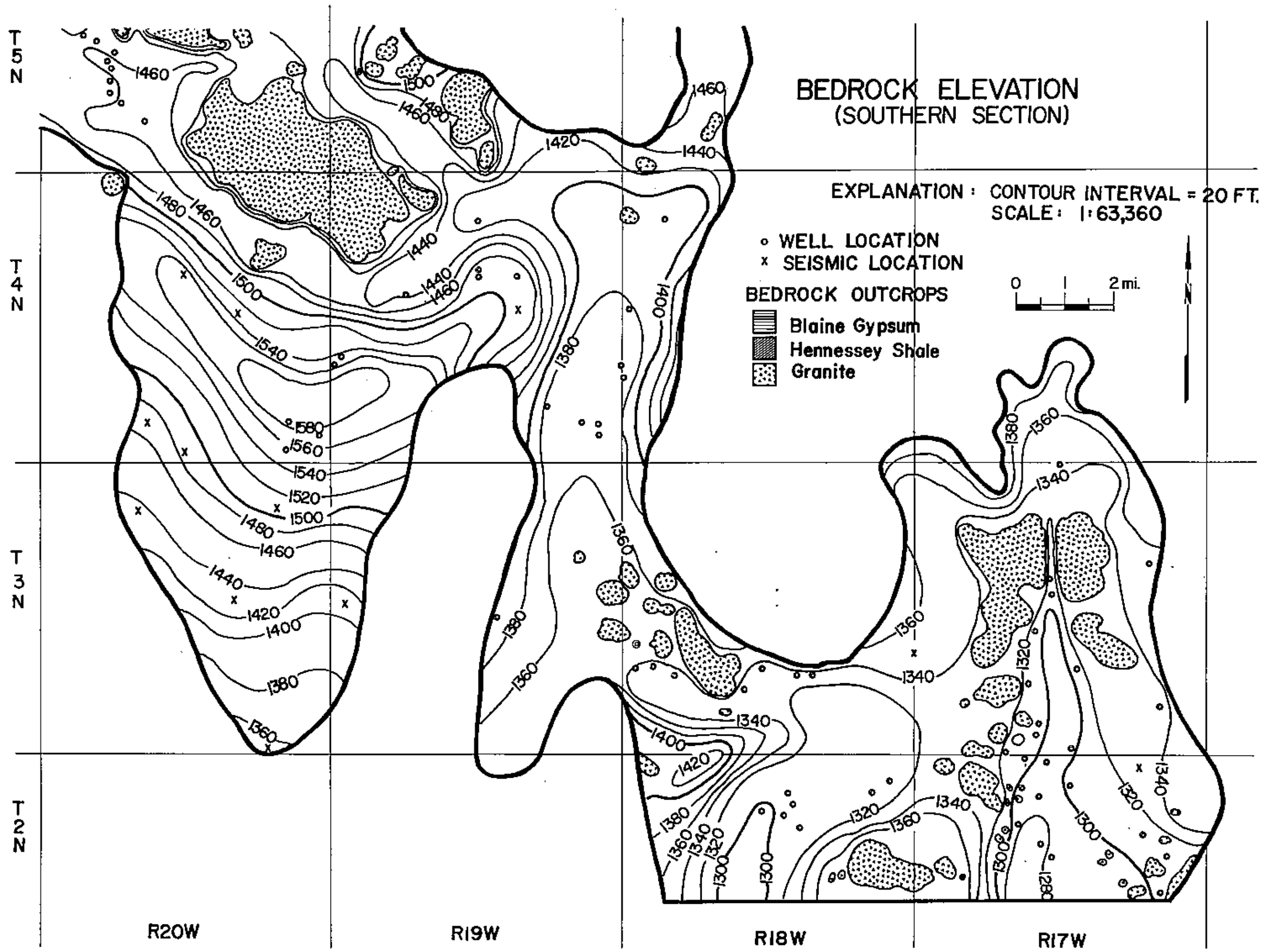

BEDROCK ELEVATION
(SOUTHERN SECTION)
EXPLANATION: CONTOUR INTERVAL = 20 FT.
SCALE: 1:63,360
WELL LOCATION
SEISMIC LOCATION
BEDROCK OUTCROPS
Blaine Gypsum
Hennessey Shale
Granite
0
1
2 mi.
N
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W

Figure 15

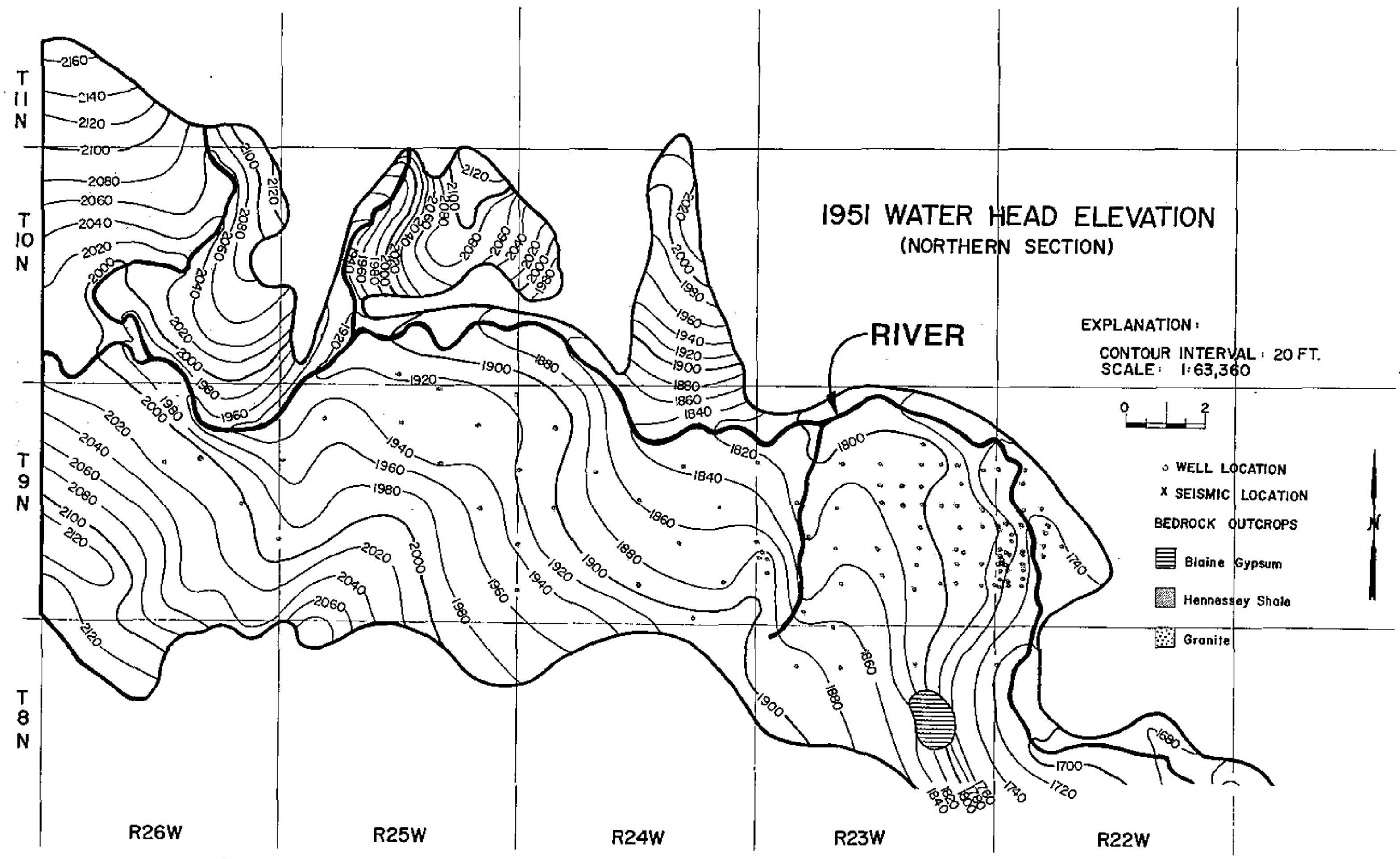

1951 WATER HEAD ELEVATION
(NORTHERN SECTION)
RIVER
EXPLANATION:
CONTOUR INTERVAL: 20 FT.
SCALE: 1:63,360
0 1 2
WELL LOCATION
X SEISMIC LOCATION
BEDROCK OUTCROPS
Blaine Gypsum
Hennessey Shale
Granite
N
T 11 N
T 10 N
T 9 N
T 8 N
R26W
R25W
R24W
R23W
R22W

Figure 16

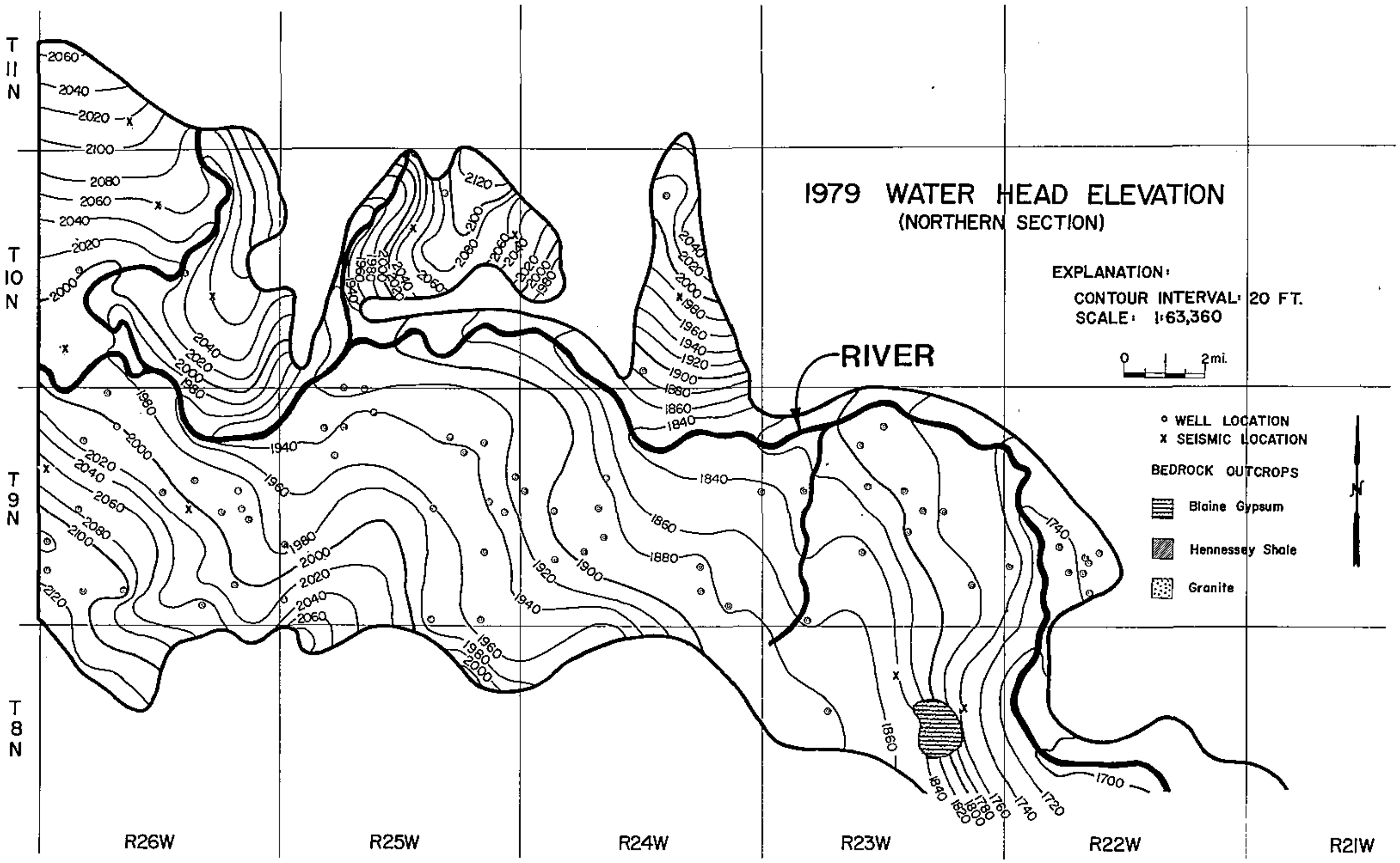
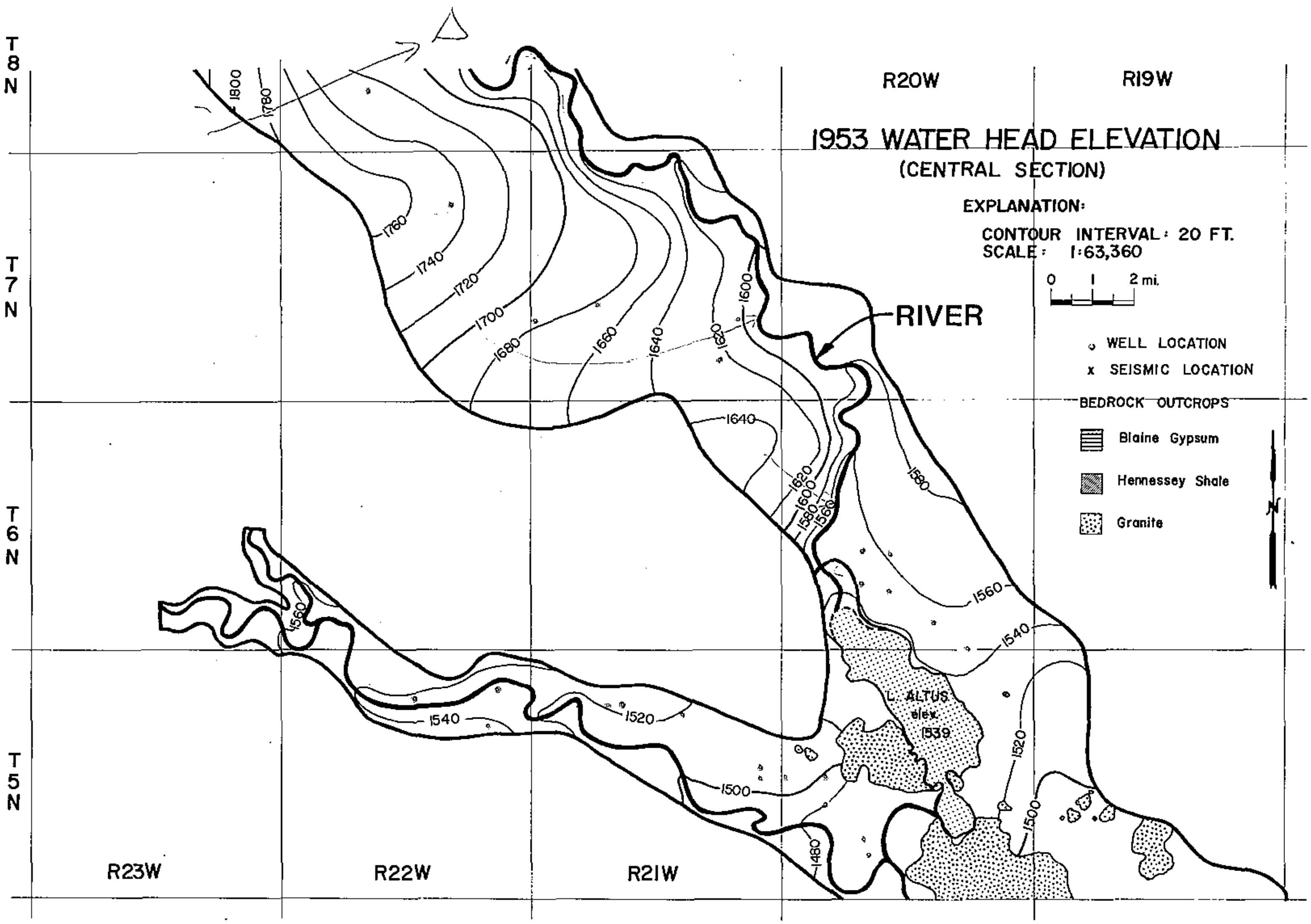

1979 WATER HEAD ELEVATION
(NORTHERN SECTION)
EXPLANATION:
CONTOUR INTERVAL: 20 FT.
SCALE: 1:63,360
0 2 mi.
RIVER
o WELL LOCATION
x SEISMIC LOCATION
BEDROCK OUTCROPS
Blaine Gypsum
Hennessey Shale
Granite
N
T 11 N
T 10 N
T 9 N
T 8 N
R26W
R25W
R24W
R23W
R22W
R21W

Figure 17



1953 WATER HEAD ELEVATION
(CENTRAL SECTION)
EXPLANATION:
CONTOUR INTERVAL: 20 FT.
SCALE: 1:63,360
0 1 2 mi.
RIVER
WELL LOCATION
x SEISMIC LOCATION
BEDROCK OUTCROPS
Blaine Gypsum
Hennessey Shale
Granite
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W
L. ALTUS
elev.
1539
1800
1780
1760
1740
1720
1700
1680
1660
1640
1620
1600
1580
1560
1540
1520
1500
1480

Figure 18

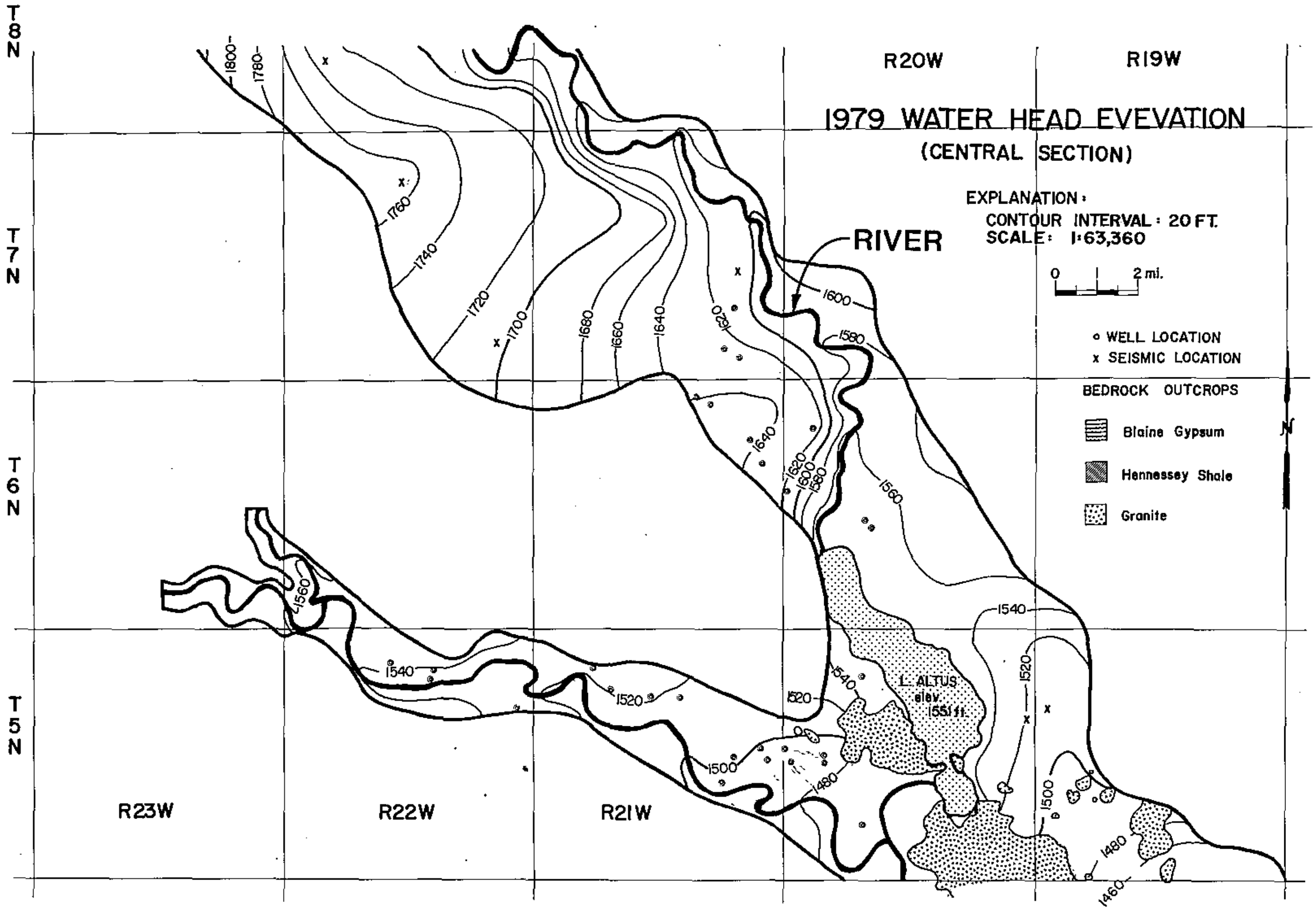
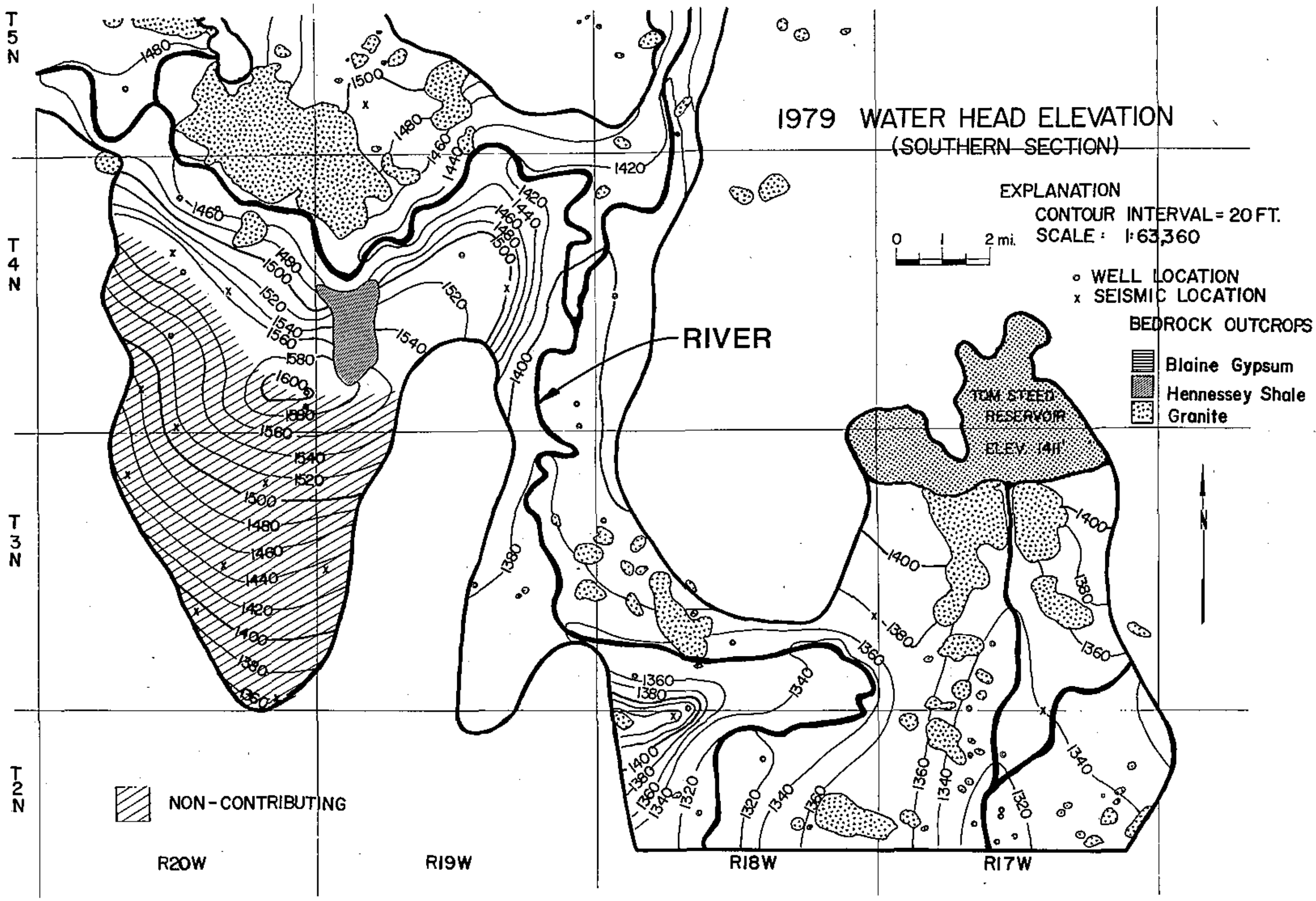

1979 WATER HEAD EVEVATION
(CENTRAL SECTION)
EXPLANATION:
CONTOUR INTERVAL: 20 FT.
SCALE: 1:63,360
0
2 mi.
RIVER
o WELL LOCATION
x SEISMIC LOCATION
BEDROCK OUTCROPS
Blaine Gypsum
Hennessey Shale
Granite
L. ALTUS
elev.
1551 ft.
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W
N

Figure 19



1979 WATER HEAD ELEVATION
(SOUTHERN SECTION)
EXPLANATION
CONTOUR INTERVAL = 20 FT.
SCALE: 1:63,360
0 1 2 mi.
WELL LOCATION
SEISMIC LOCATION
BEDROCK OUTCROPS
Blaine Gypsum
Hennessey Shale
Granite
RIVER
TOM STEED RESERVOIR
ELEV 1411
NON-CONTRIBUTING
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W
N

Figure 20

Contoured data was gridded, digitized, and punched for input into the computer model. A quarter mile grid, drawn at the same scale as the base maps, was overlaid onto each contour map. Values were assigned to each node of the grid by a perimeter-averaging technique developed by Griffen (1949). Griffen's method involves averaging the values at the corners and center of each node to obtain an average value for that node.

Recharge and Discharge

The alluvial and terrace deposits along the North Fork of the Red River occur as an unconfined aquifer. Maps showing historic and recent water table configurations are shown in Figures 16 to 20. The North Fork of the Red River is generally effluent through most of its reach within the project area, with ground water from the terrace deposits supplying water to the river most of the year.

The major source of recharge to the aquifer is from precipitation. The sandy soil of the alluvial areas has a high infiltration capacity. The presence of discontinous layers of clay and caliche near the surface does not regionally prevent infiltration, but in some localized areas may decrease it. Hydrologic studies by the Oklahoma Water Resources Board (1975) have used an average of nine percent of precipitation as an estimate of net recharge to the water table in similar areas.

The average precipitation at several localities within the area are listed in Table 1. Using the Theissen Polygon Method (Hjelmfelt and Cassidy, 1976) a weighted average precipitation of 24.28 inches per year for the entire area is obtained. A recharge rate of 2.28 inches per year can be computed based on the nine percent estimate. When this re- charge is prorated over the 343,000 acres of the aquifer area (excluding surface water), natural recharge is estimated to be 67,100 acre-feet per year. A computer simulation was performed (calibration) using historic water table elevations for the Northern section (see Figures 16 and 17) and confirmed the above recharge rate.

Return flow from irrigation, an important secondary source of recharge, has been estimated at 15 to 25 percent of pumping based on studies by the Oklahoma Water Resources Board (1975) and others. Return flow from irrigation was estimated to be 25 percent for the North Fork alluvium, based on water budget analysis and evapotranspiration estimates.

Due to a locally shallow water table and semi-arid conditions, evaporation and transpiration are important considerations. In this study, evapotranspiration was considered in the calculation and calibration of net recharge.

Subsurface flow into and out of the aquifer can be estimated based on present ground-water gradients. Using a constant gradient in conjunction with variable transmissivity at the perimeter nodes, subsurface inflow from the Texas portion of the aquifer is estimated at 746 acre-feet per year. Out flow into the Tillman Terrace in Tillman County is estimated at 869 acre-feet per year. The net result is a net subsurface outflow of 123 acre-feet per year.

Data was acquired and used by the Oklahoma Water Resources Board to prepare the final orders establishing prior appropriative pumping. These data were used to initialize model simulation, and are shown in Figures 21, 22, and 23. It is assumed that most of the prior appropriative pumping occurs during the four months of June through September. In addition, allocation pumping was added later and adjusted to determine maximum annual yield.

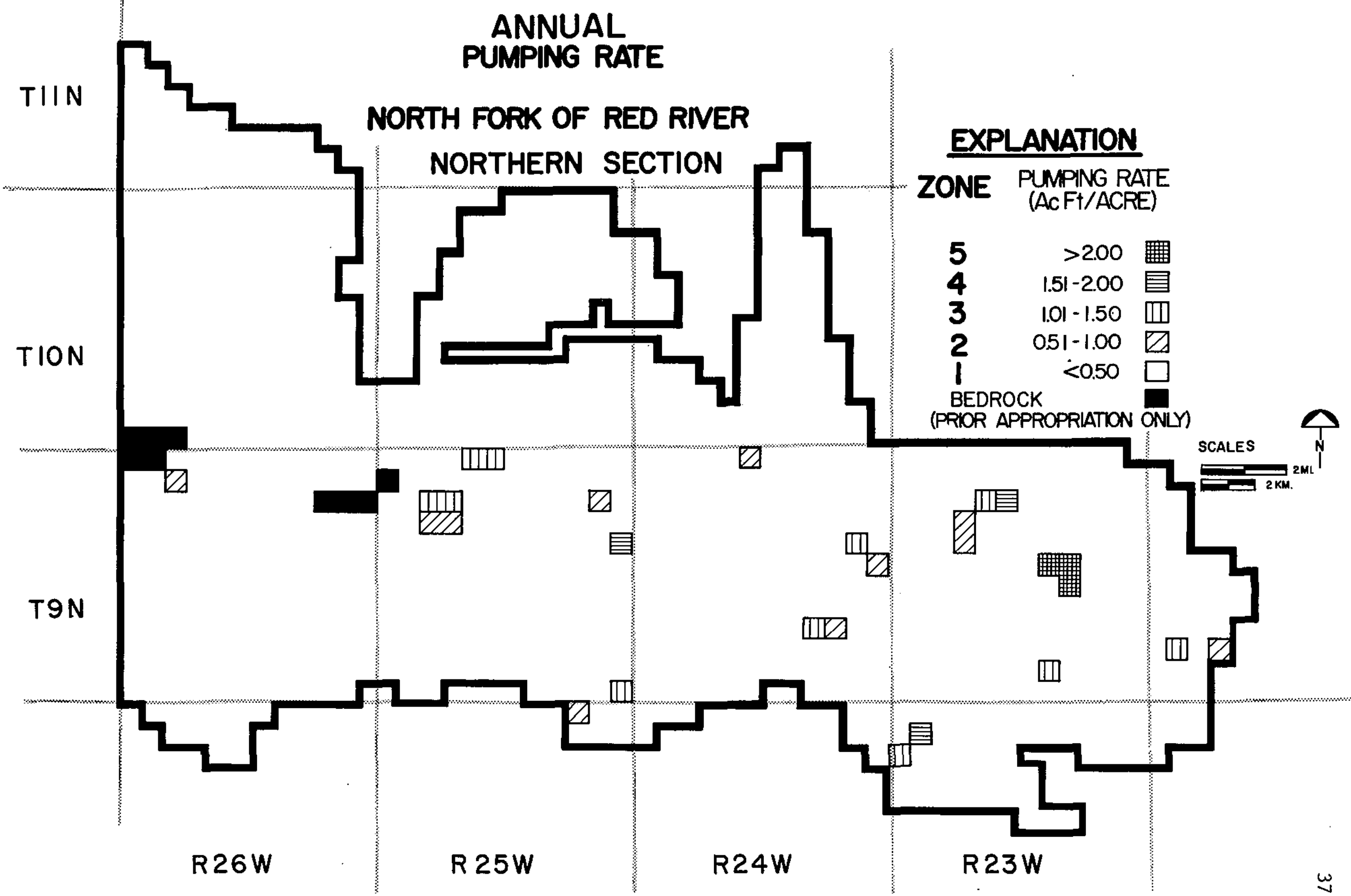
Results

The final 20-year computer simulation was conducted for the 1973 to 1993 period for each subbasin using pumping rates of prior appropriative right owners (owners with water rights established before July 1, 1973). This simulation was repeated with allocation pumping in conjunction with prior appropriative pumping.

Maximum annual yield was determined by adjusting the amount of allocated pumpage that would cause 50 percent of the nodes to go dry by the end of the simulation period. The maximum yield and allocated pumpage was optimized by repeated 20-year simulation to obtain the required 50 percent dry area. A saturated thickness of five feet was considered dry due to size limitations of a submersible pump, capable of pumping 300 gallons per minute, and set at the bottom of a fully penetrating well. A maximum annual yield of 168,000 acre-feet and an average annual allocation of 0.92 acre-feet per acre were determined.

The annual allocation of 0.92 acre-feet per acre was determined for the entire area by averaging the computed allocations for each subbasin and using a weighting factor based on the percent of total aquifer area occupied by each subbasin. A 20-year ground-water budget was computed for final computer allocation runs of each subbasin and of the entire aquifer area (Figures 24, 25, 26, and 27). In addition, a detailed ground-water budget analysis and ground-water distribution summaries for the three subbasins are shown in Appendix A.

Each node (160 acres) was pumped continuously for a 4-month period during the summer of each year at three times the allocation rate. This schedule was continued throughout the 20-year period unless the node



ANNUAL
PUMPING RATE
NORTH FORK OF RED RIVER
NORTHERN SECTION
EXPLANATION
ZONE
PUMPING RATE (Ac Ft/ACRE)
5 >2.00
4 1.51-2.00
3 1.01-1.50
2 0.51-1.00
1 <0.50
BEDROCK (PRIOR APPROPRIATION ONLY)
SCALES
2 MI.
2 KM.
N
T11N
T10N
T9N
R26W
R25W
R24W
R23W

Figure 21

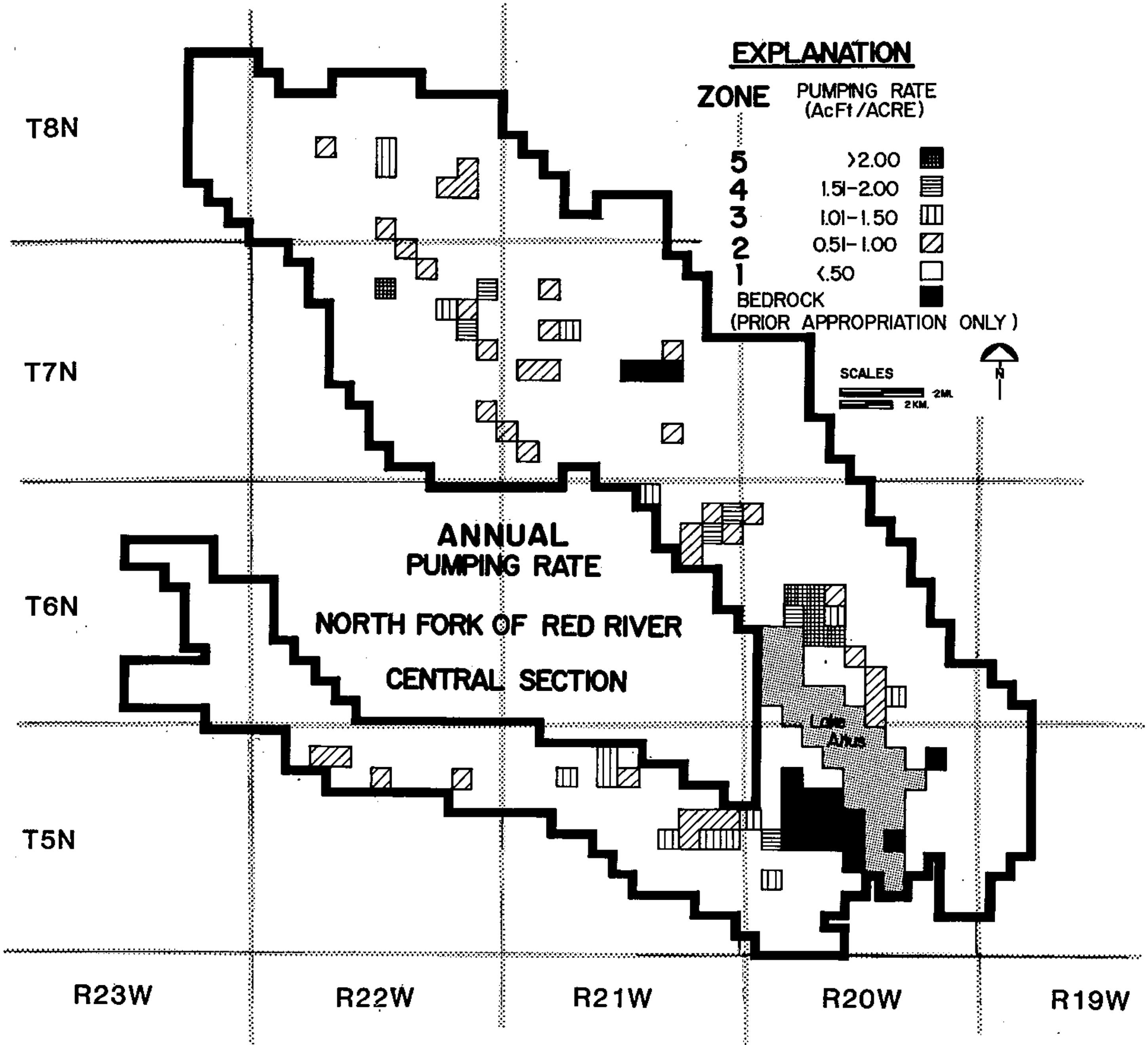
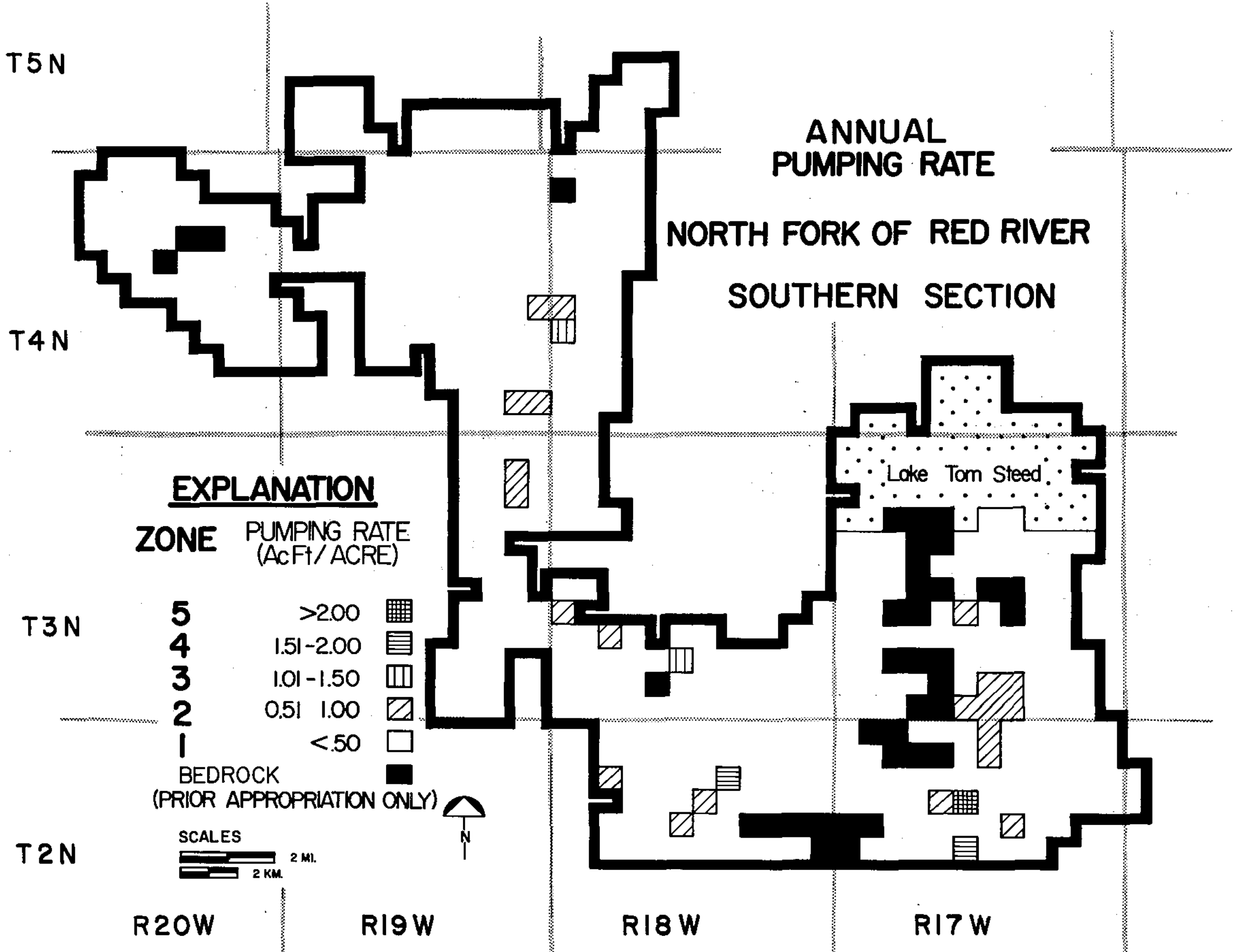

