A GROUND-WATER MANAGEMENT MODEL OF THE WASHITA RIVER ALLUVIAL AQUIFER IN GRADY, MCCLAIN, GARVIN, MURRAY, CARTER, AND JOHNSTON COUNTIES IN SOUTH-CENTRAL OKLAHOMA

By

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PREFACE

This study addresses the hydrologic properties of the Washita River alluvium aquifer in Grady, McClain, Garvin, Murray, Carter, and Johnston counties in south-central Oklahoma. The primary objective of the study was to determine the maximum annual yield and corresponding maximum allowable allocation pumping rate of the alluvium in accordance with Oklahoma water law. A computer model was used to predict changes in saturated thickness over a 20-year period (July 1, 1973 - July 1, 1993) which allowed an allocation rate and maximum annual yield to be determined.

The author would like to thank his thesis adviser, Dr. Douglas C. Kent, for his guidance and valuable assistance throughout the course of this study. He would also like to thank Lorraine LeMaster, a computer programmer for Dr. Kent, for her assistance with the computer modeling. Appreciation is extended to Dr. Wayne Pettyjohn and Dr. Arthur Hounslow, members of the advisory committee, for their critique of this thesis. Gratitude is extended to the Oklahoma Water Resources Board (OWRB) for providing pertinent data and funds for the project which was arranged through a contract with Oklahoma State University and Dr. Kent, who was the principal investigator for this project. Special thanks are given to Mr. James Barnett, OWRB Director; Paul Wilson, past chief of the Ground Water Division; Duane Smith, current chief of the Ground Water Division; and Chuck Race, for their support. Special thanks are also extended to Dr. Fred E. Witz, and Mr. J. Michael Munsil for their help with the development of several microcomputer programs, and Mr. Mark R. Schipper for his friendship and moral support. The author would also like to thank Peter W. Bayley, Denna Englehardt, and Terri DeGuire for their help and support. Special gratitude is extended to my family for their moral support.

Finally, I would like to thank my wife Cindy, for her love, understanding, moral support, and encouragement. This thesis is dedicated to her.

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CHAPTER I

ABSTRACT

The Washita River alluvial aquifer extends from the Texas Panhandle to Lake Texoma near the Oklahoma-Texas border in south-central Oklahoma. The Oklahoma Water Resources Board entered into a contract with Dr. D. C. Kent of the Oklahoma State University Geology Department to make a hydrogeologic study of the aquifer and determine an annual allocation rate and maximum annual yield for the aquifer. The aquifer study was subdivided into three portions; this study concerns itself with the alluvial aquifer in south-central Oklahoma.

The Washita River alluvial aquifer is a water-table or unconfined aquifer. It is bounded on the sides and bottom by impermeable bedrock. Aquifer material is composed primarily of fine to medium-grained sand with some gravel and clay lenses dispersed throughout the aquifer. The average width of the river valley is two miles. An undulating topography and bedrock surface has resulted in a varying saturated thickness within the aquifer. The average saturated thickness was 38 feet in 1973. Well yields ranged from less than 100 gpm to more than 1,000 gpm. The average well yield in the study area is 280 gpm. Transmissivity

ranged from 2,150 gpd/ft to 250,000 gpd/ft, averaging 42,100 gpd/ft. Chemical analyses of ground-water quality in the alluvium and the underlying bedrock showed that Permian aged rocks had a greater effect on the alluvial ground water than any other rock type north of the Arbuckle Mountains. No conclusions could be drawn on ground water quality south of the Arbuckles, due to severely limited data.

The Trescott-Pinder finite difference model was used to predict changes in head elevation and thus saturated thickness over a 20-year period (July 1, 1973-July 1, 1993) produced by various pumping rates. The reasonable adjustment of such input parameters as recharge, rate (river base flow), and aquifer gradient was made to establish a steady-state recharge-discharge relationship within the aquifer. The model was calibrated through five-year computer simulations followed by a series of 20-year computer simulations.

Full prior appropriative rights in the Washita River alluvium in the study area total 8,968 acre-feet/year. This is equivalent to an annual allocation rate of 0.93 acre-feet/acre/year distributed evenly over prior right acreage.

Twenty-year simulations were made to determine the legal annual allocation rate for the aquifer. An allocation rate of 0.99 acre-feet/acre/year was established for the study area. This is equivalent to a maximum yield of 159,905 acre-feet/year. The final projected saturated thickness and transmissivity in 1993 were 9.4 feet and 11,715 gpd/ft, respectively.

CHAPTER II

INTRODUCTION

General

The primary objective of this study was to determine the maximum annual yield and thus the maximum allocation of fresh water in acre-feet per acre per year that could be produced from the Washita River alluvium in Grady, McClain, Garvin, Murray, Carter, and Johnston counties.

Under Oklahoma Statue No. 82 S 1020.4 and 82 S 1020.2, the Oklahoma Water Resources Board is responsible for completing hydrologic surveys of each fresh ground-water basin or sub-basin within the state of Oklahoma and for determining a maximum annual safe yield which will provide a 20 year minimum life for each basin.

Oklahoma Statute No. 82 S 1020.5 states the following:

> After making the hydrologic survey, the Board shall make a determination of maximum annual yield of fresh water to be produced from each ground-water basin or sub-basin. Such determination must be based on the following:
>
> 1. The total land area overlying the basin or sub-basin;
>
> 2. The amount of water in storage in the basin or sub-basin;
>
> 3. The rate of natural recharge to the basin or sub-basin and total discharge from the basin or sub-basin;

4. Transmissivity of the basin or sub-basin; and
5. The possibility of pollution of the basin or sub-basin from natural sources.

> The maximum annual yield of each fresh ground-water basin or sub-basin shall be based upon a minimum basin or sub-basin 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 (Oklahoma Water Resources Board Rules and Regulations, 665.2).

The annual allocation in terms of acre-feet per acre per year, is that which can be produced by the aquifer to cause one-half of the area of the aquifer to be depleted of water (to a saturated thickness of 5.5 feet or less) over a 20-year pumping period starting July 1, 1973 and ending on July 1, 1993.

Location

The area of the study is located mainly in Garvin, Murray, and Carter counties with small portions in eastern Grady, southern McClain, and southwestern Johnston counties excluding the alluvium located within the Arbuckle Mountain area (Figure 1). The Washita River basin covers approximately 2,800 square miles from Alex, Oklahoma to its confluence with Lake Texoma. The river elevation at Alex, Oklahoma is 1,017 feet and its elevation at Lake Texoma is 617 feet giving an average river gradient of 2.4 feet per mile over the entire study area. The river and its alluvium meander extensively.

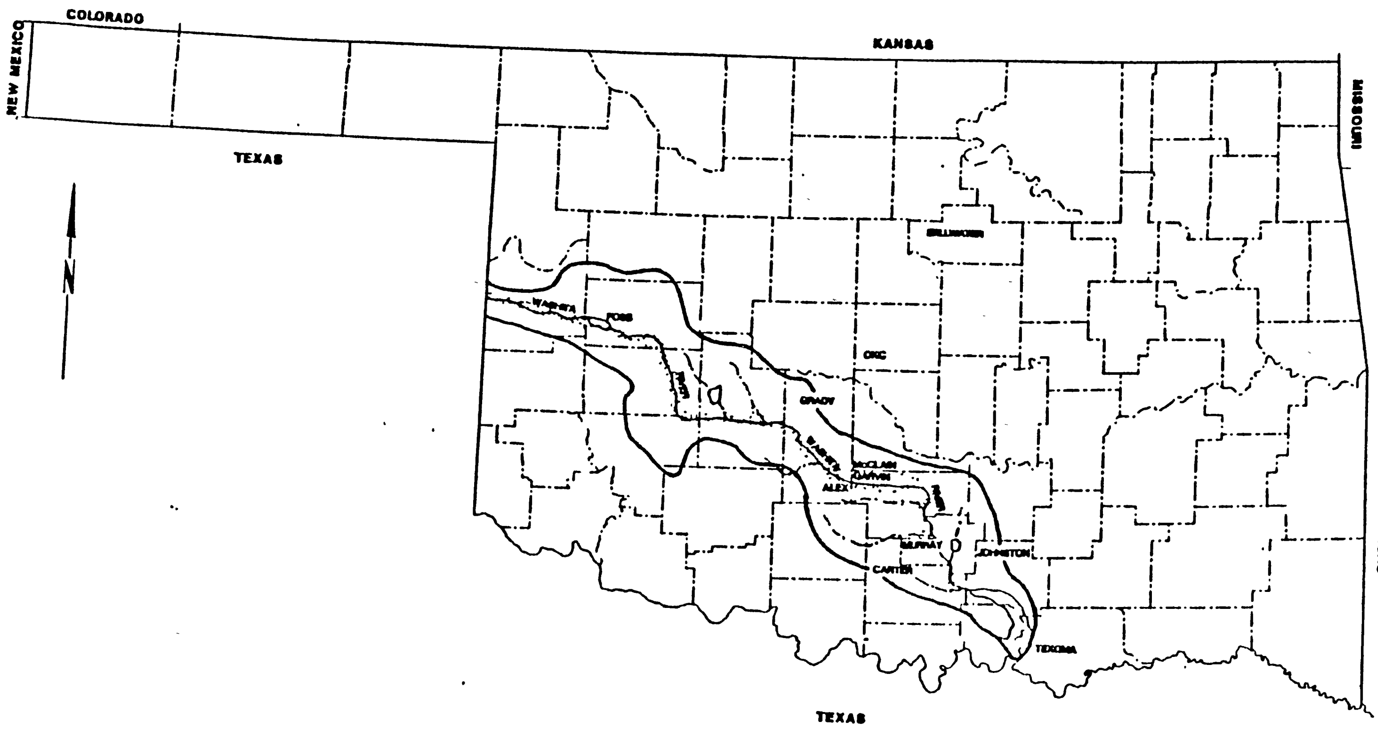


Figure 1. Location of the Study Area

The aquifer is a water table or unconfined aquifer, averaging two miles in width and it discharges into the Washita River within the study area. The surface area covered by the aquifer is 252.4 square miles (161,520 acres). Square nodes, one-half a mile on a side (2,640 feet) or 160 acres were determined to be sufficient for modeling the study area. Due to computer grid limitations, the aquifer was divided into three modeled reaches (Figures 2, 3, and 4). Alluvium found in the major tributaries within the study was modeled to where it was at least one node across.

Previous Work

Dott (1927) described the surface and subsurface geology of Garvin County. Depositional environments for the stratigraphic units in Garvin County were also discussed in the report. LaPorte (1958) and Young (1960) updated and thoroughly described the geology of Garvin County in the vicinity of Pauls Valley, Oklahoma.

The geology and dolomite resources of the Mill Creek area; Johnston County, Oklahoma were discussed by Ham (1949). Wayland and Ham (1955) described the general and economic geology of the Baum Limestone in the Ravia-Mannsville area of Oklahoma.

Bowen (1959) thoroughly discussed the sediments of the Washita arm of Lake Texoma. The report included the stratigraphy and surface geology of his study area. A