EXPLANATION
ZONE
PUMPING RATE (AcFt/ACRE)
5 >2.00
4 1.51-2.00
3 1.01-1.50
2 0.51-1.00
1 <.50
BEDROCK (PRIOR APPROPRIATION ONLY)
SCALES
2MI.
2KM.
N
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W
ANNUAL PUMPING RATE
NORTH FORK OF RED RIVER
CENTRAL SECTION
Lake Altus

Figure 22



ANNUAL PUMPING RATE
NORTH FORK OF RED RIVER
SOUTHERN SECTION
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W
Lake Tom Steed
EXPLANATION
ZONE
PUMPING RATE (AcFt/ACRE)
5 >2.00
4 1.51-2.00
3 1.01-1.50
2 0.51 1.00
1 <.50
BEDROCK (PRIOR APPROPRIATION ONLY)
SCALES
2 MI.
2 KM.
N

Figure 23

TWENTY-YEAR GROUND WATER BUDGET - North Fork of the Red River (Entire Area)

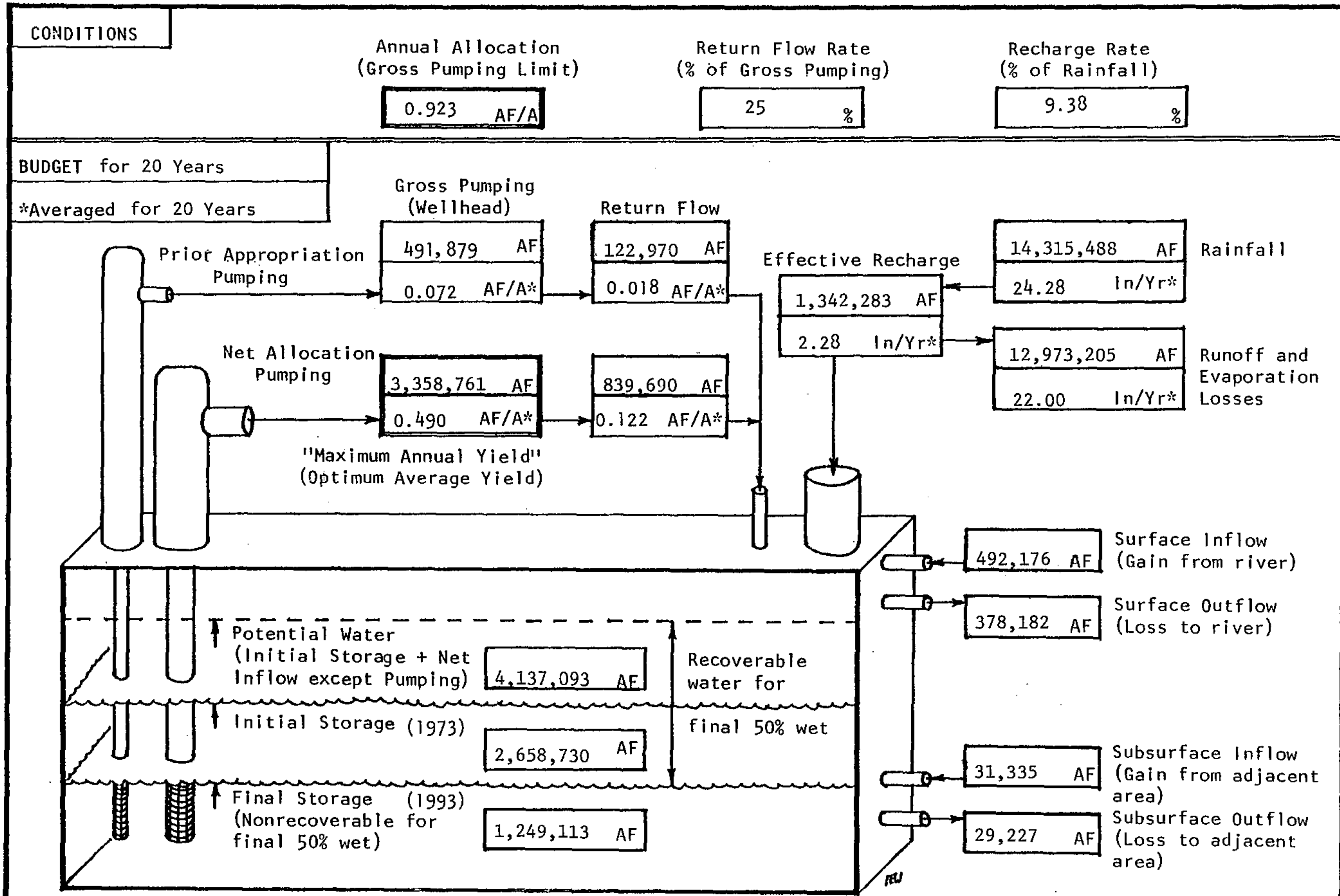


Figure 24

TWENTY-YEAR GROUND WATER BUDGET - North Fork of the Red River - Northern Section

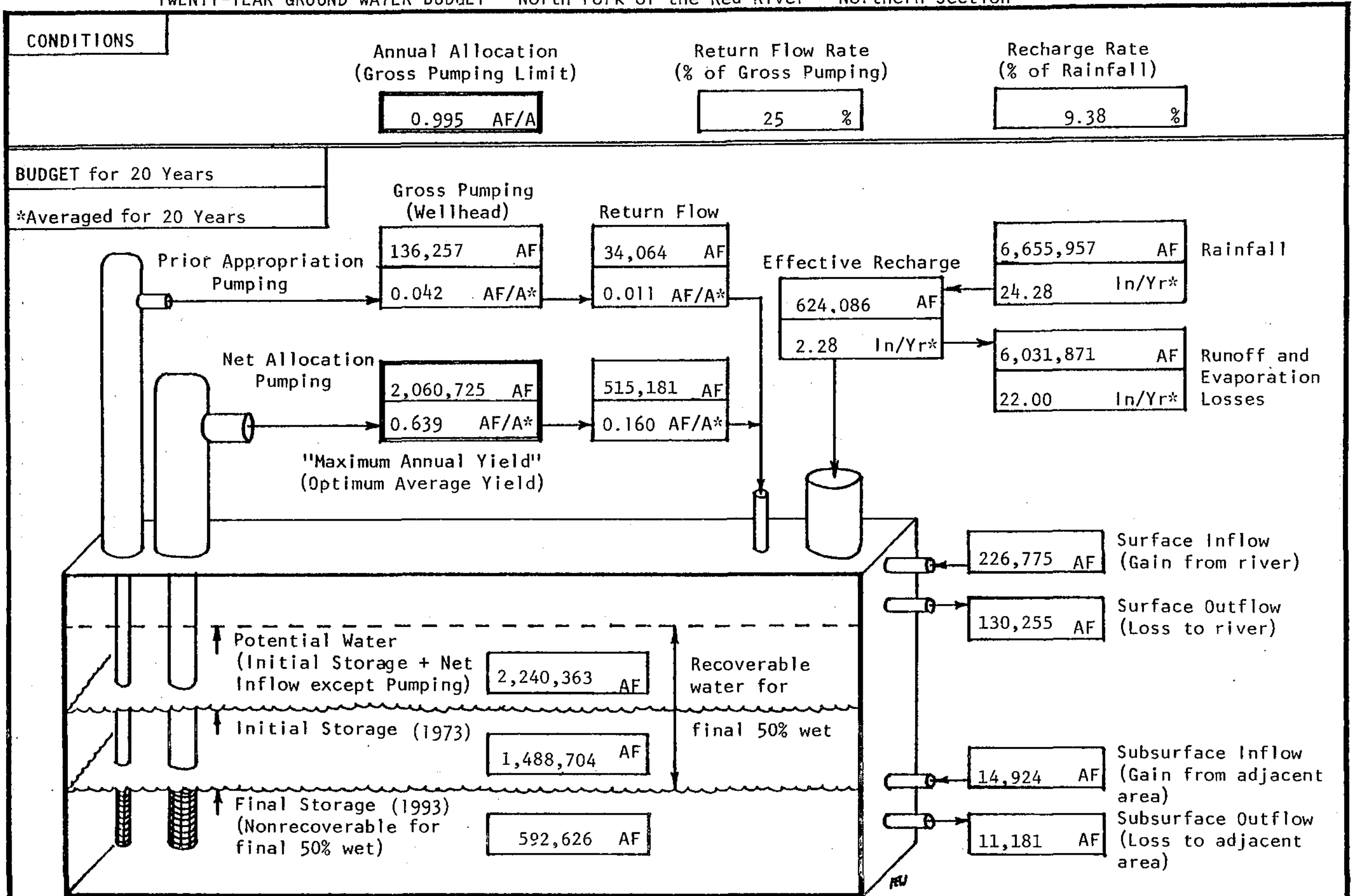


Figure 25

TWENTY-YEAR GROUND WATER BUDGET - North Fork of the Red River - Central Section

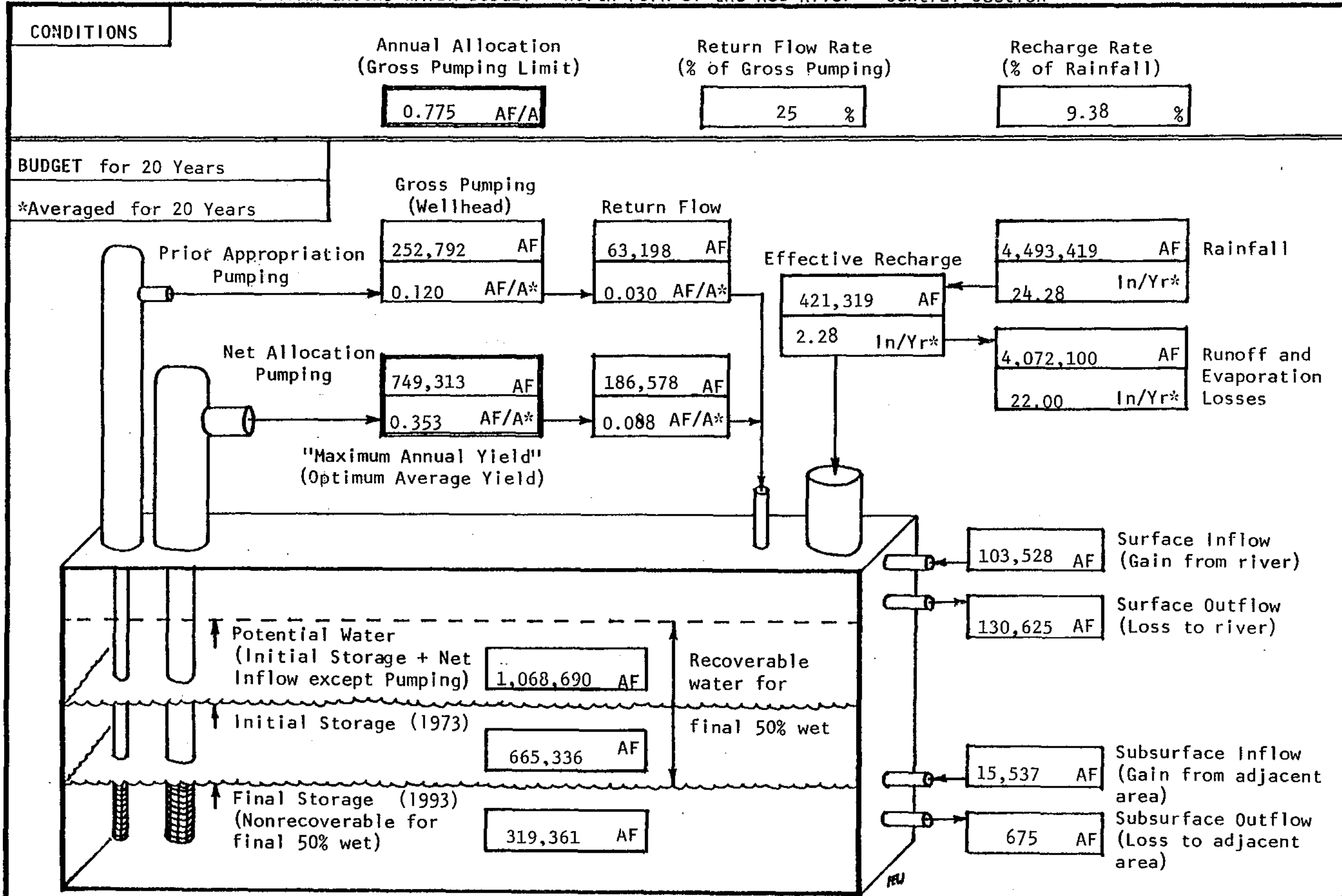


Figure 26

TWENTY-YEAR GROUND WATER BUDGET - North Fork of the Red River - Southern Section

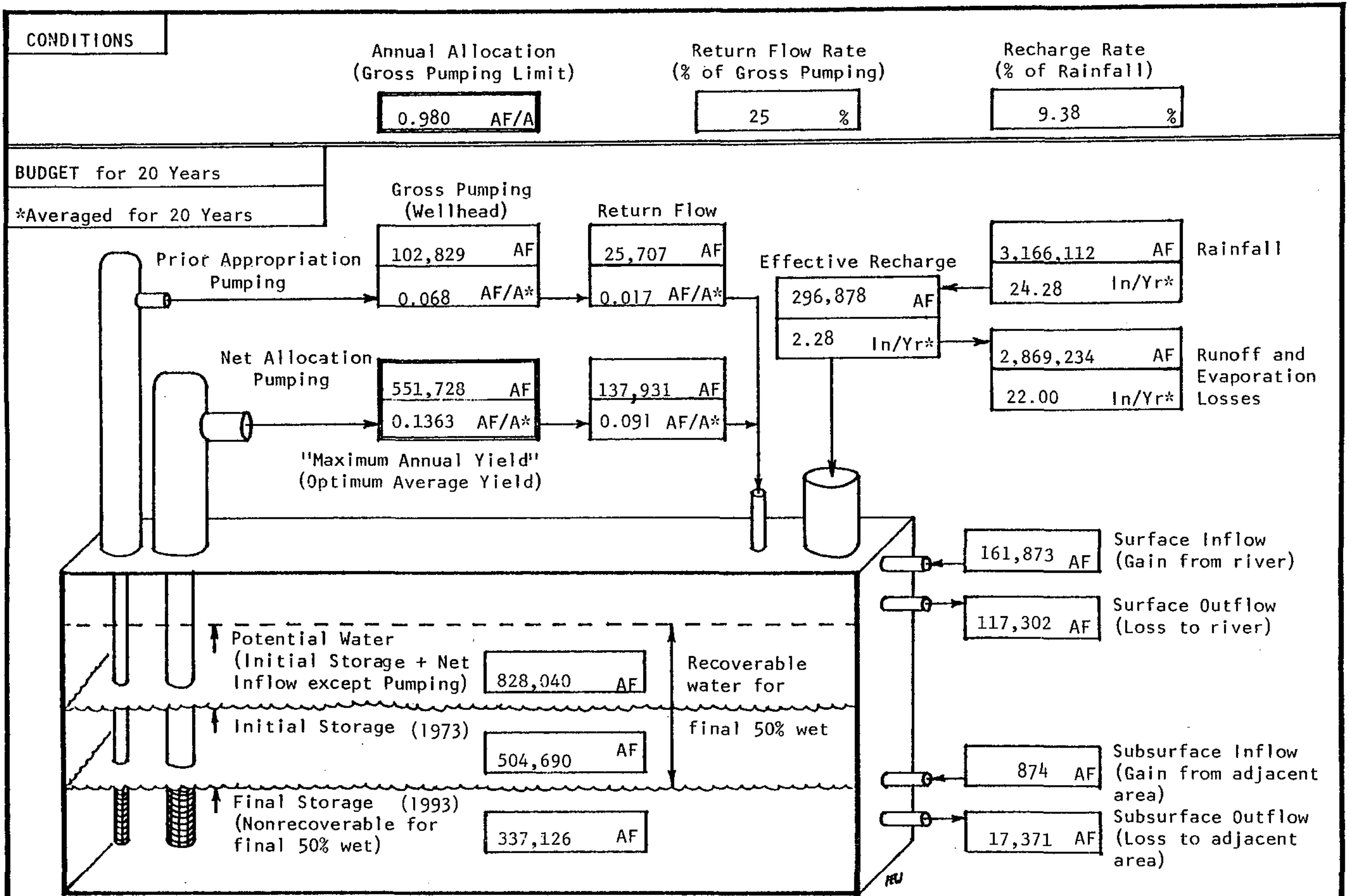


Figure 27

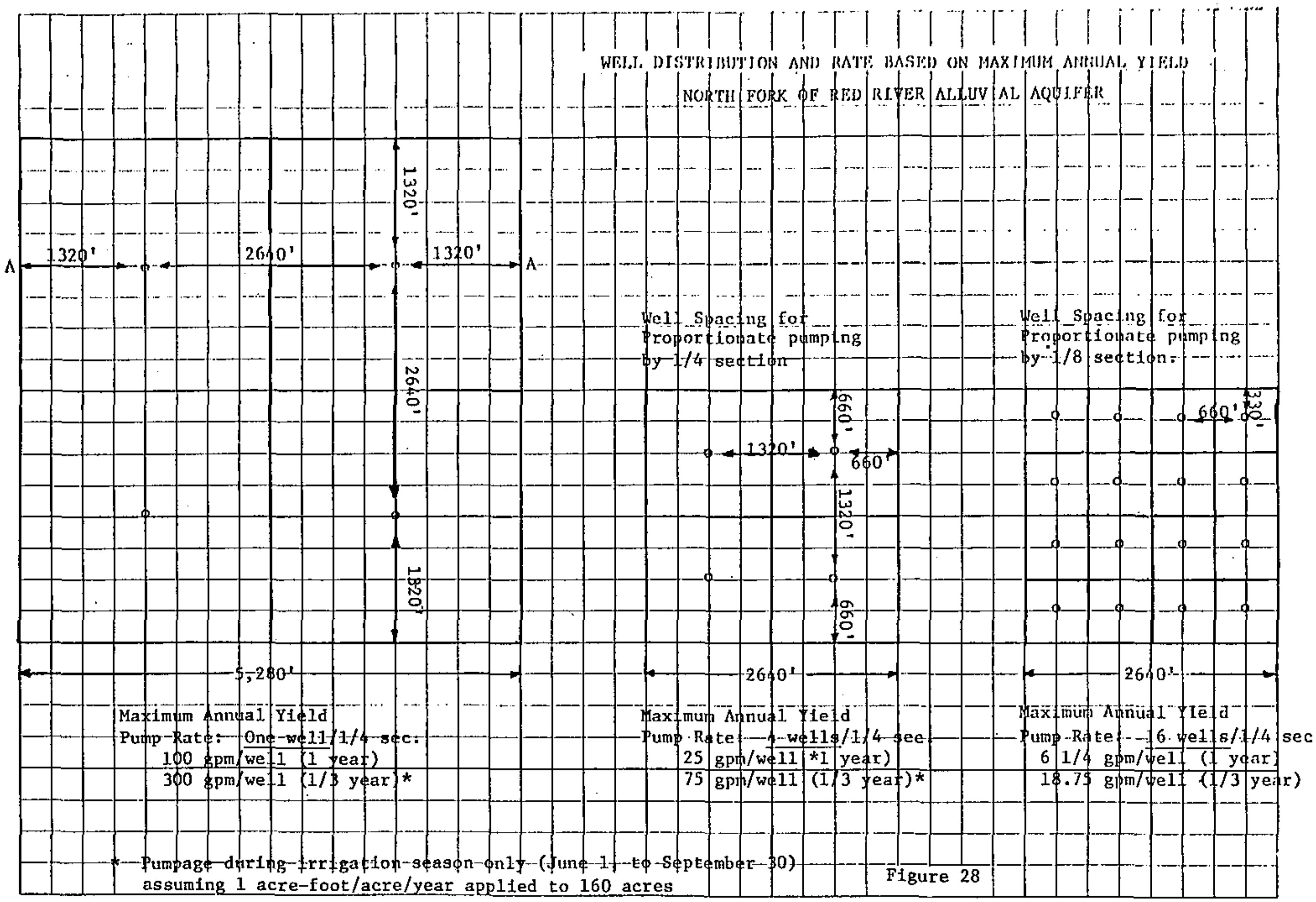
became dry prior to that time. It is assumed in the model that everyone pumps the average maximum legal limit (0.92 acre-feet per acre). This rate corresponds to an instantaneous pumping rate of approximately 300 gallons per minute continously pumped for the 4-month period between June 1 and September 30 of each year as shown in Figure 28. Under these conditions, various parts of the area go dry at different times. This is due to the nonhomogeneous nature of the alluvium (variable transmissivity and corresponding specific yield). The 50% dry criteria was used to accomodate this variability. The wells are turned off in the model when the 5-foot saturated thickness is reached and will turn on periodically to remove accumulation due to recharge. The maximum annual yield is the resulting amount of water recovered over the 20-year period during which wells are being turned off and on as the aquifer is depleted and recharged. Because of these factors, the maximum annual yield does not simply equal the product of allocation rate times the area.

It is assumed that in using the model grid spacing of 160 acres (½ mile between nodes) as shown in Figure 28, one or more wells would be required to pump an annual allocation of 1 acre-foot (0.92 acre-feet) per acre or the total of 160 acre-feet per node (160 acres). The two well rates shown in Figure 28 represent (1) pumping on a continuous basis throughout the year and (2) pumping only during the irrigation season. The well spacings are also shown in Figure 28 and represent one, four and sixteen wells, respectively, In each case, the same amount of water would be pumped but at lower rates per well as the number of wells increases. The need for different numbers of wells for various nodes would reflect the variable nature of the aquifer properties as inferred by the differences in transmissivity shown in Figures 8, 9, and 10. Well yield is directly proportional to transmissivity; thus, in areas of relatively low transmissivity, a greater number of wells would be required to produce the same amount of water as could be produced by fewer wells in areas of higher transmissivity.

Well spacing requirements are also necessary to minimize adverse affects to neighboring wells and to prevent excessive drawdown caused by wells which are too closely spaced. The pump test which was conducted near Granite, Oklahoma was used to estimate a well spacing which could be used in this study area. A spacing of 340 feet was determined graphically for 100 gpm using the drawdown configuration occuring after 50 hours of pumping. The drawdown is shown graphically in Figure 29. The radius of the cone of depression shown in Figure 29 is doubled in order to account for an adjacent well. The estimated well spacing of 340 feet should be extended to accommodate higher pumping rates and because drawdown equilibrium (no change) was not achieved. It is therefore recommended that a minimum well spacing of at least 660 feet be used when a maximum of 20 gpm is pumped assuming that 16 wells are pumped simultaneously to achieve annual allocation pumping for 160 acres; similarly, well spacings of 1320 feet (4 wells) and 2640 feet (1 well) would be used for well rates up to 75 gpm and 300 gpm, respectively (see Figure 28).

The computer simulation results are summarized in the ground-water budget shown in Figures 24 to 27. Simulated changes in saturated thickness, and of areas that become dry within each subbasin (Norther, Central, and Southern sections) between 1973 and 1993, are shown in Figures 30 to 44. Other computer simulation results for the same period include transmissivity and water depth (Appendix A).

Natural pollution is considered negligible throughout the simulation period. This conclusion is based on water quality data derived from



WELL DISTRIBUTION AND RATE BASED ON MAXIMUM ANNUAL YIELD
NORTH FORK OF RED RIVER ALLUVIAL AQUIFER
A 1320' 2640' 1320' A
1320'
2640'
1320'
5,280'
Maximum Annual Yield
Pump Rate: One well/1/4 sec.
100 gpm/well (1 year)
300 gpm/well (1/3 year)*
Well Spacing for Proportionate pumping by 1/4 section
1320'
660'
660'
1320'
660'
2640'
Maximum Annual Yield
Pump Rate: 4 wells/1/4 sec.
25 gpm/well *1 year)
75 gpm/well (1/3 year)*
Well Spacing for Proportionate pumping by 1/8 section.
660'
330'
2640'
Maximum Annual Yield
Pump Rate: 16 wells/1/4 sec.
6 1/4 gpm/well (1 year)
18.75 gpm/well (1/3 year)
* Pumpage during irrigation season only (June 1, to September 30) assuming 1 acre-foot/acre/year applied to 160 acres

Figure 28

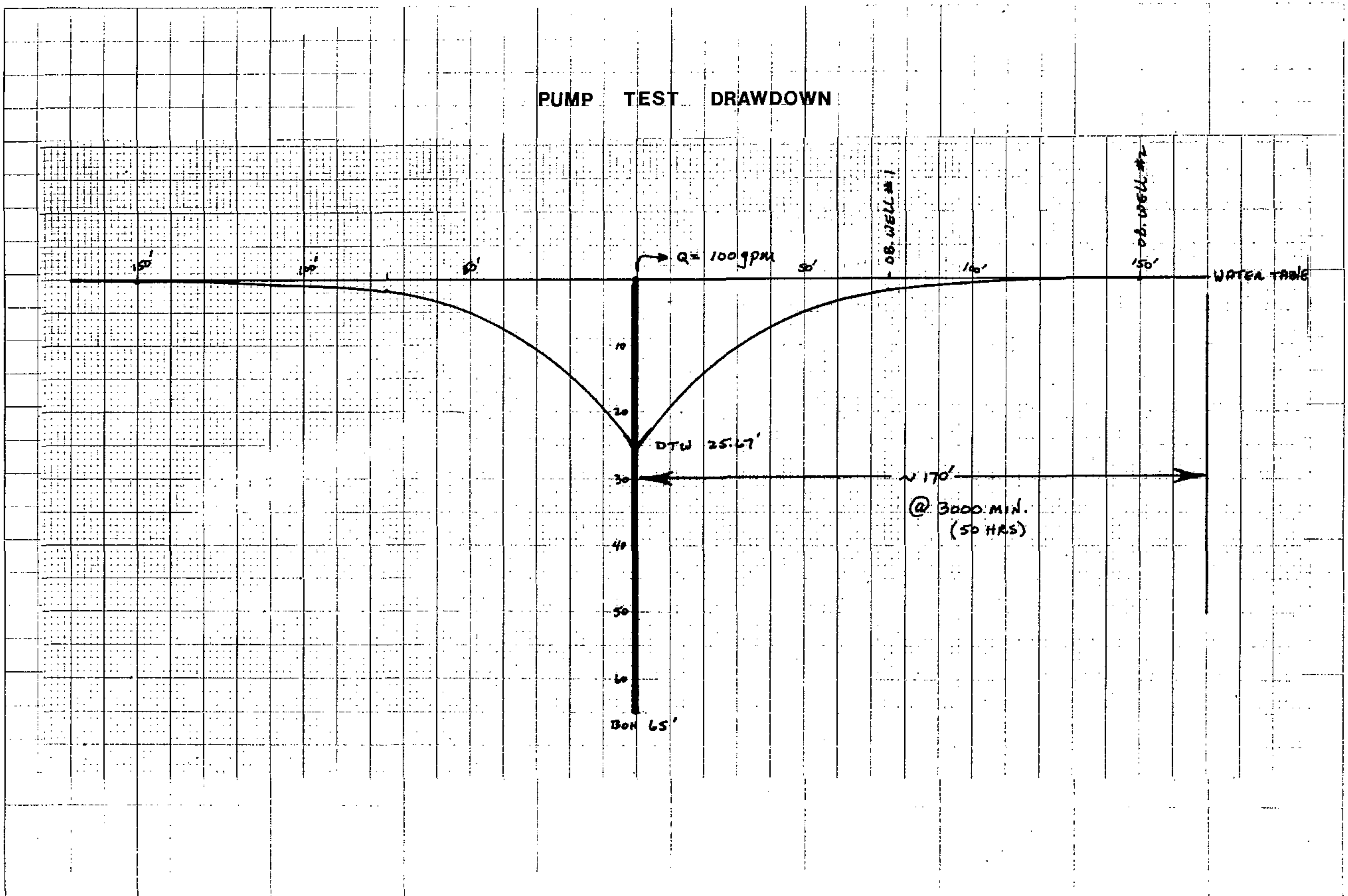

PUMP TEST DRAWDOWN
Q= 100 gpm
OB. WELL #1
OB. WELL #2
WATER TABLE
150'
100'
50'
50'
100'
150'
10
20
30
40
50
60
DTW 25.67'
~170'
@ 3000 MIN.
(50 HRS)
BOH 65'

Figure 29

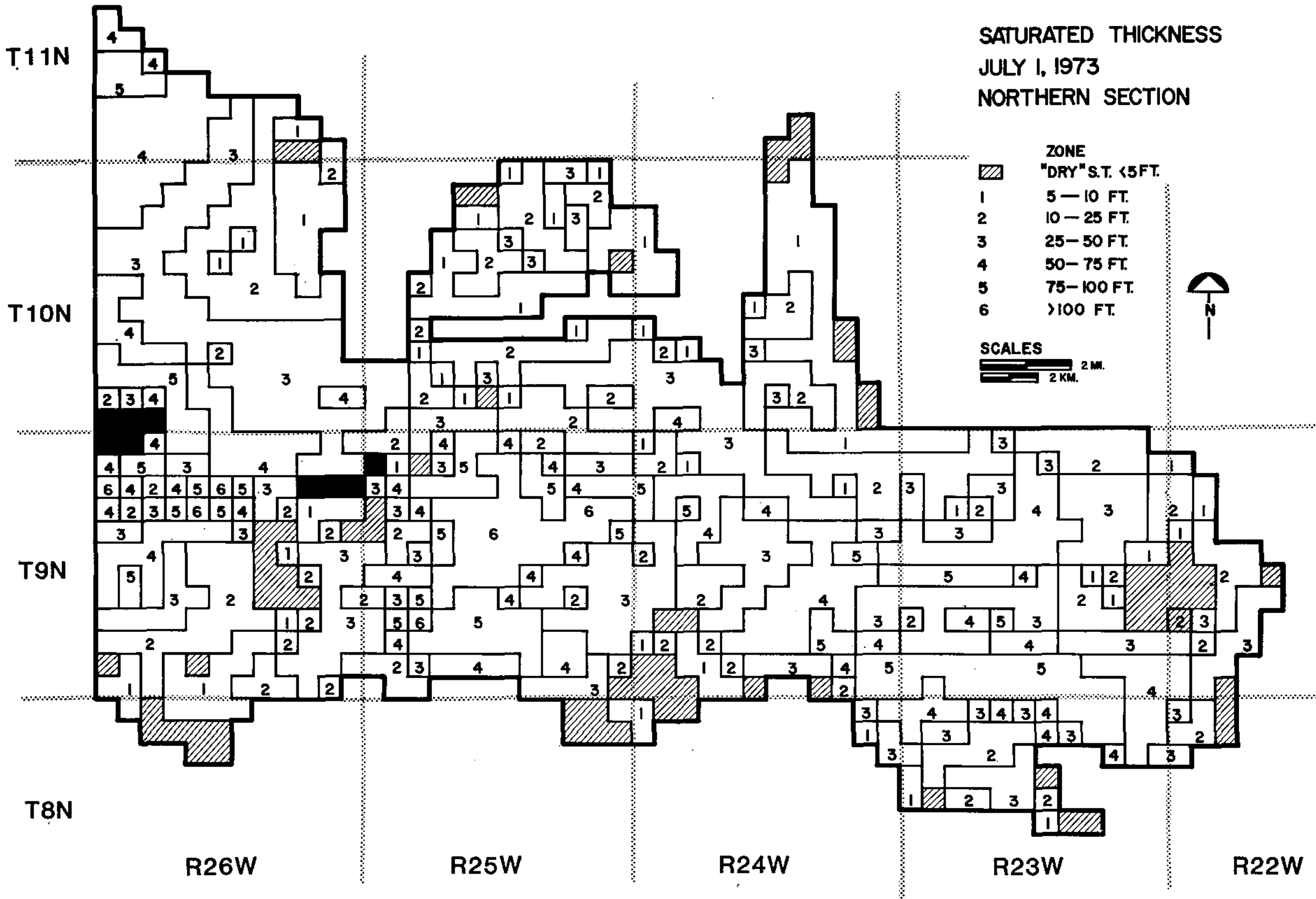

SATURATED THICKNESS
JULY 1, 1973
NORTHERN SECTION
ZONE
"DRY" S.T. <5 FT.
1 5 — 10 FT.
2 10 — 25 FT.
3 25 — 50 FT.
4 50 — 75 FT.
5 75 — 100 FT.
6 >100 FT.
SCALES
2 MI.
2 KM.
N
T11N
T10N
T9N
T8N
R26W
R25W
R24W
R23W
R22W

Figure 30

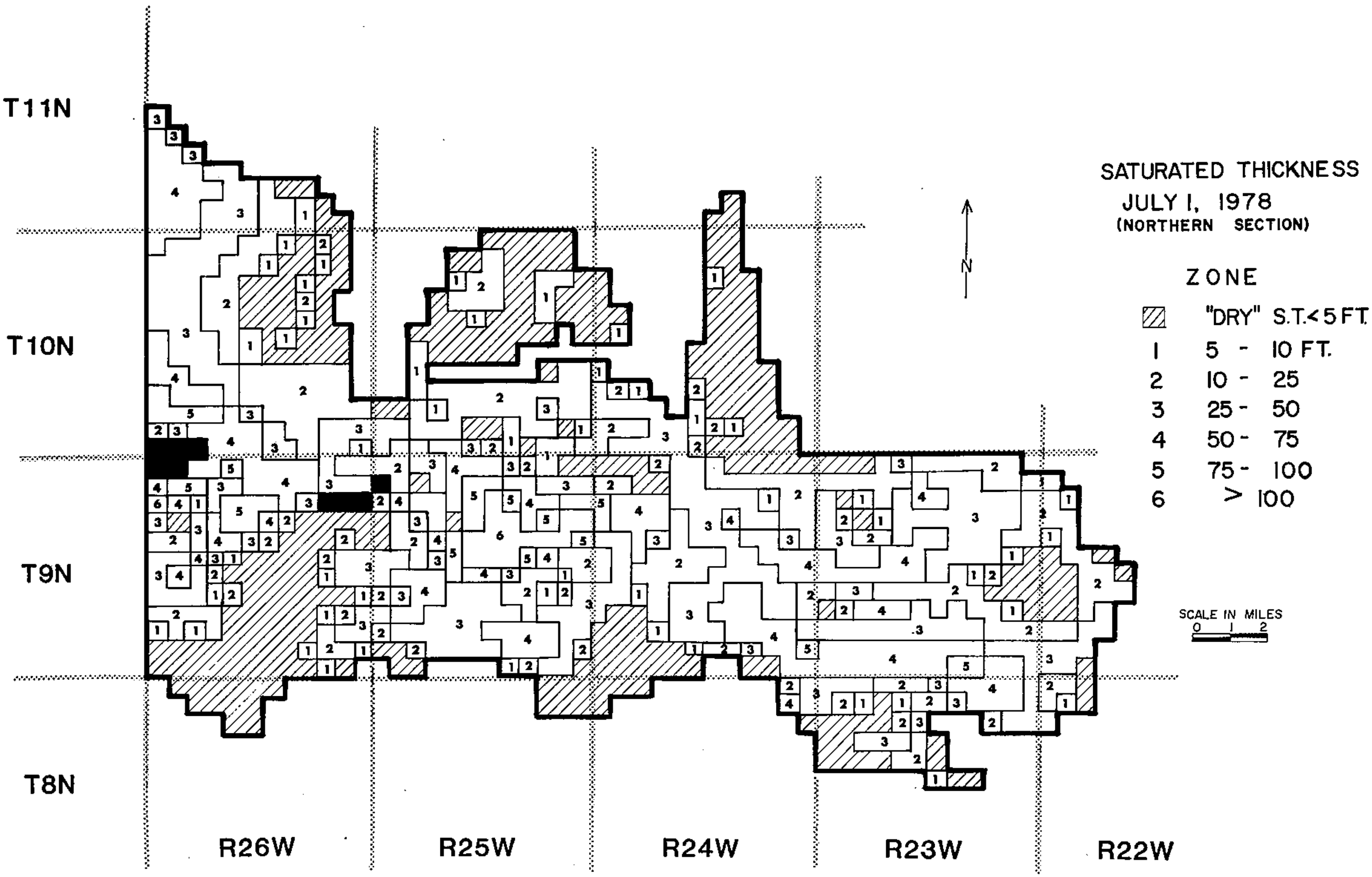

SATURATED THICKNESS
JULY 1, 1978
(NORTHERN SECTION)
ZONE
"DRY" S.T.<5 FT.
1 5 - 10 FT.
2 10 - 25
3 25 - 50
4 50 - 75
5 75 - 100
6 > 100
N
SCALE IN MILES
0 1 2
T11N
T10N
T9N
T8N
R26W
R25W
R24W
R23W
R22W

Figure 31

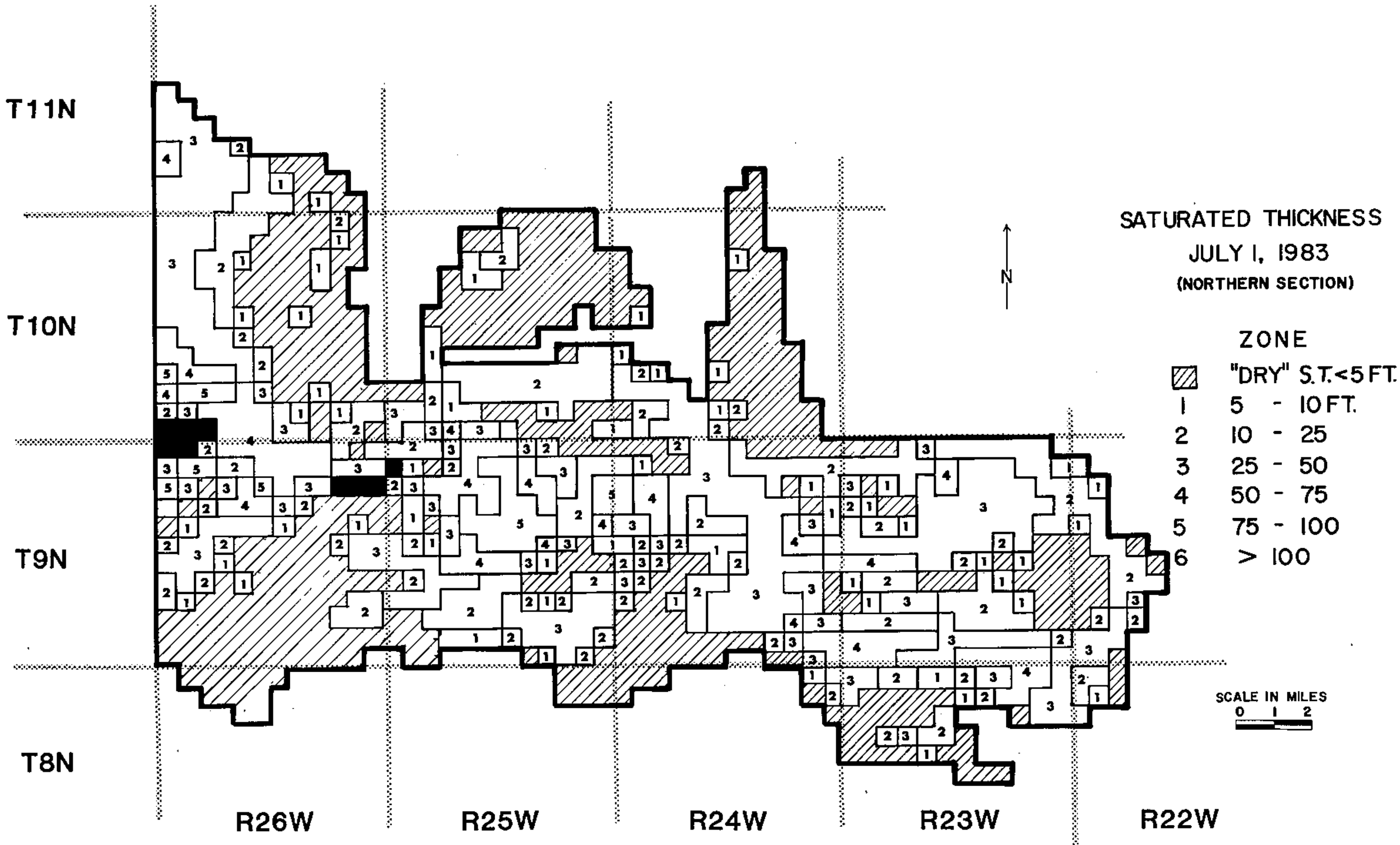

SATURATED THICKNESS
JULY 1, 1983
(NORTHERN SECTION)
N
ZONE
"DRY" S.T.<5 FT.
1 5 - 10 FT.
2 10 - 25
3 25 - 50
4 50 - 75
5 75 - 100
6 > 100
SCALE IN MILES
0 1 2
T11N
T10N
T9N
T8N
R26W
R25W
R24W
R23W
R22W

Figure 32

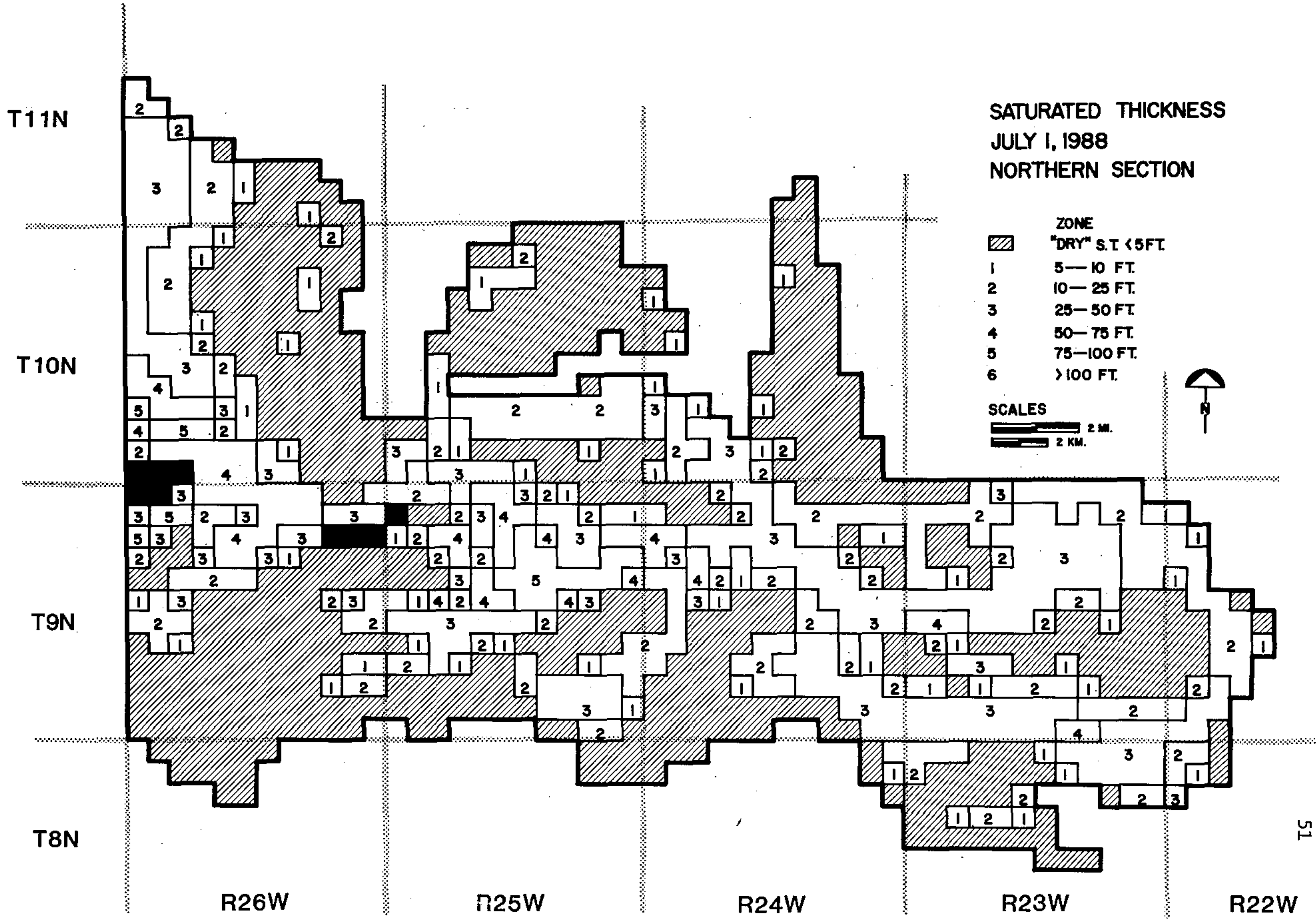

SATURATED THICKNESS
JULY 1, 1988
NORTHERN SECTION
ZONE
"DRY" S.T. <5FT.
1 5—10 FT.
2 10—25 FT.
3 25—50 FT.
4 50—75 FT.
5 75—100 FT.
6 >100 FT.
SCALES
2 MI.
2 KM.
N
T11N
T10N
T9N
T8N
R26W
R25W
R24W
R23W
R22W

Figure 33

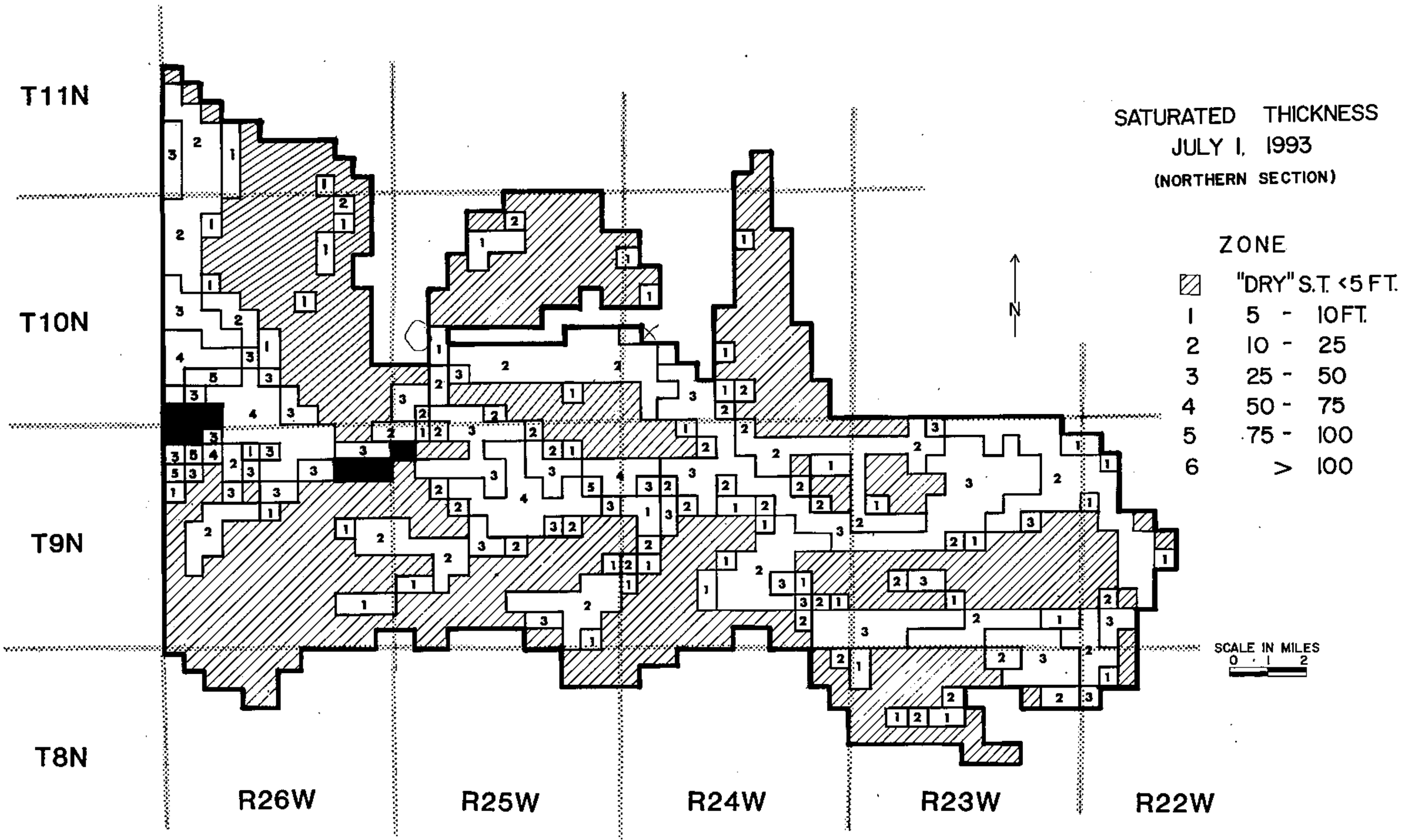

SATURATED THICKNESS
JULY 1, 1993
(NORTHERN SECTION)
ZONE
"DRY" S.T. <5 FT.
1 5 - 10 FT.
2 10 - 25
3 25 - 50
4 50 - 75
5 75 - 100
6 > 100
N
SCALE IN MILES
0 1 2
T11N
T10N
T9N
T8N
R26W
R25W
R24W
R23W
R22W

Figure 34

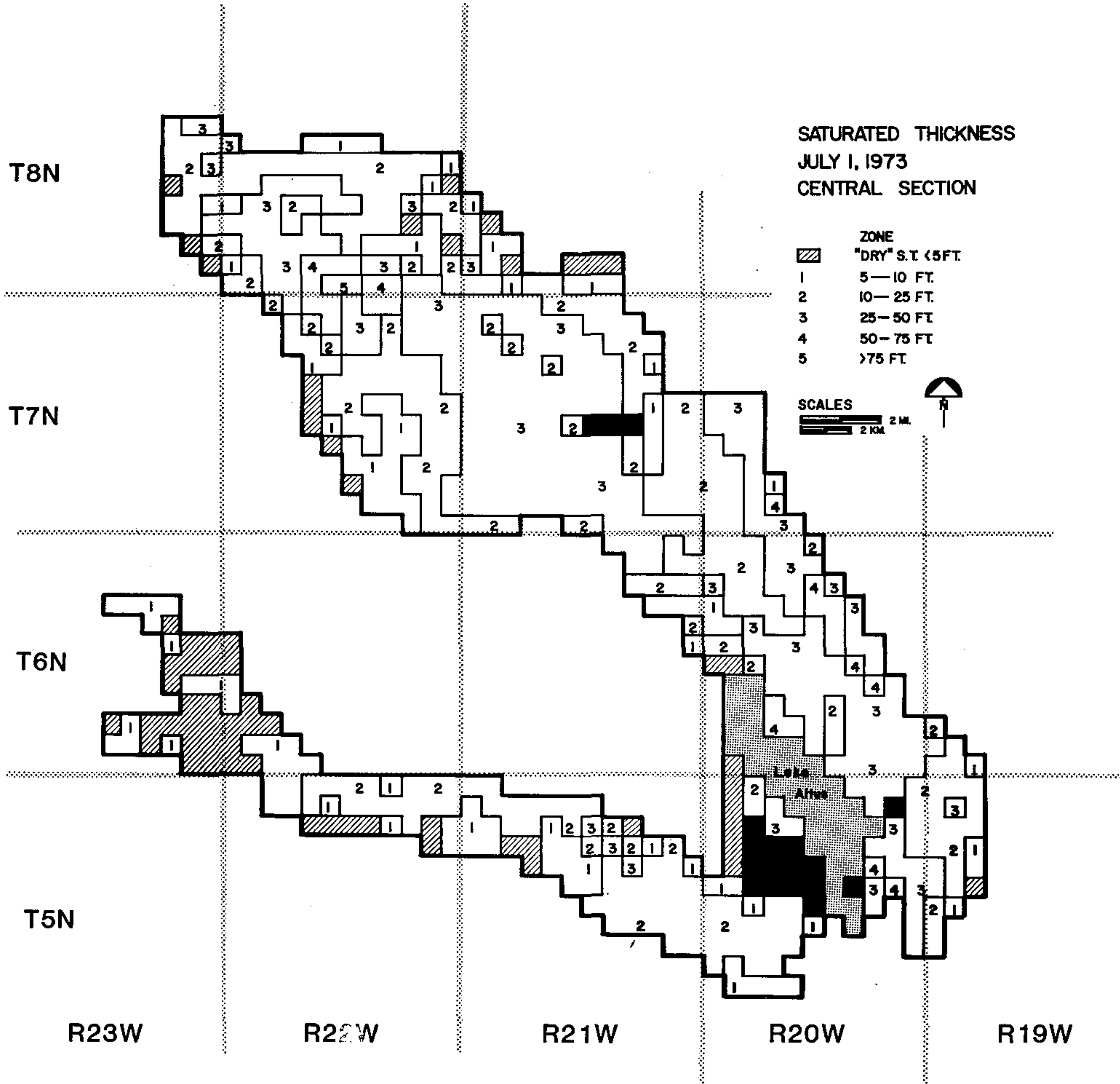

SATURATED THICKNESS
JULY 1, 1973
CENTRAL SECTION
ZONE
"DRY" S.T. <5 FT.
1 5—10 FT.
2 10—25 FT.
3 25—50 FT.
4 50—75 FT.
5 >75 FT.
SCALES
2 MI.
2 KM.
N
Lake Altus
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W

Figure 35

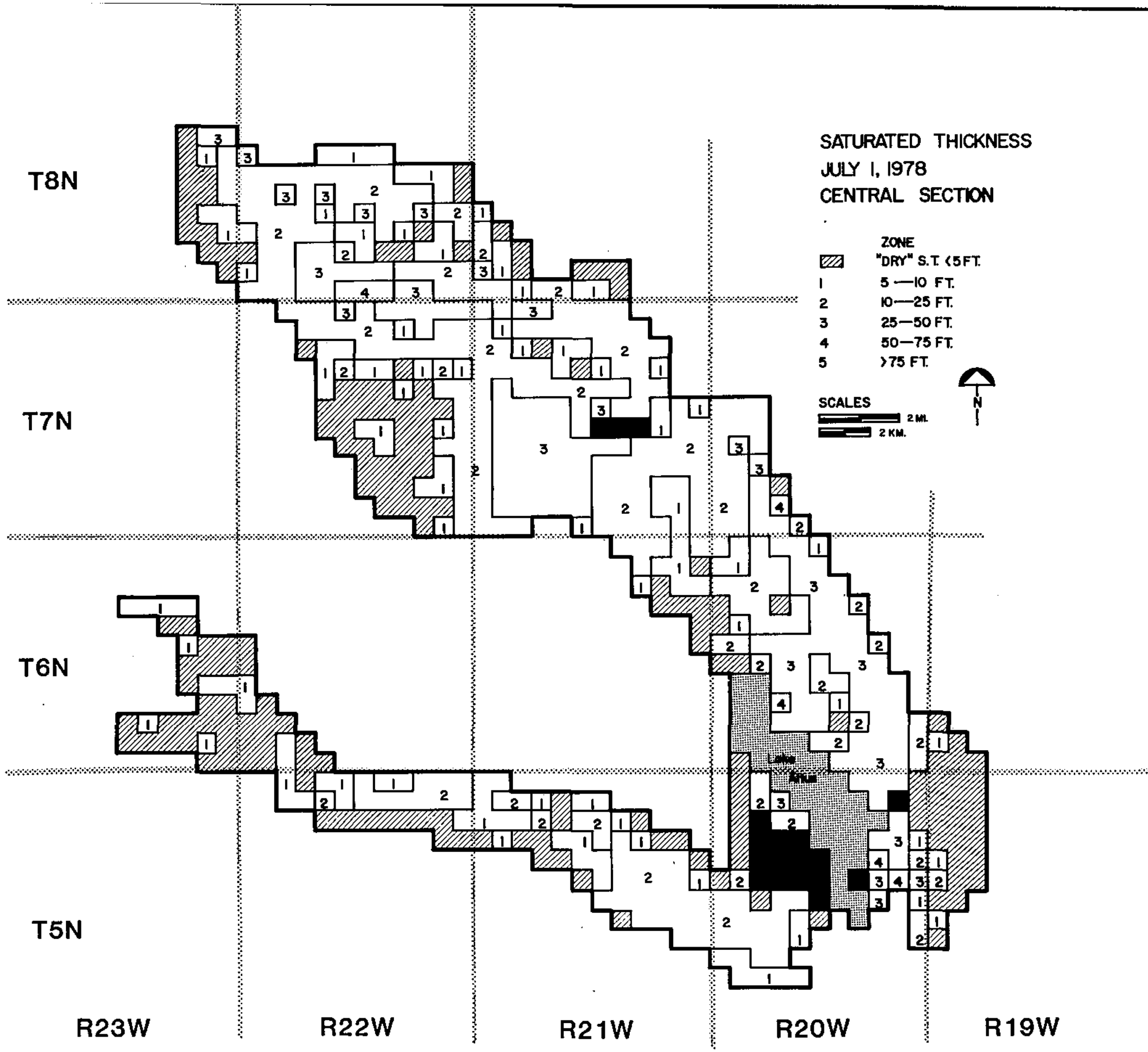

SATURATED THICKNESS
JULY 1, 1978
CENTRAL SECTION
ZONE
"DRY" S.T. <5 FT.
1 5—10 FT.
2 10—25 FT.
3 25—50 FT.
4 50—75 FT.
5 >75 FT.
SCALES
2 MI.
2 KM.
N
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W

Figure 36

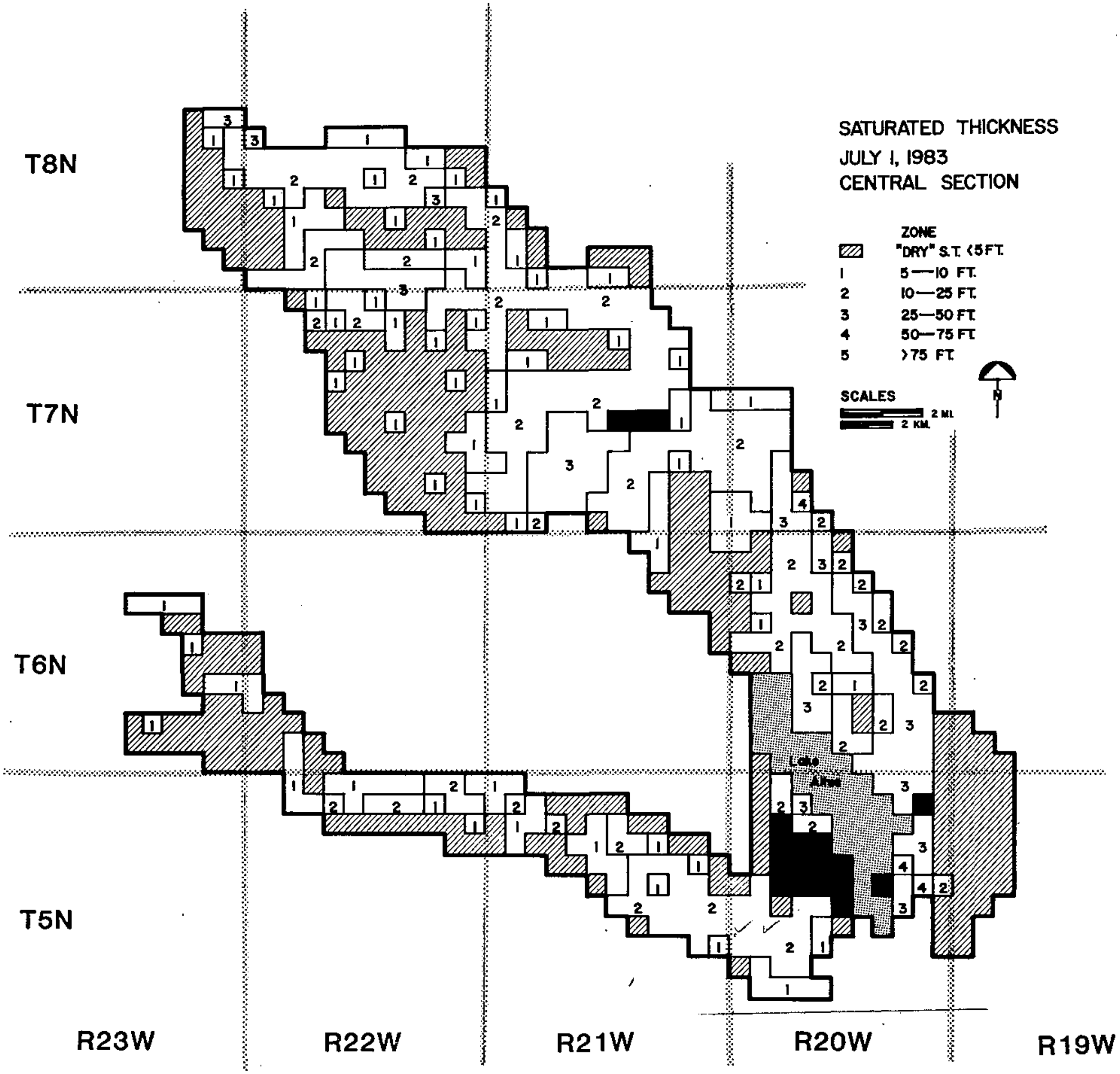

SATURATED THICKNESS
JULY 1, 1983
CENTRAL SECTION
ZONE
"DRY" S.T. <5 FT.
1 5—10 FT.
2 10—25 FT.
3 25—50 FT.
4 50—75 FT.
5 >75 FT.
SCALES
2 MI.
2 KM.
N
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W

Figure 37

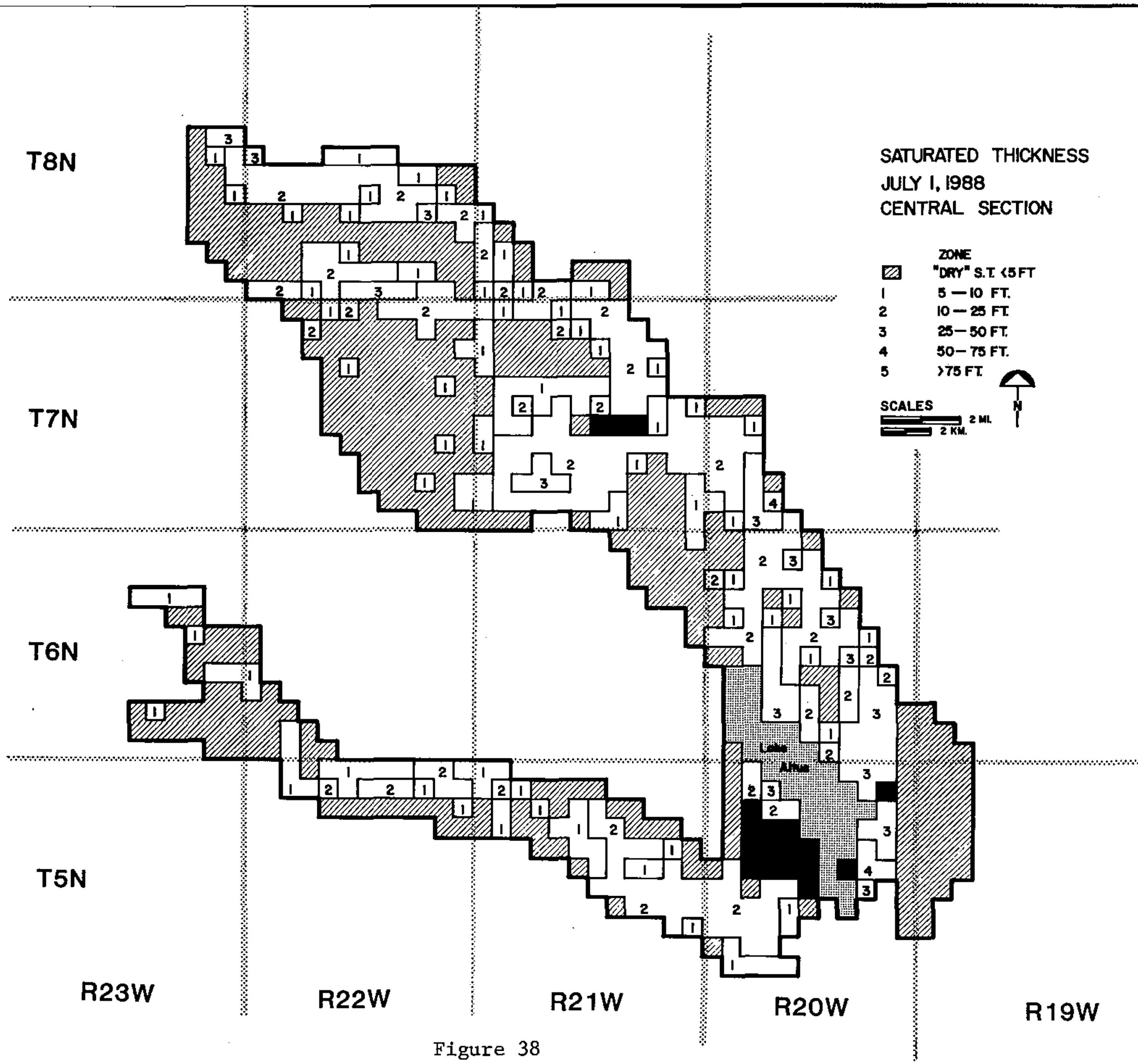

SATURATED THICKNESS
JULY 1, 1988
CENTRAL SECTION
ZONE
"DRY" S.T. <5 FT
1 5 — 10 FT.
2 10 — 25 FT.
3 25 — 50 FT.
4 50 — 75 FT.
5 >75 FT.
SCALES
2 MI.
2 KM.
N
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W
Lake Altus

Figure 38

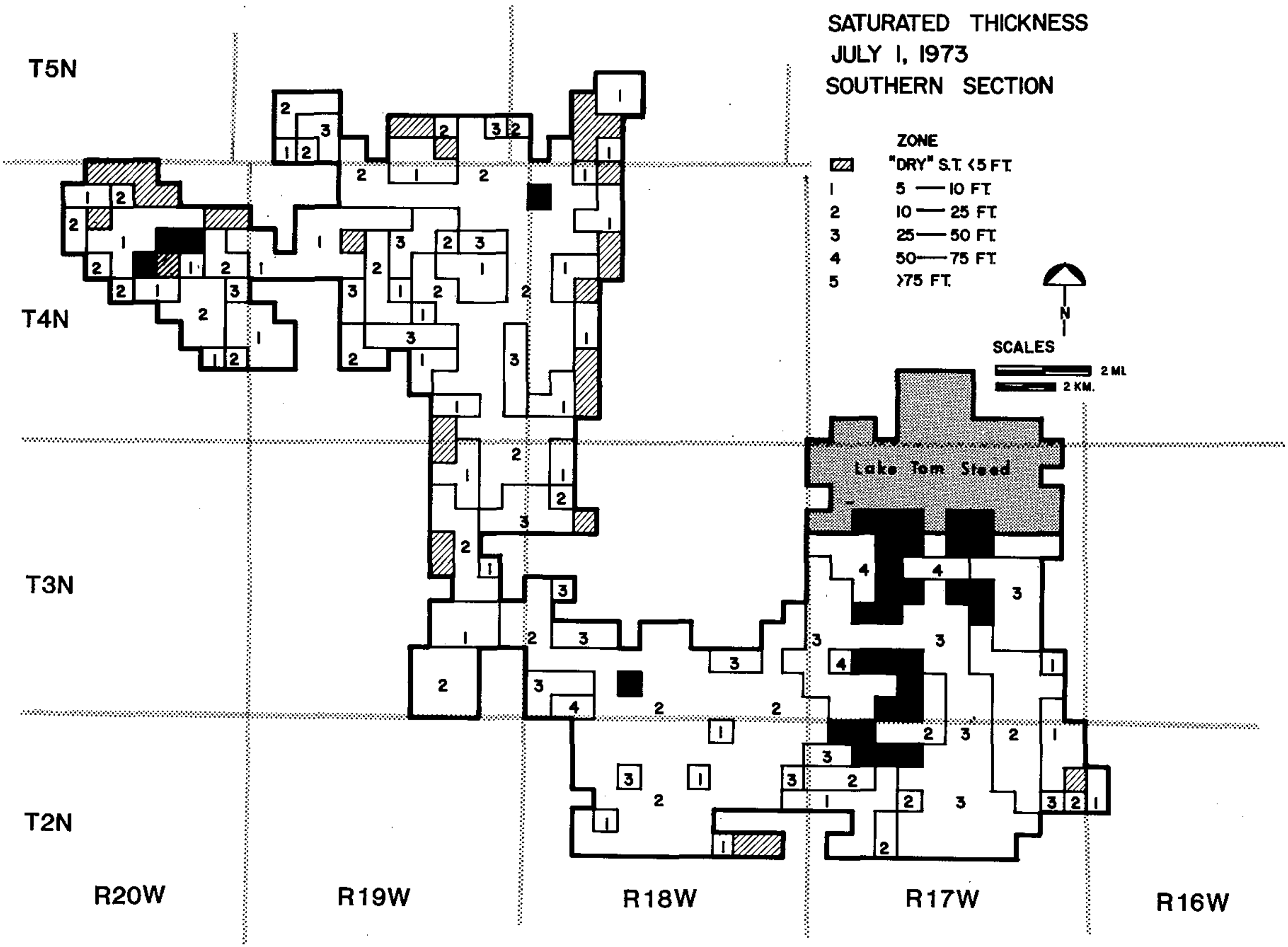

SATURATED THICKNESS
JULY 1, 1973
SOUTHERN SECTION
ZONE
"DRY" S.T. <5 FT.
1 5 — 10 FT.
2 10 — 25 FT.
3 25 — 50 FT.
4 50 — 75 FT.
5 >75 FT.
N
SCALES
2 MI.
2 KM.
Lake Tom Steed
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W
R16W

Figure 40

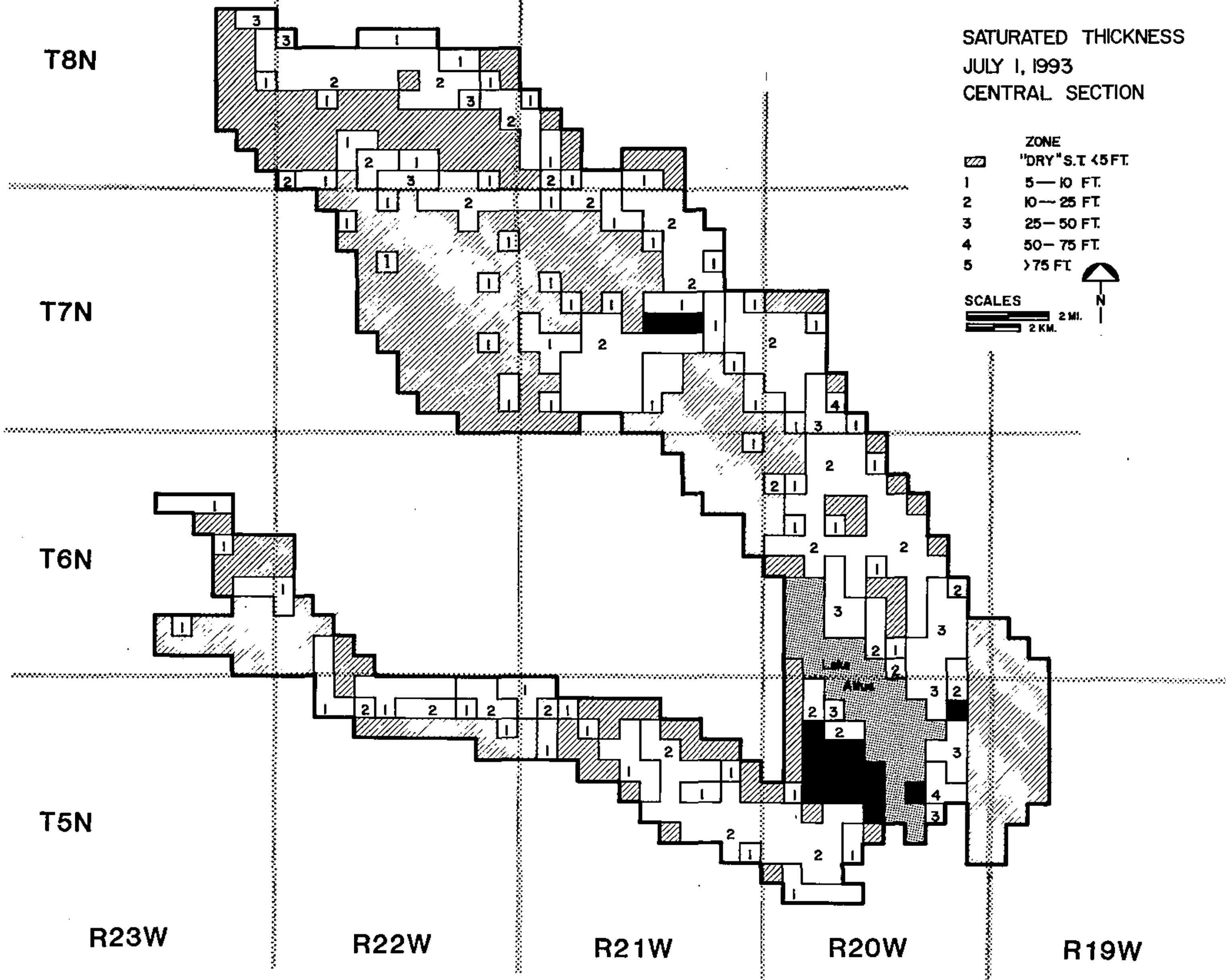
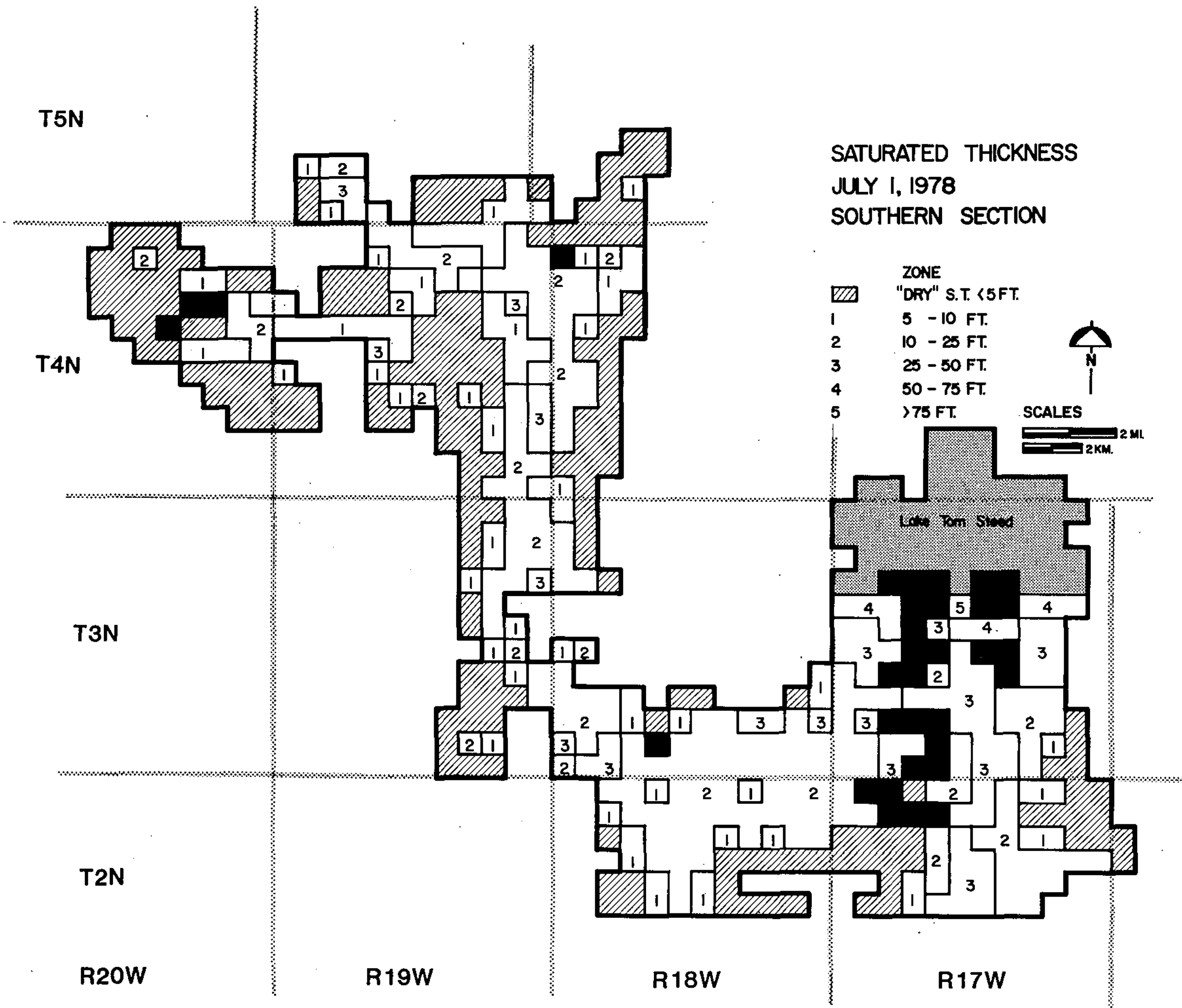

SATURATED THICKNESS
JULY 1, 1993
CENTRAL SECTION
ZONE
"DRY" S.T. <5 FT.
1 5—10 FT.
2 10—25 FT.
3 25—50 FT.
4 50—75 FT.
5 >75 FT.
N
SCALES
2 MI.
2 KM.
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W
Lake Altus

Figure 39



SATURATED THICKNESS
JULY 1, 1978
SOUTHERN SECTION
ZONE
"DRY" S.T. <5 FT.
1 5 - 10 FT.
2 10 - 25 FT.
3 25 - 50 FT.
4 50 - 75 FT.
5 >75 FT.
N
SCALES
2 MI.
2 KM.
Lake Tom Steed
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W