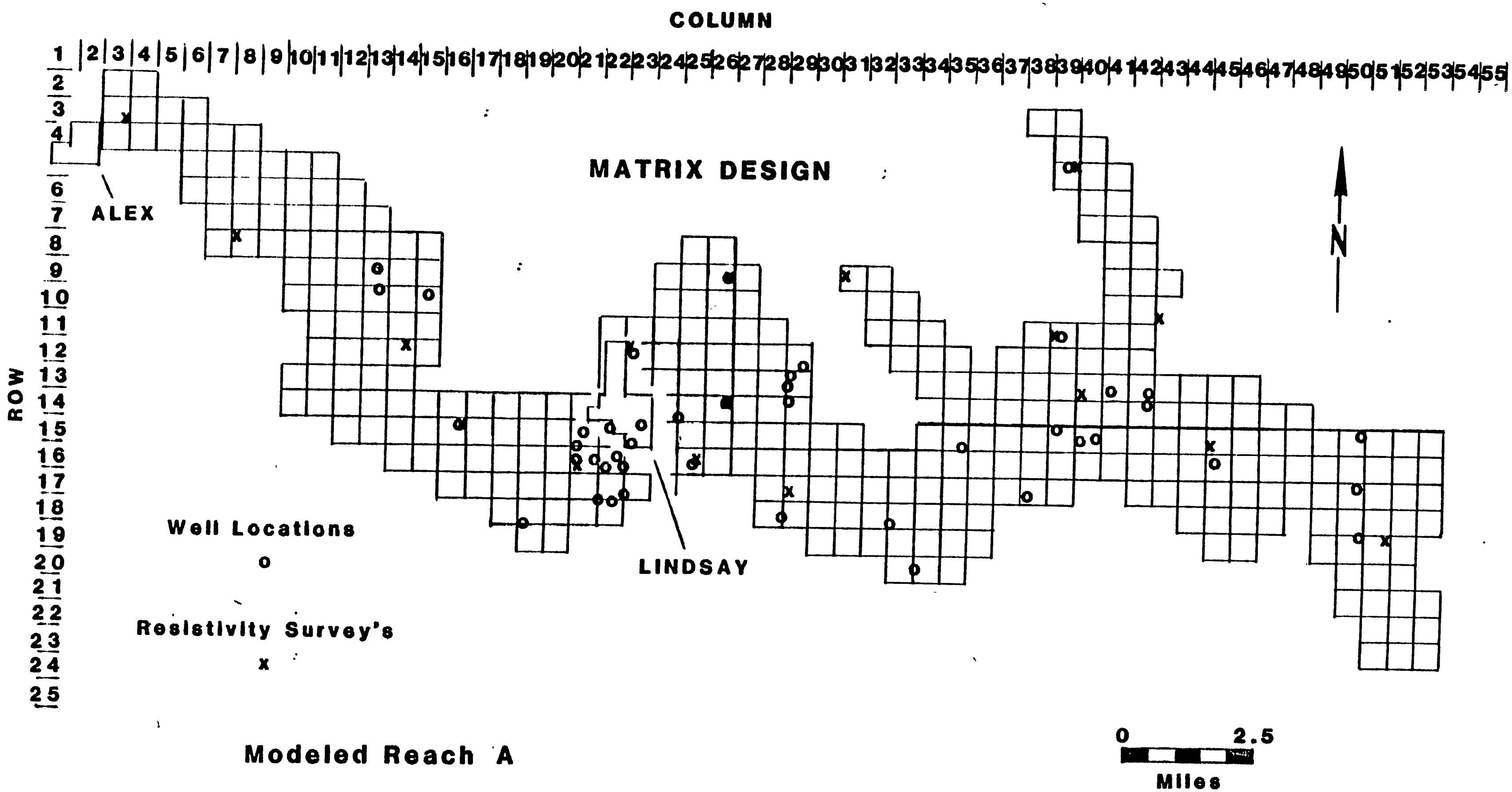


Figure 2. Computer Grid - Modeled Reach A

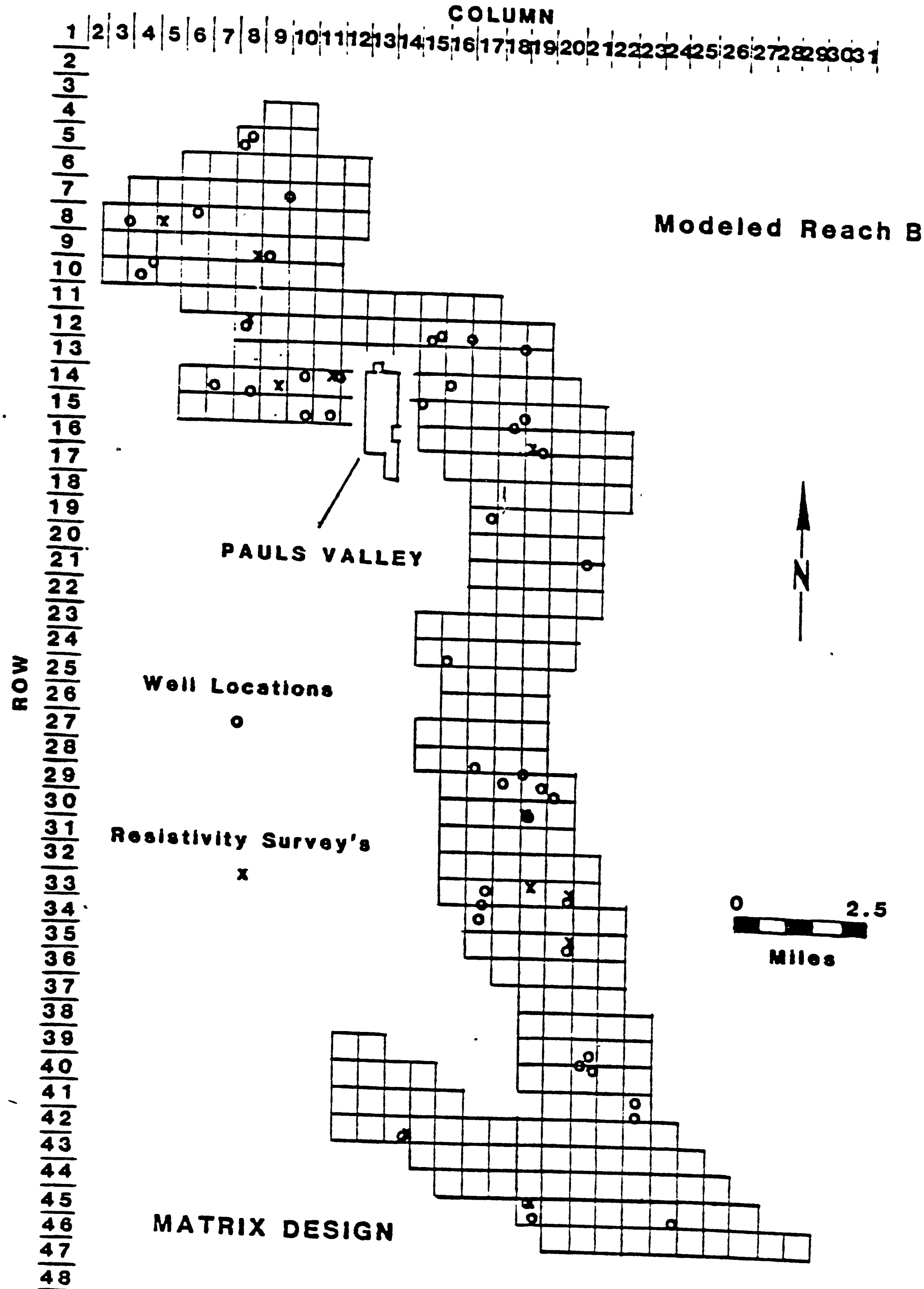


Figure 3. Computer Grid - Modeled Reach B

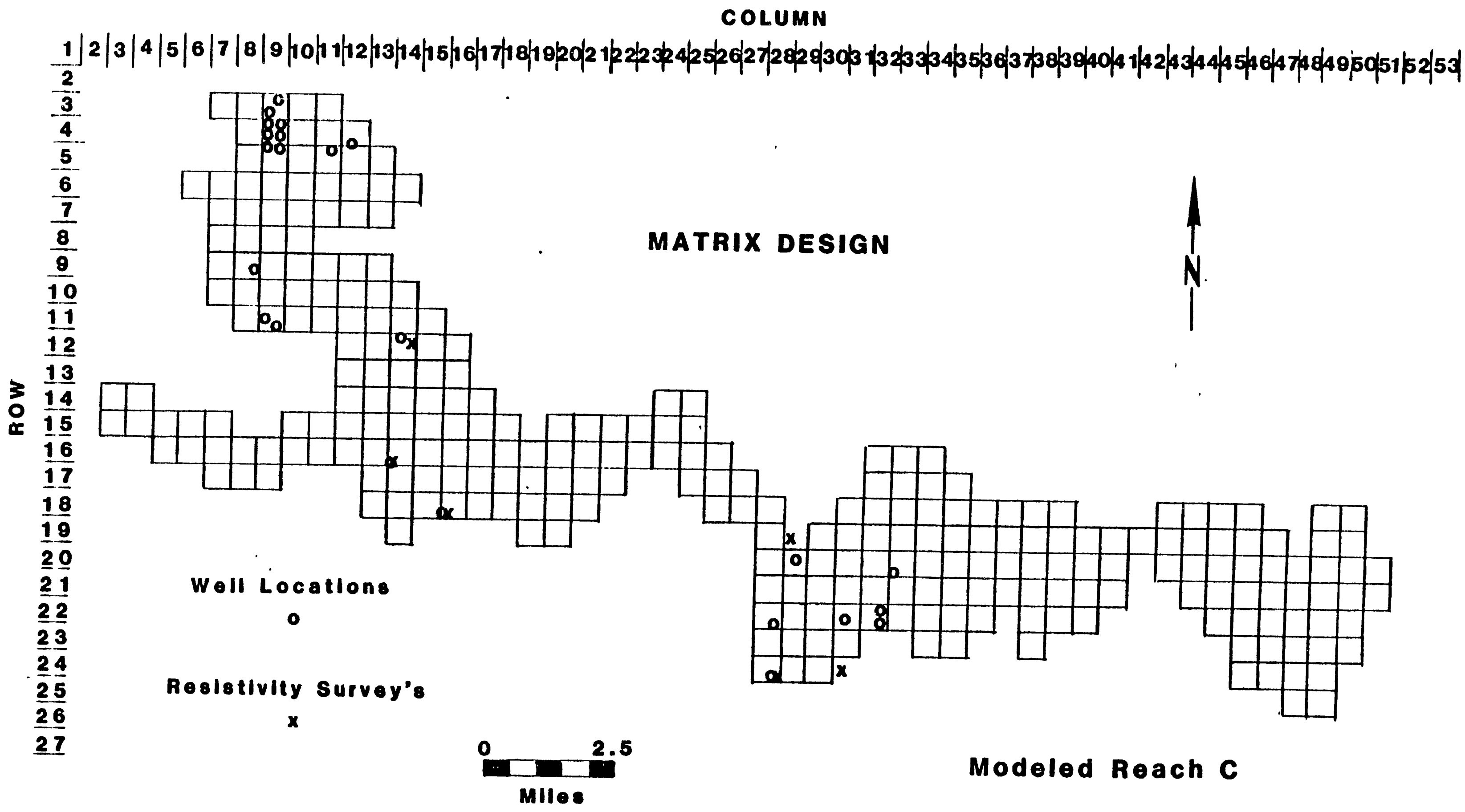


Figure 4. Computer Grid - Modeled Reach C

precipitation climatological study was done by Nicks (1971) of the Washita River area between Anadarko and Alex. This area is the most comprehensively studied portion of the Washita River basin.

Goss, Ross, Allen, and Naney (1972) reported on the geomorphology of the central Washita River basin between Alex and Anadarko. The report reconstructs the history of the Washita River. Ham et al. (1980) thoroughly described the regional geology of the Arbuckle Mountains. Included in the report is a detailed stratigraphic description of the Arbuckles.

A report on the Washita River and its drainage basin (Anonymous, 1938) describes the alluvial deposits and their applications along the entire reach of the Washita River in Oklahoma. Dott (1942) discussed the geology of Oklahoma ground-water supplies.

Davis (1955) described the geology and ground-water resources of Grady and northern Stephens counties, Oklahoma. His study outlined the stratigraphy and structure of the two counties. Also included in the report was a geologic map and several well logs. The ground water in the Arbuckle and Simpson Groups was discussed by Davis in 1955. This report has been updated by Fairchild, Hanson, and Davis (1982).

The hydrology of the Washita River and its alluvium was investigated by Leonard, Davis, and Stacy (1958). Their report gives a general description of the physiography, hydrogeology, water quality, and well yields along the entire length of the river in Oklahoma.

Hart (1965) reported on the ground water in the alluvial deposits of the Washita basin from Clinton to Anadarko, Oklahoma. Ten cross-sectional valley transects were made of the alluvium at points along the study area. Each transect consisted of three to eight test holes that were completed in the alluvium. Detailed well logs are contained in the report of the completed test holes. Specific capacity data was provided for five test holes that were completed as water wells.

The Oklahoma Water Resources Board (1968) made an appraisal of the water and related land resources of Oklahoma. These appraisals were broken into 11 regions. Region three pertains to the area of the study by the author. The appraisal contains information on the geology, climatology, hydrology, water quality, and ground water of the region.

A reconnaissance study of the water resources Ardmore-Sherman one-by-two degree quadrangle was made by Hart (1974). The report is formatted as a hydrologic atlas and contains maps showing geology, availability of ground water, water quality, and selected well hydrographs. Complete coverage of the Washita River alluvium in Garvin, McClain, Murray, Carter, Johnston, and western Grady counties is provided in the atlas. Computerized data processing techniques were applied to the Washita River alluvium between Anadarko and Alex in Caddo and Grady Counties, Oklahoma by Kent, Naney, and Barnes (1973).

Pinder (1970) developed a finite difference model to simulate two-dimensional aquifer flow. This model has been modified several times and is described by Trescott and Larson (Trescott, Pinder, and Larson, 1976). New input-output options were described by Witz (1978) under the direction of D. C. Kent for use with the IBM 370-158 computer and were used in this study. Kent (1980) and Paukstaitis (1981) used the model to model alluvium and terrace deposits of the North Fork of the Red River. Lyons (1981), Beausoleil (1981), and Schipper (1982) under the direction of D. C. Kent applied the model to ground water management studies of the Elk City Sandstone in west-central Oklahoma, the Enid isolated terrace deposit in north-central Oklahoma, and the Washita River alluvial deposits in western Oklahoma, respectively. Two of these studies have been published as final reports to the Oklahoma Water Resources Board by Kent, Lyons, and Witz (1982) and Kent, Beausoleil, and Witz (1982).

CHAPTER III

GEOLOGY

Geologically, the study area is represented by formations ranging from Precambrian to Quaternary in age. These formations are illustrated in Figures 5 and 6 and are briefly described in Figures 7 and 8. Figures 9, 10, and 11 show those formations that directly underlie the Washita River alluvial aquifer by modeled reach. Of these formations, the Garber-Wellington and the Antlers Sand are potential aquifer units.

The principal aquifer unit of the Garber-Wellington lies north of the study area in Logan and Oklahoma counties, however since it is found in the study area it is considered to be a potential aquifer unit. The Garber Sandstone and the Wellington Formation are geologically recognized as two separate units, yet hydrologically recognized as one unit. The Wellington Formation is the older of these two Permian aged formations and is comprised of reddish-brown shale and orange-brown fine-grained sandstone. The Garber Sandstone is mostly orange-brown to reddish-brown fine-grained irregularly bedded with red-brown shale and some chert and mudstone conglomerate.