Figure 41

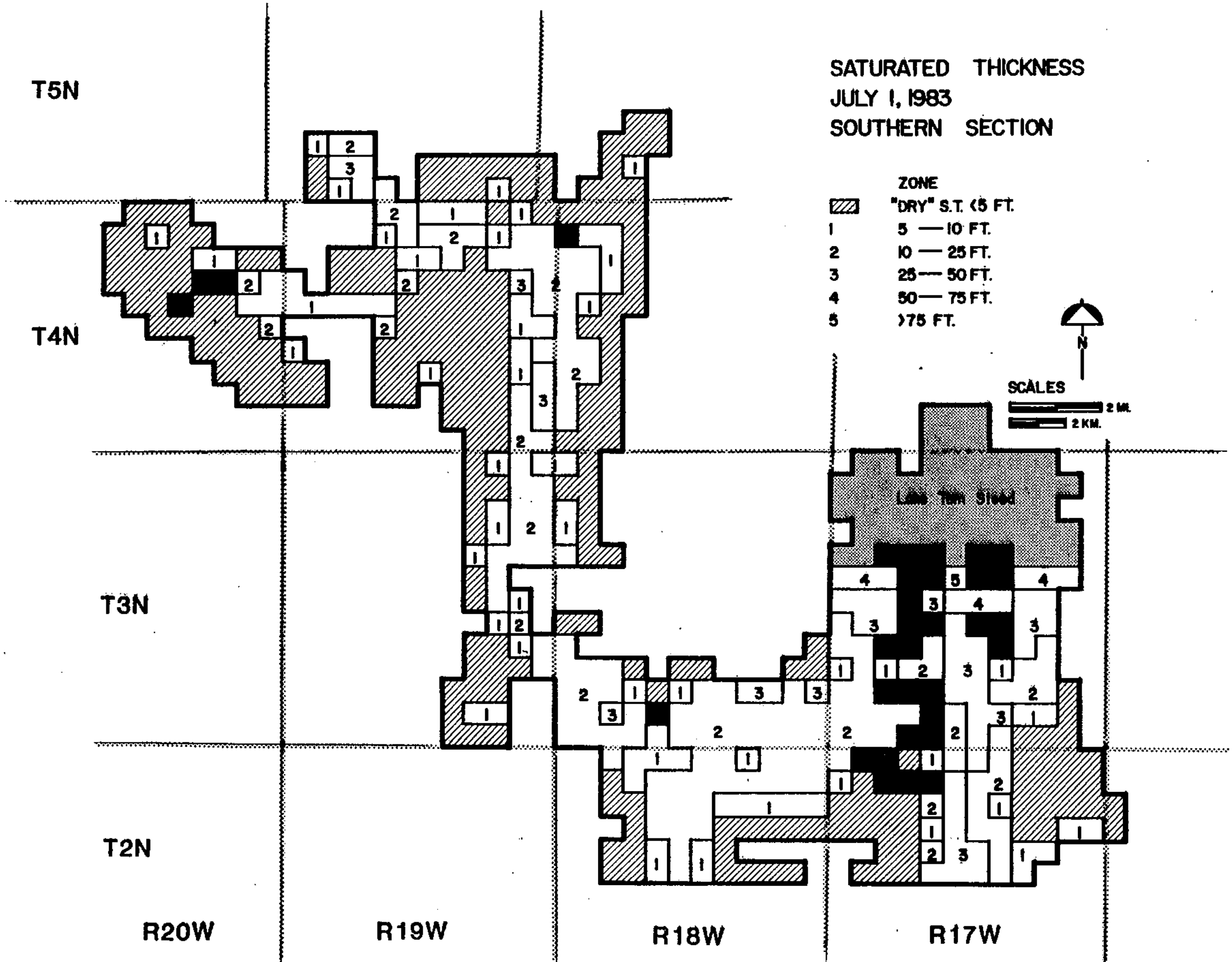

SATURATED THICKNESS
JULY 1, 1983
SOUTHERN SECTION
ZONE
"DRY" S.T. <5 FT.
1 5 — 10 FT.
2 10 — 25 FT.
3 25 — 50 FT.
4 50 — 75 FT.
5 >75 FT.
N
SCALES
2 MI.
2 KM.
Lake Tom Steed
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W

Figure 42

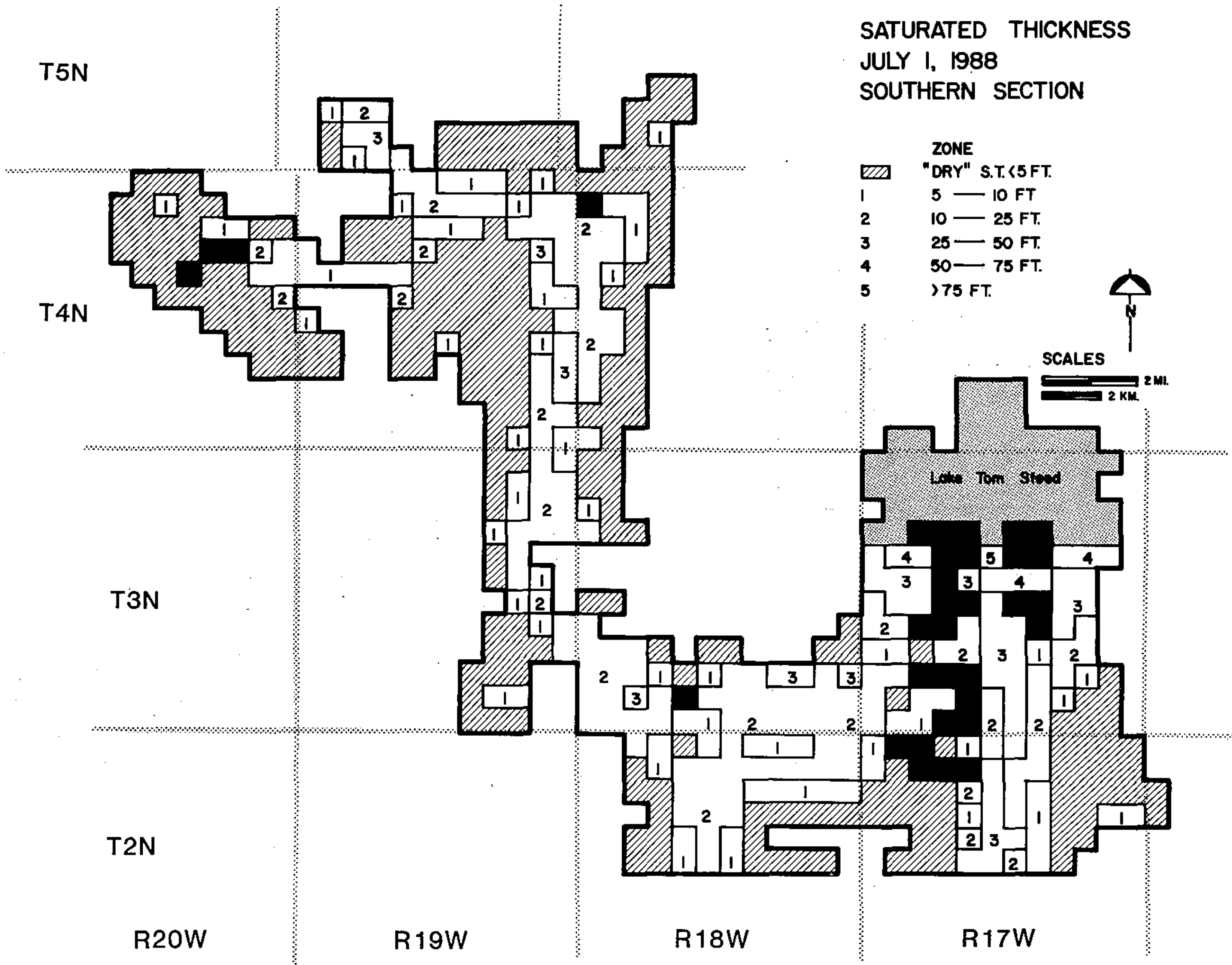

SATURATED THICKNESS
JULY 1, 1988
SOUTHERN SECTION
ZONE
"DRY" S.T.<5 FT.
1 5 — 10 FT
2 10 — 25 FT.
3 25 — 50 FT.
4 50 — 75 FT.
5 >75 FT.
N
SCALES
2 MI.
2 KM.
Lake Tom Steed
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W

Figure 43

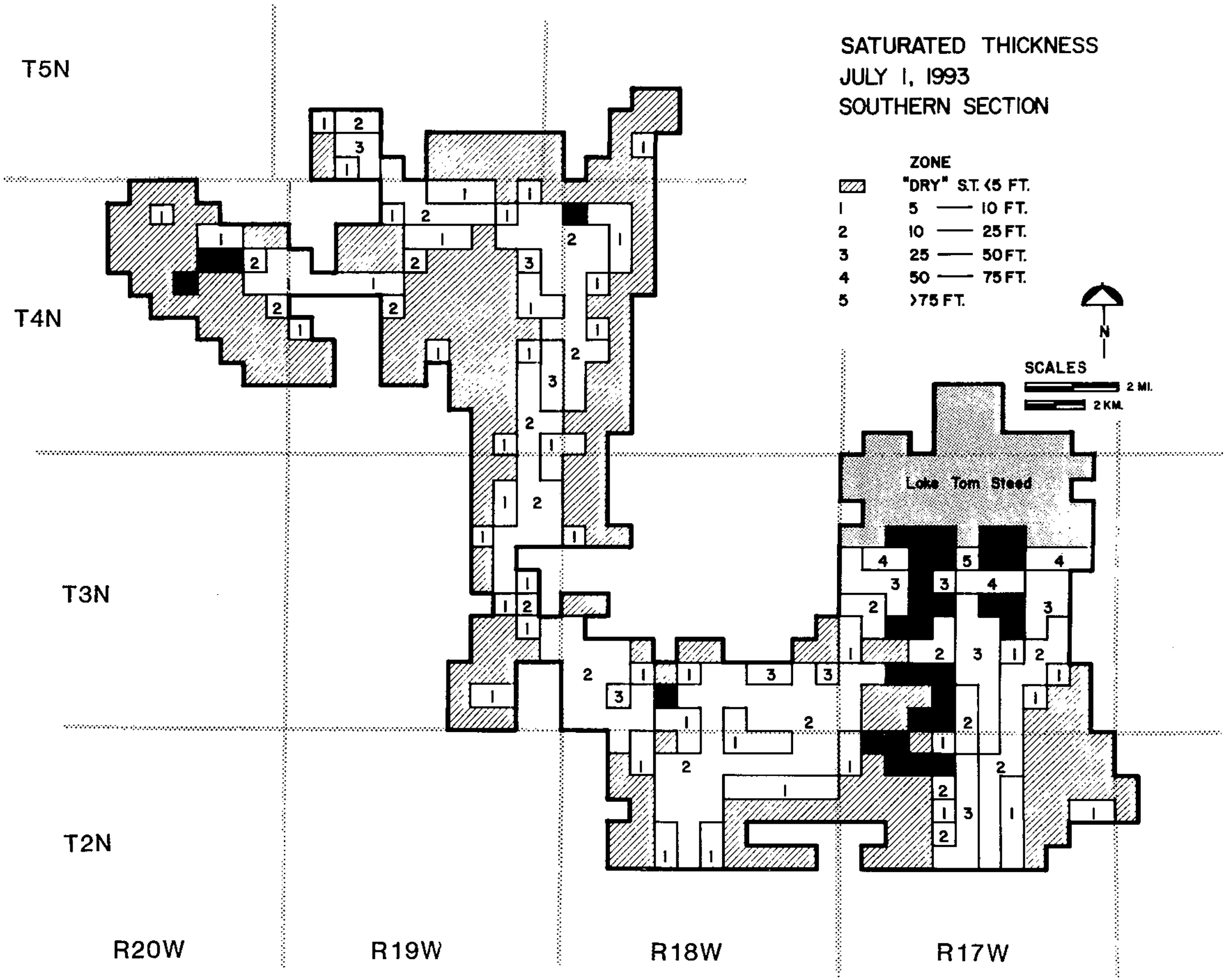

SATURATED THICKNESS
JULY 1, 1993
SOUTHERN SECTION
ZONE
"DRY" S.T. <5 FT.
1 5 — 10 FT.
2 10 — 25 FT.
3 25 — 50 FT.
4 50 — 75 FT.
5 >75 FT.
N
SCALES
2 MI.
2 KM.
Lake Tom Steed
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W

Figure 44

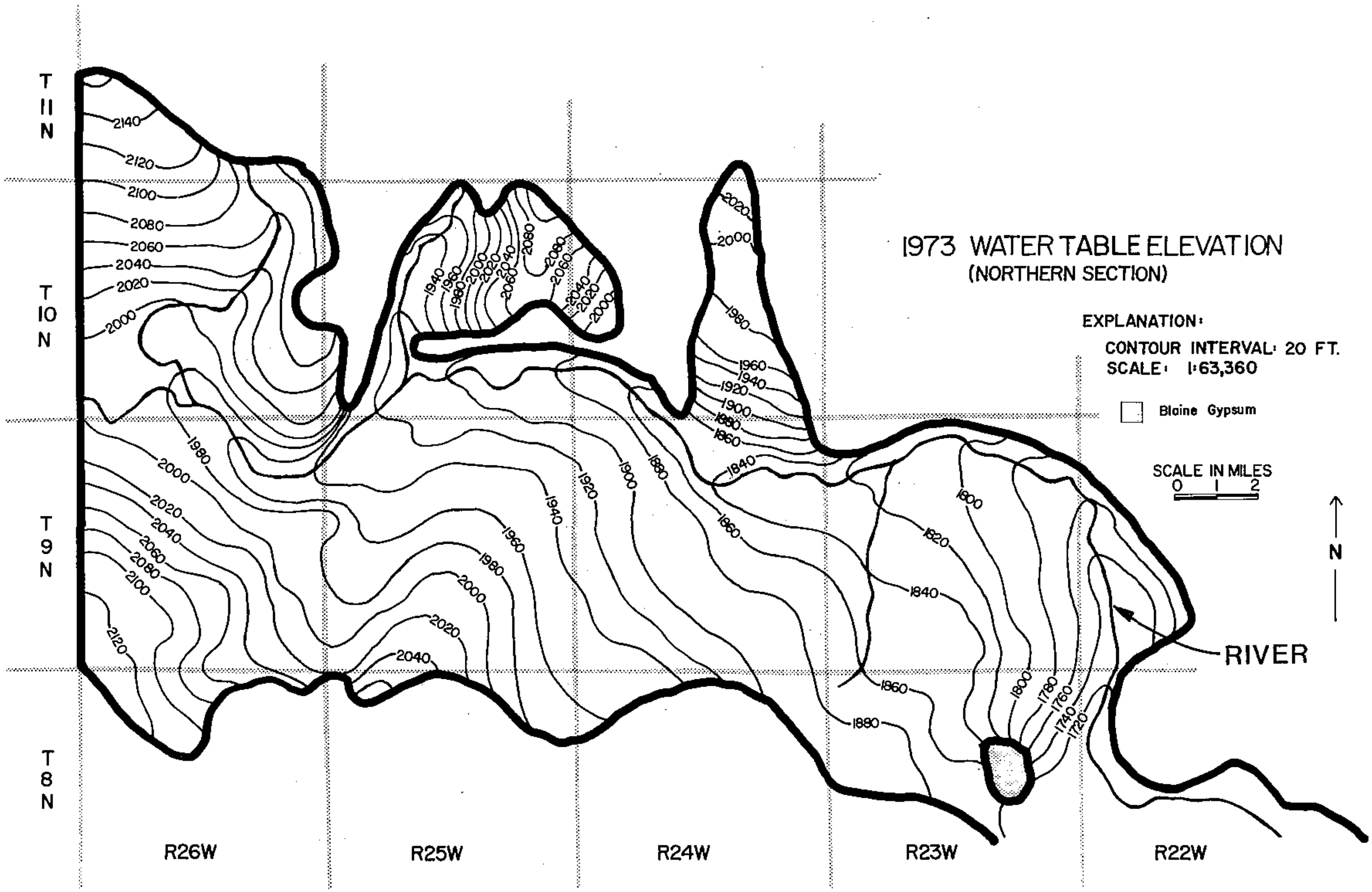
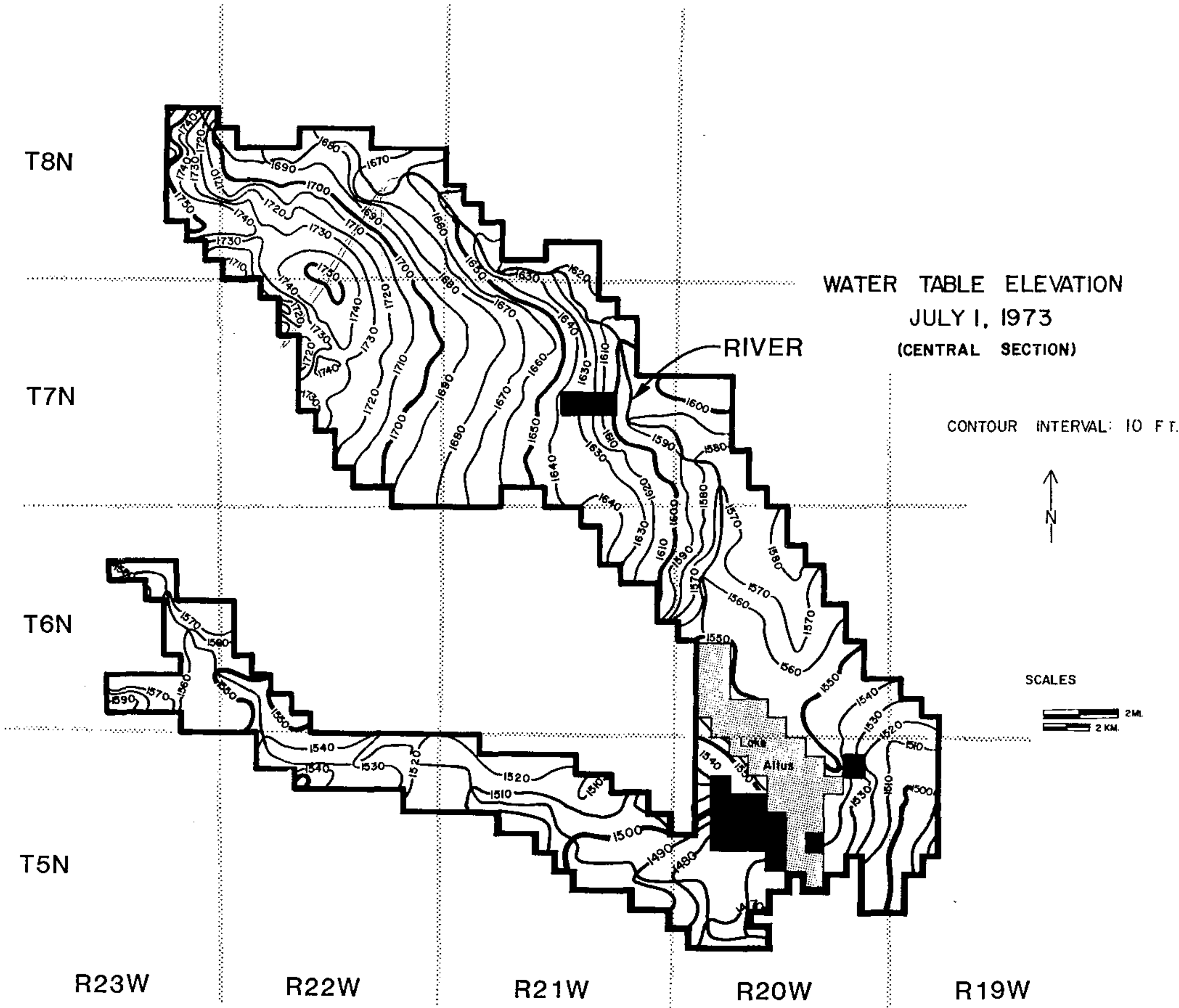

1973 WATER TABLE ELEVATION
(NORTHERN SECTION)
EXPLANATION:
CONTOUR INTERVAL: 20 FT.
SCALE: 1:63,360
Blaine Gypsum
SCALE IN MILES
0 1 2
N
RIVER
T 11 N
T 10 N
T 9 N
T 8 N
R26W
R25W
R24W
R23W
R22W

Figure 45



WATER TABLE ELEVATION
JULY 1, 1973
(CENTRAL SECTION)
RIVER
CONTOUR INTERVAL: 10 FT.
N
SCALES
2 MI.
2 KM.
Lake
Altus
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W

Figure 46

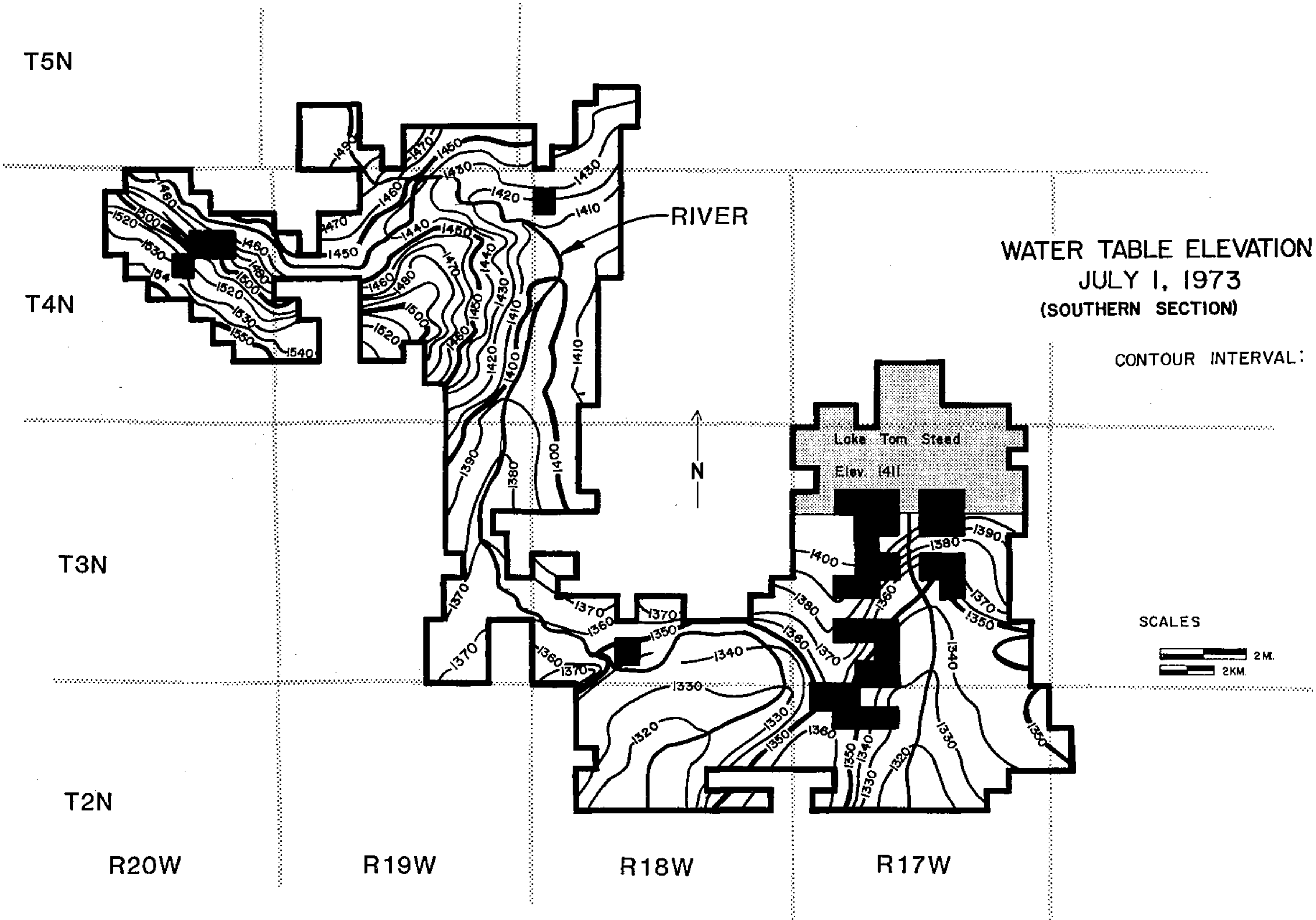

T5N
T4N
T3N
T2N
RIVER
WATER TABLE ELEVATION
JULY 1, 1973
(SOUTHERN SECTION)
CONTOUR INTERVAL: 10 FT.
N
Lake Tom Steed
Elev. 1411
SCALES
2 M.
2 KM.
R20W
R19W
R18W
R17W

Figure 47

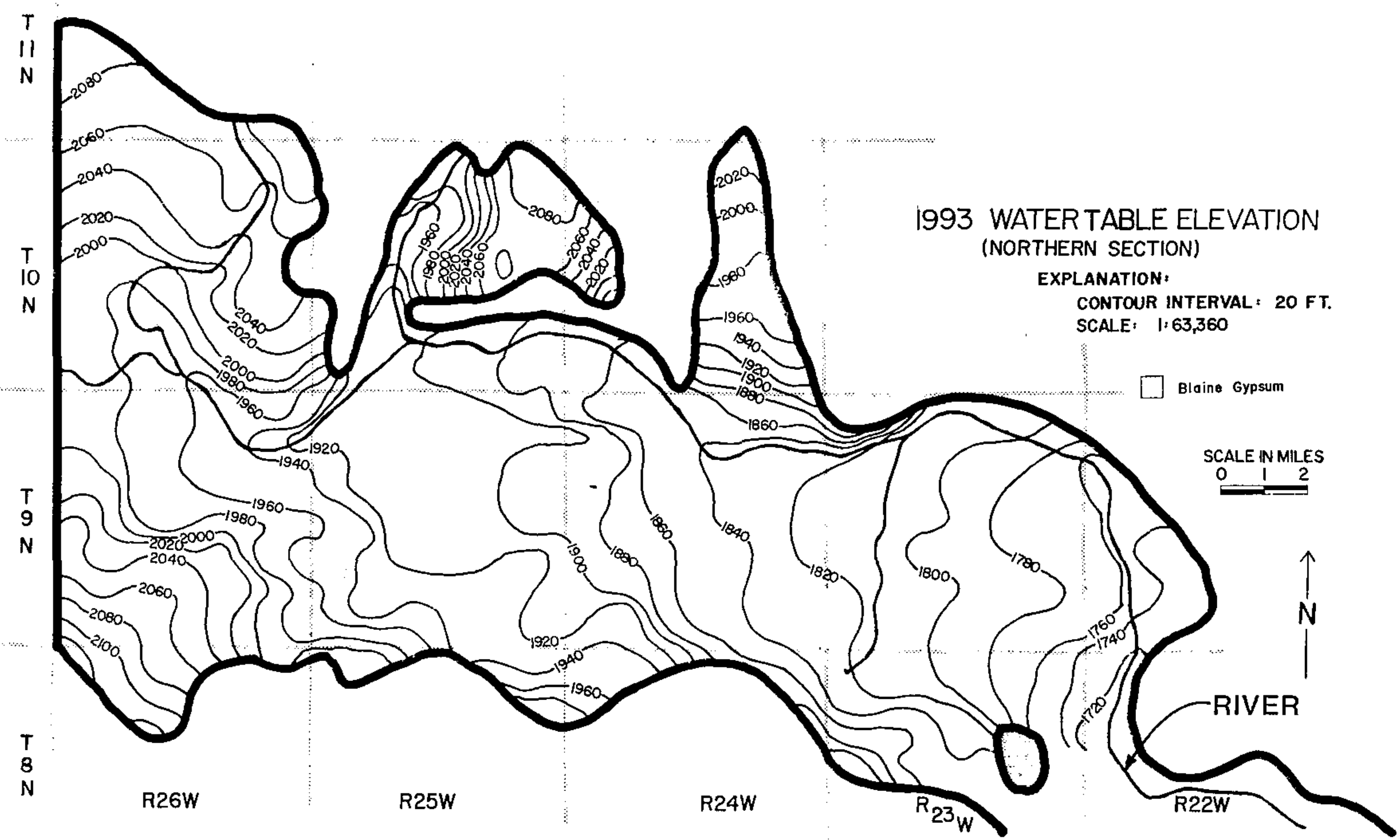

1993 WATER TABLE ELEVATION
(NORTHERN SECTION)
EXPLANATION:
CONTOUR INTERVAL: 20 FT.
SCALE: 1:63,360
Blaine Gypsum
SCALE IN MILES
0 1 2
N
RIVER
T 11 N
T 10 N
T 9 N
T 8 N
R26W
R25W
R24W
R23W
R22W

Figure 48

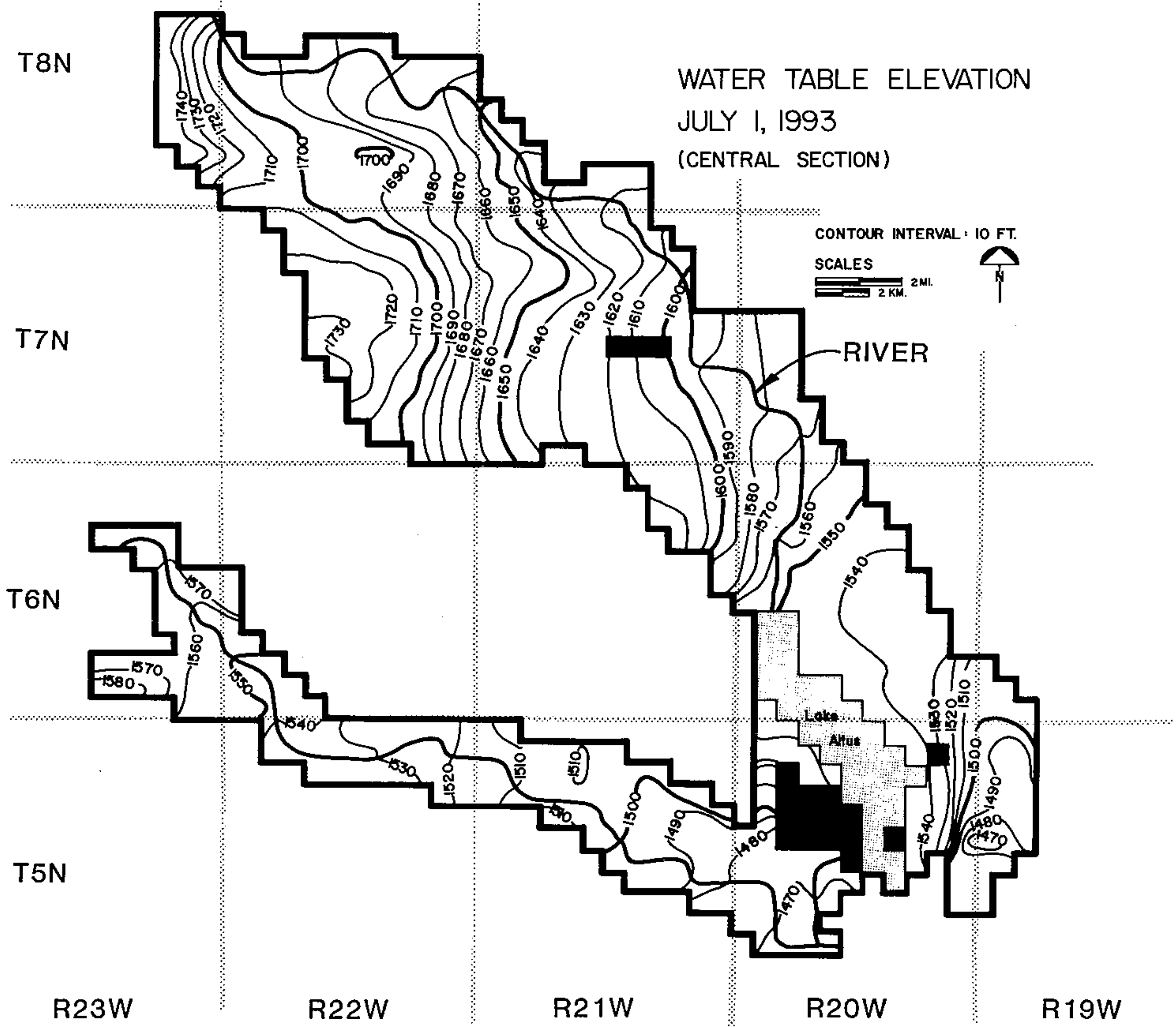
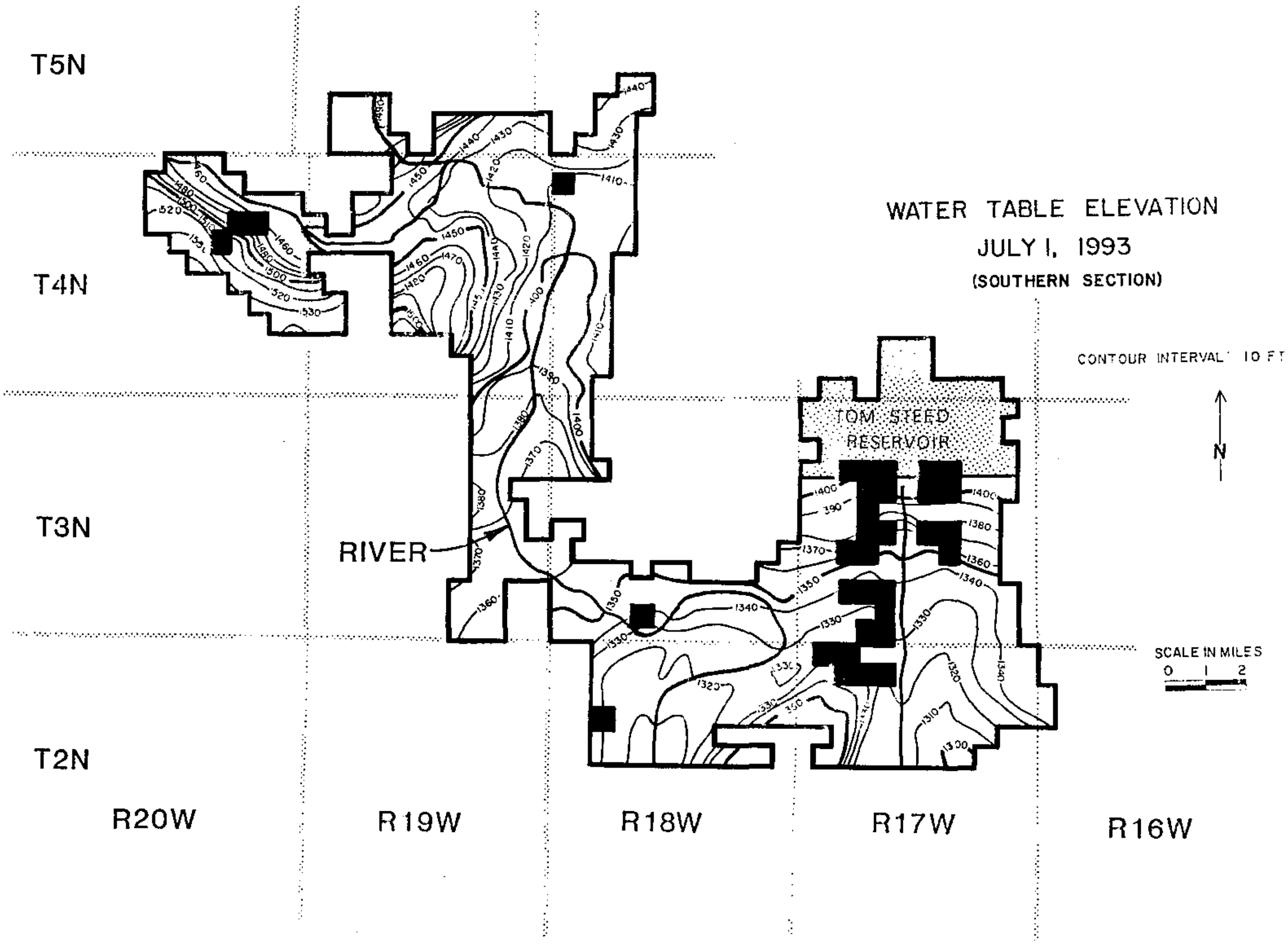

WATER TABLE ELEVATION
JULY 1, 1993
(CENTRAL SECTION)
CONTOUR INTERVAL: 10 FT.
SCALES
2 MI.
2 KM.
N
RIVER
Lake Altus
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W

Figure 49



WATER TABLE ELEVATION
JULY 1, 1993
(SOUTHERN SECTION)
CONTOUR INTERVAL 10 FT
N
SCALE IN MILES
0 1 2
TOM STEED RESERVOIR
RIVER
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W
R16W

Figure 50

Havens (1977) and Carr and Bergman (1976), and from an assessment of the 1973 and 1993 simulated water-table elevations shown in Figures 45 through 50. Mean values of total dissolved solids vary within the aquifer from 843 ppm in Jackson, Kiowa, and southern Greer Counties to 419 ppm in northern Greer and Beckham Counties. Twenty-five percent of the sampling points are higher in concentration than those indicated above. Stream quality is variable between high and low flows and between northern and southern areas of the aquifer. Data was acquired from the "Water Resources Data for Oklahoma" published by the US Geological Survey (USGS, 1973-1977). Concentrations of total dissolved solids average between 1,210 ppm (high flow) to 6,465 ppm (low flow) for the southern edge of the aquifer area (near Hedrick) and between 1,519 ppm (high flow) and 2,195 ppm (low flow) for the southern edge of the Northern section (near Carter). The higher salinity concentrations in the southern river reaches are due to high sulfate and sodium chloride concentrations derived from the Permian redbed formations (Dog Creek Shale, Blaine Gypsum and Flowerpot Shale) occuring in the Northern and Central sections of the aquifer.

The main source of salinity to the ground water would be stream flow when ground water was recharged by the streams or lakes during influent conditions. With the exception of lakes, these conditions generally do not exist when evaluating the 1993 water-head elevation maps in Figures 48, 49, and 50. Ground-water pumping apparently does not induce influent conditions over a large regional extent as noted on the 1993 water table maps. However, influent conditions will occur for short periods during high flow periods. Therefore, in general, influent conditions will occur only locally near Lake Altus and Lake Tom Steed, or occur during high flows when lower salinity concentrations can be expected. Under these circumstances, natural pollution events will be temporary and restricted to the areas adjacent to the river or lake; therefore, natural pollution is not expected to be induced by regional pumping if the recommended allocation rate based on maximum annual yield is assumed.