The Garber-Wellington is a deltaic deposit laid down by

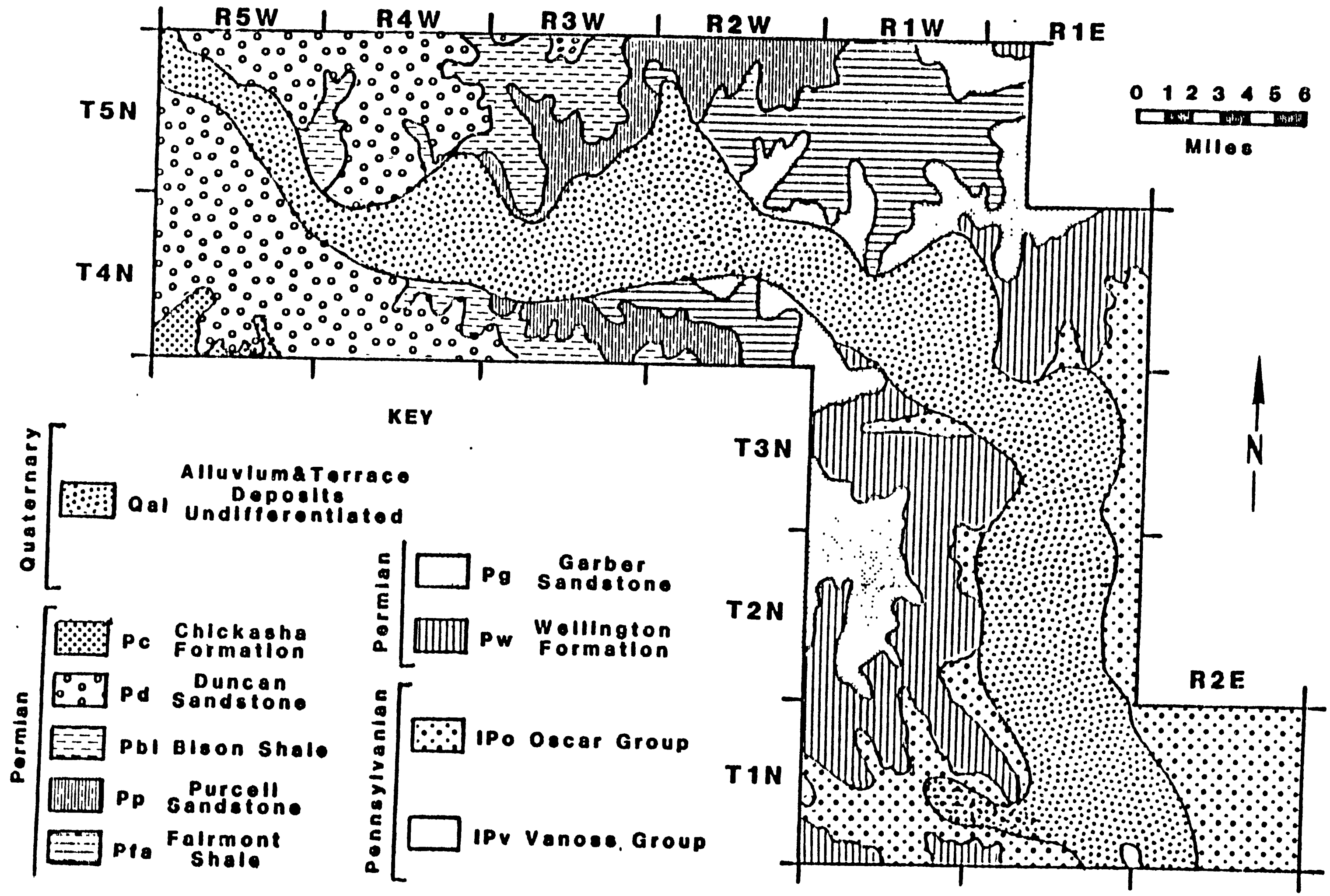


Figure 5. Geologic Map of the Study Area North of the Arbuckles

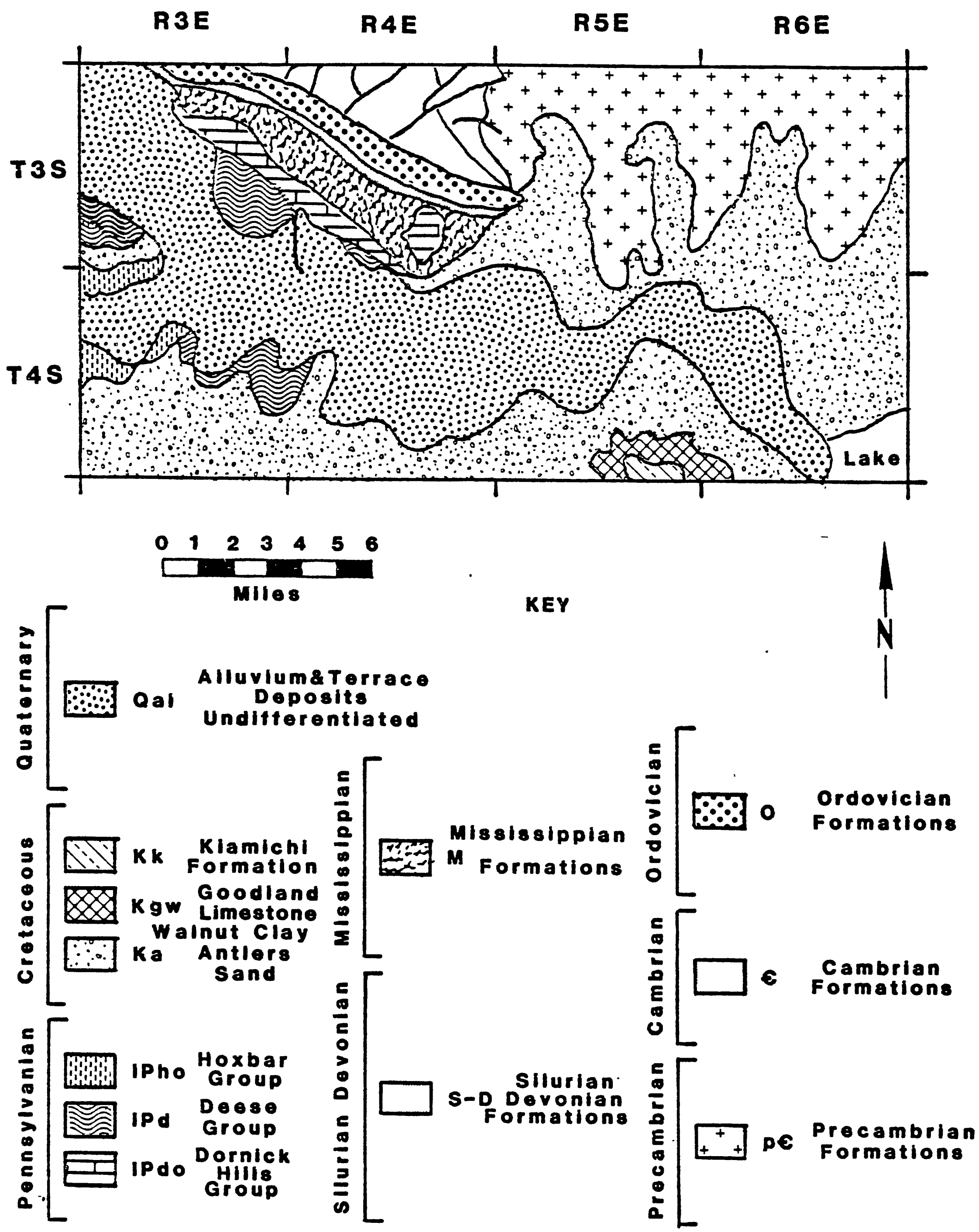


Figure 6. Geologic Map of the Study Area South of the Arbuckles

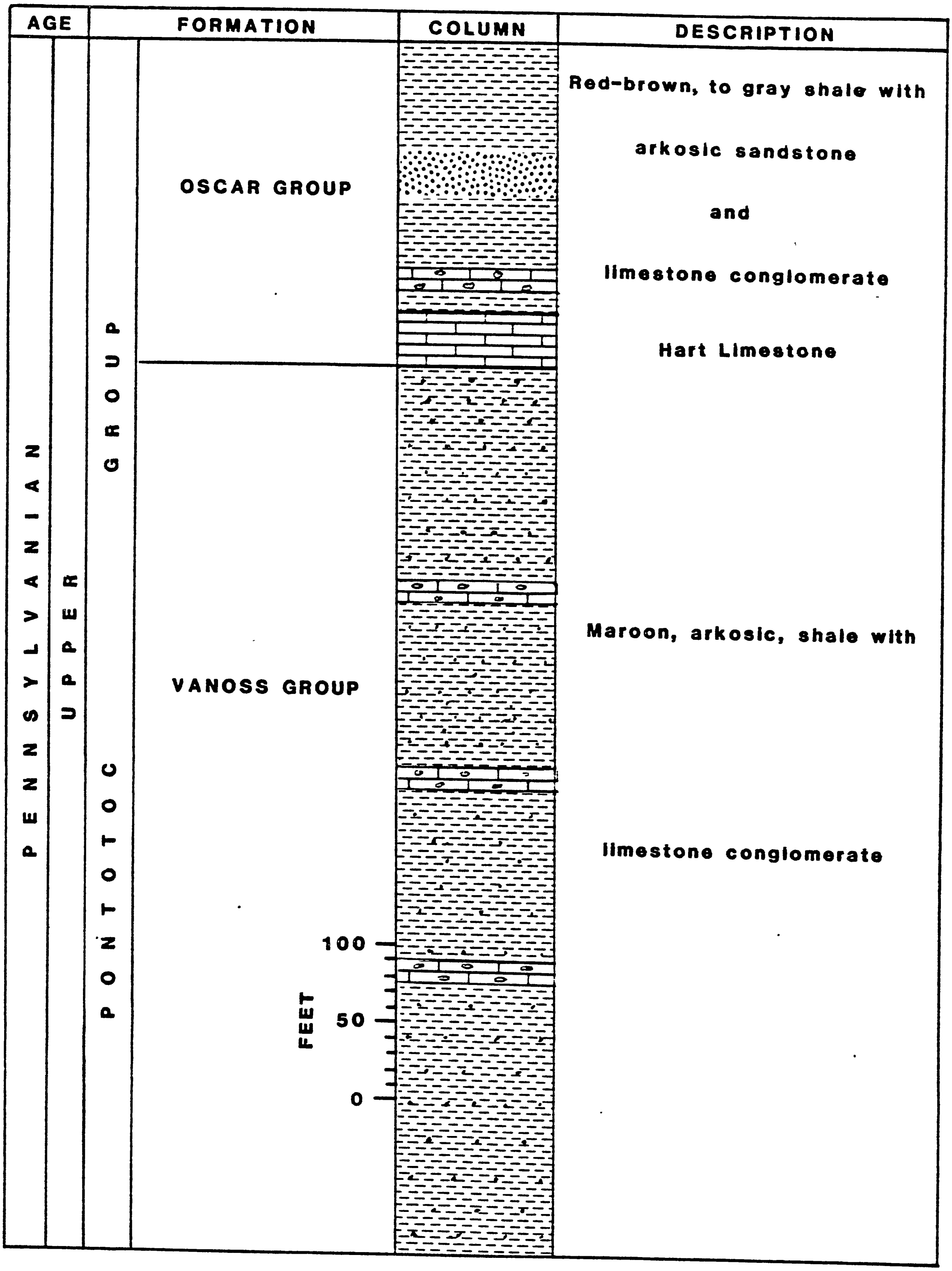


Figure 7. Stratigraphic Column of Formations North of the Arbuckle Mountains (after Hart, 1974)

AGE		FORMATION		COLUMN	DESCRIPTION
PERMIAN		EL RENO GROUP	DUNCAN SANDSTONE		White to buff, fine to coarse grained with lenses of mudstone conglomerate and siltstone
PERMIAN		HENNESSEY GROUP	BISON SHALE		Gray to red-brown, calcareous, blocky
PERMIAN		HENNESSEY GROUP	PURCELL SANDSTONE		Red-brown to maroon, and greenish-gray, fine to coarse grained with some shale and mudstone conglomerate
PERMIAN		HENNESSEY GROUP	FAIRMONT SHALE		Red-brown, blocky
PERMIAN		GARBER SANDSTONE			Red-brown, fine to coarse grained
PERMIAN		WELLINGTON FORMATION			Red-brown shale Ryan Sandstone
PENNSYLVANIAN	UPPER	PONTOTOC GROUP	OSCAR GROUP		Red-brown to gray shale with arkosic sandstone and limestone conglomerate

Figure 7. Continued

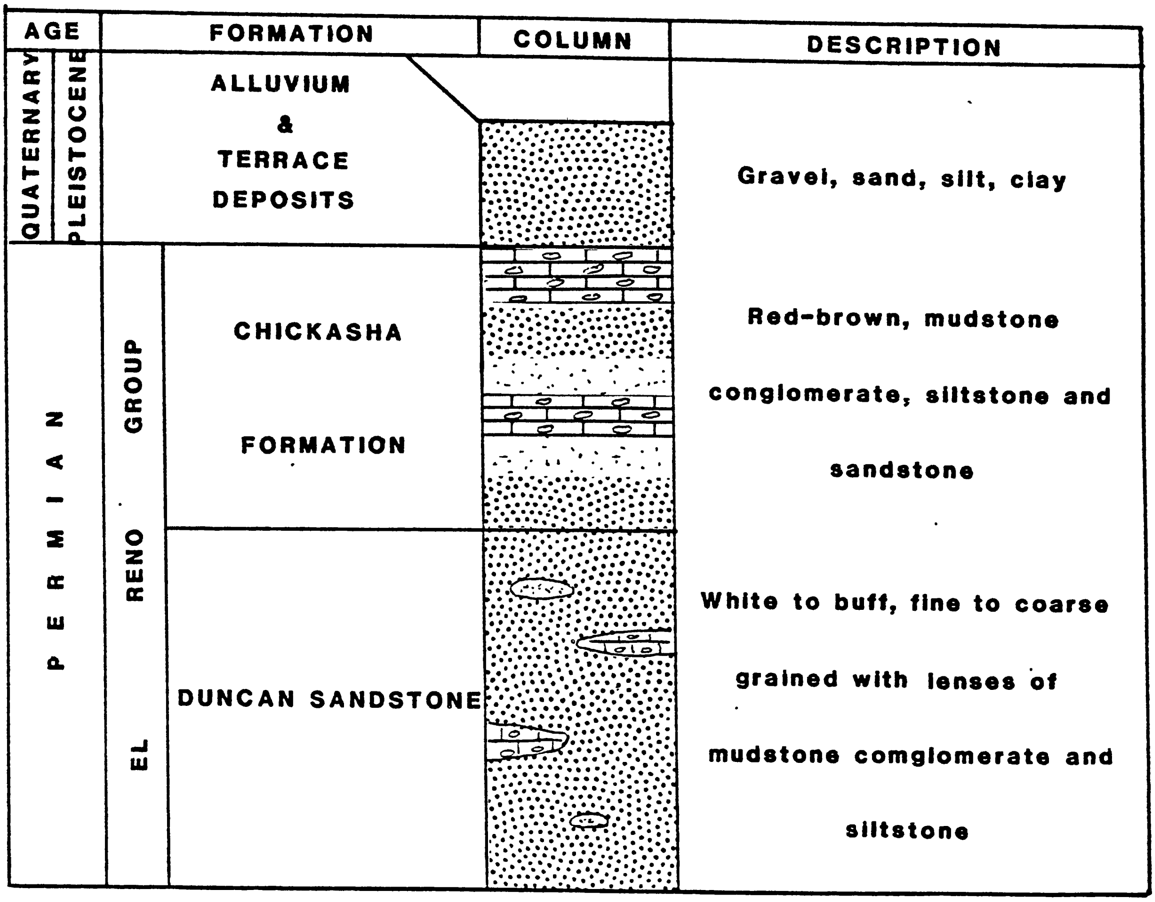


Figure 7. Continued

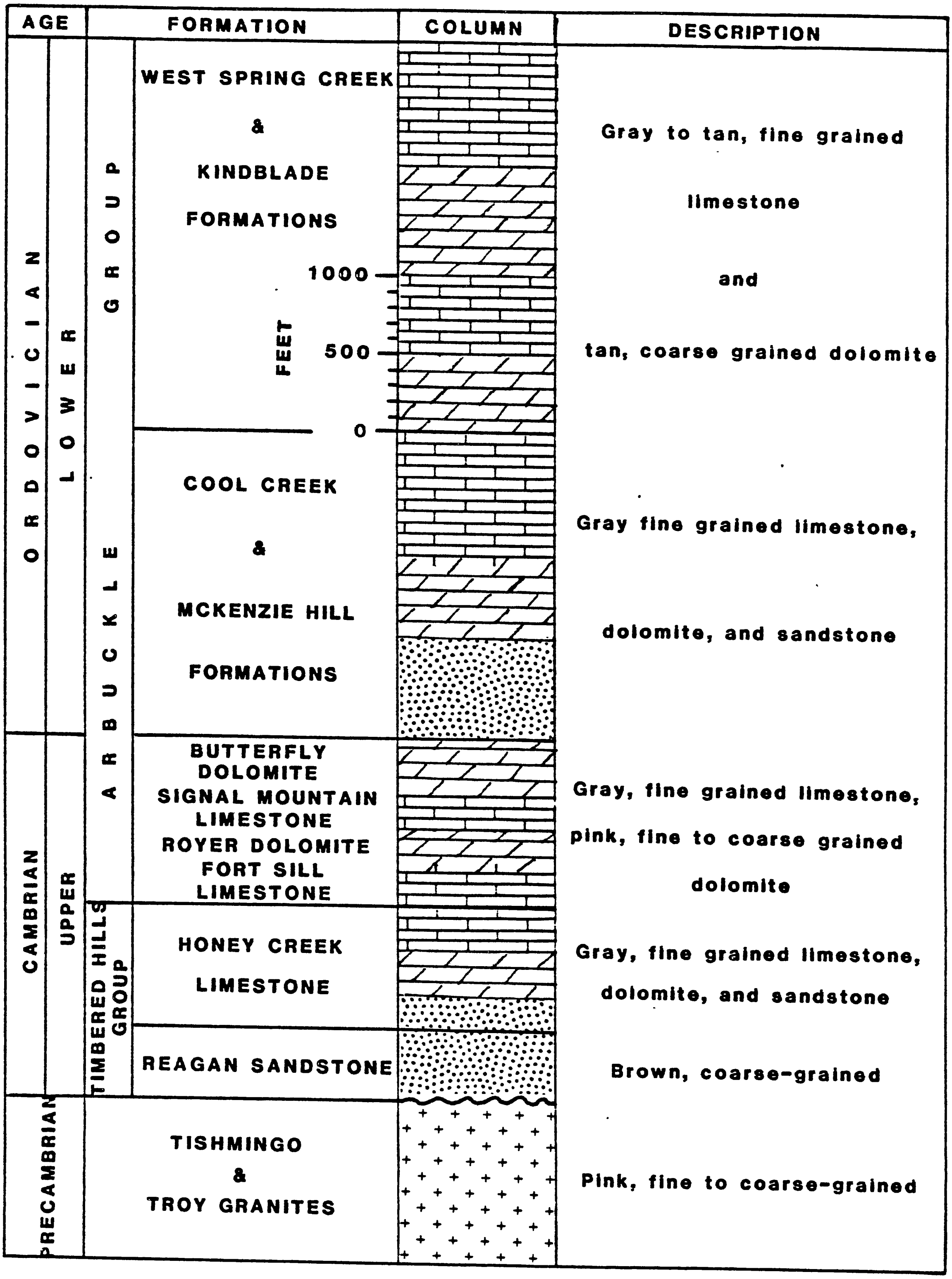


Figure 8. Stratigraphic Column of Formations South of the Arbuckle Mountains (after Hart, 1974)