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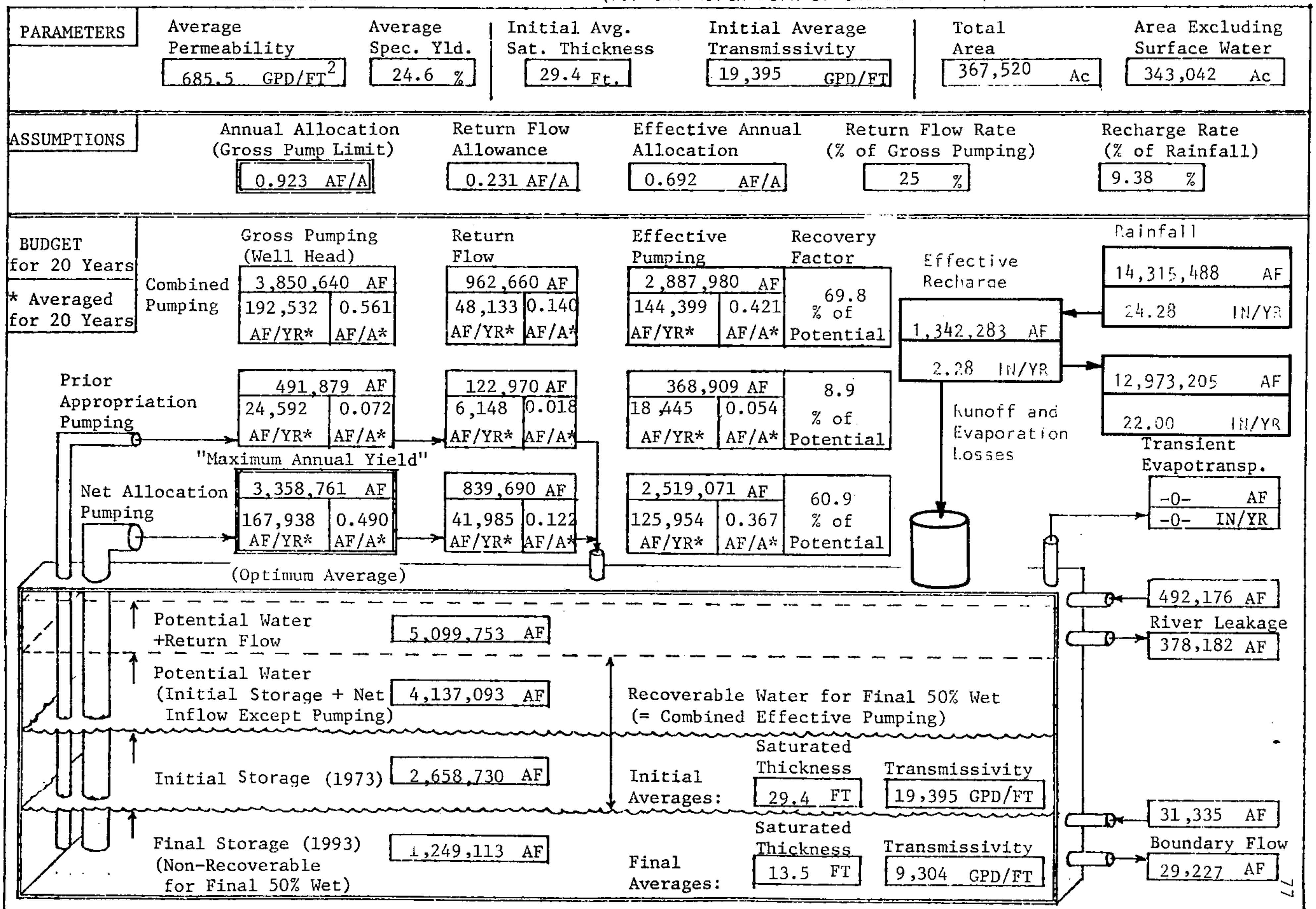
APPENDIX A

COMPUTER SIMULATION RESULTS

APPENDIX A-1

COMBINED RESULTS FOR ENTIRE AREA

TWENTY YEAR GROUND WATER BUDGET (for the North Fork of the Red River) - Entire Area



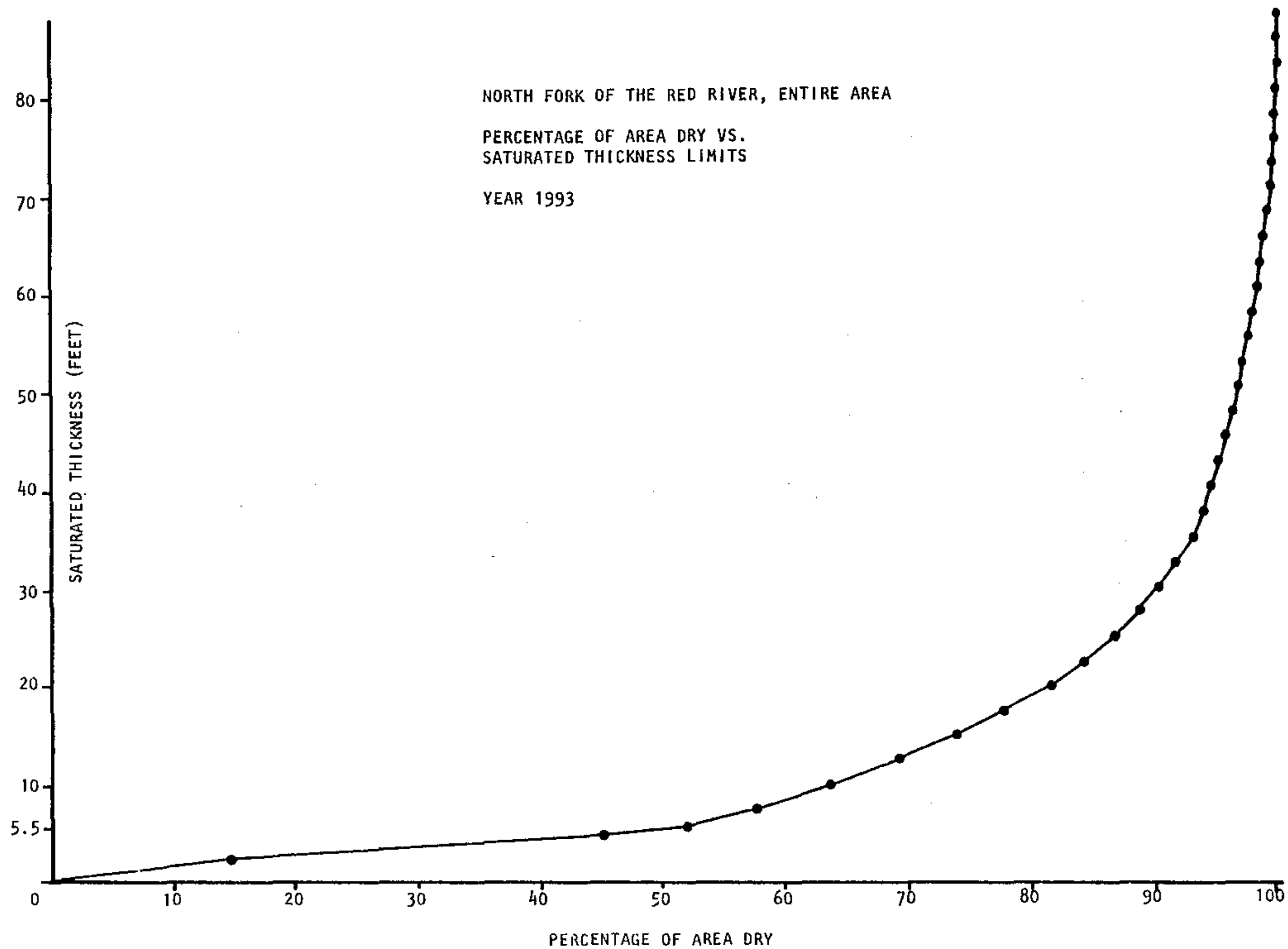
MASS BALANCE

North Fork of the Red River (Entire Area)

Prior Appropriative and Allocation Pumping

July 1, 1973 and July 1, 1993

	AVERAGE ANNUAL (ACRE FT.)		TOTAL (ACRE FT.)	
	INFLOW	OUTFLOW	INFLOW	OUTFLOW
RECHARGE	+67,114		+1,342,283	
PUMPAGE		-144,399		-2,887,980
RIVER LEAKAGE	+24,609	- 18,909	+ 492,176	- 378,182
SUBSURFACE FLOW	+ 1,567	- 1,461	+ 31,335	- 29,227
TOTALS	+93,290	-164,769	+1,865,794	-3,295,389
NET STORAGE		- 71,480		-1,429,595

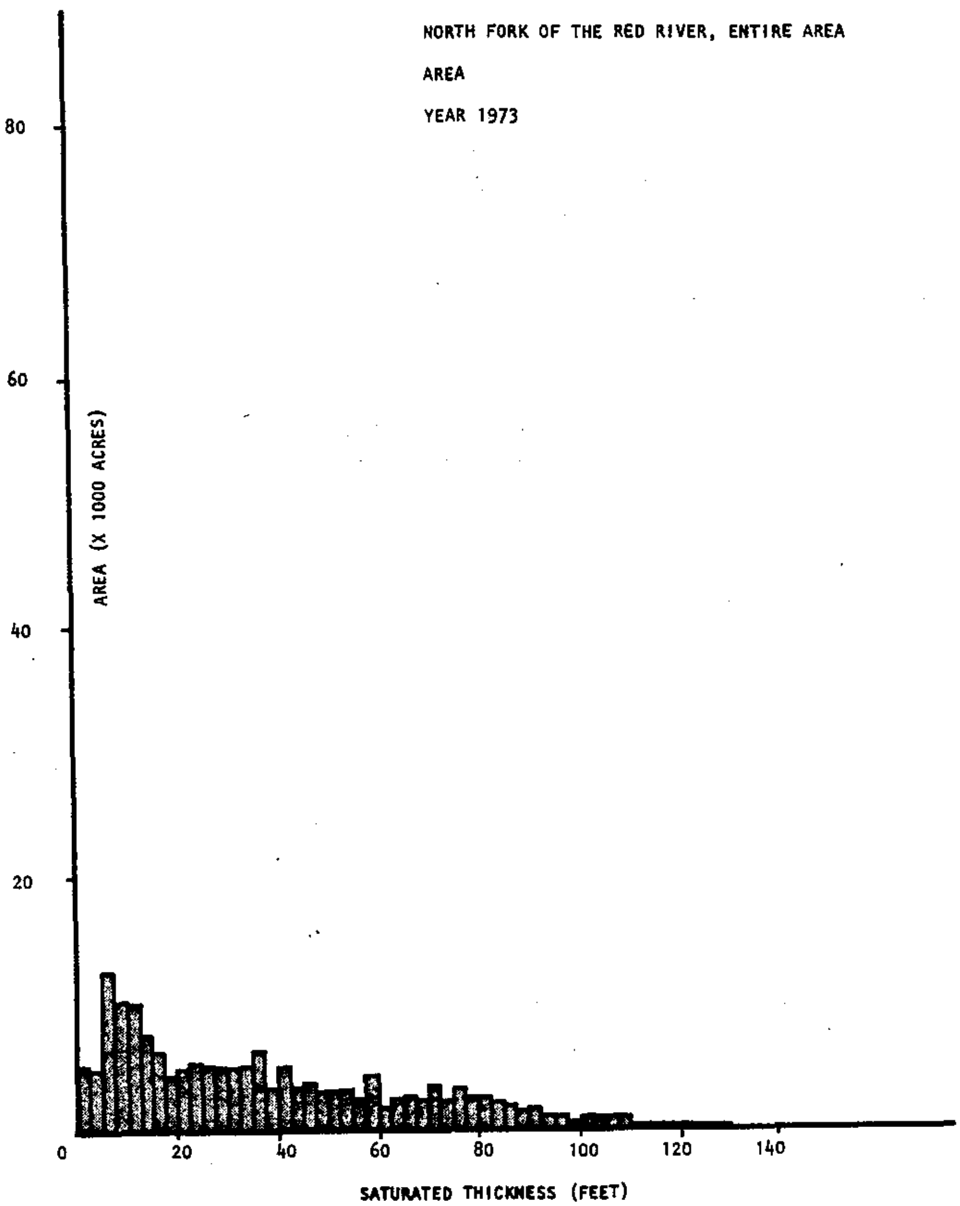

NORTH FORK OF THE RED RIVER, ENTIRE AREA
PERCENTAGE OF AREA DRY VS.
SATURATED THICKNESS LIMITS
YEAR 1993
SATURATED THICKNESS (FEET)
80
70
60
50
40
30
20
10
5.5
0
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF AREA DRY

WATER DISTRIBUTION SUMMARY
NORTH FORK OF THE RED RIVER - ENTIRE AREA
JULY 1, 1973

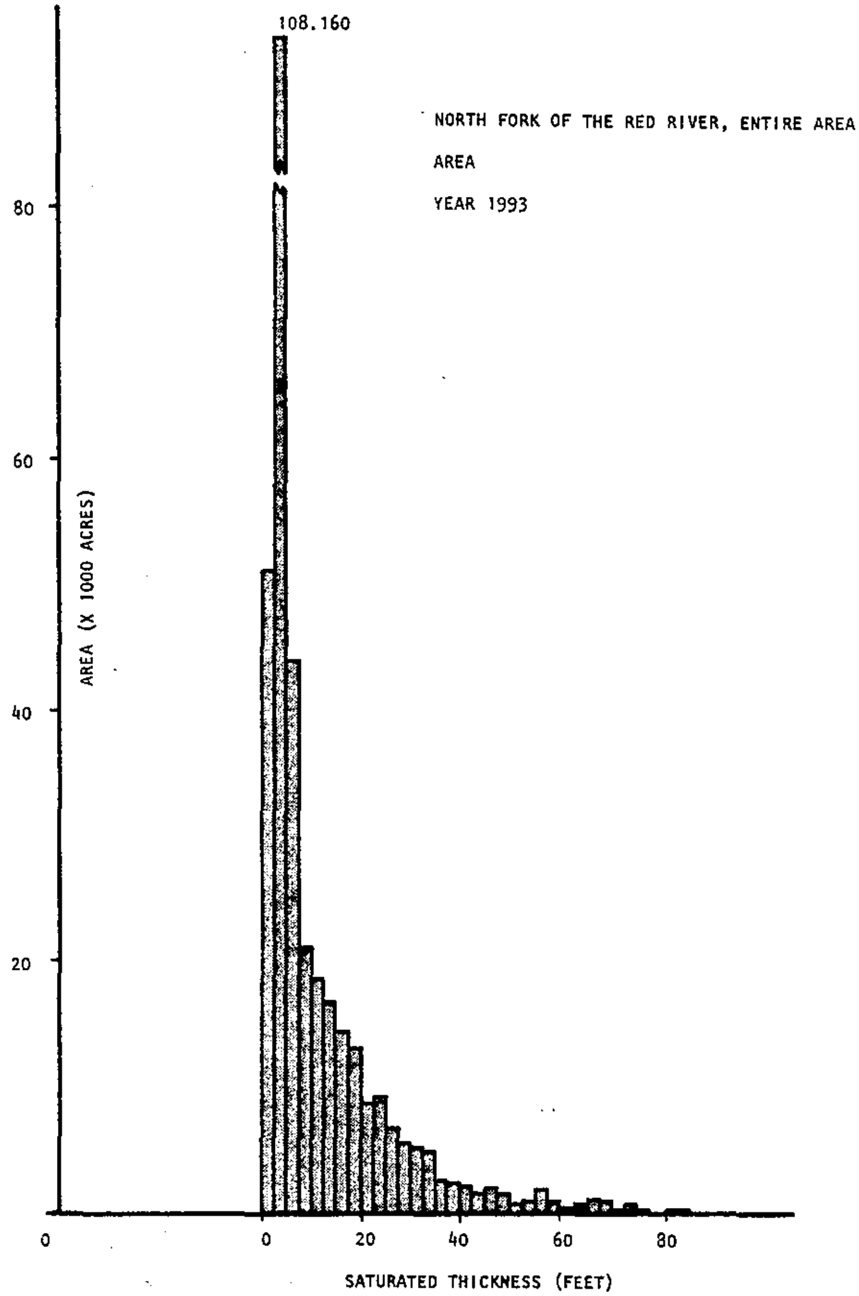
SATURATED THICKNESS RANGE (FEET)	AREA (% OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (%)	STORED WATER (ACRE FT.)
0-5.5	8.9	31,360	3.6	25.0	28,259
5.5-10	15.1	53,280	7.9	23.5	98,266
10-20	23.4	82,720	14.8	25.1	307,004
20-30	16.4	58,080	24.8	24.8	357,152
30-40	12.7	44,800	34.7	24.5	380,547
40-50	7.7	27,200	44.3	24.3	292,632
50-60	5.1	18,080	55.3	24.6	245,463
60-70	3.0	10,560	65.2	24.0	165,282
70-80	3.3	11,520	74.9	23.3	201,105
80-90	2.3	8,000	84.3	24.6	165,710
90-100	0.9	3,040	93.9	25.4	72,587
100-110	0.6	2,080	105.6	24.7	54,285
110-120	0.3	1,120	118.5	25.7	34,170
120-130	0.3	1,120	125.3	25.9	36,377
130-140	0.1	480	134.9	25.8	16,680
140-150	0.1	320	142.5	25.8	11,753
ALL RANGES	100.0	353,760	28.5	24.5	2,467,272

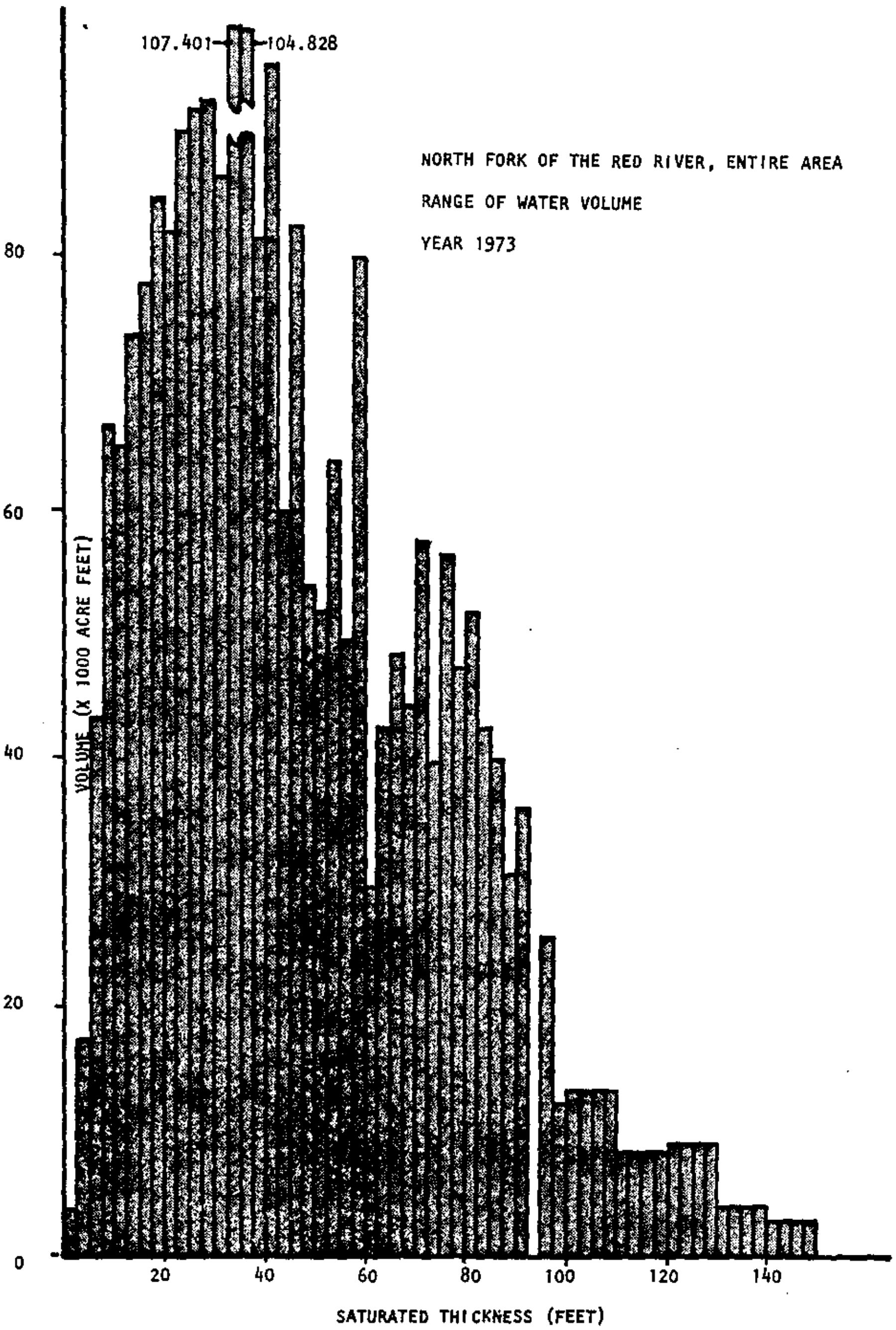
WATER DISTRIBUTION SUMMARY
NORTH FORK OF THE RED RIVER - ENTIRE AREA
JULY 1, 1993

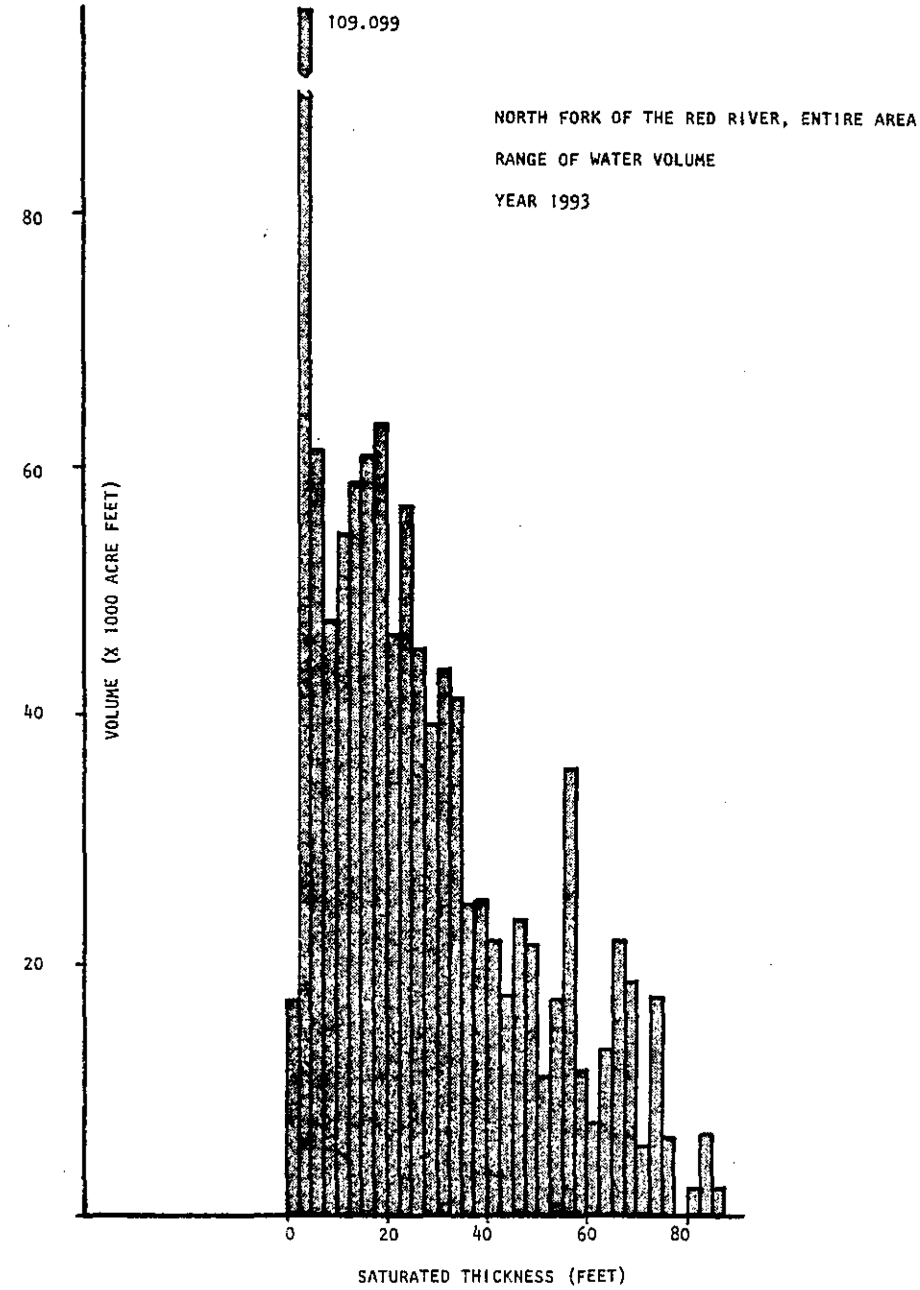
SATURATED THICKNESS RANGE (FEET)	AREA (% OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (%)	STORED WATER (ACRE FT.)
0-5.5	51.6	182,560	3.6	23.2	154,209
5.5-10	12.1	42,720	7.4	25.5	80,961
10-20	17.9	63,200	14.6	25.7	237,704
20-30	8.6	30,560	24.5	25.1	188,378
30-40	4.4	15,680	34.2	25.3	135,663
40-50	2.1	7,520	44.7	25.4	85,381
50-60	1.6	5,600	55.5	24.5	75,998
60-70	1.0	3,680	66.0	25.3	61,590
70-80	0.5	1,600	73.5	25.2	29,680
80-90	0.2	640	83.0	24.4	12,942
ALL RANGES	100.0	353,760	12.0	25.0	1,062,505



NORTH FORK OF THE RED RIVER, ENTIRE AREA
AREA
YEAR 1973
80
60
40
20
AREA (X 1000 ACRES)
0
20
40
60
80
100
120
140
SATURATED THICKNESS (FEET)


108.160
NORTH FORK OF THE RED RIVER, ENTIRE AREA
AREA
YEAR 1993
AREA (X 1000 ACRES)
80
60
40
20
0
0
20
40
60
80
SATURATED THICKNESS (FEET)


107.401
104.828
NORTH FORK OF THE RED RIVER, ENTIRE AREA
RANGE OF WATER VOLUME
YEAR 1973
VOLUME (X 1000 ACRE FEET)
0
20
40
60
80
20
40
60
80
100
120
140
SATURATED THICKNESS (FEET)

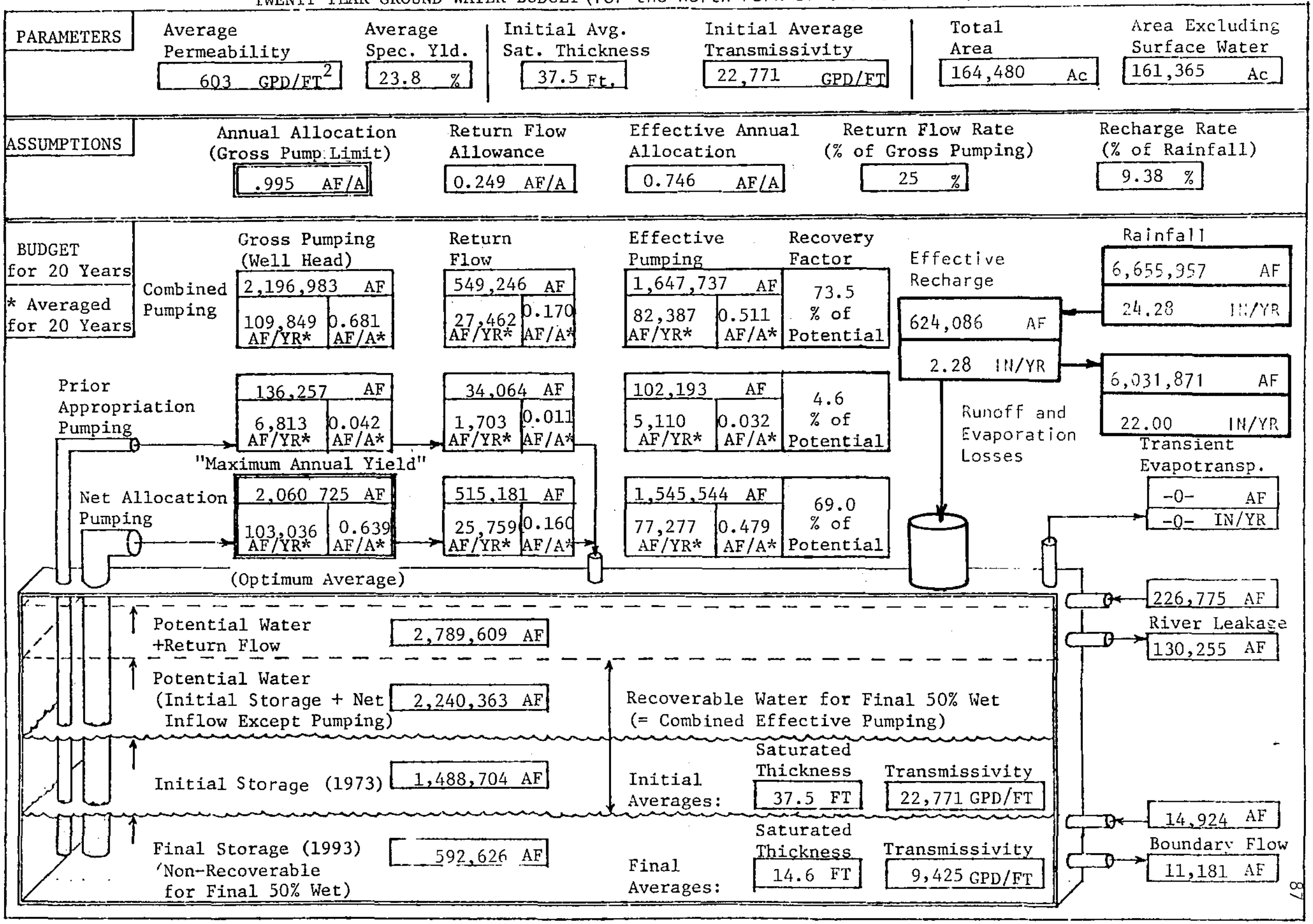


109.099
NORTH FORK OF THE RED RIVER, ENTIRE AREA
RANGE OF WATER VOLUME
YEAR 1993
80
60
40
20
VOLUME (X 1000 ACRE FEET)
0
20
40
60
80
SATURATED THICKNESS (FEET)

APPENDIX A-2

RESULTS FOR THE NORTHERN SECTION

TWENTY YEAR GROUND WATER BUDGET (for the North Fork of the Red River) - Northern Section



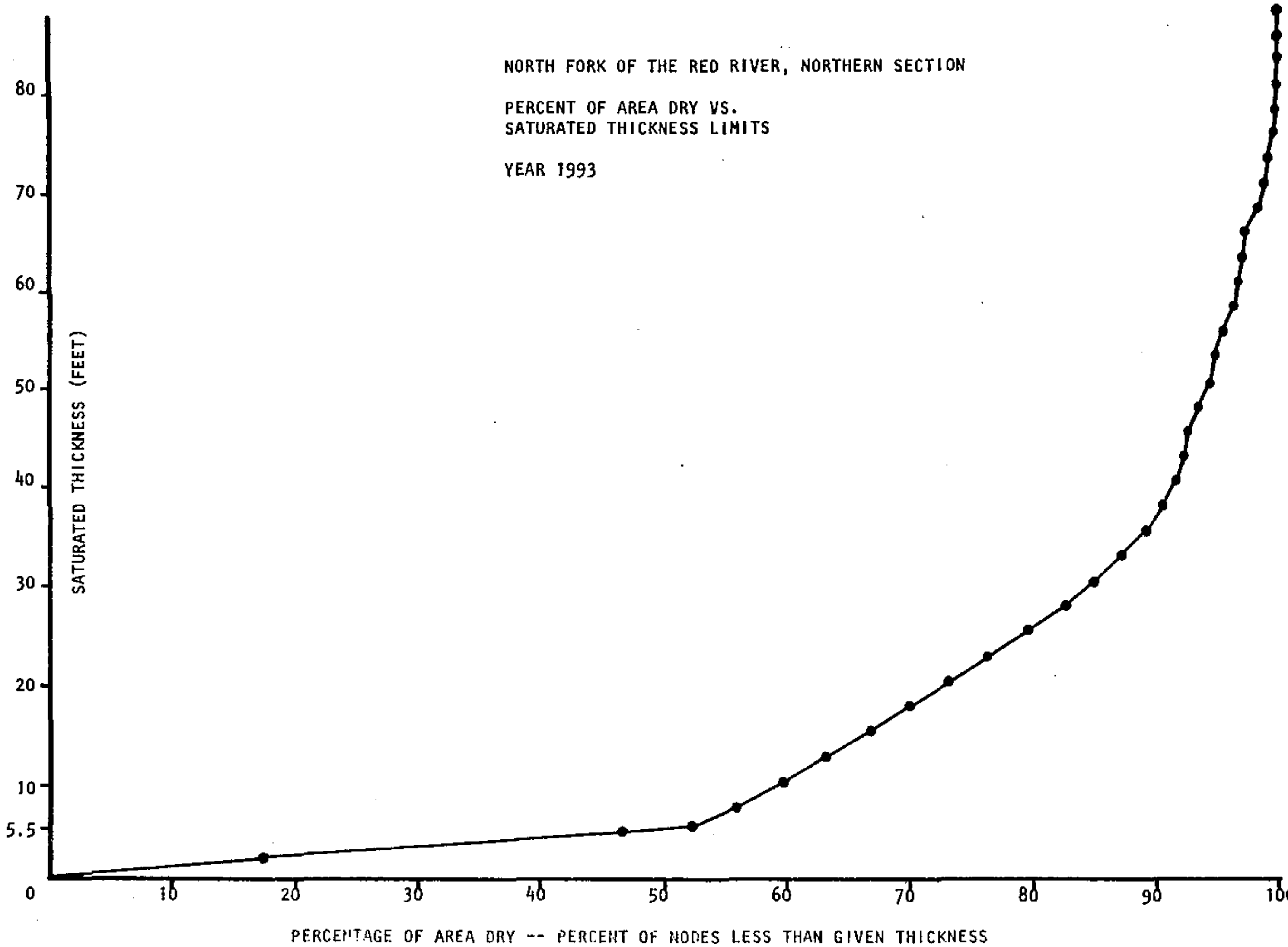
MASS BALANCE

North Fork of the Red River - Northern Section

Prior Appropriative and Allocation Pumping

July 1, 1973 to July 1, 1993

	AVERAGE ANNUAL (ACRE FT.)		TOTAL (ACRE FT.)	
	INFLOW	OUTFLOW	INFLOW	OUTFLOW
RECHARGE	+ 31,204		+624,086	
PUMPAGE		-82,387		-647,737
RIVER LEAKAGE	+11,339	- 6,513	+226,775	-130,255
SUBSURFACE FLOW	+ 746	- 559	+ 14,924	- 11,181
TOTALS	+43,289	-89,459	+865,785	-789,173
NET STORAGE		-46,169		-923,388

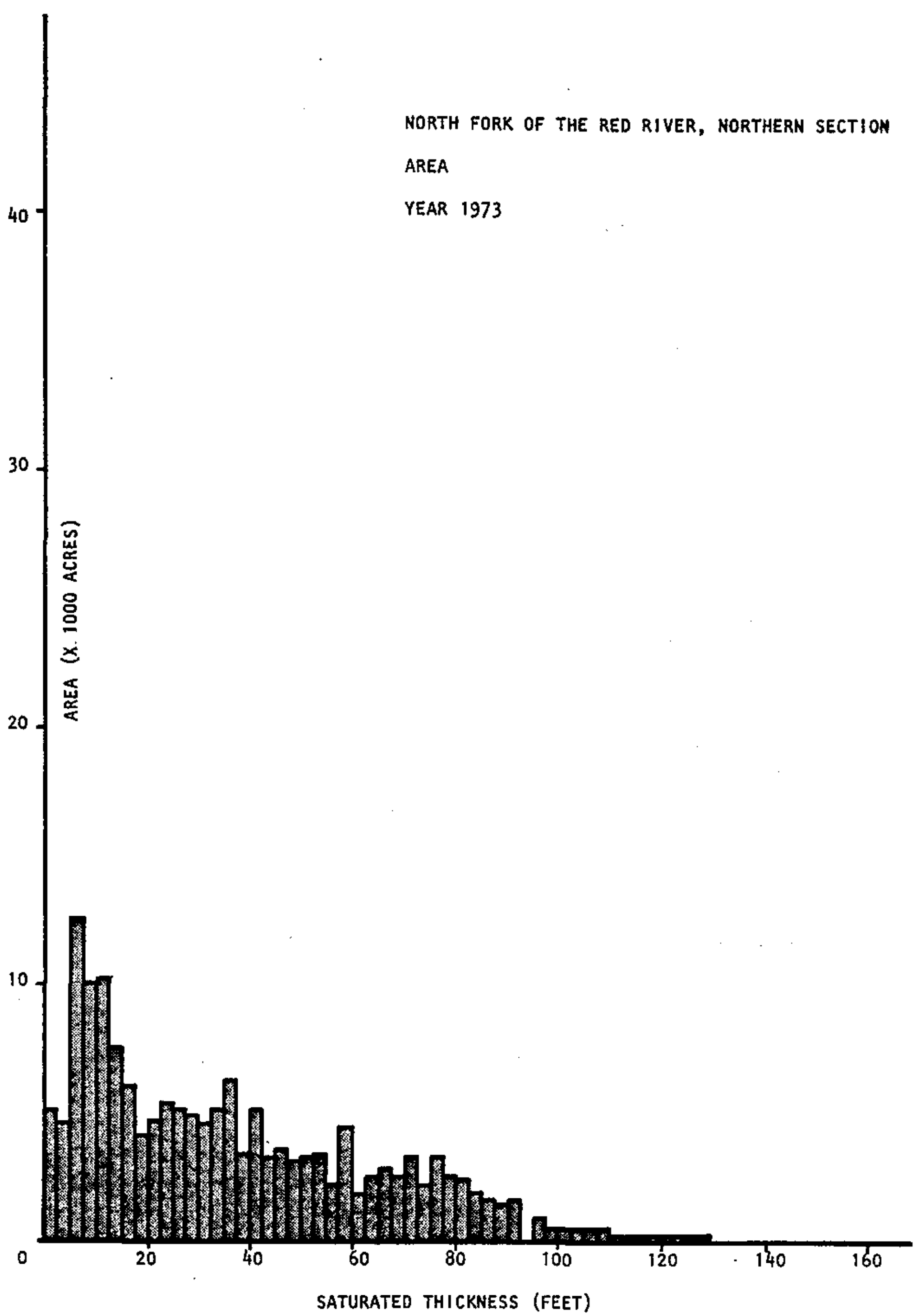

NORTH FORK OF THE RED RIVER, NORTHERN SECTION
PERCENT OF AREA DRY VS.
SATURATED THICKNESS LIMITS
YEAR 1993
SATURATED THICKNESS (FEET)
0
5.5
10
20
30
40
50
60
70
80
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF AREA DRY -- PERCENT OF NODES LESS THAN GIVEN THICKNESS