AGE			FORMATION	COLUMN	DESCRIPTION
PENNSYLVANIAN	MIDDLE		DEESE GROUP		Blue-gray, tan shale, brown, medium grained sandstone
PENNSYLVANIAN	LOWER		DORNICK HILLS GROUP		Gray to tan, fine to medium grained, oolitic, limestone basal sandstone fine to coarse grained
MISSISSIPPIAN			GODDARD SHALE		Gray, limonitic
MISSISSIPPIAN			DELAWARE CREEK SHALE		Gray to black, fissle calcareous
DEVONIAN	UPPER		WOODFORD SHALE		Black, fissle cherty
SILURIAN			HUNTON GROUP		Buff, marlstone, shale, limestone
ORDOVICIAN	UPPER		SYLVAN SHALE		Dark greenish-gray
ORDOVICIAN	UPPER		FERNVALE & VIOLA LIMESTONE		Gray, fine to coarse grained
ORDOVICIAN	MIDDLE	SIMPSON GROUP	BROMIDE, TULIP, CREEK, & MCLISH FORMATIONS		Buff limestone, grayish-green shale, white, fine to medium grained sandstone
ORDOVICIAN	MIDDLE	SIMPSON GROUP	OIL CREEK & JOINS FORMATIONS		Gray to tan granular limestone, greenish-gray shale, brown, fine to medium grained sandstone

Figure 8. Continued

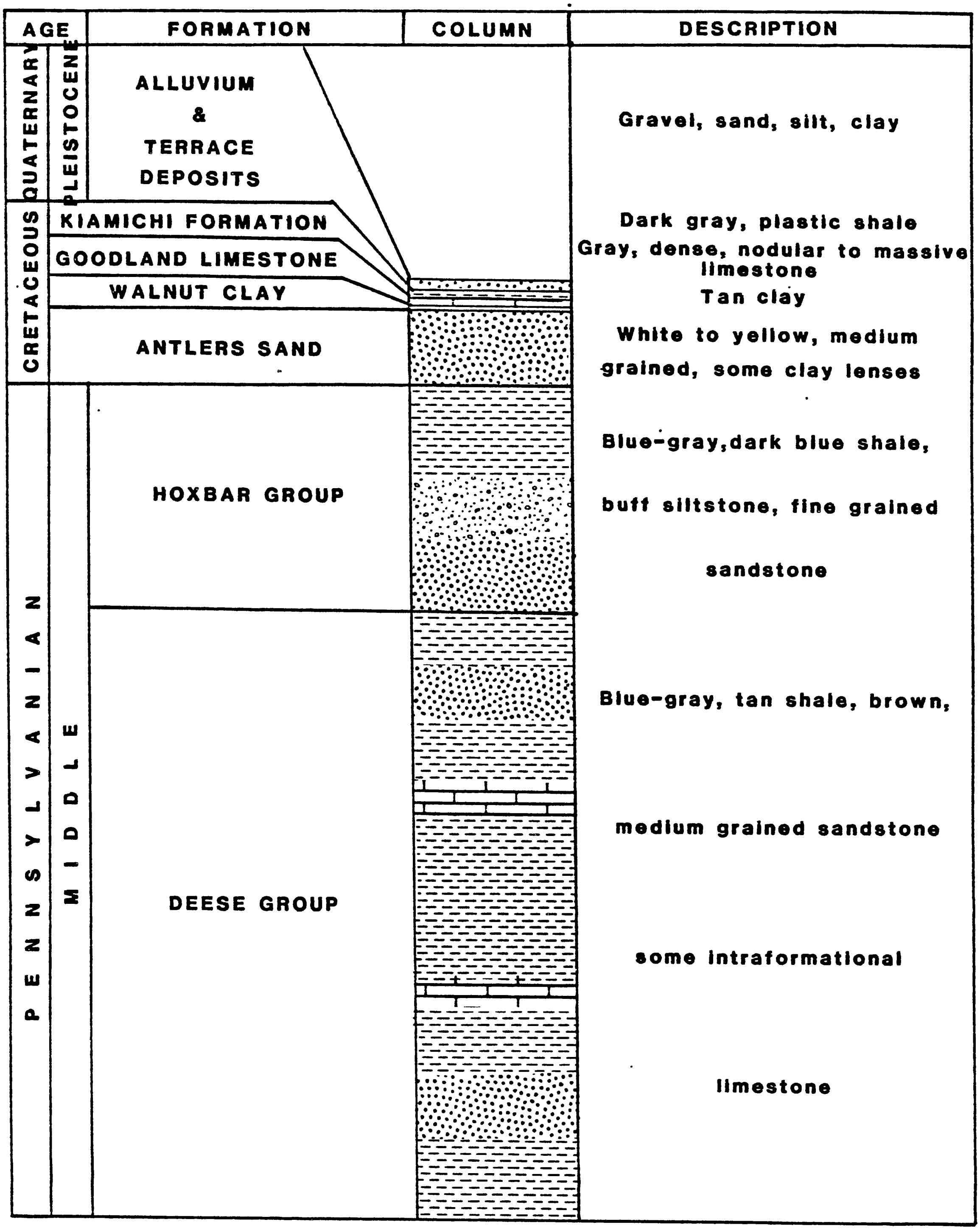


Figure 8. Continued

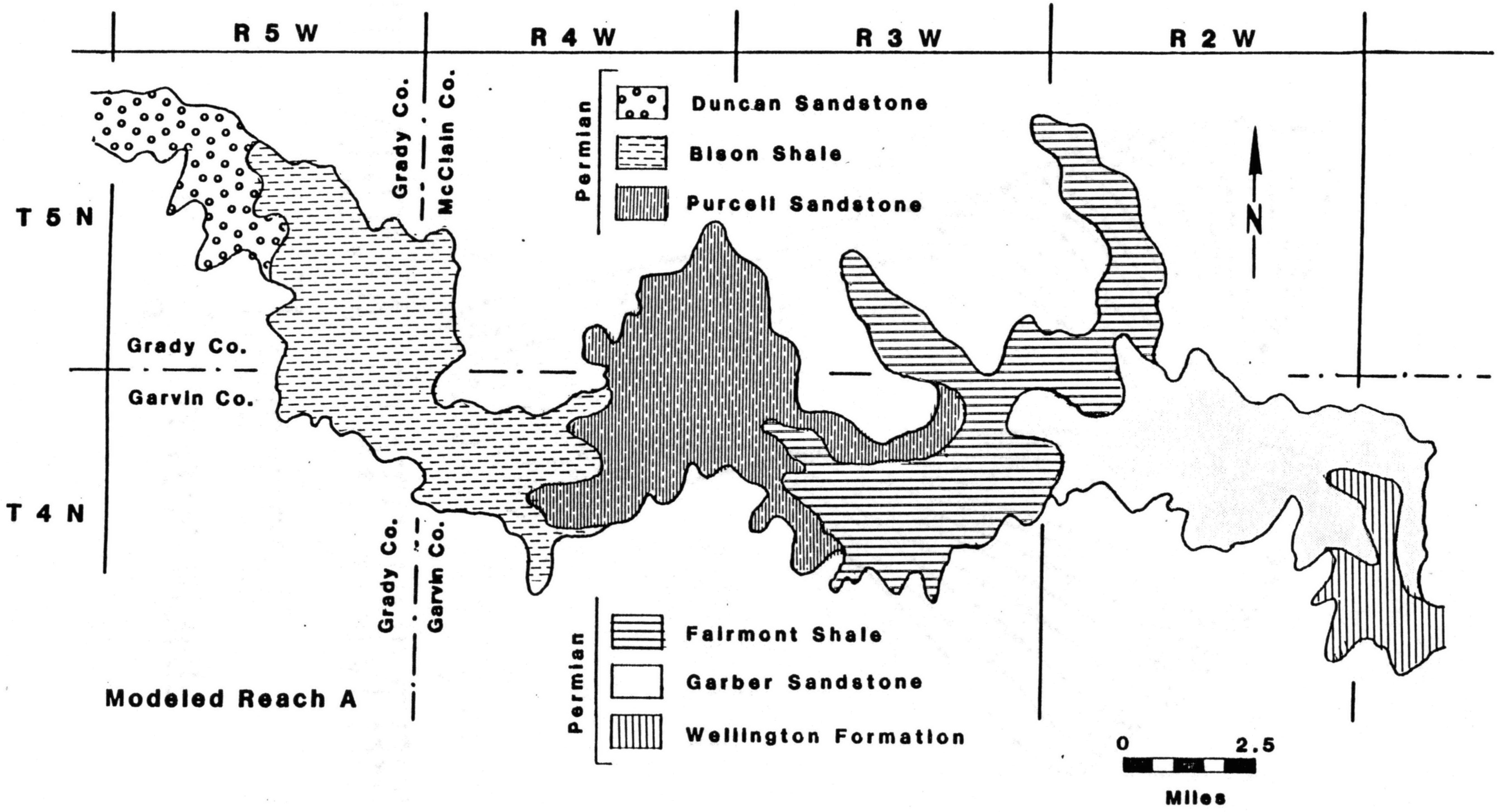


Figure 9. Formations That Directly Underlie the Alluvial Aquifer - Modeled Reach A

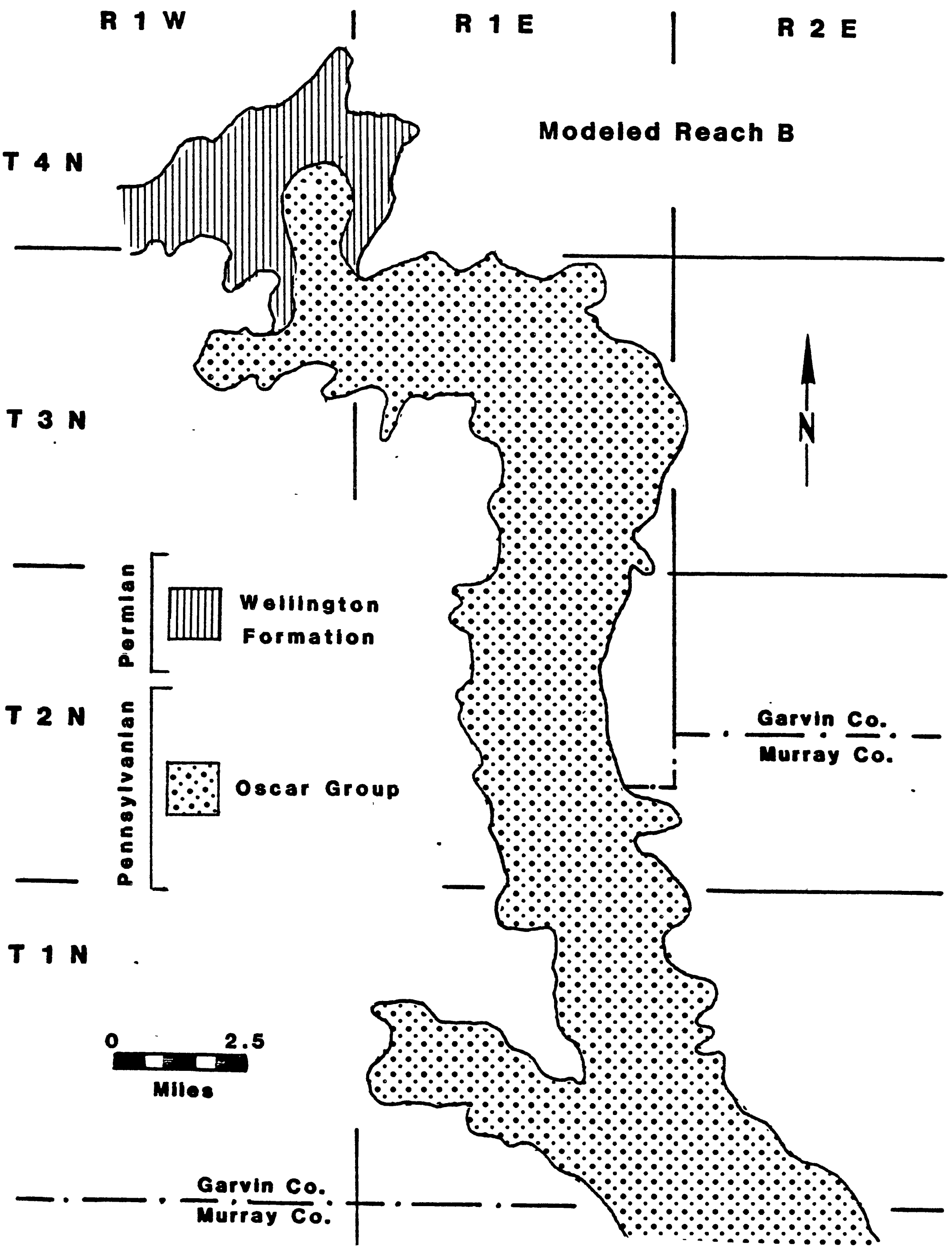


Figure 10. Formations That Directly Underlie the Alluvial Aquifer - Modeled Reach B

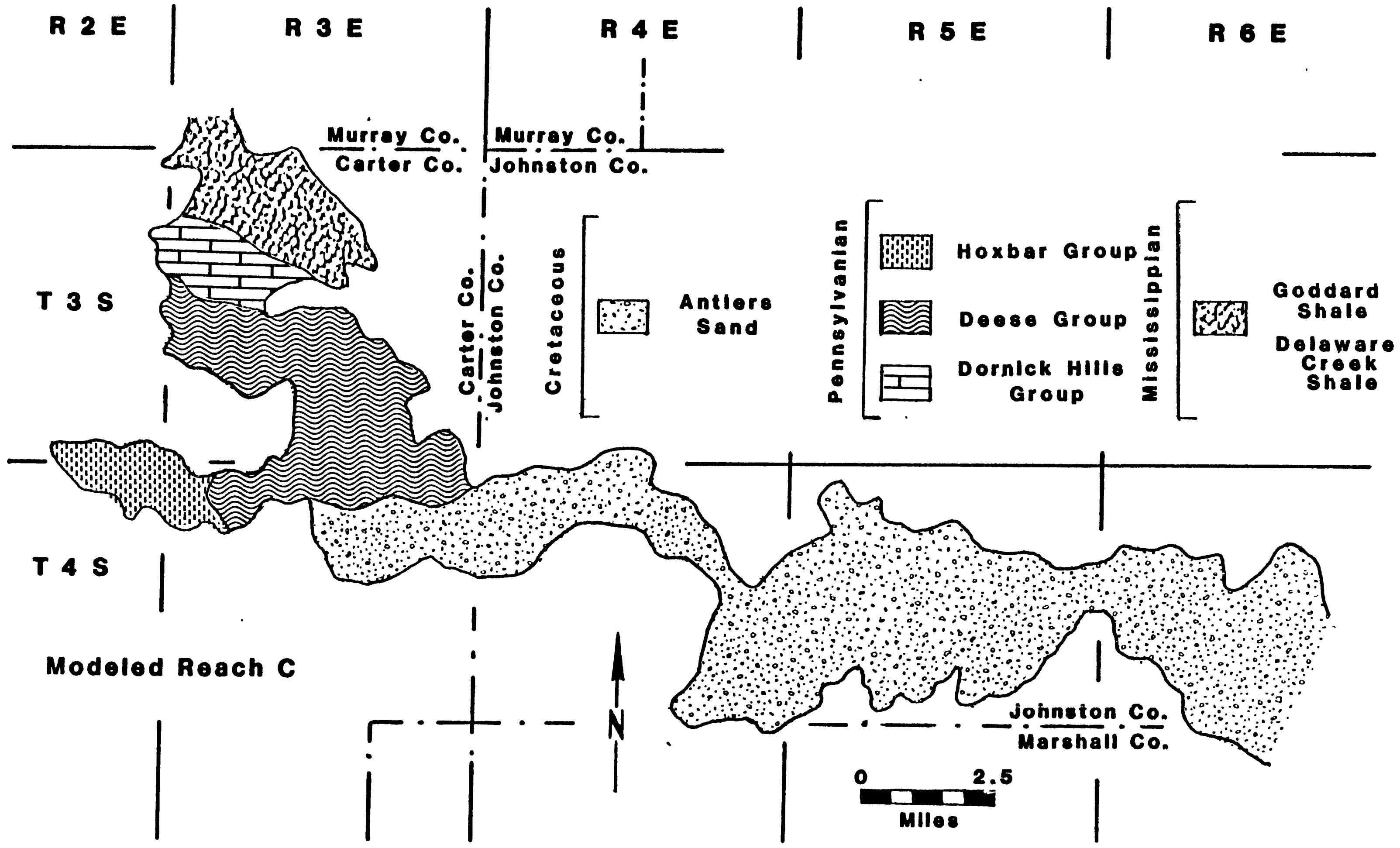


Figure 11. Formations That Directly Underlie the Alluvial Aquifer - Modeled Reach C

streams flowing from the east into a broad basin that extended into western Oklahoma and Texas. The primary portion of the delta was deposited in the latitude of central Oklahoma County where the sandstone comprises approximately 75% of the aquifer. North and south of this area, the proportion of sandstone to shale decreases and the deltaic deposits interfinger with and grade into marine-type rocks consisting mainly of shale (Carr and Marcher, 1977). The Garber-Wellington within the study area (Figure 5) consists of a near equal percentage of sandstone and shale (Hart, 1974).