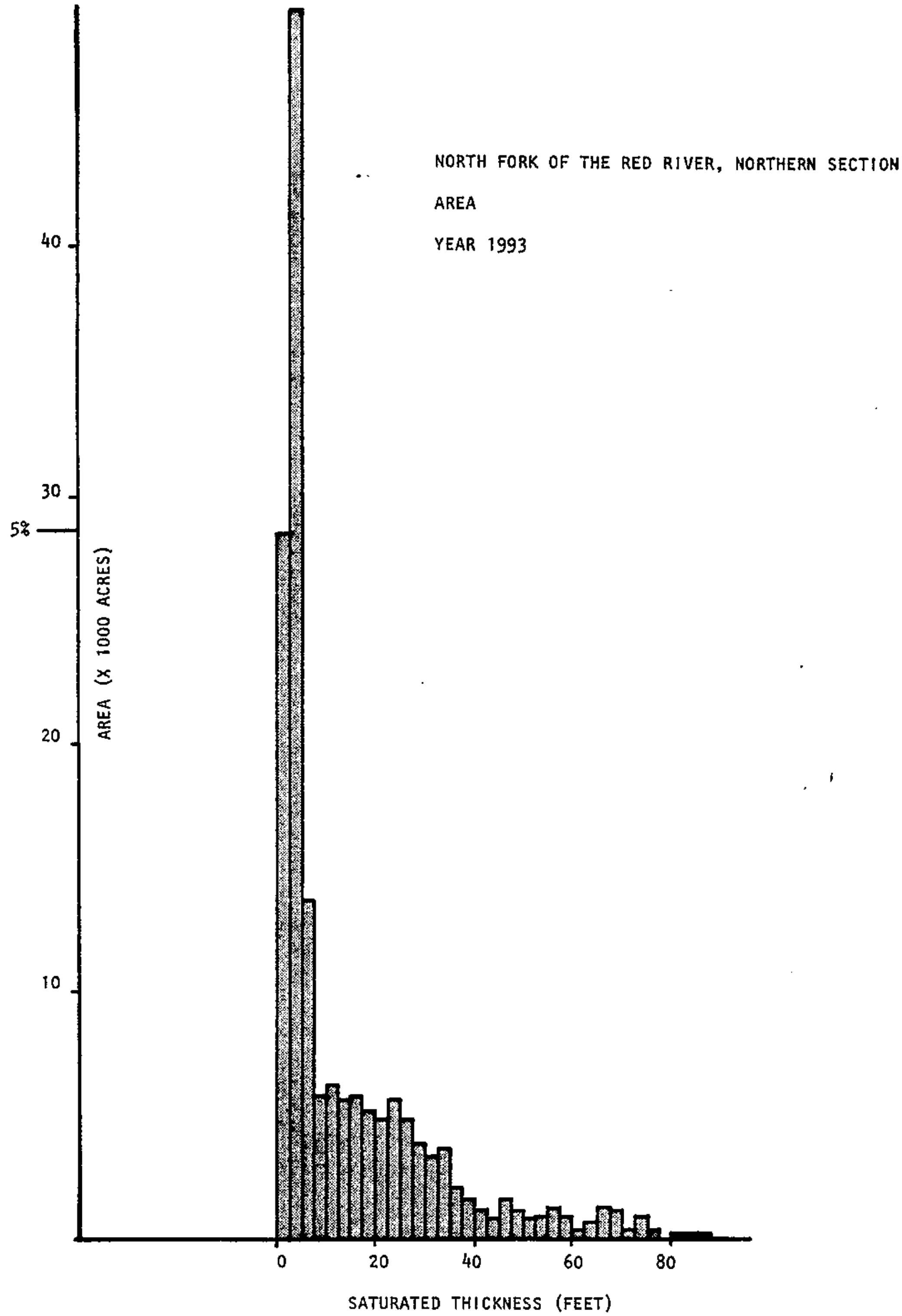
WATER DISTRIBUTION SUMMARY
NORTH FORK OF THE RED RIVER - NORTHERN SECTION
JULY 1, 1973

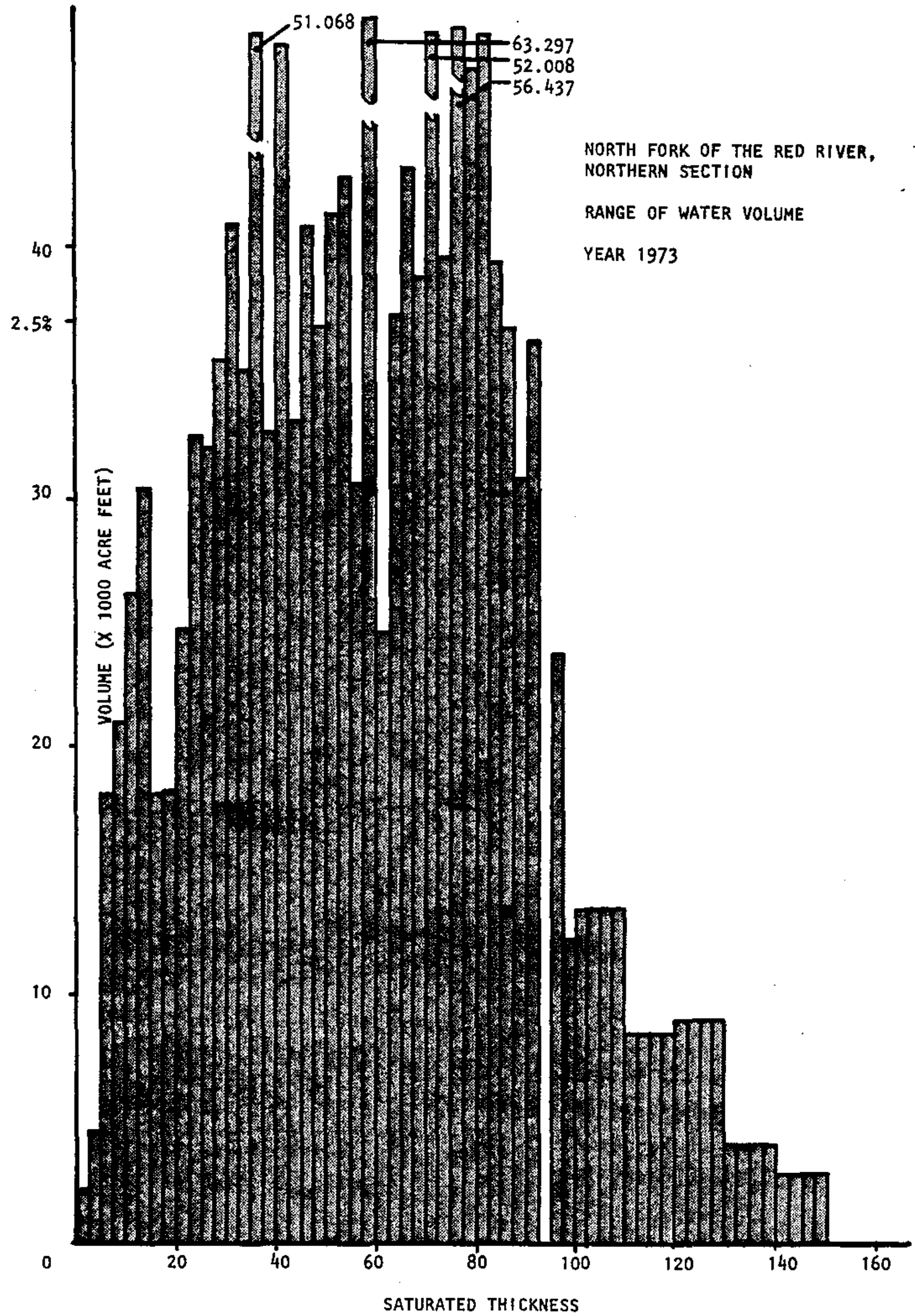
SATURATED THICKNESS RANGE (FEET)	AREA (% OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (%)	STORED WATER (ACRE FT.)
0-5.5	7.2	11,840	3.3	23.5	9,181
5.5-10	12.5	20,640	7.7	23.2	36,723
10-20	17.0	28,000	14.1	23.5	92,669
20-30	12.3	20,160	25.0	24.7	124,718
30-40	11.8	19,360	34.9	23.6	159,601
40-50	9.1	15,040	44.5	23.7	158,795
50-60	8.1	13,280	55.3	24.3	177,974
60-70	5.6	9,280	65.2	23.8	143,978
70-80	6.8	11,200	74.9	23.3	195,355
80-90	4.6	7,560	84.3	24.6	155,741
90-100	1.8	3,040	93.9	25.4	72,587
100-110	1.3	2,080	105.6	24.7	54,285
110-120	0.7	1,120	118.5	25.7	34,170
120-130	0.7	1,120	215.3	25.9	36,377
130-140	0.3	480	134.9	25.8	16,680
140-150	0.2	320	142.5	25.8	11,753
ALL RANGES	100.0	164,480	37.4	24.1	1,480,585

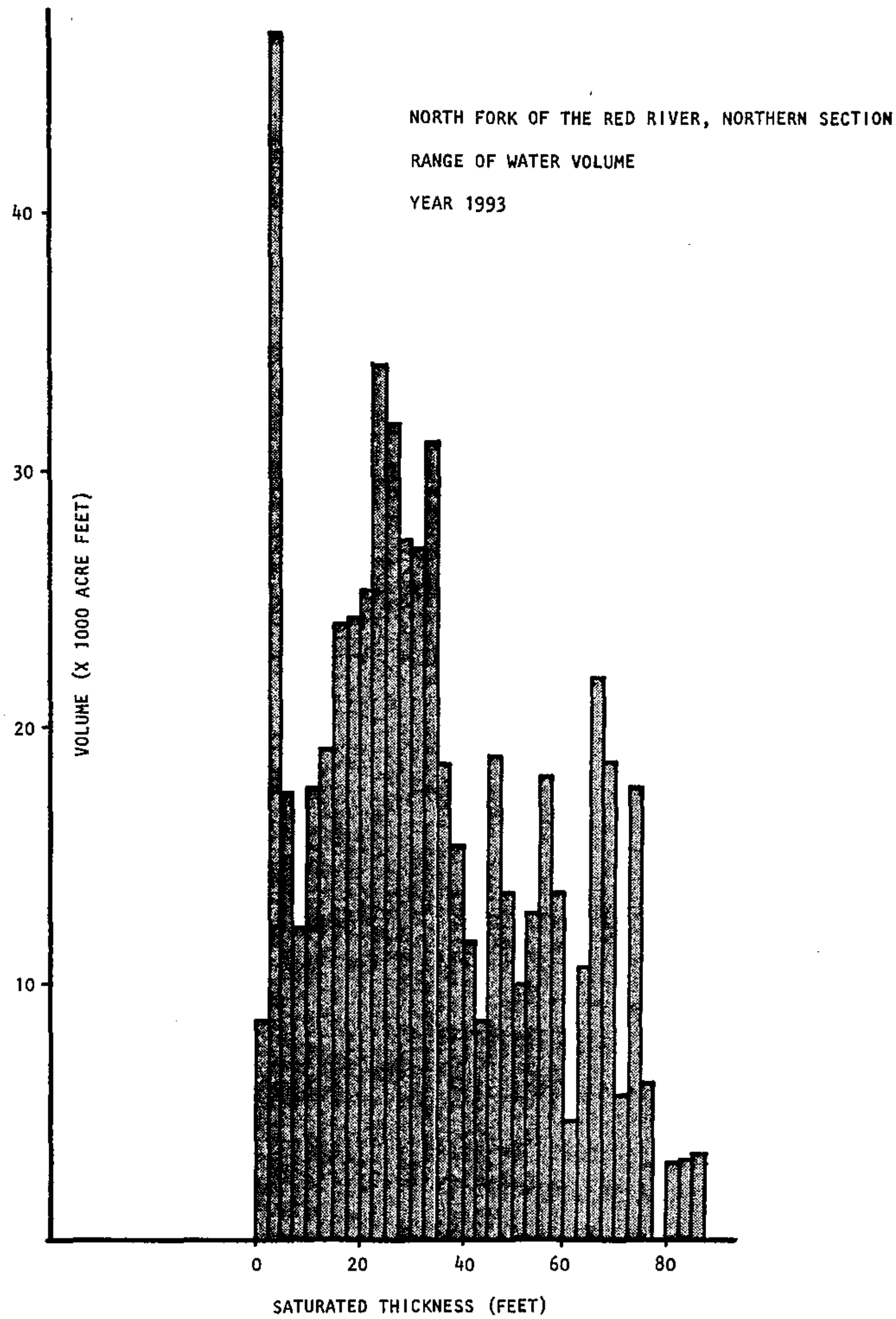
WATER DISTRIBUTION SUMMARY
NORTH FORK OF THE RED RIVER - NORTHERN SECTION
JULY 1, 1993

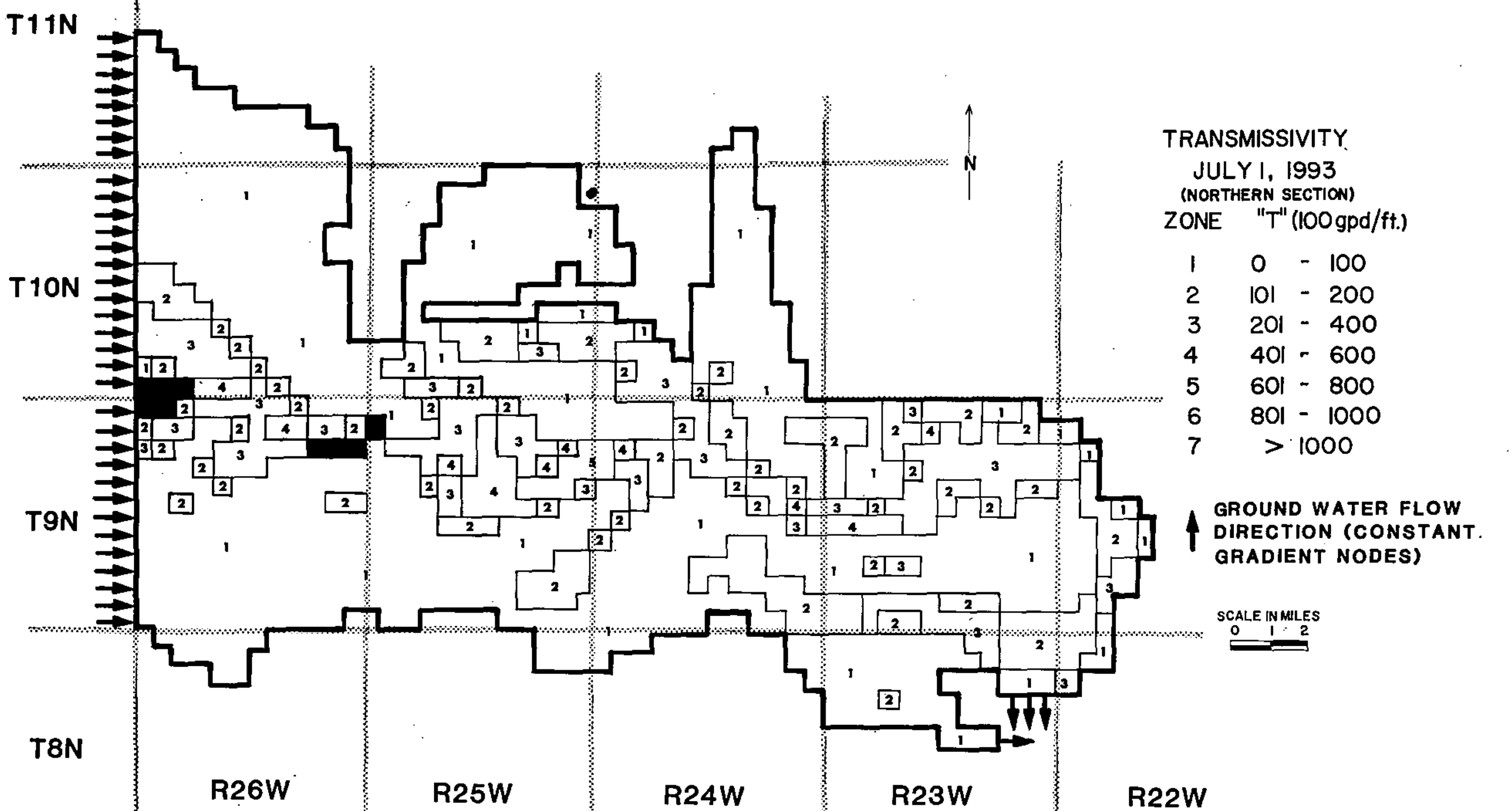
SATURATED THICKNESS RANGE (FEET)	AREA (% OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (%)	STORED WATER (ACRE FT.)
0-5.5	52.4	86,240	3.5	21.6	64,689
5.5-10	7.1	11,680	7.3	24.5	20,852
10-20	13.8	22,720	14.9	25.3	85,673
20-30	11.6	19,040	24.8	25.2	119,036
30-40	6.5	10,720	34.3	25.1	92,514
40-50	2.8	4,640	44.9	25.4	52,933
50-60	2.4	4,000	55.5	24.7	54,314
60-70	2.0	3,360	66.3	25.3	56,393
70-80	1.0	1,600	73.5	25.2	29,680
80-90	0.3	480	83.4	23.9	9,561
ALL RANGES	100.0	164,480	14.4	24.7	586,150

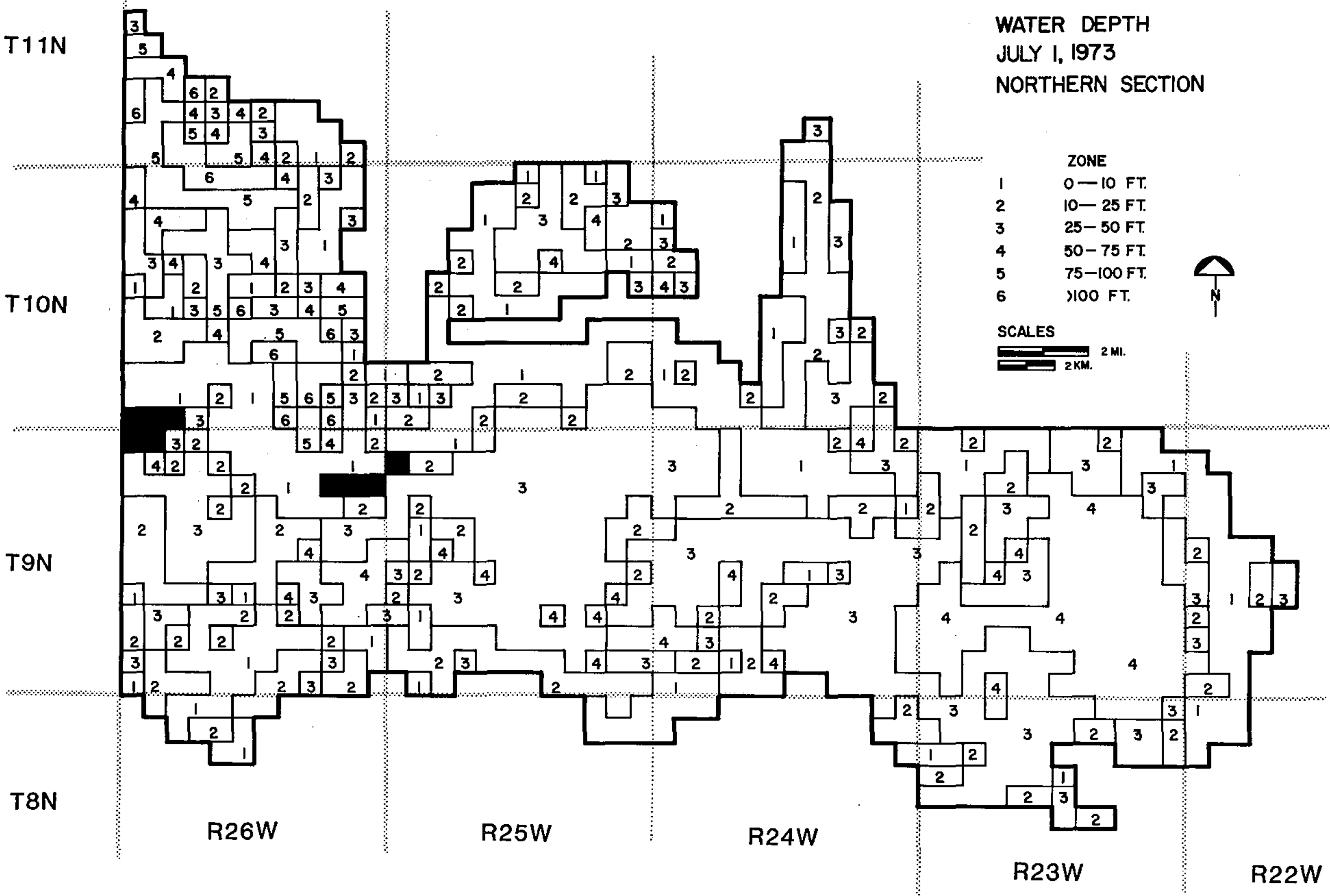

NORTH FORK OF THE RED RIVER, NORTHERN SECTION
AREA
YEAR 1973
AREA (X 1000 ACRES)
0
10
20
30
40
20
40
60
80
100
120
140
160
SATURATED THICKNESS (FEET)

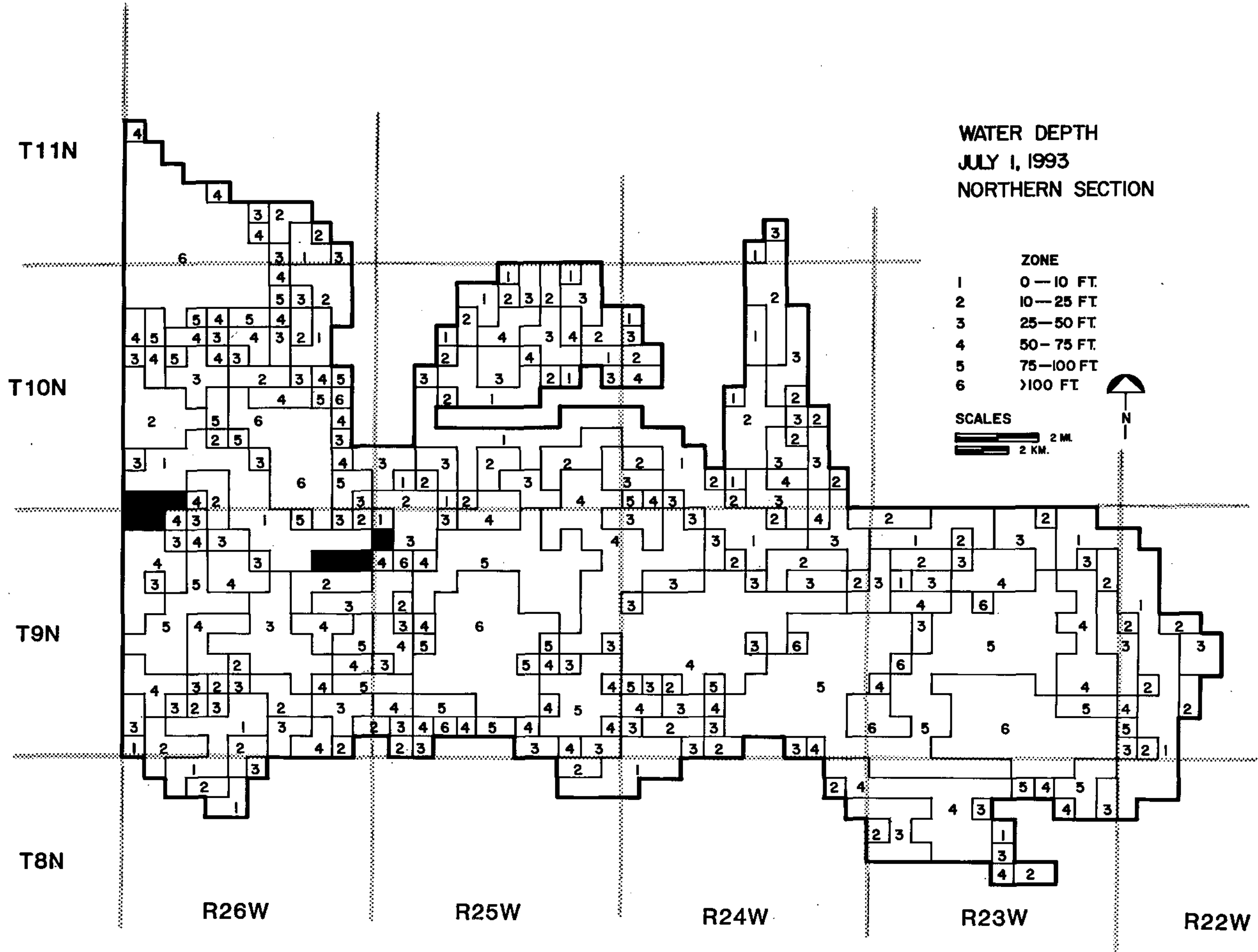

NORTH FORK OF THE RED RIVER, NORTHERN SECTION
AREA
YEAR 1993
40
30
5%
20
10
AREA (X 1000 ACRES)
0
20
40
60
80
SATURATED THICKNESS (FEET)


51.068
63.297
52.008
56.437
NORTH FORK OF THE RED RIVER,
NORTHERN SECTION
RANGE OF WATER VOLUME
YEAR 1973
40
2.5%
30
20
10
0
VOLUME (X 1000 ACRE FEET)
20
40
60
80
100
120
140
160
SATURATED THICKNESS


NORTH FORK OF THE RED RIVER, NORTHERN SECTION
RANGE OF WATER VOLUME
YEAR 1993
VOLUME (X 1000 ACRE FEET)
40
30
20
10
0
20
40
60
80
SATURATED THICKNESS (FEET)


TRANSMISSIVITY
JULY 1, 1993
(NORTHERN SECTION)
ZONE "T" (100 gpd/ft.)
1 0 - 100
2 101 - 200
3 201 - 400
4 401 - 600
5 601 - 800
6 801 - 1000
7 > 1000
GROUND WATER FLOW DIRECTION (CONSTANT GRADIENT NODES)
SCALE IN MILES
0 1 2
N
T11N
T10N
T9N
T8N
R26W
R25W
R24W
R23W
R22W


WATER DEPTH
JULY 1, 1973
NORTHERN SECTION
ZONE
1 0—10 FT.
2 10—25 FT.
3 25—50 FT.
4 50—75 FT.
5 75—100 FT.
6 >100 FT.
SCALES
2 MI.
2 KM.
N
T11N
T10N
T9N
T8N
R26W
R25W
R24W
R23W
R22W


WATER DEPTH
JULY 1, 1993
NORTHERN SECTION
ZONE
1 0 — 10 FT.
2 10 — 25 FT.
3 25 — 50 FT.
4 50 — 75 FT.
5 75 — 100 FT.
6 >100 FT.
SCALES
2 MI.
2 KM.
N
T11N
T10N
T9N
T8N
R26W
R25W
R24W
R23W
R22W

APPENDIX A-3

RESULTS FOR THE CENTRAL SECTION

TWENTY YEAR GROUND WATER BUDGET (for the North Fork of the Red River) - Central Section

PARAMETERS

Average Permeability	Average Spec. Yld.	Initial Avg. Sat. Thickness	Initial Average Transmissivity	Total Area	Area Excluding Surface Water
754 GPD/FT^2	24.9 %	22.9 Ft.	16,734 GPD/FT	116,640 Ac	105,686 Ac

ASSUMPTIONS

Annual Allocation (Gross Pump Limit)	Return Flow Allowance	Effective Annual Allocation	Return Flow Rate (% of Gross Pumping)	Recharge Rate (% of Rainfall)
.775 AF/A	.194 AF/A	.581 AF/A	25 %	9.38 %

BUDGET for 20 Years

* Averaged for 20 Years

	Gross Pumping (Well Head)		Return Flow		Effective Pumping		Recovery Factor
Combined Pumping	999,105 AF		249,776 AF		749,329 AF		70.1 % of Potential
	49,955 AF/YR*	0.473 AF/A*	12,489 AF/YR*	0.118 AF/A*	37,466 AF/YR*	0.355 AF/A*	
Prior Appropriation Pumping	252,792 AF		63,198 AF		189,594 AF		17.7 % of Potential
	12,640 AF/YR*	0.120 AF/A*	3,160 AF/YR*	0.030 AF/A*	9,480 AF/YR*	0.090 AF/A*	
Net Allocation Pumping "Maximum Annual Yield" (Optimum Average)	746,313 AF		186,578 AF		559,735 AF		52.4 % of Potential
	37,316 AF/YR*	0.353 AF/A*	9,329 AF/YR*	0.088 AF/A*	27,987 AF/YR*	0.265 AF/A*	

Rainfall: 4,493,419 AF; 24.28 IN/YR

Effective Recharge: 421,319 AF; 2.28 IN/YR

Runoff and Evaporation Losses: 4,072,100 AF; 22.00 IN/YR

Transient Evapotransp.: -0- AF; -0- IN/YR

River Leakage: 103,528 AF (in); 130,625 AF (out)

Boundary Flow: 15,537 AF (in); 675 AF (out)

Potential Water +Return Flow	1,318,466 AF
Potential Water (Initial Storage + Net Inflow Except Pumping)	1,068,690 AF
Initial Storage (1973)	665,336 AF
Final Storage (1993) (Non-Recoverable for Final 50% Wet)	319,361 AF

Recoverable Water for Final 50% Wet (= Combined Effective Pumping)

	Saturated Thickness	Transmissivity
Initial Averages:	22.9 FT	16,734 GPD/FT
Final Averages:	10.9 FT	7,895 GPD/FT

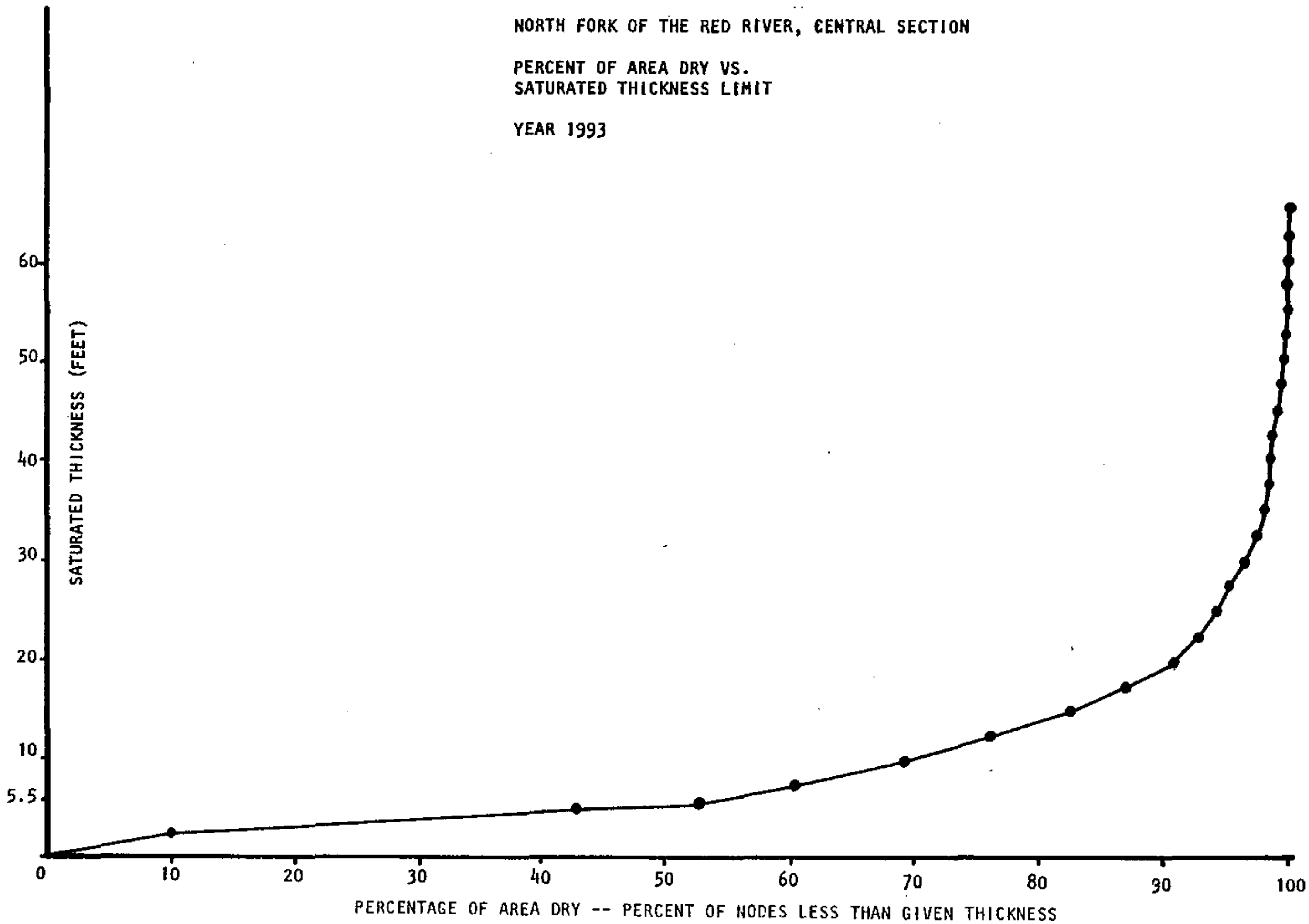
MASS BALANCE

North Fork of the Red River - Central Section

Prior Appropriative and Allocation Pumping

July 1, 1973 to July 1, 1993

	AVERAGE ANNUAL (ACRE FT.)		TOTAL (ACRE FT.)	
	INFLOW	OUTFLOW	INFLOW	OUTFLOW
RECHARGE	+21,066		+421,319	
PUMPAGE		-37,466		-749,329
RIVER LEAKAGE	+ 5,176	- 6,531	+103,428	-130,625
SUBSURFACE FLOW	+ 777	- 34	+ 15,537	- 675
TOTALS	+27,019	-44,031	+540,384	-880,629
NET STORAGE		-17,012		-340,245


NORTH FORK OF THE RED RIVER, CENTRAL SECTION
PERCENT OF AREA DRY VS.
SATURATED THICKNESS LIMIT
YEAR 1993
SATURATED THICKNESS (FEET)
60
50
40
30
20
10
5.5
0
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF AREA DRY -- PERCENT OF NODES LESS THAN GIVEN THICKNESS

WATER DISTRIBUTION SUMMARY
NORTH FORK OF THE RED RIVER - CENTRAL SECTION
JULY 1, 1973

SATURATED THICKNESS RANGE (FEET)	AREA (% OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (%)	STORED WATER (ACRE FT.)
0-5.5	12.0	13,280	3.8	25.7	12,961
5.5-10	15.9	17,600	8.0	21.7	30,669
10-20	23.8	26,400	15.1	26.1	103,904
20-30	20.5	22,720	24.8	24.3	136,717
30-40	16.1	17,920	34.7	24.8	154,503
40-50	7.9	8,800	44.1	24.7	96,079
50-60	2.7	3,040	54.8	54.8	25,136
60-70	0.7	800	65.8	25.4	13,405
70-80	0.1	160	72.3	24.1	2,784
80-90	0.3	320	84.8	24.3	6,538
ALL RANGES	100.0	111,040	21.8	24.8	599,743

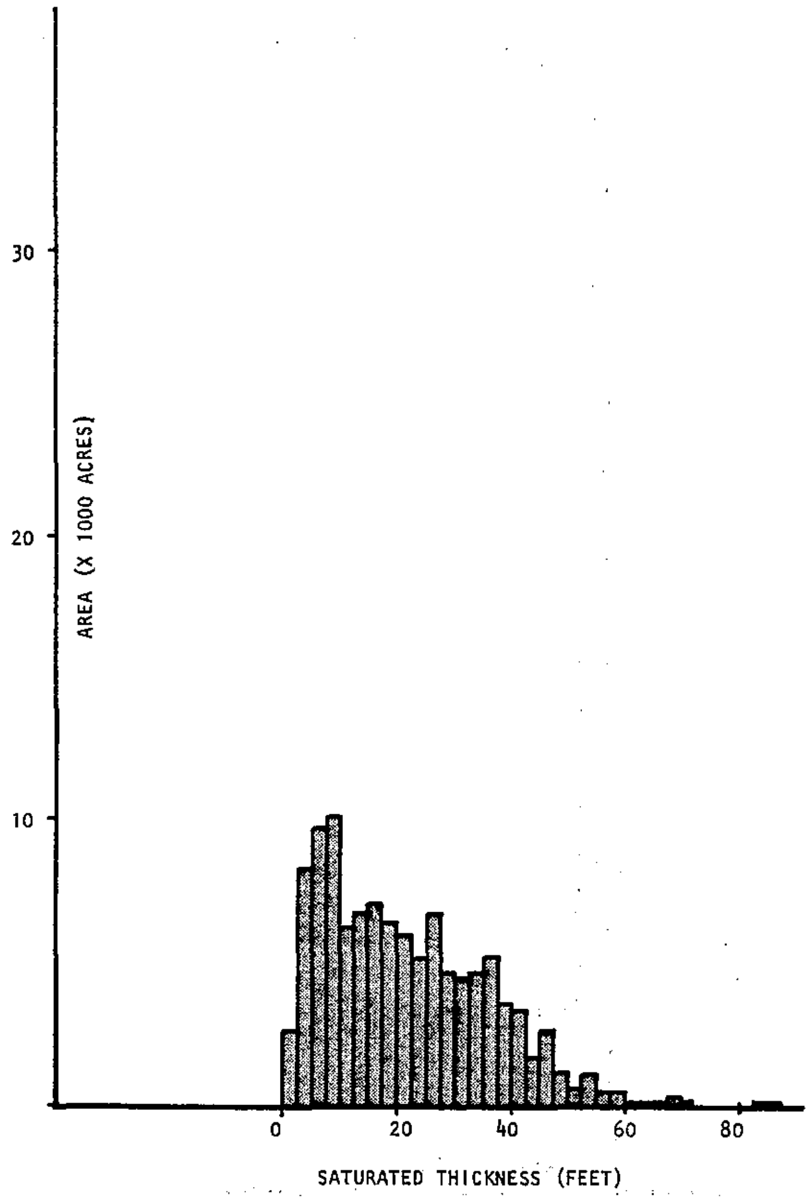
WATER DISTRIBUTION SUMMARY
NORTH FORK OF THE RED RIVER - CENTRAL SECTION
JULY 1, 1993

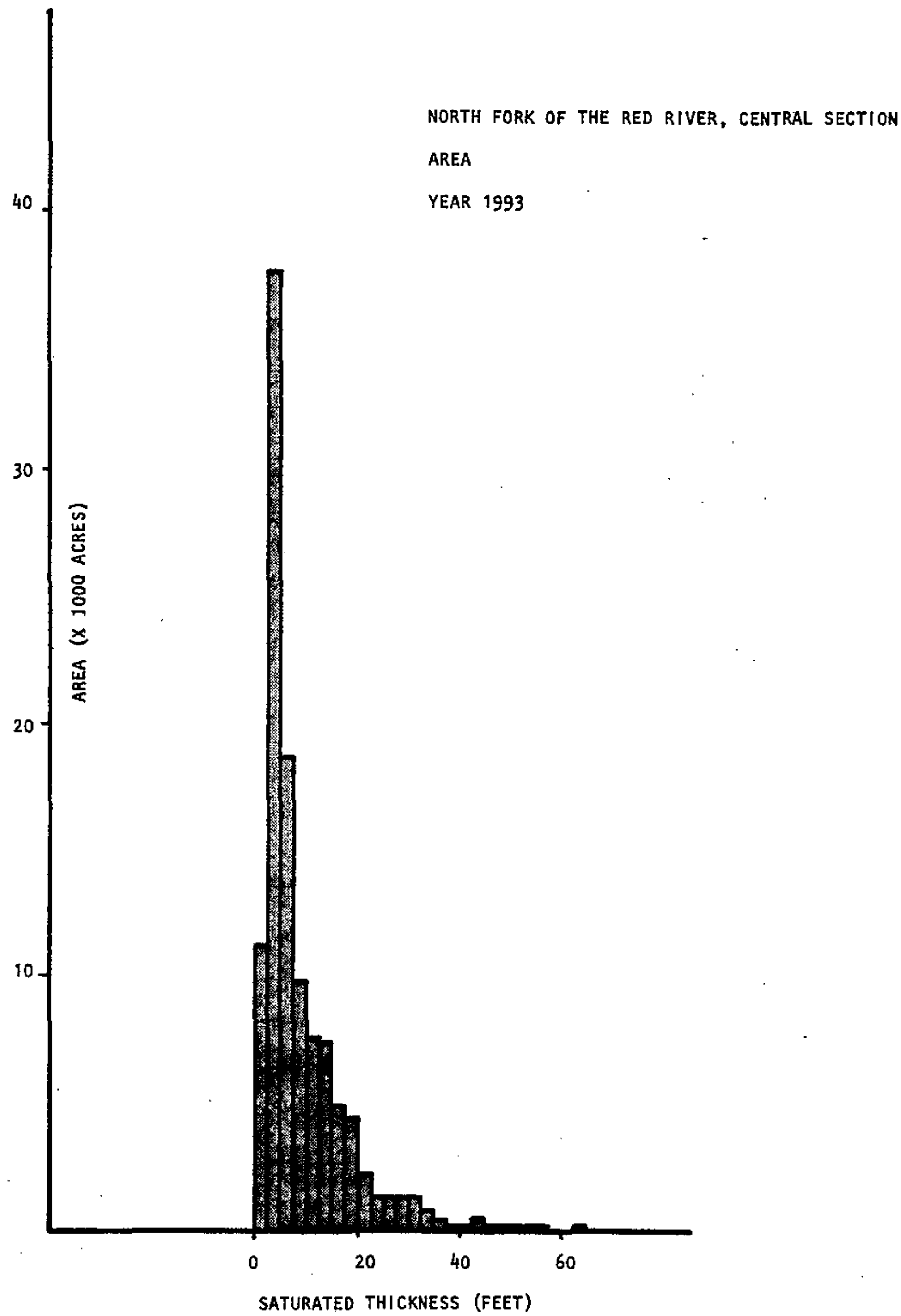
SATURATED THICKNESS RANGE (FEET)	AREA (% OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (%)	STORED WATER (ACRE FT.)
0-5.5	52.9	58, 720	3.9	23.7	54, 832
5.5-10	16.4	18, 240	7.7	26.0	36, 378
10-20	21.6	24, 000	14.3	26.2	89, 670
20-30	5.5	6, 080	24.3	24.4	36, 043
30-40	2.2	2, 400	33.1	25.4	20, 182
40-50	0.9	960	44.9	24.4	10, 514
50-60	0.4	480	53.6	19.1	4, 912
60-70	0.1	160	63.9	25.7	2, 630
ALL RANGES	100.0	111, 040	9.2	25.0	255, 161