Hydraulic properties of the Garber-Wellington are controlled by the shape, size, and sorting of the sand grains. The sand grains are angular to subangular, average 0.006 inches in diameter (fine sand), and have an average sorting coefficient of 1.26 (a well-sorted sediment). The shales in the Garber-Wellington are generally blocky, nonlaminated, contain a high proportion of clay, and vary in thickness (Carr and Marcher, 1977). Because of the near equal percent of sandstone to shale in the study area and the high proportion of clay in the shales, the clay particles would have the tendency to fill those void spaces created by the sand grains in the Garber-Wellington. This would create a lower hydraulic conductivity in the Garber-Wellington in the study area than to the north where the principal Garber-Wellington aquifer is composed of 75% sand in Logan and Oklahoma counties.

The Antlers Sand, located in Love, Marshall, Johnston, Atoka, Bryan, and Choctaw counties in south-central and south-eastern Oklahoma is a Lower Cretaceous transgressive sheet of sand consisting of sand, clay, conglomerate, and limestone deposited over an erosional surface of Paleozoic rocks. The sediments of the Antlers Sand represent materials derived from a nearby shoreline of an advancing sea (Hart and Davis, 1981). Within the study area the Antlers is composed of an arkosic conglomerate (Hart, 1974). This conglomeratic material is composed mostly of chert, quartz, and limestone pebbles derived from the underlying Paleozoic strata.

The average saturated sand thickness of the Antlers is 250 feet and the average transmissivity is 11,045 gpd/ft (Hart and Davis, 1981). Thus the average hydraulic conductivity is 44 gpd/ft^2. This is representative of a very fine to fine-grained sand. The greatest percentage of sand to total thickness of the aquifer is south of the outcrop area. The Antlers Sand found within the study area is located in this outcrop area (Figure 12) and is of a lower hydraulic conductivity than the average value found for the entire Antlers Sand (Hart, 1974).

In the absence of head elevations in the bedrock and because of the lower hydraulic conductivity of these potential aquifer units (Garber-Wellington; Antlers Sand) and the other bedrock units (Figures 5 and 6) underlying the alluvium when compared to the higher hydraulic conductivity

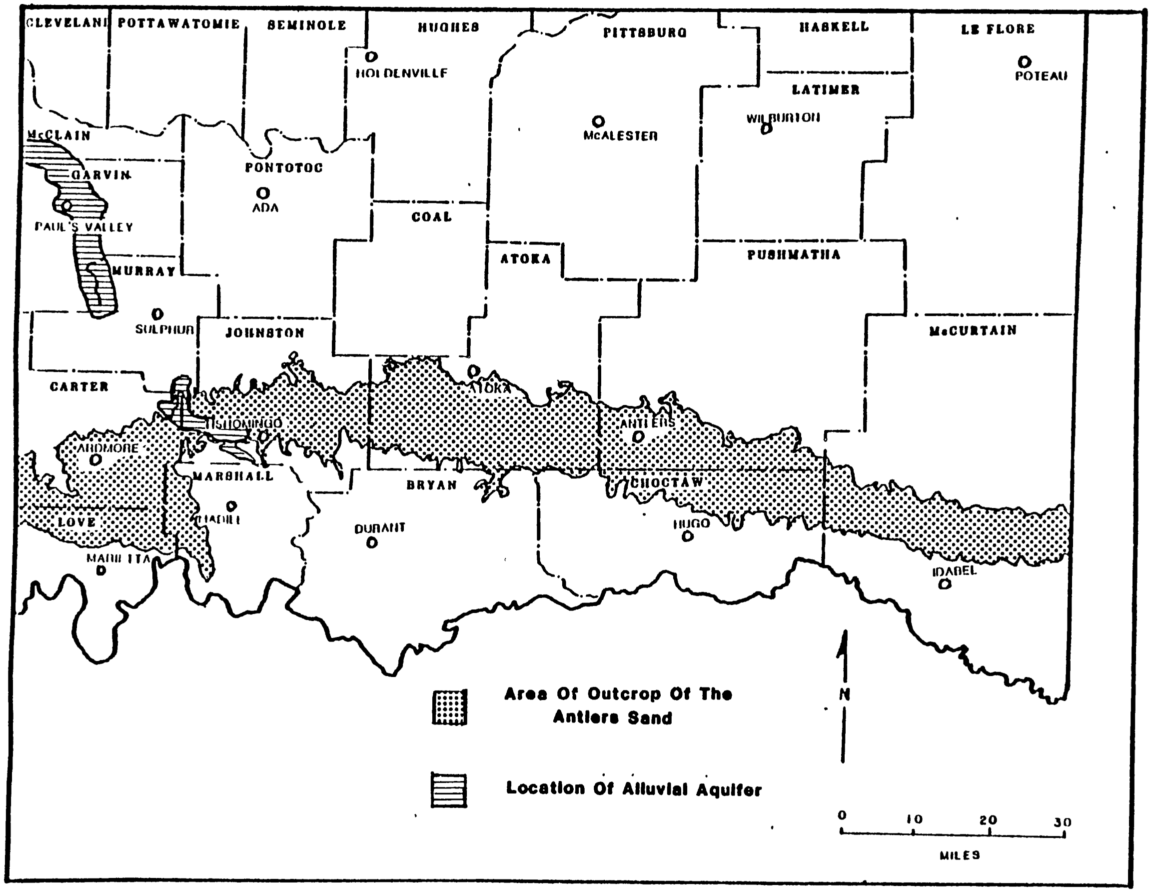


Figure 12. Outcrop Area of the Antlers Sand (after White and Back, 1983)

of the alluvium, it was assumed for the purposes of the model that the bedrock did not contribute significant amounts of ground water through upward leakage.

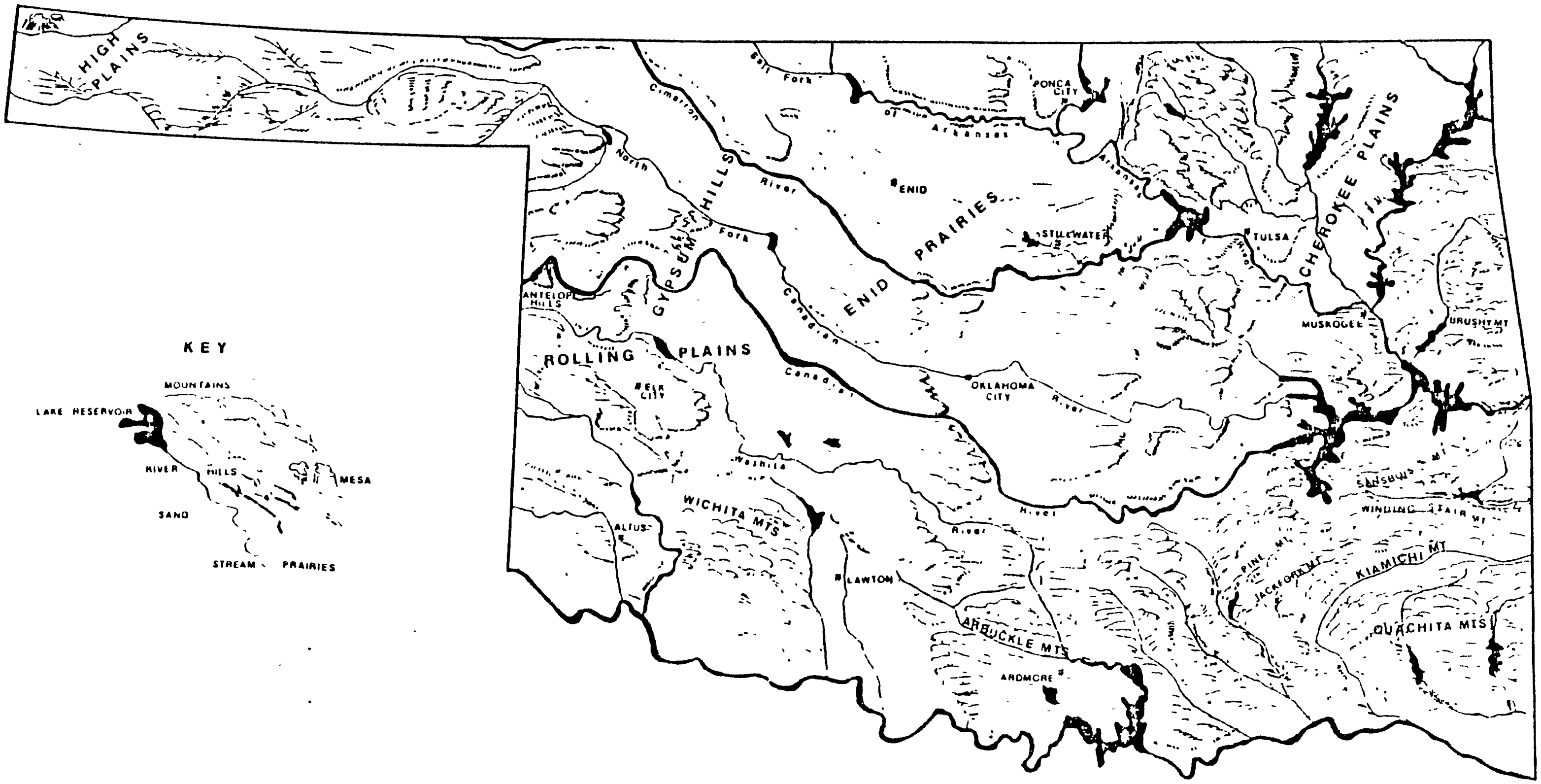
CHAPTER IV

HYDROGEOLOGY

The generalized physiography of the State of Oklahoma is shown in Figure 13. A more detailed physiographic map of the study area is shown in Figure 14. The physiography of the study area also was a controlling factor used in determining the breakdown of the area into reaches. Figure 14 shows how the physiography controlled where the modeled reaches were located. A generalized topography map of Oklahoma is shown in Figure 15. Elevations within the study area range from 1,170 feet in the northwest to 617 feet in the southeast.

Climate

The climate in Grady, McClain, Garvin, Murray, Carter, and Johnston counties fluccuates from sub-humid to humid. The average annual temperature is 63° F. Prevailing winds are generally southerly. The average annual rainfall for a 31-year period (1950-1980) for Lindsay and Pauls Valley was 33.9 and 33.3 inches, respectively (Figures 16 and 17). The average rainfall over the entire study area for the above period was 34.9 inches per year. This number agrees with the average annual precipitation determined by Pettyjohn et



Source - OSU Cartography Service (1979)

PHYSIOGRAPHIC DIAGRAM

Figure 13. Generalized Physiographic Map of Oklahoma (after Pettyjohn et al., 1983)

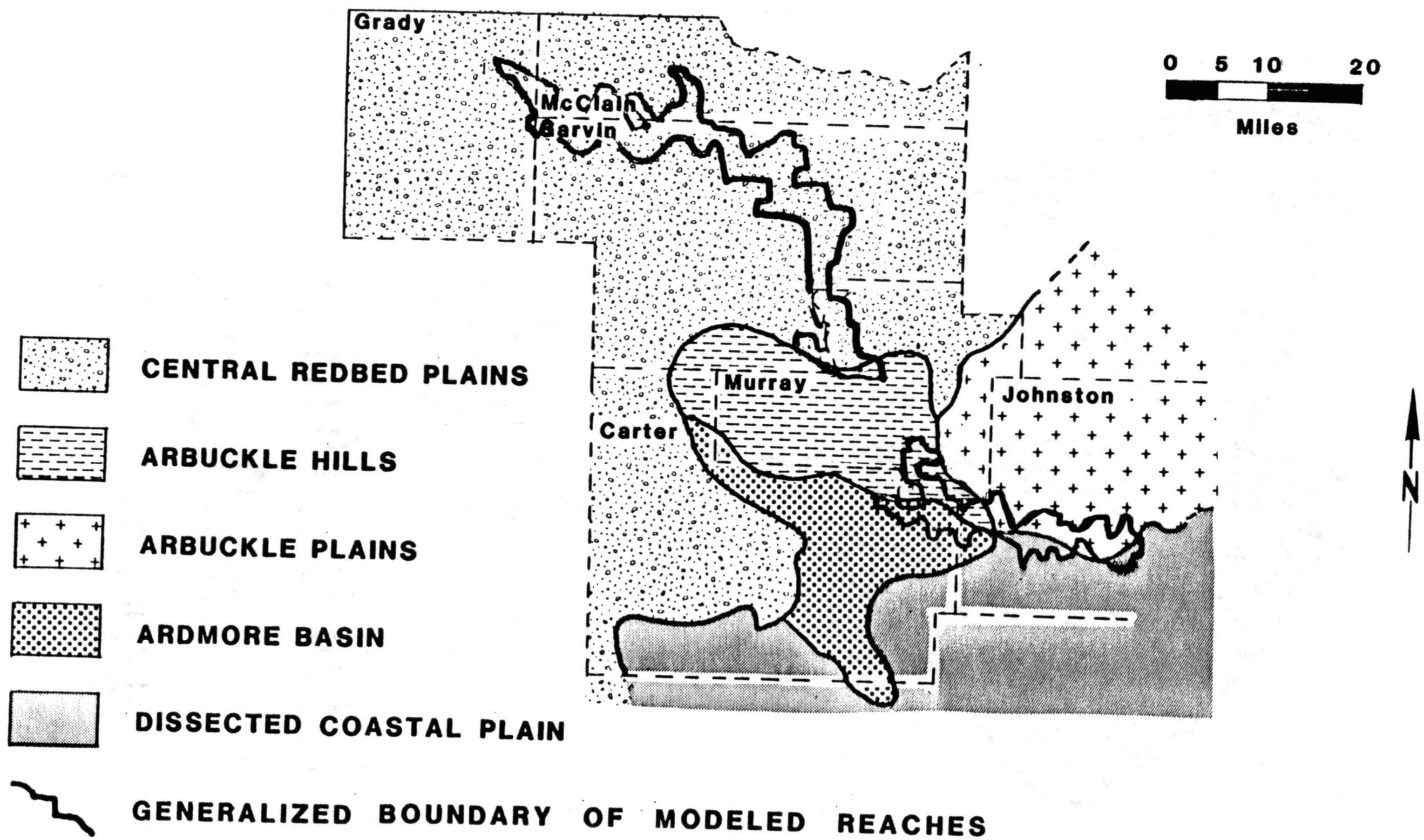


Figure 14. Physiographic Provinces Within the Study Area

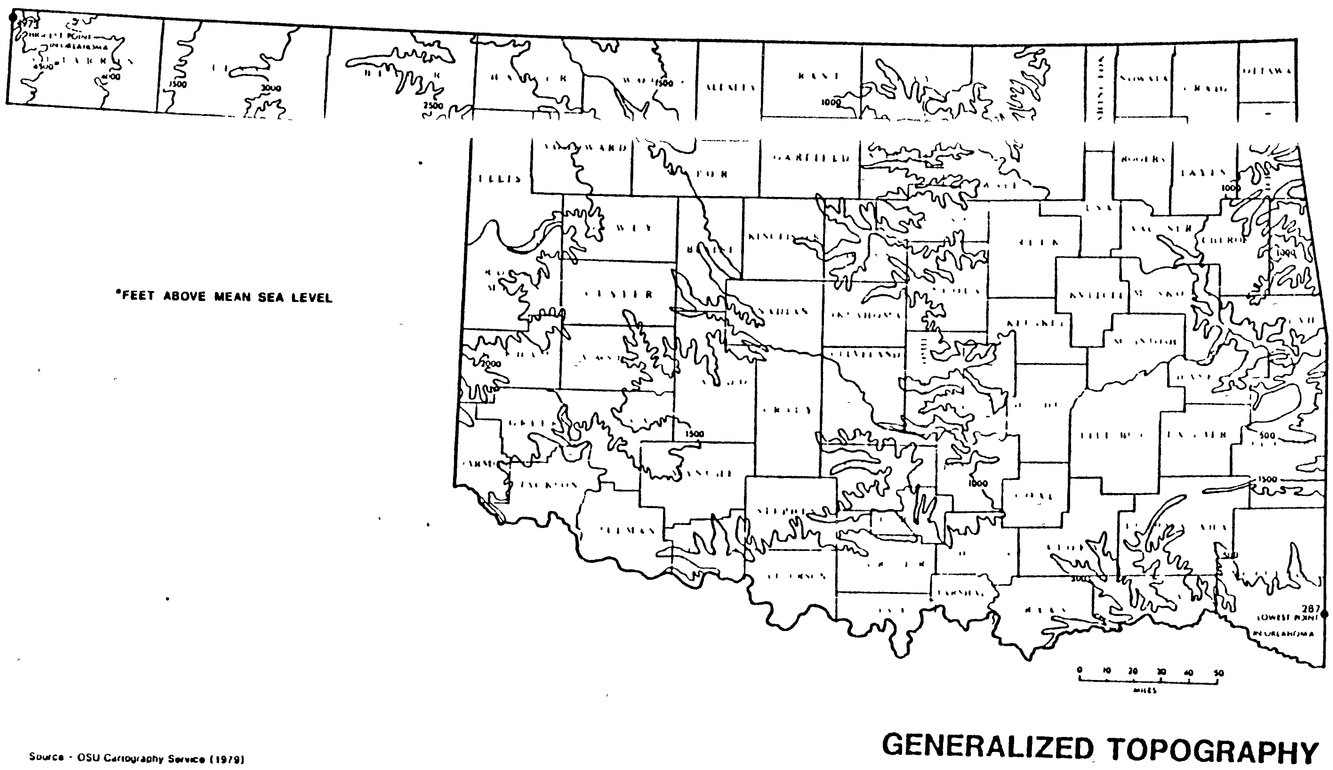


Figure 15. Generalized Topographic Map of Oklahoma (after Pettyjohn et al., 1983)

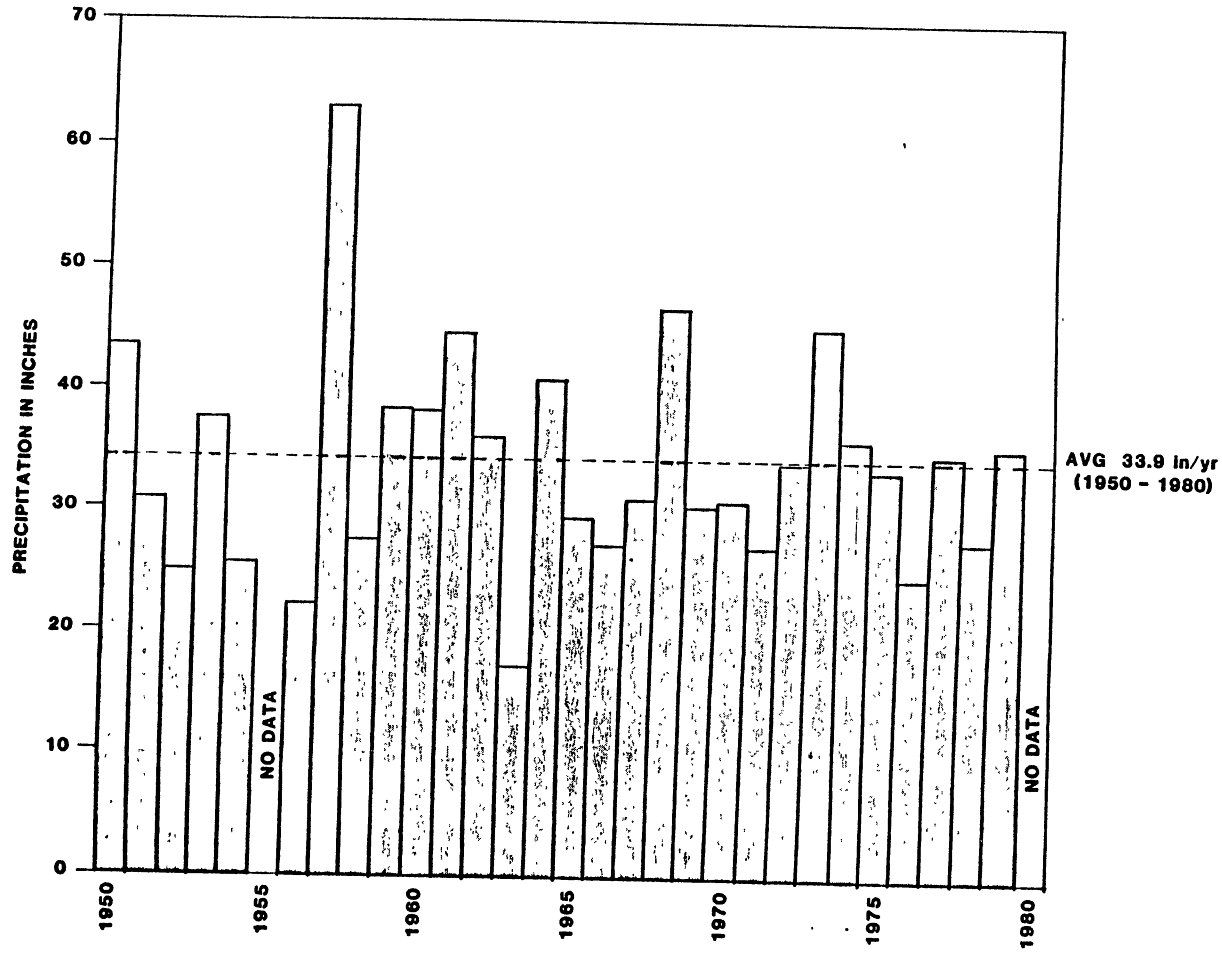


Figure 16. Average Annual Precipitation, Lindsey, Oklahoma

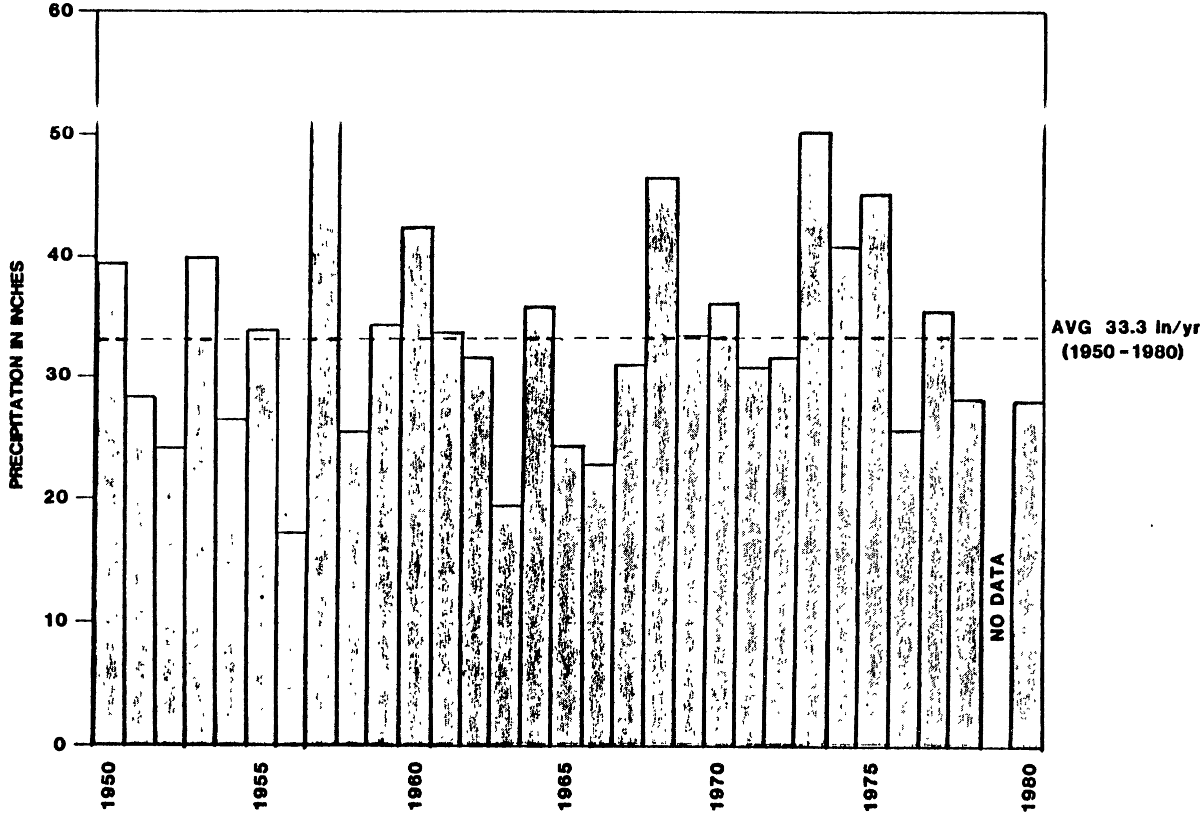


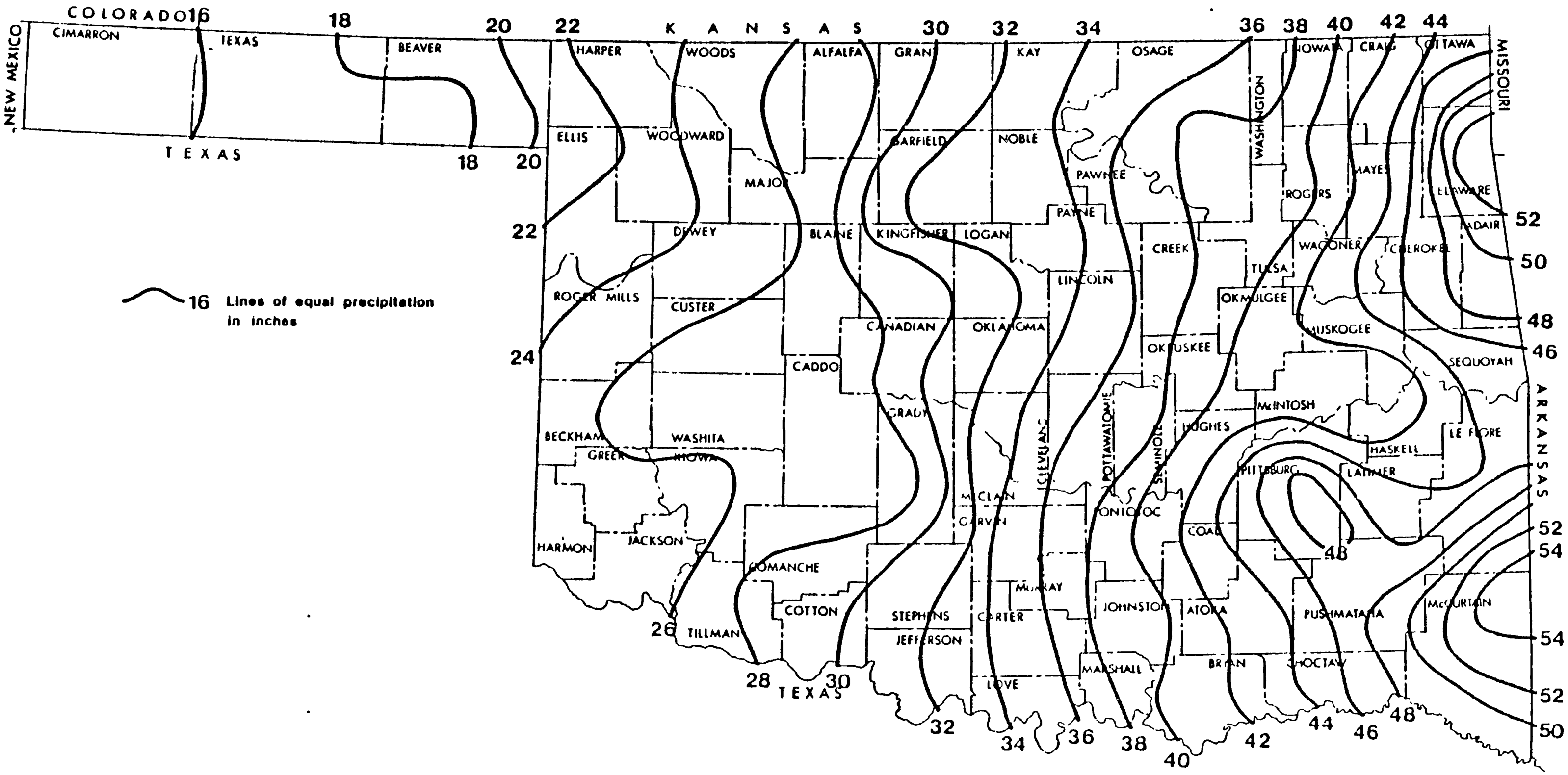
Figure 17. Average Annual Precipitation, Pauls Valley, Oklahoma

al. (1983) for the period 1970-1979 as is shown in Figure 18. The monthly distribution of precipitation for the two above cities is shown in Figures 19 and 20. May is commonly the wettest month with January being the driest.

An average evapotranspiration rate of 26.8 inches per year was determined for the entire study area. This value is slightly lower than the range determined by Pettyjohn, White, and Dunn (1983) as is shown in Figure 21.