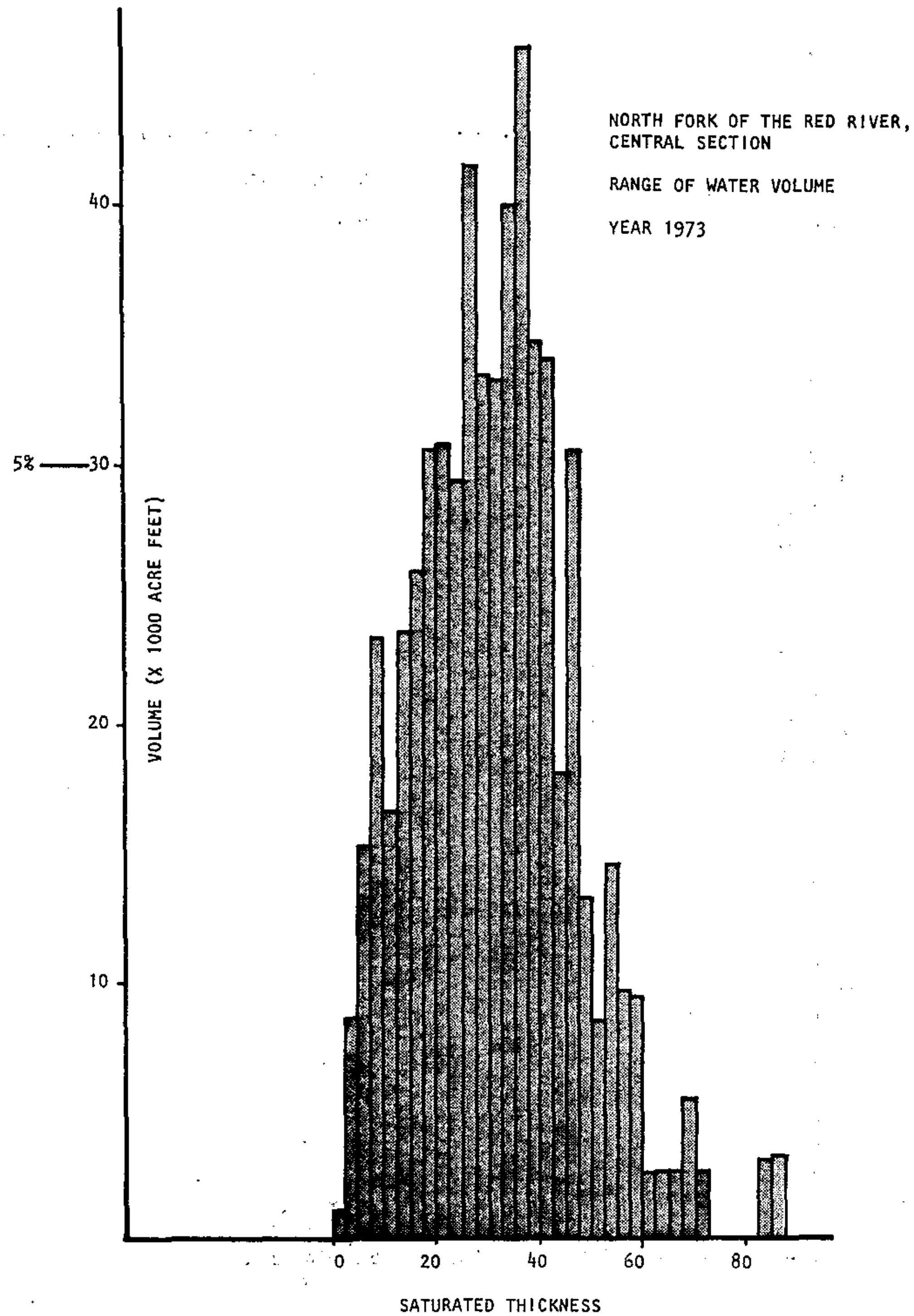
NORTH FORK OF THE RED RIVER, CENTRAL SECTION

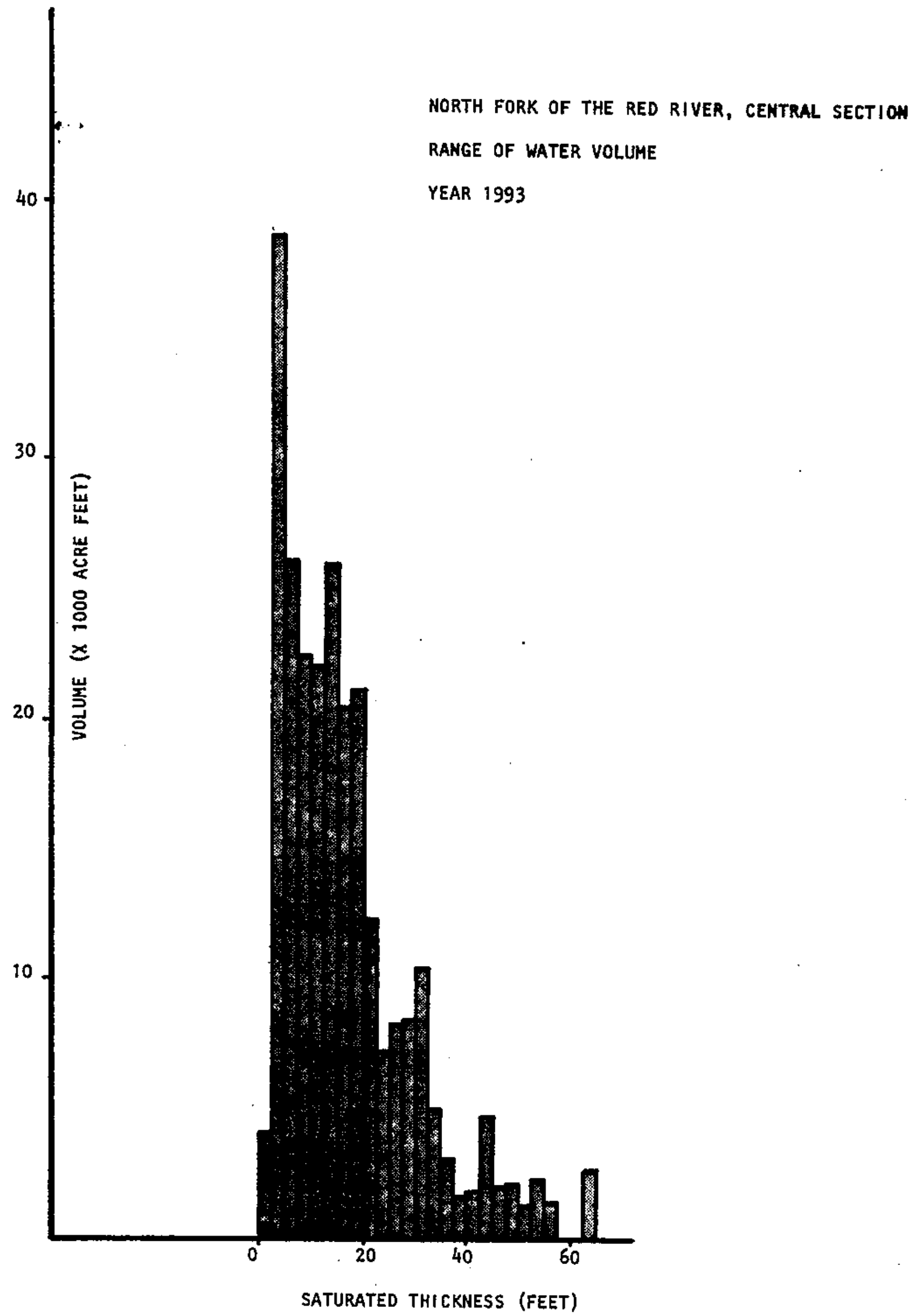
AREA

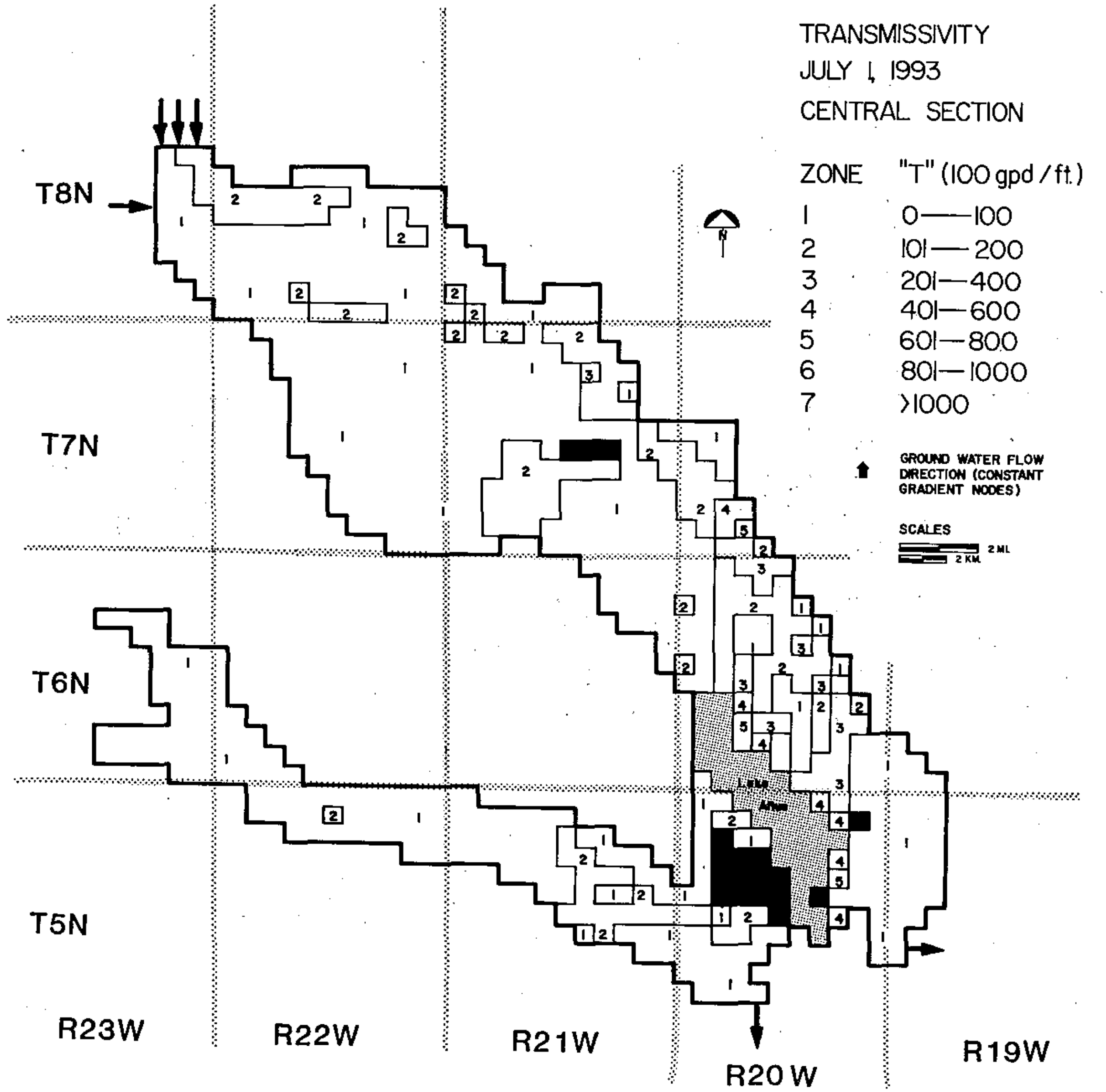
YEAR 1973

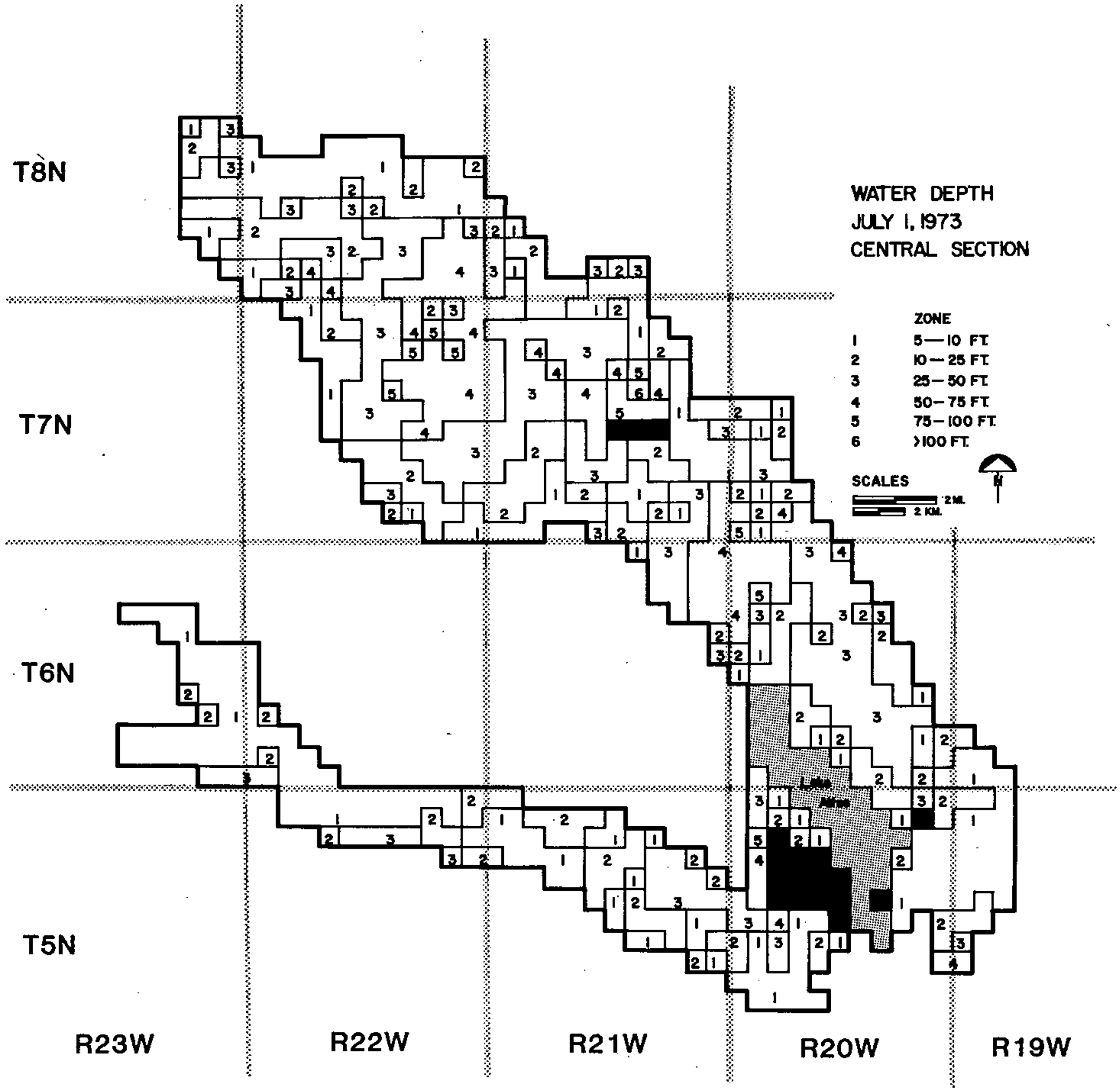


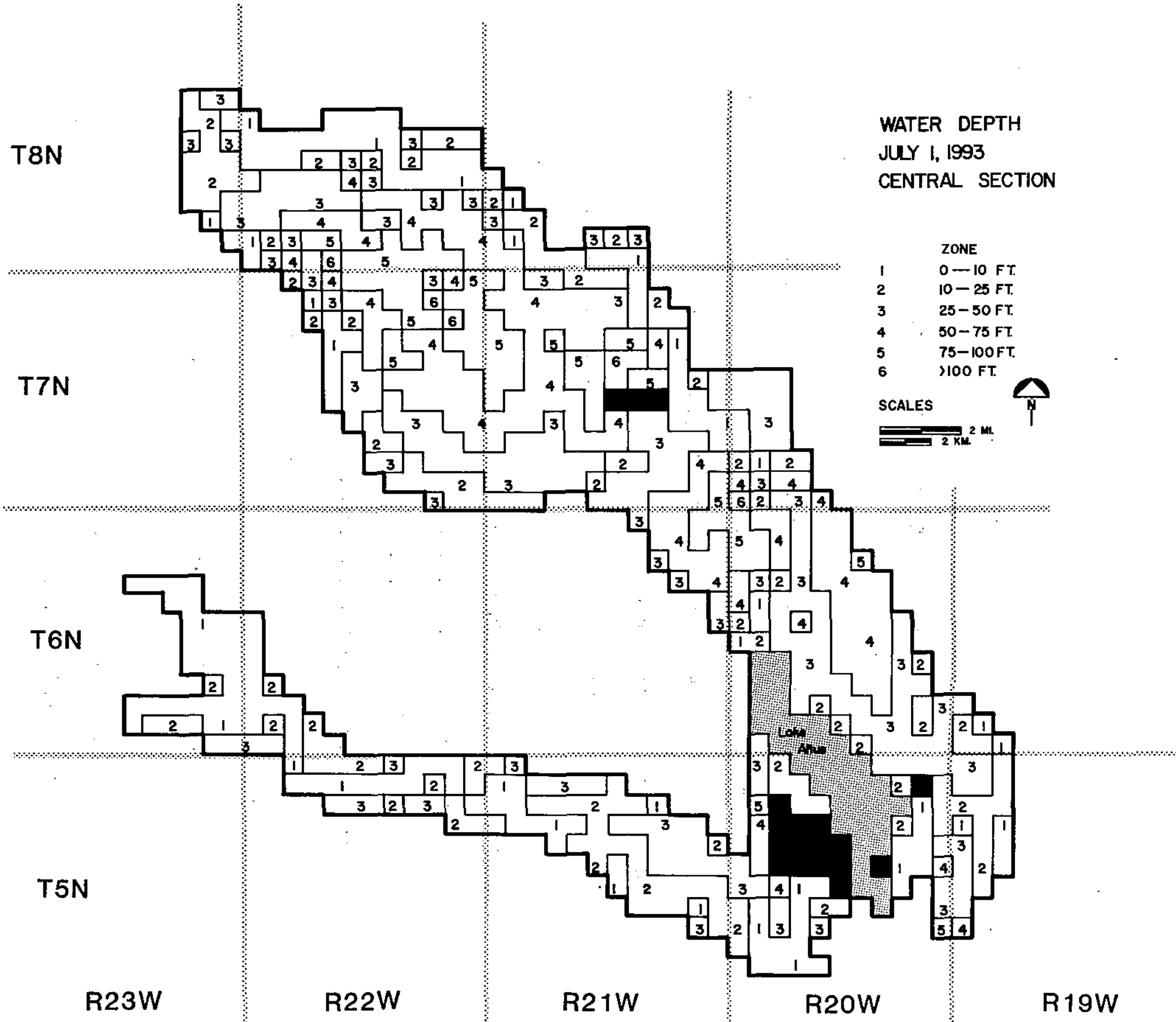

NORTH FORK OF THE RED RIVER, CENTRAL SECTION
AREA
YEAR 1993
40
30
20
10
AREA (X 1000 ACRES)
0
20
40
60
SATURATED THICKNESS (FEET)


NORTH FORK OF THE RED RIVER, CENTRAL SECTION
RANGE OF WATER VOLUME
YEAR 1973
VOLUME (X 1000 ACRE FEET)
5%
40
30
20
10
0
20
40
60
80
SATURATED THICKNESS


NORTH FORK OF THE RED RIVER, CENTRAL SECTION
RANGE OF WATER VOLUME
YEAR 1993
VOLUME (X 1000 ACRE FEET)
40
30
20
10
0
20
40
60
SATURATED THICKNESS (FEET)


TRANSMISSIVITY
JULY 1, 1993
CENTRAL SECTION
ZONE "T" (100 gpd / ft.)
1 0—100
2 101—200
3 201—400
4 401—600
5 601—800
6 801—1000
7 >1000
GROUND WATER FLOW DIRECTION (CONSTANT GRADIENT NODES)
SCALES
2 MI.
2 KM.
N
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W

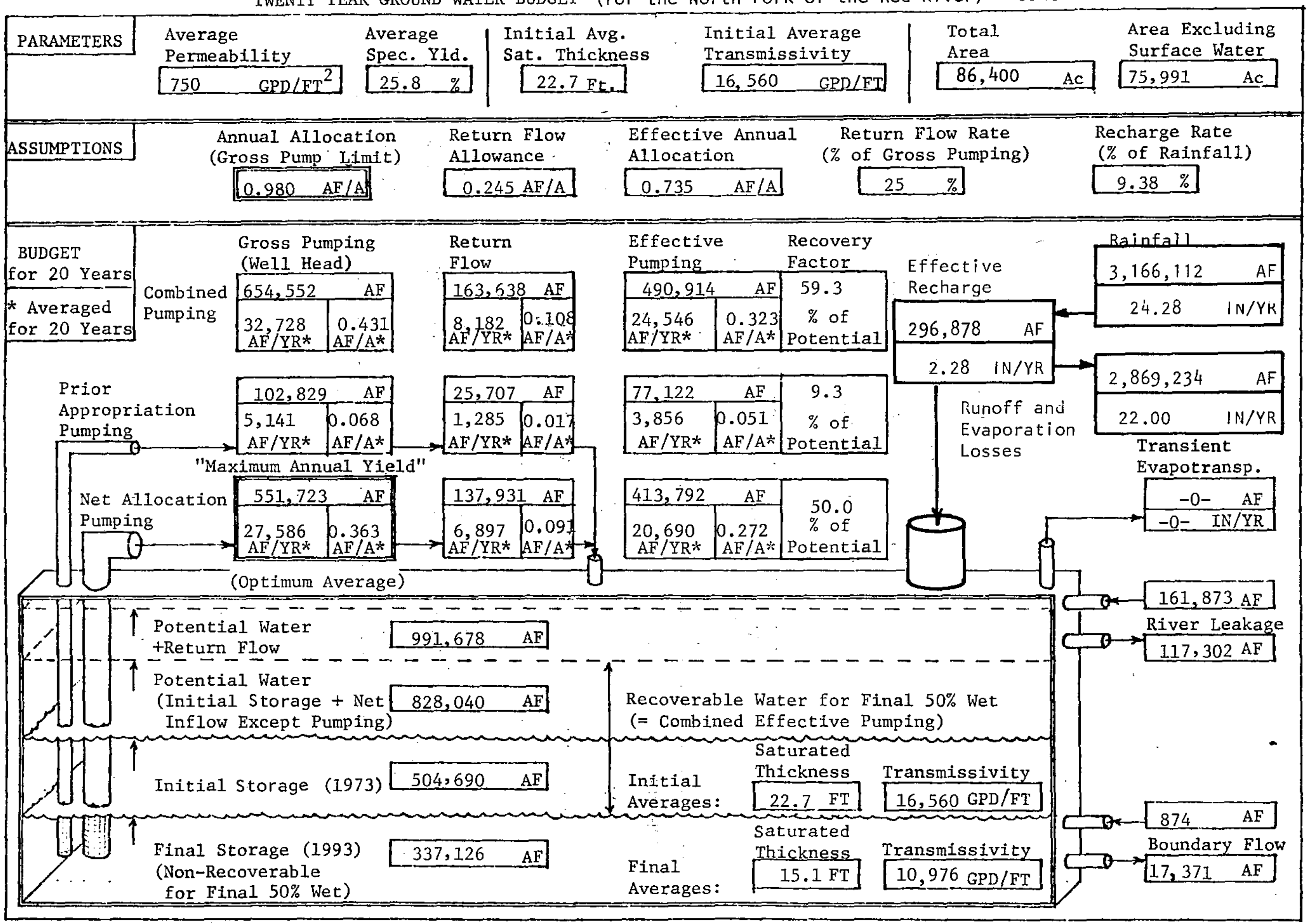

WATER DEPTH
JULY 1, 1973
CENTRAL SECTION
ZONE
1 5—10 FT.
2 10—25 FT.
3 25—50 FT.
4 50—75 FT.
5 75—100 FT.
6 >100 FT.
SCALES
2 MI.
2 KM.
N
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W


WATER DEPTH
JULY 1, 1993
CENTRAL SECTION
ZONE
1 0 — 10 FT.
2 10 — 25 FT.
3 25 — 50 FT.
4 50 — 75 FT.
5 75 — 100 FT.
6 >100 FT.
SCALES
2 MI.
2 KM.
N
T8N
T7N
T6N
T5N
R23W
R22W
R21W
R20W
R19W

APPENDIX A-4

RESULTS FOR THE SOUTHERN SECTION

TWENTY YEAR GROUND WATER BUDGET (for the North Fork of the Red River) - Southern Section



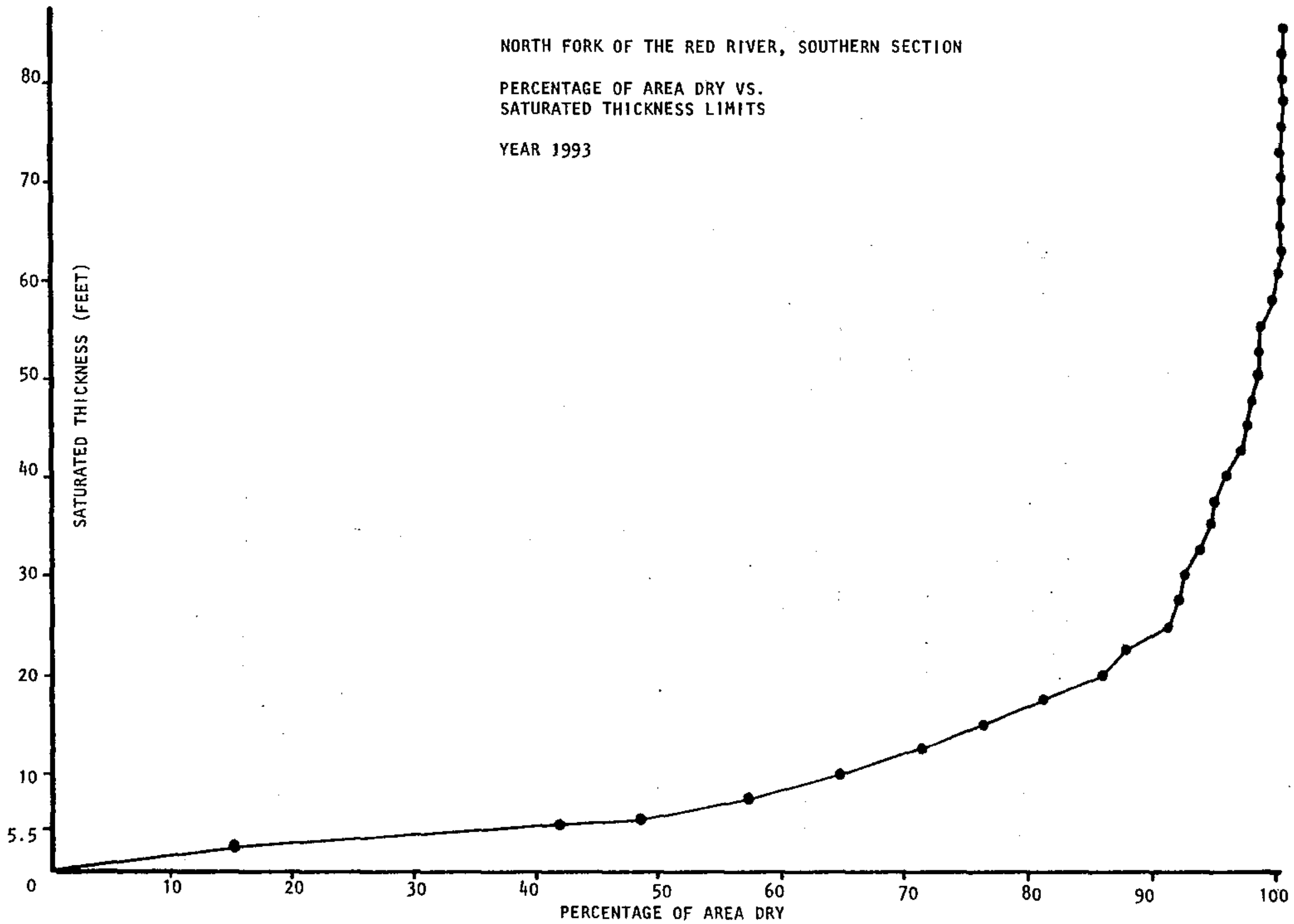
MASS BALANCE

North Fork of the Red River - Southern Section

Prior Appropriative and Allocation Pumping

July 1, 1973 to July 1, 1993

	AVERAGE ANNUAL (ACRE FT.)		TOTAL (ACRE FT.)	
	INFLOW	OUTFLOW	INFLOW	OUTFLOW
RECHARGE	+14,844		+296,878	
PUMPAGE		-24,546		-490,914
RIVER LEAKAGE	+ 8,094	- 5,865	+161,873	-117,302
SUBSURFACE FLOW	+ 44	- 869	+ 874	- 17,371
TOTALS	+22,981	-31,279	+459,625	-625,587
NET STORAGE		- 8,298		-165,962

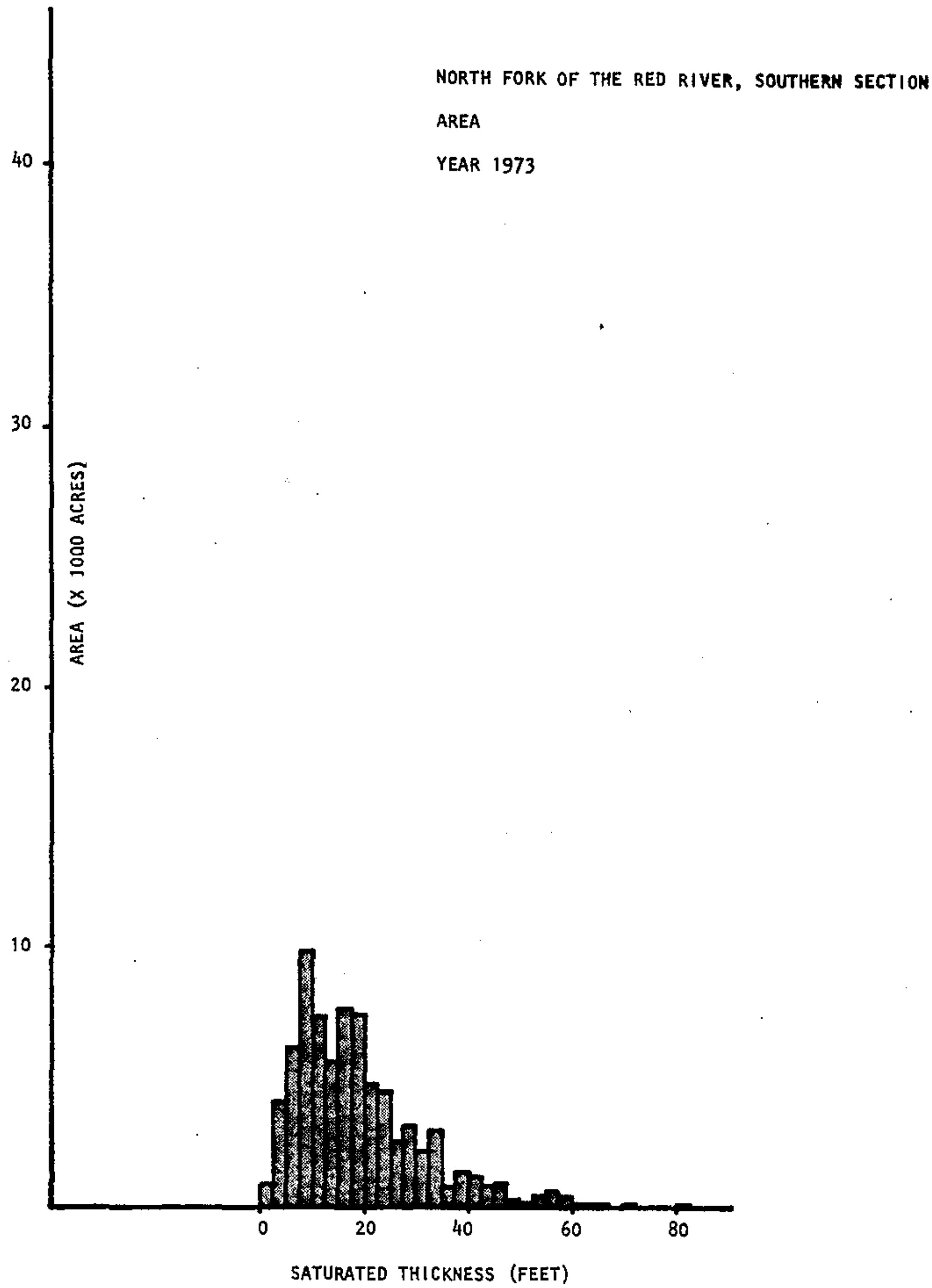

NORTH FORK OF THE RED RIVER, SOUTHERN SECTION
PERCENTAGE OF AREA DRY VS.
SATURATED THICKNESS LIMITS
YEAR 1993
SATURATED THICKNESS (FEET)
80
70
60
50
40
30
20
10
5.5
0
10
20
30
40
50
60
70
80
90
100
PERCENTAGE OF AREA DRY

WATER DISTRIBUTION SUMMARY
NORTH FORK OF THE RED RIVER - SOUTHERN SECTION
JULY 1, 1973

SATURATED THICKNESS RANGE (FEET)	AREA (% OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (%)	STORED WATER (ACRE FT.)
0-5.5	8.0	6,240	3.8	25.8	6,117
5.5-10	19.2	15,040	8.0	25.8	30,874
10-20	36.2	28,320	15.1	25.8	110,431
20-30	19.4	15,200	24.4	25.8	95,717
30-40	9.6	7,520	34.3	25.8	66,443
40-50	4.3	3,360	43.6	25.8	37,758
50-60	2.2	1,760	55.9	25.8	25,353
60-70	0.6	480	63.9	25.8	7,899
70-80	0.2	160	71.9	25.8	2,966
80-90	0.2	160	82.0	25.8	3,381
ALL RANGES	100.0	78,240	19.2	25.8	386,939

WATER DISTRIBUTION SUMMARY
NORTH FORK OF THE RED RIVER - SOUTHERN SECTION
JULY 1, 1993

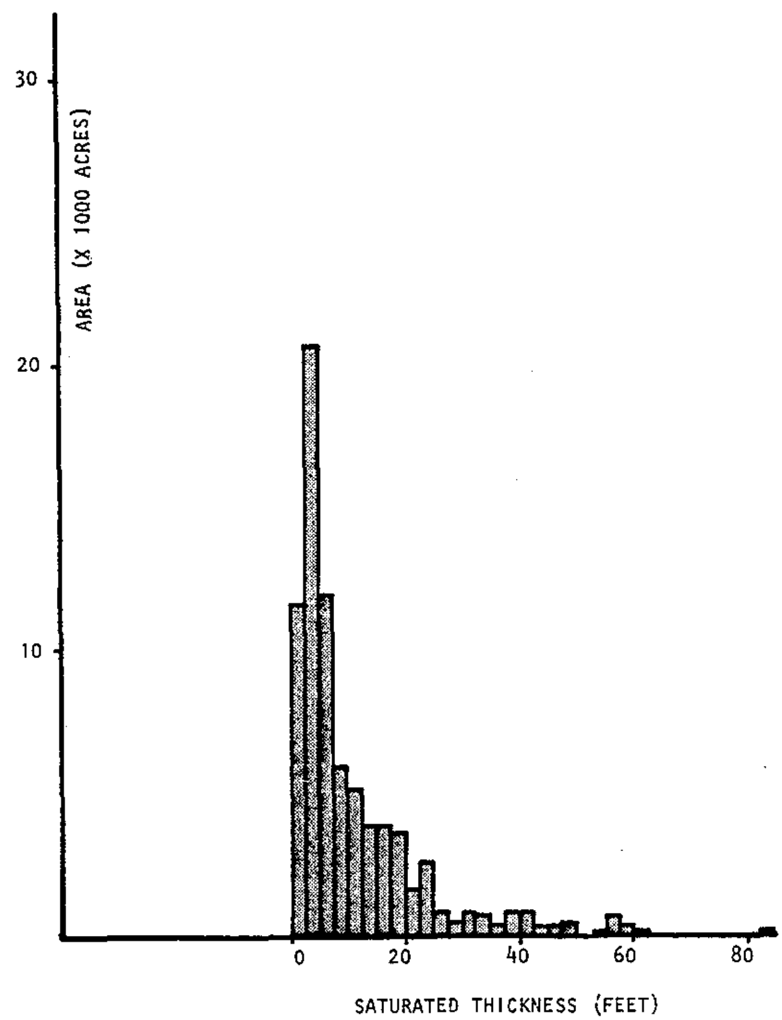
SATURATED THICKNESS RANGE (FEET)	AREA (% OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (%)	STORED WATER (ACRE FT.)
0-5.5	48.1	37,600	3.6	25.8	34,688
5.5-10	16.4	12,800	7.2	25.8	23,731
10-20	21.1	16,480	14.7	25.8	62,356
20-30	7.0	5,440	23.8	25.8	33,299
30-40	3.3	2,560	34.8	25.8	22,967
40-50	2.5	1,920	44.3	25.8	21,934
50-60	1.4	1,120	56.4	25.8	16,272
60-70	0.2	160	62.3	25.8	2,567
70-80	0.0	0	-	-	0
80-90	0.2	160	82.0	25.8	3,381
ALL RANGES	100.0	78,240	11.0	25.8	221,194