Surface Water

Streamflow is measured at three United States Geological Survey gaging stations along the Washita River within the study area; near Alex and Pauls Valley, north of the Arbuckle Mouuntains and near Durwood, south of the Arbuckle Mountains. The average annual discharge (Q) at the three gages are 368, 688, and 1,368 cubic feet per second (cfs), respectively. Stream hydrographs for a wet, average, and dry year with their respective flow duration curves are shown in Figures 22, 23, and 24 for Pauls Valley, Oklahoma. The highest flows generally occur during May, whereas the lowest flows occur during January. Fifty percent of the time, the flow near Pauls Valley is less than 0.1 cfs per square mile. The greatest flow (35,800 cfs) occurred during a flood in May of 1957. Although reported to have been dry on rare occasions, flows in the range of 25-70 cfs are common in late summer. The fact that the stream almost always contain some flow attests to the fact that the stream



AVERAGE ANNUAL PRECIPITATION (In Inches)
(Period 1970-79)

Data National Oceanic and Atmospheric Administration (1970-79)

Figure 18. Average Annual Precipitation (1970-1979) for Oklkahoma (after Pettyjohn et al., 1983)

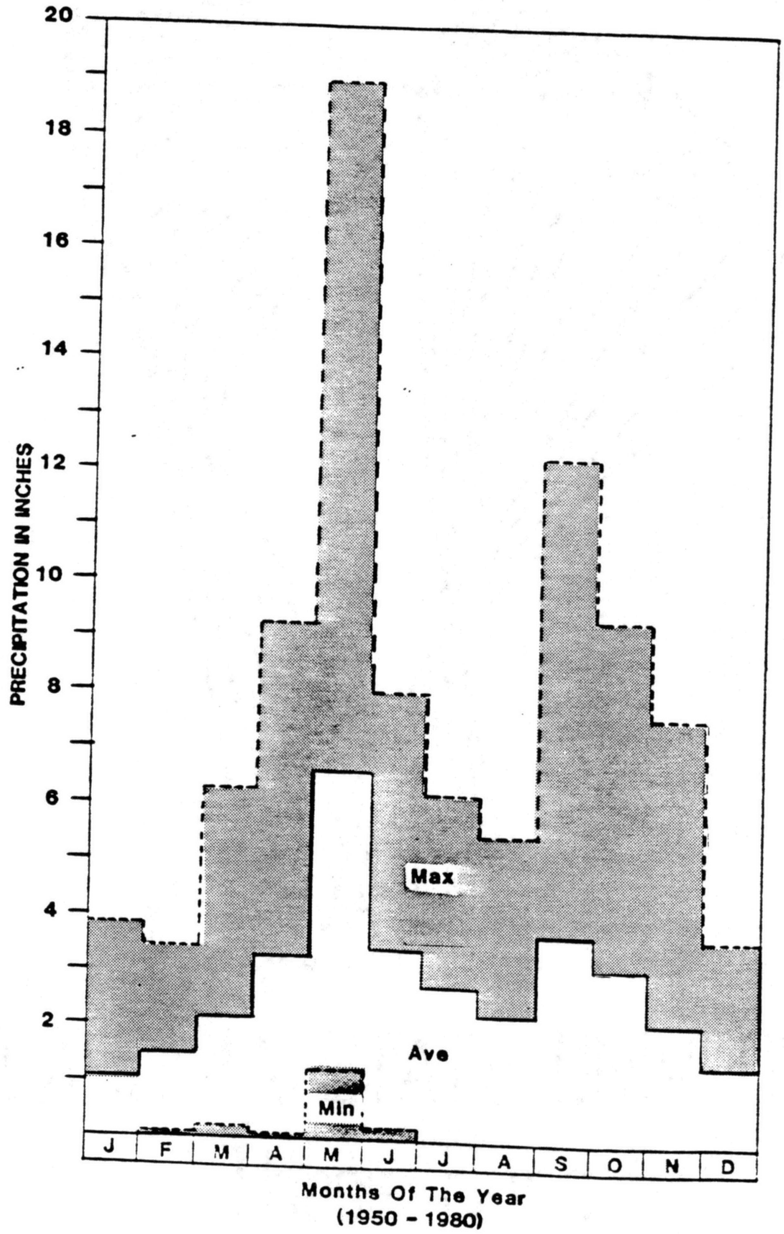


Figure 19. Average Monthly Precipitation, Lindsey, Oklahoma

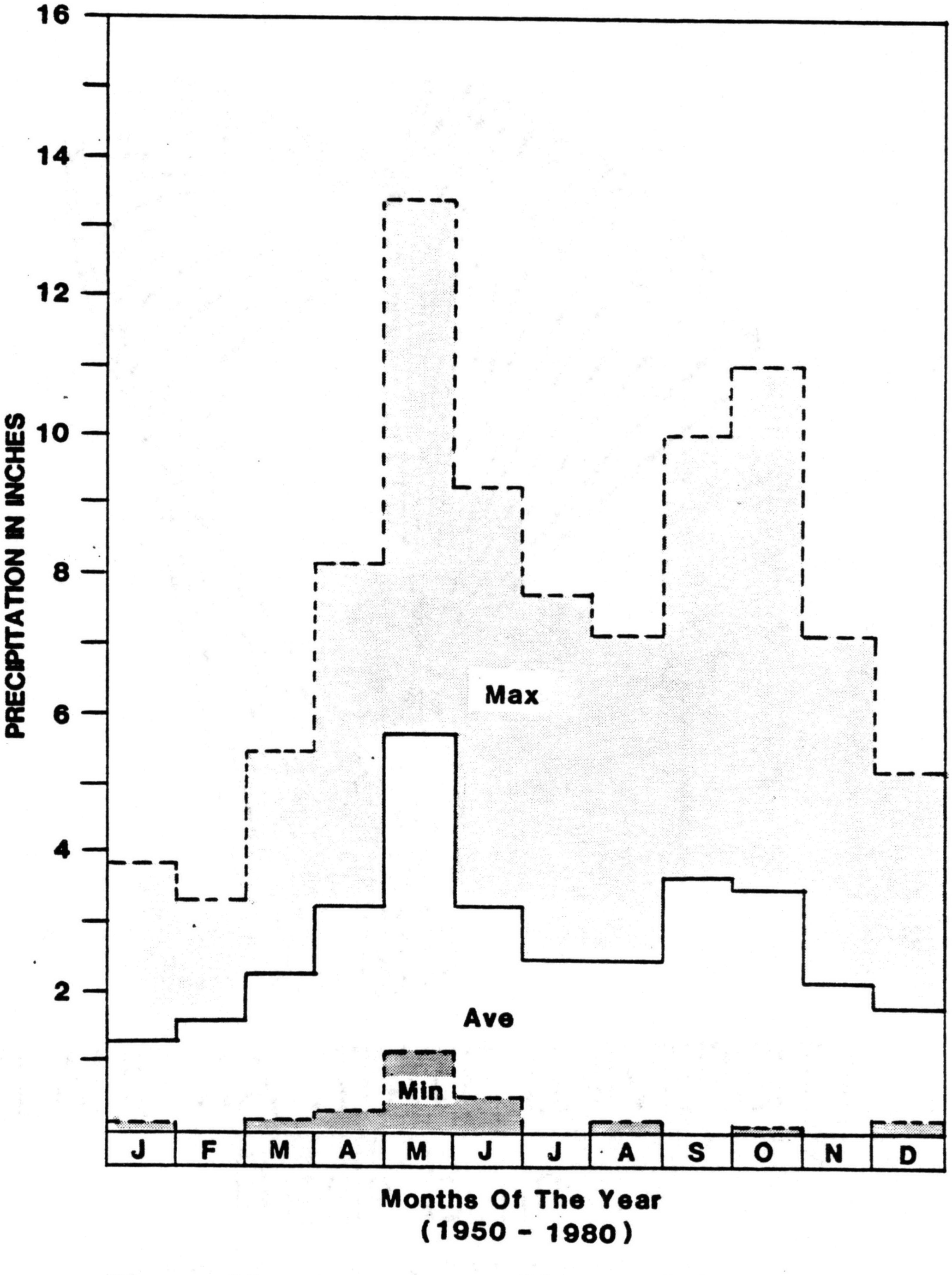


Figure 20. Average Monthly Precipitation, Pauls Valley, Oklahoma

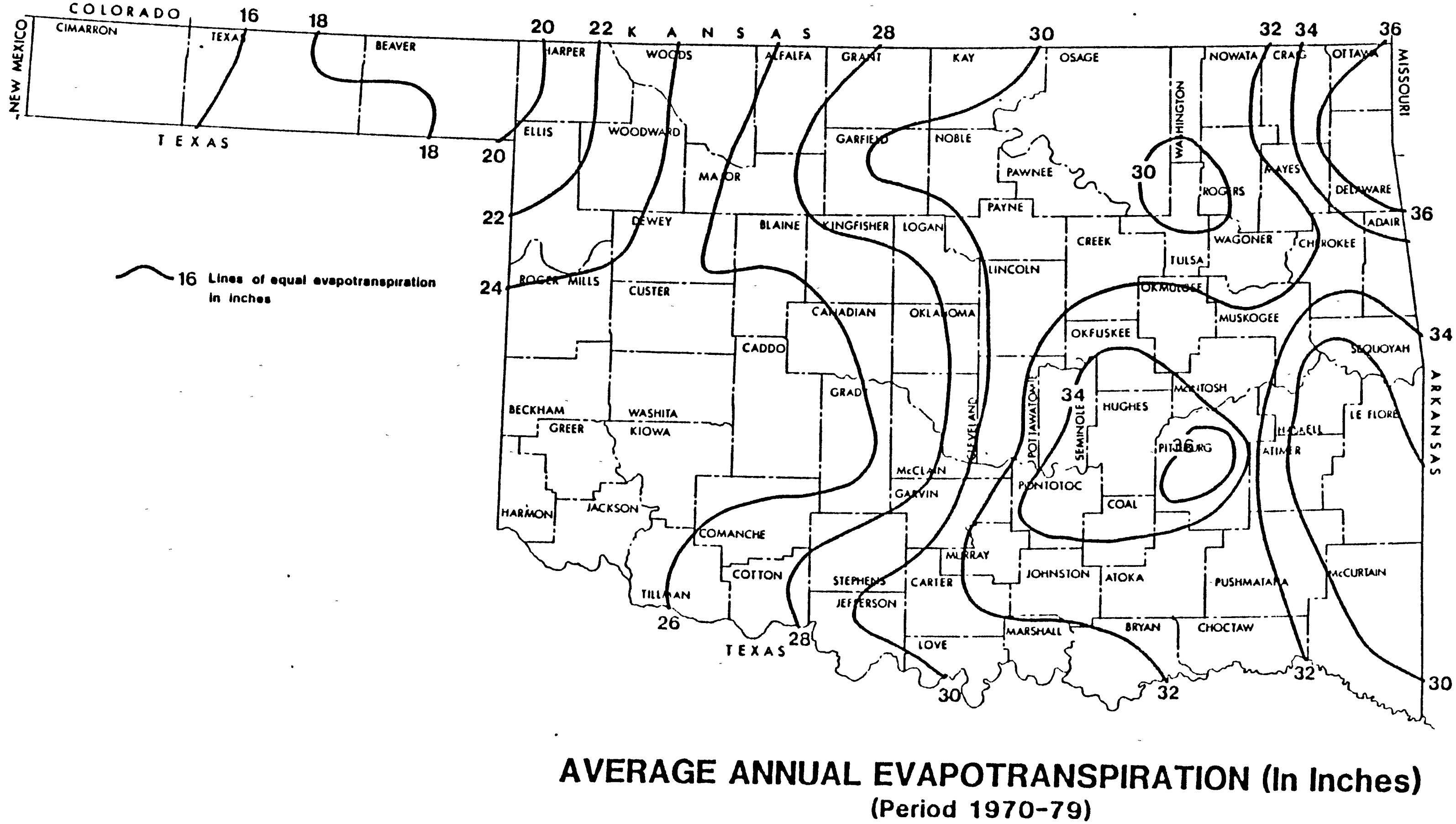
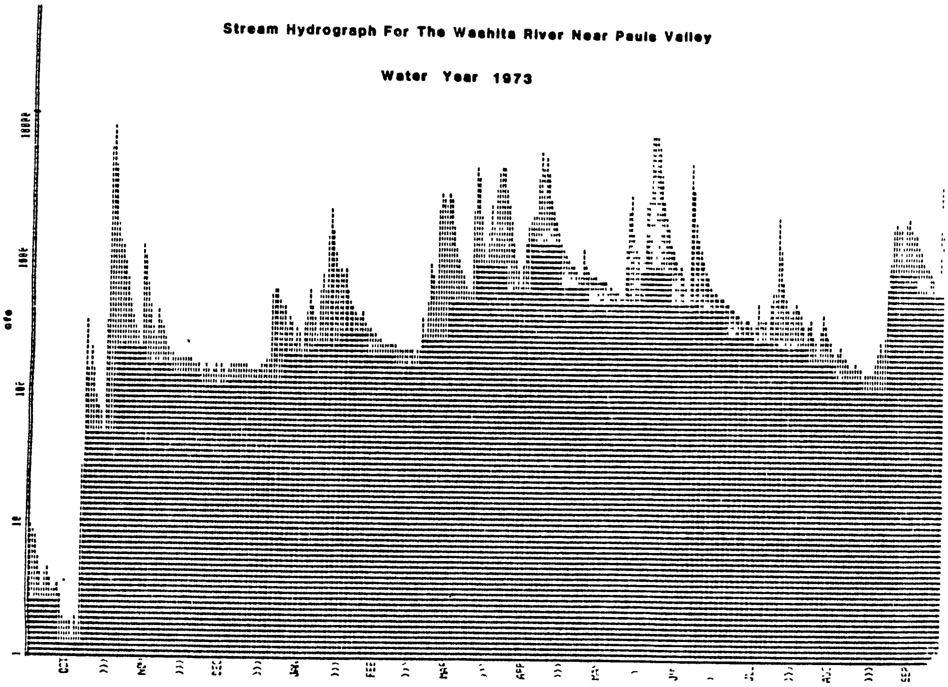


Figure 21. Average Annual Evapotranspiration (1970-1979) for Oklahoma (after Pettyjohn et al., 1983)



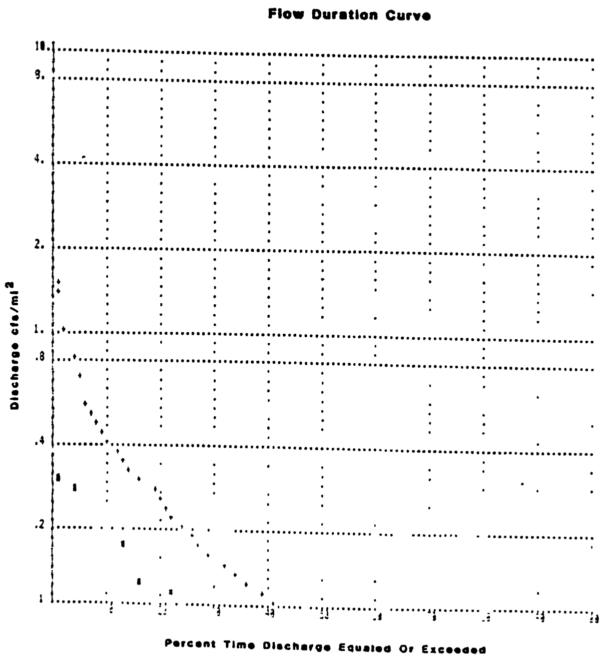
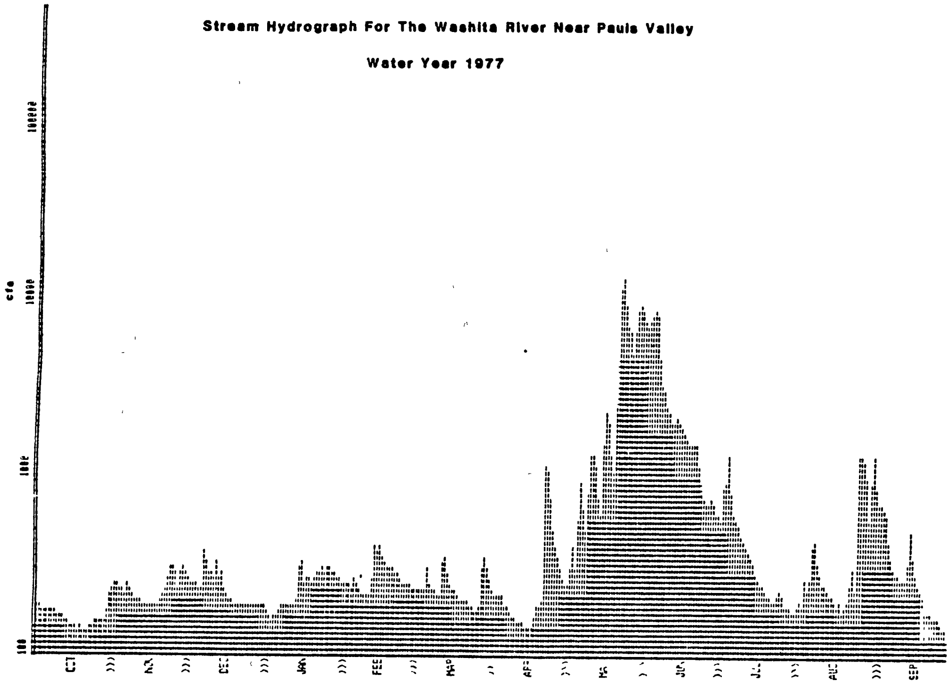