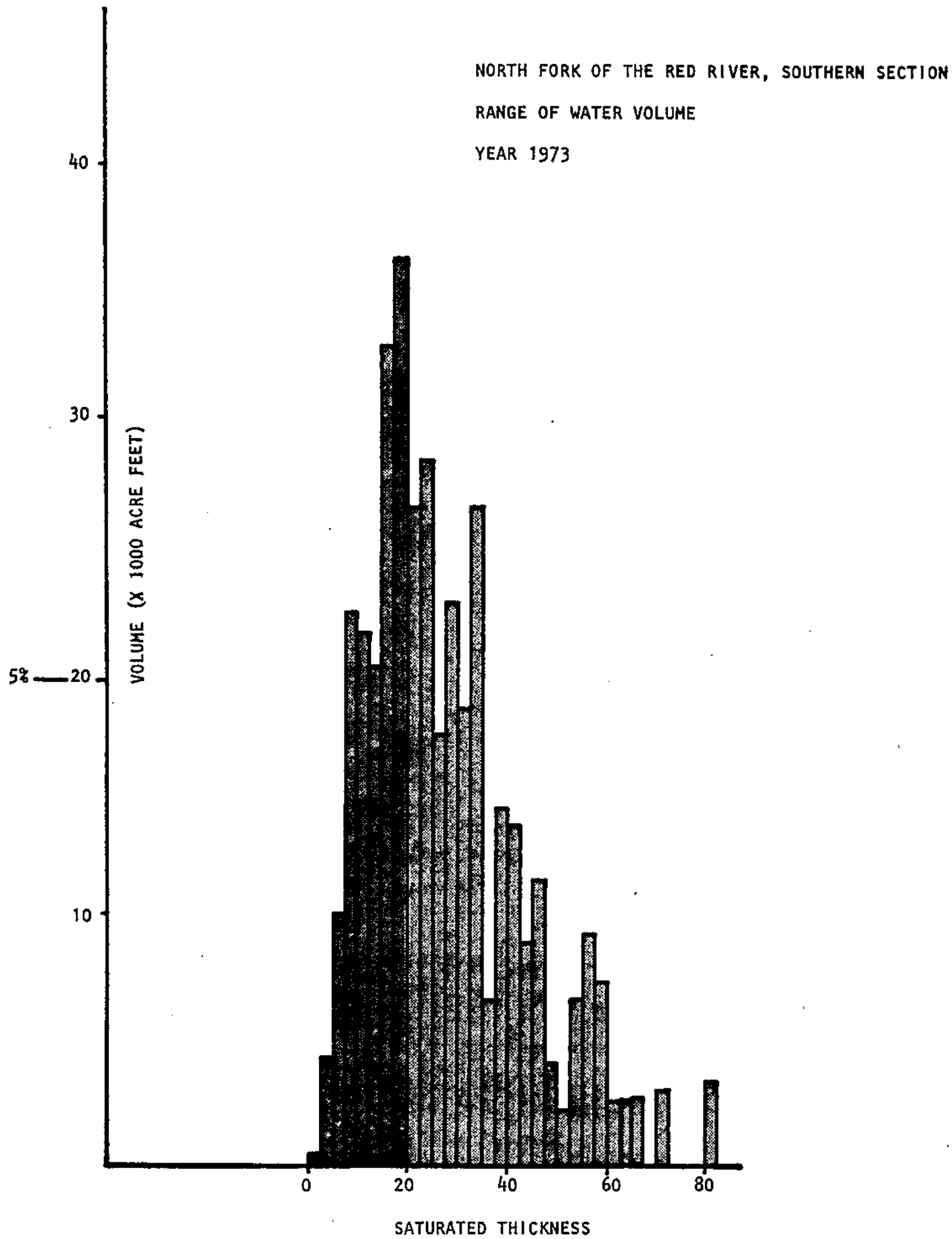

NORTH FORK OF THE RED RIVER, SOUTHERN SECTION
AREA
YEAR 1973
40
30
20
10
AREA (X 1000 ACRES)
0
20
40
60
80
SATURATED THICKNESS (FEET)

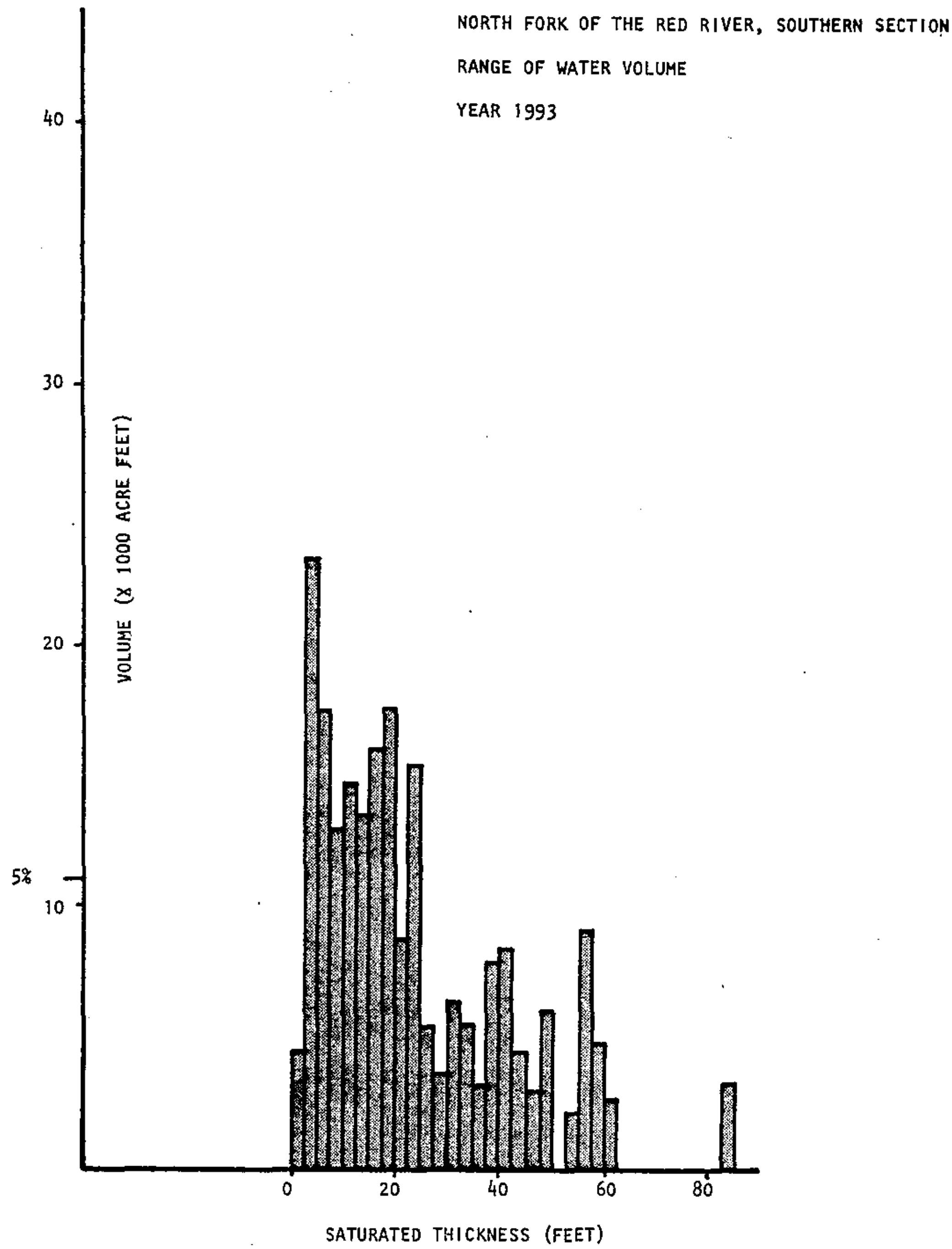
NORTH FORK OF THE RED RIVER, SOUTHERN SECTION

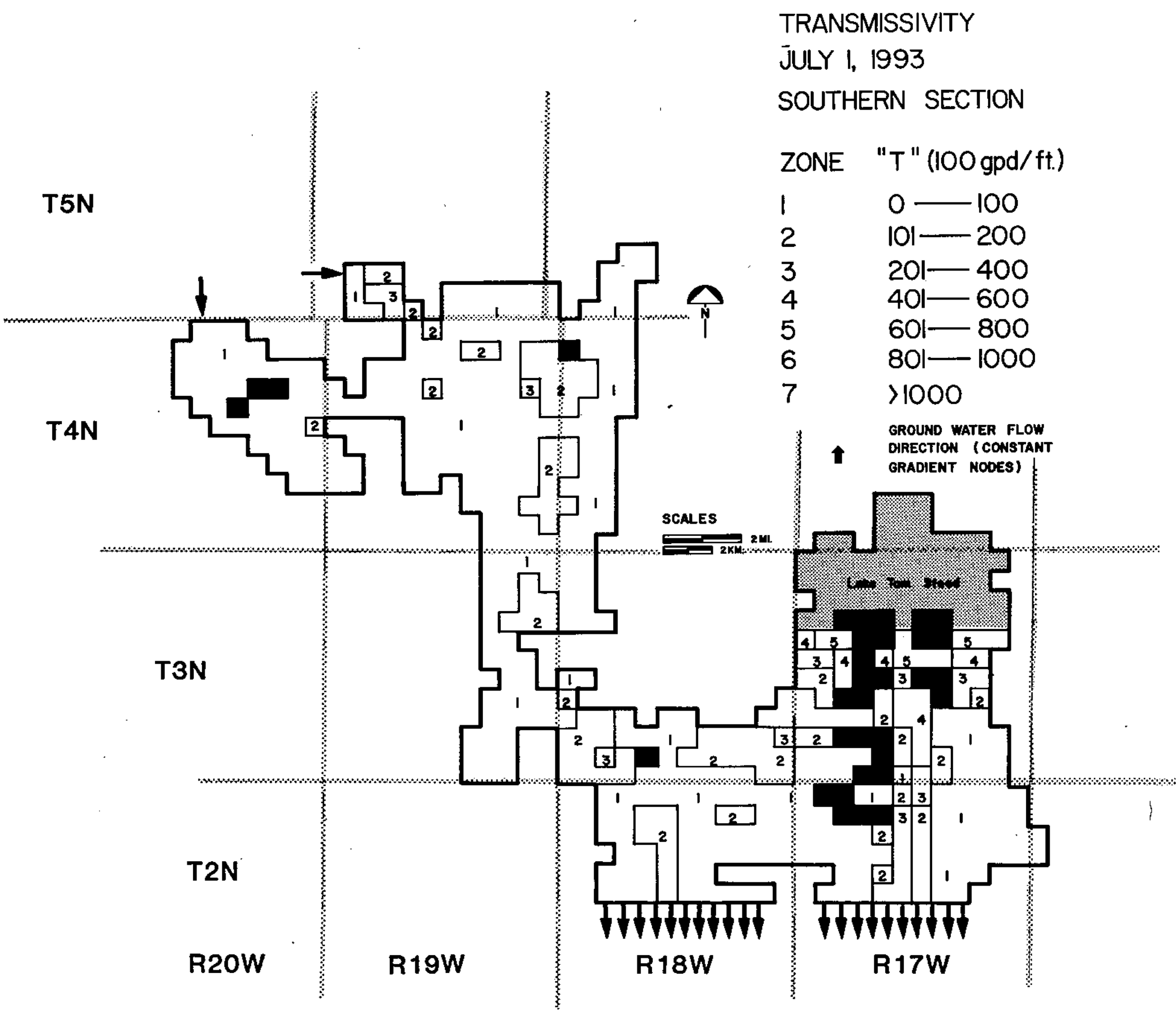
AREA

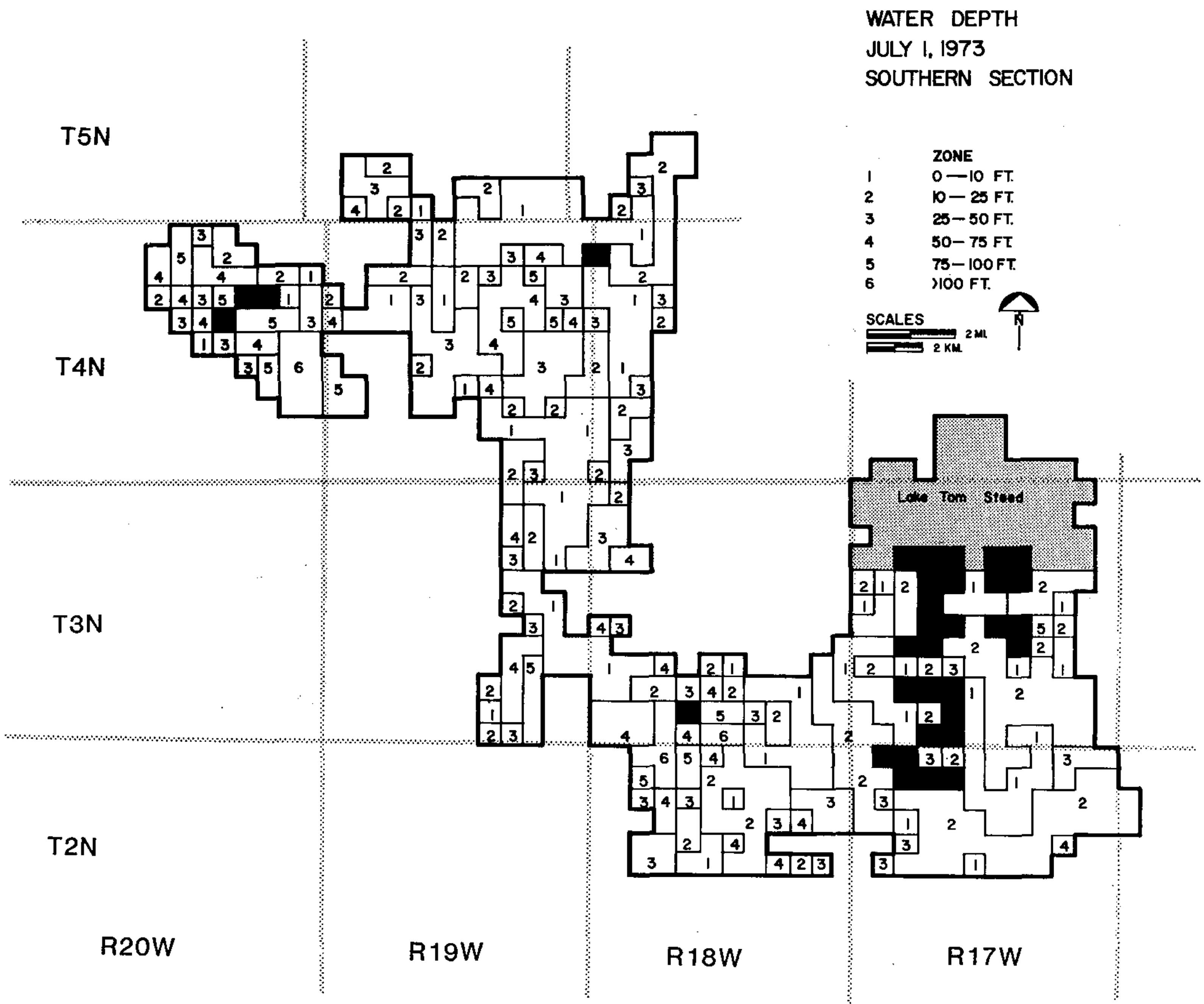
YEAR 1993

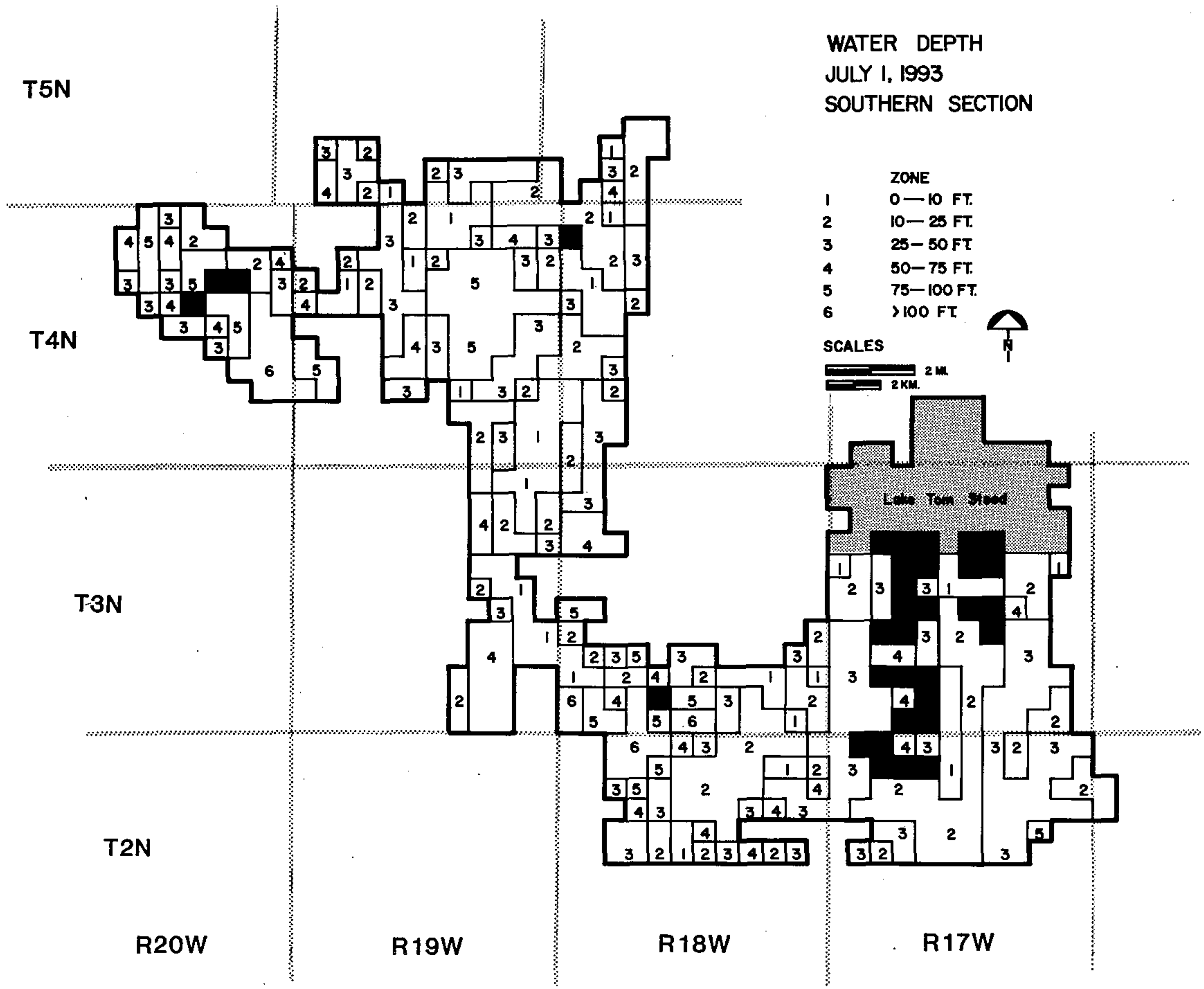



NORTH FORK OF THE RED RIVER, SOUTHERN SECTION
RANGE OF WATER VOLUME
YEAR 1973
VOLUME (X 1000 ACRE FEET)
40
30
5% 20
10
0
20
40
60
80
SATURATED THICKNESS


NORTH FORK OF THE RED RIVER, SOUTHERN SECTION
RANGE OF WATER VOLUME
YEAR 1993
VOLUME (X 1000 ACRE FEET)
40
30
20
10
5%
0
20
40
60
80
SATURATED THICKNESS (FEET)


TRANSMISSIVITY
JULY 1, 1993
SOUTHERN SECTION
ZONE "T" (100 gpd/ft.)
1 0 —— 100
2 101 —— 200
3 201 —— 400
4 401 —— 600
5 601 —— 800
6 801 —— 1000
7 >1000
GROUND WATER FLOW DIRECTION (CONSTANT GRADIENT NODES)
SCALES
2 MI.
2 KM.
N
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W


WATER DEPTH
JULY 1, 1973
SOUTHERN SECTION
ZONE
1 0—10 FT.
2 10—25 FT.
3 25—50 FT.
4 50—75 FT.
5 75—100 FT.
6 >100 FT.
SCALES
2 MI.
2 KM.
N
Lake Tom Steed
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W


WATER DEPTH
JULY 1, 1993
SOUTHERN SECTION
ZONE
1 0—10 FT.
2 10—25 FT.
3 25—50 FT.
4 50—75 FT.
5 75—100 FT.
6 >100 FT.
SCALES
2 MI.
2 KM.
N
Lake Tom Steed
T5N
T4N
T3N
T2N
R20W
R19W
R18W
R17W

APPENDIX B

PUMP TEST DATA

PUMP TEST CALCULATIONS

Oklahoma State Reformatory
Observation Well #1

Q = 100 gpm
r = 75 ft.
Saturated Thickness = 36 ft.

Prickett Method

Early Match Point

s = 0.16 ft.
t = 9.0 min.
W(u) = 0.49
u = 0.4

$$T = \frac{114.6\ Q}{s}\ (W_{(u)})$$

$$T = \frac{(114.6)(100)}{0.16}\ (0.49)$$

T = 35,096 gpd/ft.

$$K = \frac{T}{\text{Saturated Thickness}}$$

$$K = \frac{35{,}096}{36}$$

K = 975 gpd/ft.^{2}

Late Match Point

s = 0.72 ft.
t = 260 min.
W(u) = 2.1
(u) = 0.083

$$T = \frac{114.6\ Q}{s}\ (W_{(u)})$$

$$T = \frac{(114.6)(100)}{(0.72)}\ (2.1)$$

T = 33,425 gpd/ft.

$$K = \frac{T}{\text{Saturated Thickness}}$$

$$K = \frac{33{,}425}{36}$$

K = 928 gpd/ft.^{2}

Jacob Method

Q = 100 gpm
Δs = 0.998 ft.

$$T = \frac{264\ Q}{\Delta s}$$

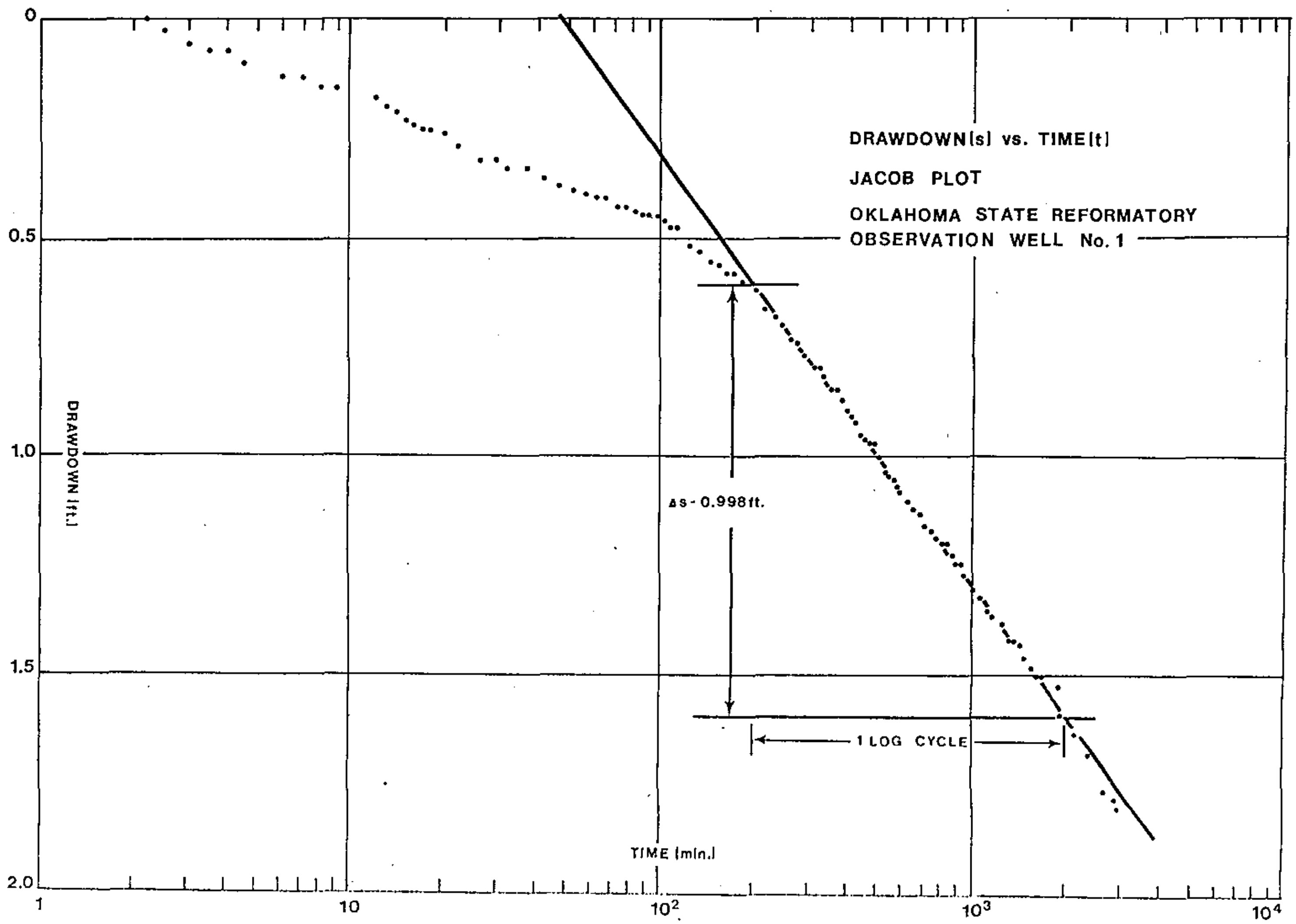
$$T = \frac{(264)(100)}{(0.998)}$$

T = 26,453 gpd/ft.

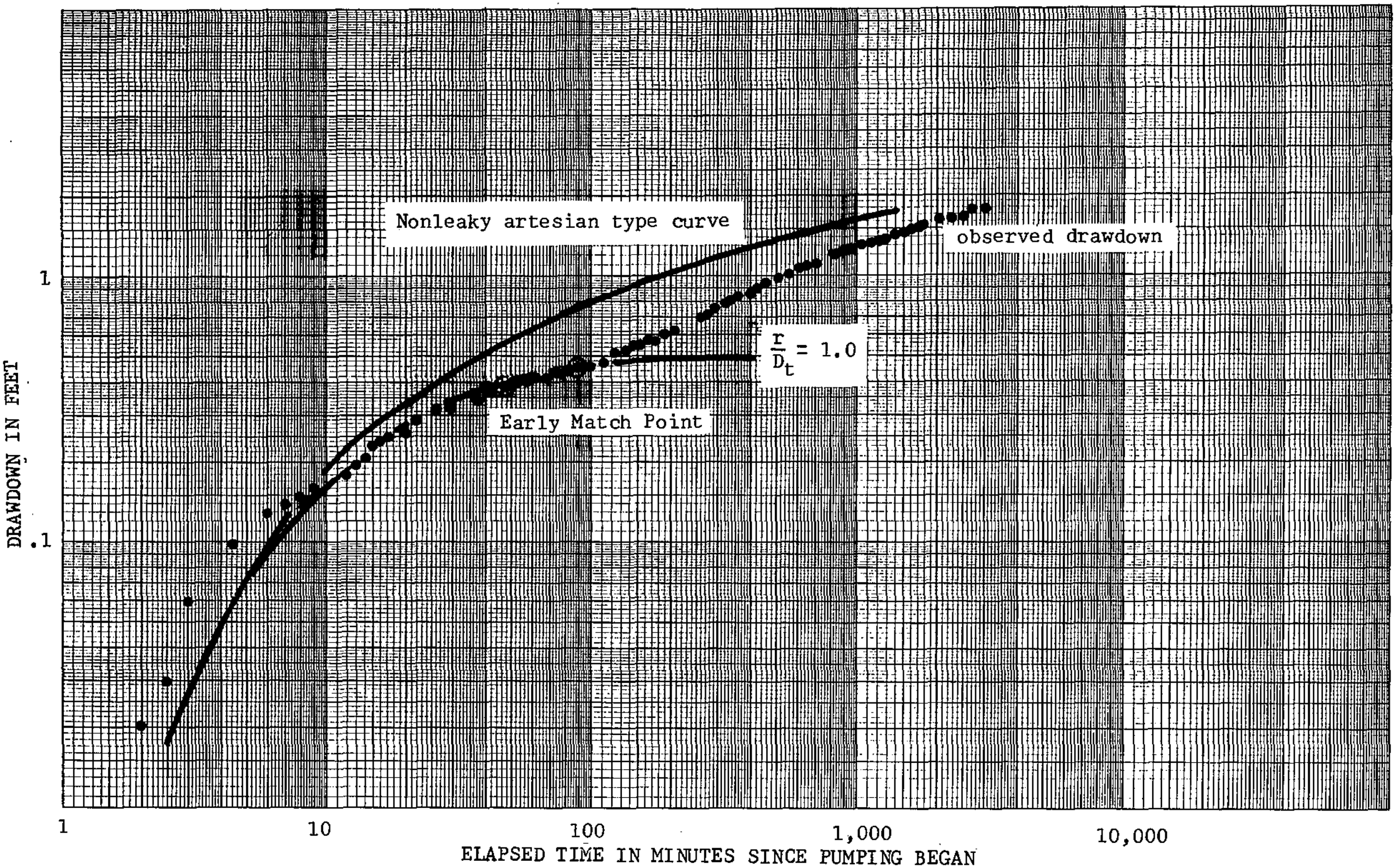
$$K = \frac{T}{\text{Saturated Thickness}}$$

$$K = \frac{26{,}453}{36}$$

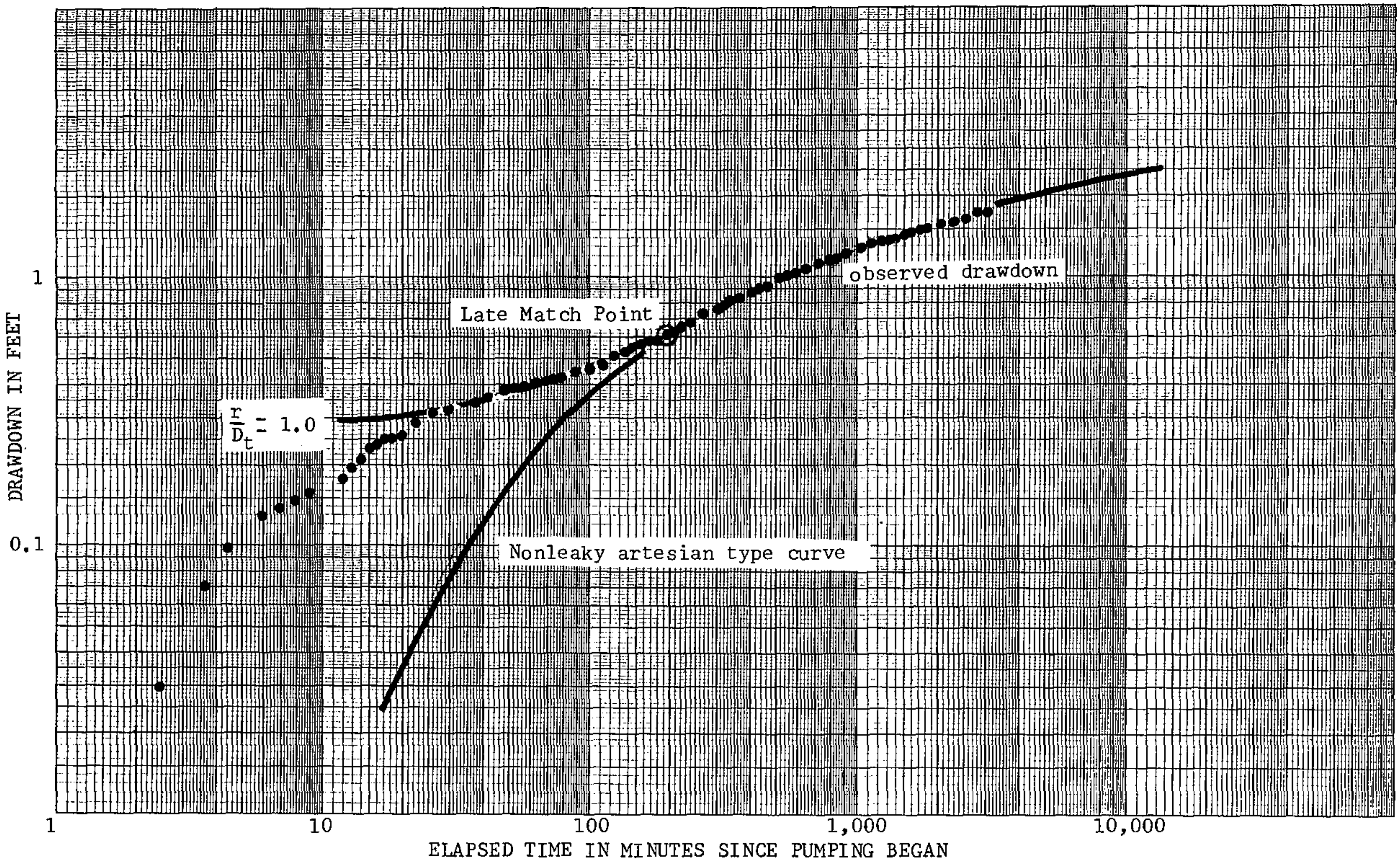
K = 735 gpd/ft.^{2}


DRAWDOWN(s) vs. TIME(t)
JACOB PLOT
OKLAHOMA STATE REFORMATORY
OBSERVATION WELL No. 1
DRAWDOWN (ft.)
TIME (min.)
Δs - 0.998 ft.
1 LOG CYCLE
0
0.5
1.0
1.5
2.0
1
10
10²
10³
10⁴

PRICKETT METHOD
Curve (Early Match)



PRICKETT METHOD
Curve (Late Match)



AQUIFER PUMP TEST

Oklahoma State Reformatory, Granite, Oklahoma

Observation Well #1, NW¼, Sec. 28, T. 6 N., R. 20 W.

Static Water Level - 28.90' (measured from Ground Elevation)

Discharge(Q) = 100 Gallons per Minute

DATE	TIME OF DAY	ELAPSED TIME (MINUTES)	WATER LEVEL BELOW GR. ELEV. (FEET)	DRAWDOWN (FEET)	CUMULATIVE DRAWDOWN (FEET)
Mar 15	10:08	0.0	28.90	0.00	0.00
	10:08:30	0.5	28.90	0.00	0.00
	10:09	1.0	28.90	0.00	0.00
	10:09:30	1.5	28.90	0.00	0.00
	10:10	2.0	28.92	0.02	0.02
	10:10:30	2.5	28.93	0.01	0.03
	10:11	3.0	28.96	0.03	0.06
	10:11:30	3.5	28.97	0.01	0.07
	10:12	4.0	28.97	0.00	0.07
	10:12:30	4.5	29.00	0.03	0.10
	10:14	6.0	29.03	0.03	0.13
	10:15	7.0	29.04	0.01	0.14
	10:16	8.0	29.05	0.01	0.15
	10:17	9.0	29.06	0.01	0.16
	10:20	12.0	29.08	0.02	0.18
	10:21	13.0	29.10	0.02	0.20
	10:22	14.0	29.11	0.01	0.21
	10:23	15.0	29.13	0.02	0.23
	10:24	16.0	29.14	0.01	0.24
	10:25	17.0	29.15	0.01	0.25
	10:26	18.0	29.15	0.00	0.25
	10:28	20.0	29.16	0.01	0.26
	10:30	22.0	29.19	0.03	0.29
	10:34	26.0	29.22	0.03	0.32
	10:37	29.0	29.22	0.00	0.32
	10:40	32.0	29.24	0.02	0.34
	10:45	37.0	29.24	0.00	0.34
	10:50	42.0	29.26	0.02	0.36
	10:55	47.0	29.28	0.02	0.38
	11:00	52.0	29.29	0.01	0.39

DATE	TIME OF DAY	ELAPSED TIME (MINUTES)	WATER LEVEL BELOW GR. ELEV. (FEET)	DRAWDOWN (FEET)	CUMULATIVE DRAWDOWN (FEET)
	11:05	57.00	29.30	0.01	0.40
	11:10	62.00	29.31	0.01	0.41
	11:15	67.00	29.31	0.00	0.41
	11:20	72.00	29.33	0.02	0.43
	11:25	77.00	29.33	0.00	0.43
	11:30	82.00	29.34	0.01	0.44
	11:35	87.00	29.35	0.01	0.45
	11:40	92.00	29.35	0.00	0.45
	11:45	97.00	29.35	0.00	0.45
	11:50	102.00	29.36	0.01	0.46
	11:55	107.00	29.38	0.02	0.48
	12:00	112.00	29.38	0.00	0.48
	12:10	122.00	29.42	0.04	0.52
	12:20	132.00	29.43	0.01	0.53
	12:30	142.00	29.45	0.02	0.55
	12:40	152.00	29.46	0.01	0.56
	12:50	162.00	29.48	0.02	0.58
	13:00	172.00	29.48	0.00	0.58
	13:10	182.00	29.50	0.02	0.60
	13:20	192.00	29.52	0.02	0.62
	13:30	202.00	29.53	0.01	0.63
	13:45	217.00	29.56	0.03	0.66
	14:00	232.00	29.58	0.02	0.68
	14:15	247.00	29.60	0.02	0.70
	14:30	262.00	29.63	0.03	0.73
	14:45	277.00	29.64	0.01	0.74
	15:00	292.00	29.67	0.03	0.77
	15:20	312.00	29.70	0.03	0.80
	15:30	322.00	29.70	0.00	0.80
	15:45	337.00	29.72	0.02	0.82
	16:00	352.00	29.75	0.03	0.85
	16:15	367.00	29.75	0.00	0.85
	16:30	383.00	29.77	0.02	0.87
	16:45	397.00	29.79	0.02	0.89
	17:00	412.00	29.81	0.02	0.91
	17:15	427.00	29.82	0.01	0.92
	17:30	442.00	29.85	0.03	0.95
	17:45	457.00	29.86	0.01	0.96
	18:00	472.00	29.87	0.01	0.97
	18:15	487.00	29.87	0.00	0.97
	18:30	502.00	29.90	0.03	1.00
	18:45	517.00	29.92	0.02	1.02
	19:00	532.00	29.93	0.01	1.03
	19:15	547.00	29.94	0.01	1.04
	19:30	562.00	29.95	0.01	1.05
	19:45	577.00	29.97	0.02	1.07
	20:00	592.00	29.98	0.01	1.08

DATE	TIME OF DAY	ELAPSED TIME (MINUTES)	WATER LEVEL BELOW GR. ELEV. (FEET)	DRAWDOWN (FEET)	CUMULATIVE DRAWDOWN (FEET)
	20:30	622.00	30.00	0.02	1.10
	21:00	652.00	30.02	0.02	1.12
	21:30	682.00	30.03	0.01	1.13
	22:00	712.00	30.06	0.03	1.16
	22:30	742.00	30.07	0.01	1.17
	23:00	772.00	30.09	0.02	1.19
	23:30	802.00	30.10	0.01	1.20
Mar 16	24:00	932.00	30.10	0.00	1.20
	00:30	862.00	30.12	0.02	1.22
	01:00	892.00	30.15	0.03	1.25
	01:30	922.00	30.15	0.00	1.25
	02:00	952.00	30.17	0.02	1.27
	03:00	1012.00	30.20	0.03	1.30
	04:00	1072.00	30.22	0.02	1.32
	05:00	1132.00	30.25	0.03	1.35
	06:00	1192.00	30.27	0.02	1.37
	07:00	1252.00	30.28	0.01	1.38
	08:00	1312.00	30.32	0.04	1.42
	09:00	1372.00	30.32	0.00	1.42
	10:00	1432.00	30.33	0.01	1.43
	11:00	1492.00	30.36	0.03	1.46
	12:00	1552.00	30.38	0.02	1.48
	13:00	1612.00	30.40	0.02	1.50
	14:00	1672.00	30.40	0.00	1.50
	15:00	1732.00	30.42	0.02	1.52
	18:00	1912.00	30.49	0.08	1.59
	22:00	2152.00	30.53	0.04	1.63
Mar 17	02:00	2392.00	30.58	0.05	1.68
	06:00	2632.00	30.66	0.08	1.76
	10:00	2872.00	30.68	0.02	1.78
	12:00	2992.00	30.70	0.02	1.80