Figure 22. Stream Hydrograph and Respective Flow Duration Curve for the Washita River Near Pauls Valley; Water Year 1973



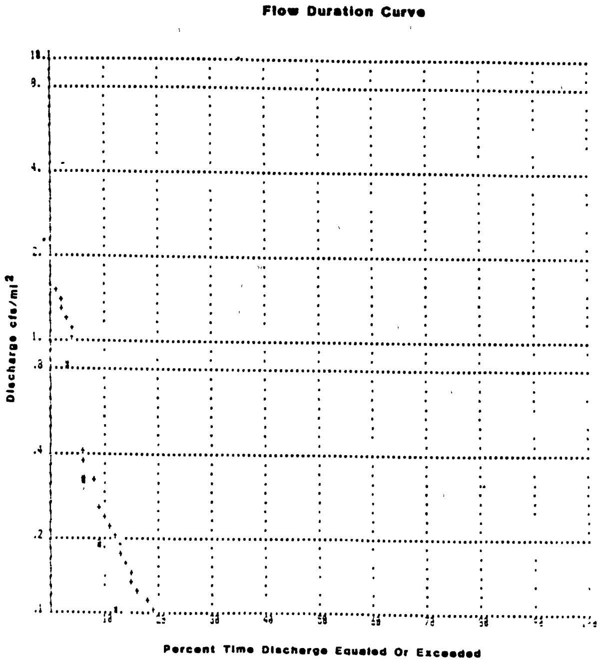
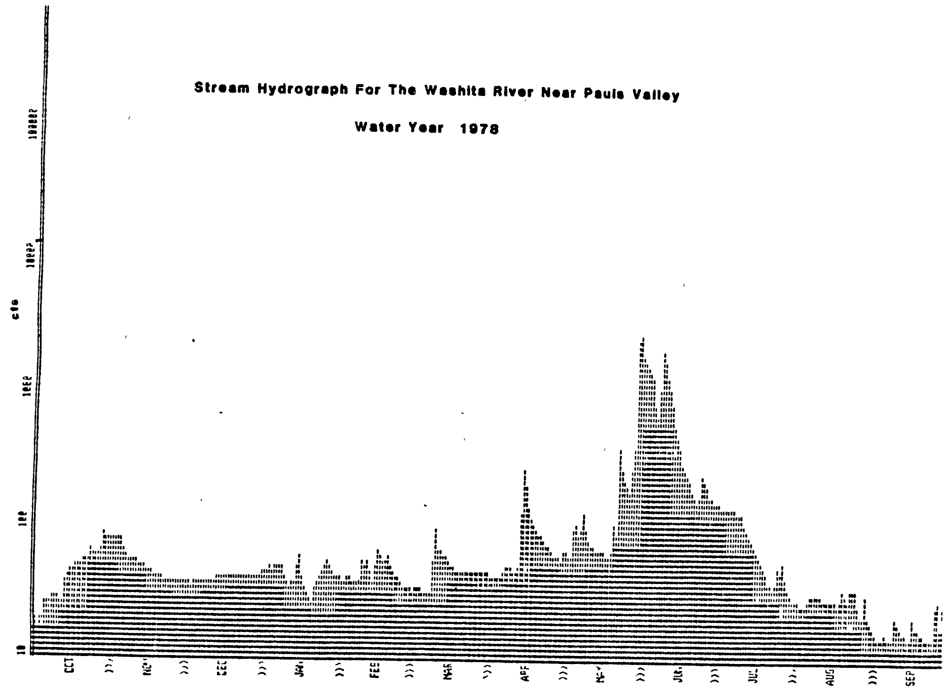


Figure 23. Stream Hydrograph and Respective Flow Duration Curve for the Washita River Near Pauls Valley; Water Year 1977



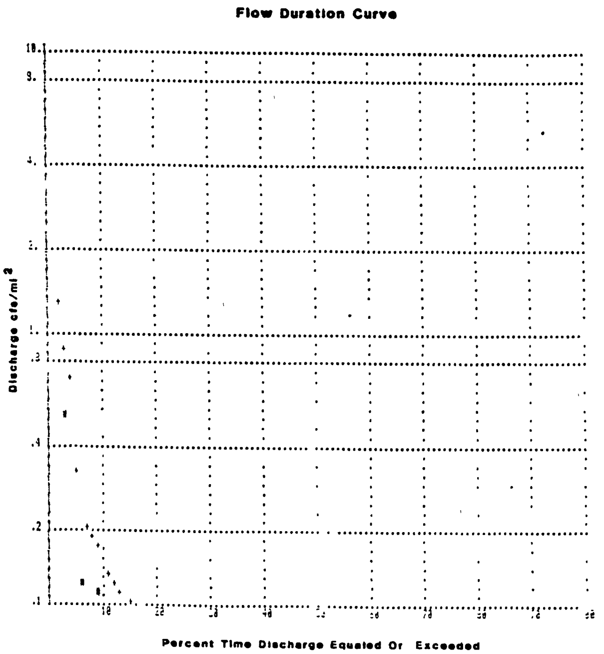


Figure 24. Stream Hydrograph and Respective Flow Duration Curve for the Washita River Near Pauls Valley; Water Year 1978

is being contributed to through ground-water runoff or baseflow.

Chemical quality analyses of the surface water are available for the gaging stations near Alex and Durwood. Water-quality records extending from 1964 to present were published by the United States Geological Survey. Continuous records were available from 1965 to 1970 with random records available from 1971 to present. Analyses of the wet and dry periods for both stations are presented in Table I and summarized graphically in Figure 25.

The Oklahoma Water Resources Board has set the upper limit of fresh water to be used for irrigation at 5,000 mg/l of dissolved solids. By these standards, the surface water in the study area is considered to be fresh.

Ground Water

Hydrogeology

The Washita River alluvium forms an unconfined or water-table aquifer, although in some areas it may be locally confined by clay layers. The average aquifer thickness for the entire study area is approximately 65 feet. Due to variable bedrock topography, the alluvial thickness can vary drastically over short distances. This is shown from Lindsay to Pauls Valley, Oklahoma where the alluvial thickness is 85 and 33 feet, respectively.

The depth to water ranges from 0 to 108 feet and averages 26 feet. Depth to water was determined from

TABLE I

SURFACE WATER ANALYSES FOR DRY AND WET MONTHS AT ALEX AND DURWOOD, OKLAHOMA FROM 1965 TO 1970

Dry Period (July-August, December-February)*

Alex						Durwood			
Ca	Mg	Na	HCO_3	SO_4	Cl	Na	HCO_3	SO_4	Cl
121.9	47.8	75.5	195.4	389.5	62.9	87.1	181.1	206.8	127.4
167.4	53.4	74.6	201.3	499.0	77.5	69.2	180.7	347.0	76.7
85.5	39.3	45.0	147.2	267.5	43.8	35.8	142.5	174.1	43.4
107.0	55.8	62.0	134.7	414.3	57.3	58.7	168.9	204.4	73.9
109.3	41.5	54.1	155.3	326.1	61.8	57.3	135.1	237.5	79.0
126.9	38.2	52.6	153.2	360.5	55.6	56.0	134.4	276.2	68.5
183.9	66.8	73.6	152.2	641.5	92.4	67.4	144.0	297.0	90.6
183.1	60.8	65.7	219.8	552.2	63.4	65.9	211.1	478.7	74.1
243.2	69.2	94.5	250.5	695.6	106.5	107.4	241.6	522.0	124.2
-	-	94.3	271.1	630.7	112.7	61.3	235.6	277.5	77.2
164.1	44.9	63.4	213.5	438.5	67.2	43.3	201.2	132.1	60.6
257.7	75.8	81.0	264.4	753.1	109.7	74.1	210.2	334.1	97.4
159	54	70	196	497	76	65	182	291	83
		1052					621		

TABLE I (Continued)

Wet Period (April-June, September-October)*

Alex						Durwood			
Ca	Mg	Na	HCO_3	SO_4	Cl	Na	HCO_3	SO_4	Cl
137.6	43.6	50.2	117.3	434.2	53.8	45.4	156.7	190.6	61.3
168.2	60.7	75.2	180.4	550.9	77.1	38.5	162.7	168.1	47.6
159.2	42.5	62.6	147.3	471.6	64.4	32.1	154.0	105.7	47.5
97.2	45.0	41.5	148.9	317.6	44.2	38.6	147.4	165.2	49.6
148.4	43.0	49.4	186.6	400.0	52.7	73.7	154.0	420.7	86.3
150.5	42.8	55.2	159.4	430.0	57.2	46.2	158.7	195.1	62.6
116.7	33.2	44.8	142.4	305.1	59.1	40.2	157.6	159.3	49.4
100.4	26.5	32.9	152.0	249.0	30.7	44.2	122.2	207.8	52.3
111.8	67.5	60.7	151.4	380.2	62.7	30.5	142.1	162.7	31.7
101.2	47.5	44.6	148.0	339.5	49.3	47.0	138.7	195.7	61.9
115.9	34.8	39.1	151.0	320.4	35.1	34.7	134.0	186.7	38.4
114.9	37.1	52.3	164.2	345.0	50.0	33.5	141.1	156.6	51.2
127	44	51	155	378	53	42	148	192	53
		808					435		

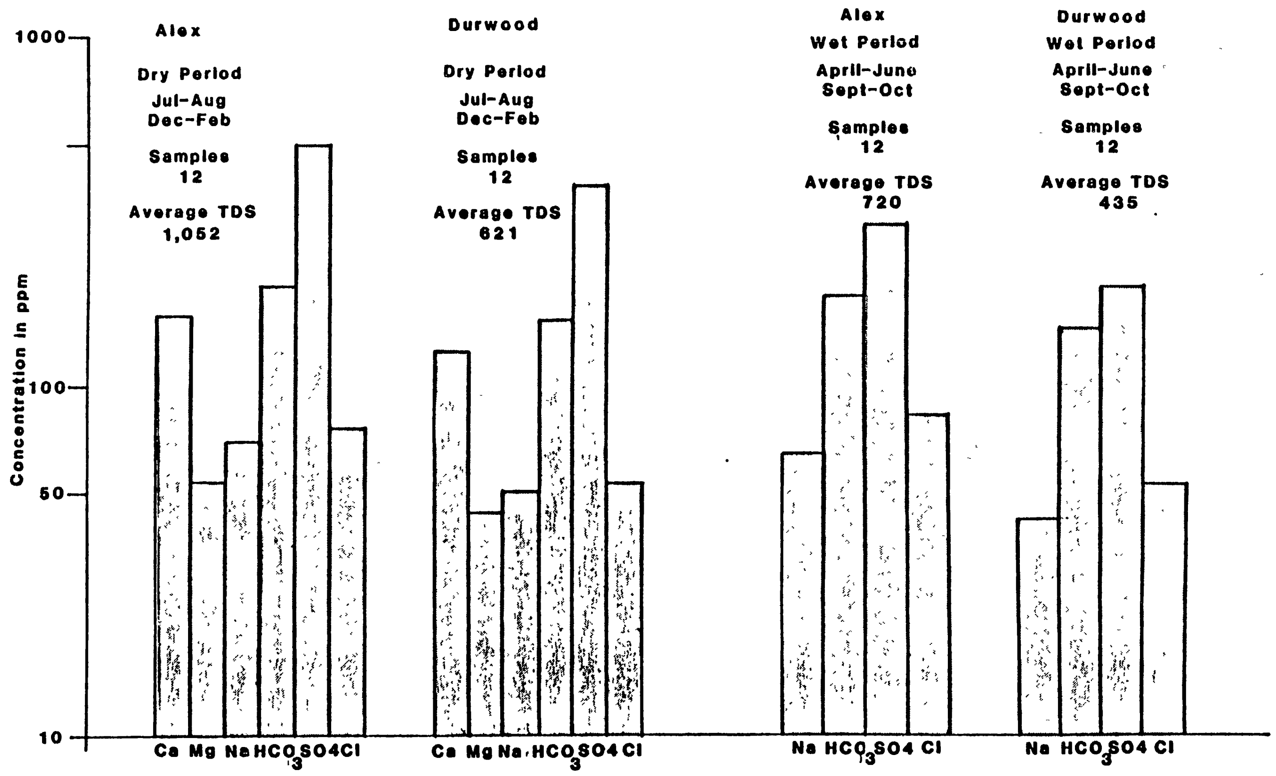


Figure 25. Water Analyses From the Washita River Near Alex and Durwood, Oklahoma Showing the Effect of Wet and Dry Periods on the River Water Quality

geologic logs obtained from the Oklahoma Water Resources Board and the United States Geological Survey. Saturated thickness varies from 11 to 76 feet within the study area. The average saturated thickness is 38 feet. Saturated thickness was determined from water table elevations and from bedrock elevations. Depth to water and saturated thickness maps are included in Appendixes M, J, and R, respectively.

Transmissivity (T) is the rate at which an aquifer will transmit water through a unit width of the aquifer under a unit hydraulic gradient (Lohman, 1972). The transmissivity ranges from 2,150 to 250,000 gpd/ft. It is dependent on the hydraulic conductivity and the saturated thickness. The average transmissivity is 42,123 gpd/ft. Transmissivity maps are included in Appendix L.

The storage coefficient is approximately equal to the specific yield (SY) where water table conditions are found. The storage coefficient is the volume of water an aquifer releases from storage per unit surface area of the aquifer per unit change in head (Freeze and Cherry, 1979). It is a dimensionless number and generally ranges from 0.20 to 0.30 in the alluvial material found in the study area.

Hydraulic conductivity (K) or permeability is the capacity of an aquifer to transmit, in unit time, a unit volume of water at the prevailing viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head through unit length of flow (Lohman, 1972). The hydraulic conductivity varies over the study area; increasing from Modeled Reach A to Modeled Reach C. The average hydraulic conductivity for Modeled Reach A is 201 gpd/ft^2, Modeled Reach B is 1,047 gpd/ft^2, and Modeled Reach C is 2,294 gpd/ft^2. Hydraulic conductivity maps are found in Appendix K.

Well Design and Well Yield

Generally, 12- to 14-inch diameter casing is used to construct irrigation wells in the study area. The casing is slotted or screened opposite water bearing zones and the annular space around the casing is usually gravel-packed.

Several wells in the study area produce about 1,000 gpm, with one well reported as producing 1,200 gpm. A few wells produced less than 100 gpm. The average yield in the study area is 280 gpm. The great variation in yield is due to differences in hydraulic conductivity and saturated thickness. The hydraulic conductivity is affected by the varying composition of the deposits and their lenticular nature and the saturated thickness varies due to an undulating bedrock topography. The type of well completion can also affect the well yields.

Land Use, Irrigation, and Return Flow

Approximately two-thirds of the land in the study area is used as cropland, while the other one-third is used as pasture. The major crops are listed in order of importance by income as follows; hay, wheat, alfalfa, cotton, grain sorghum, oats, corn, peanuts, and barley (Oklahoma Water Resources Board, 1968).

Figures 26, 27, and 28 show the prior appropriative rights distribution over the study area. Prior appropriative rights are water rights that were held prior to 1973. Any owner that had claimed rights to water prior to 1973 had those rights legally established. Any rights claimed after 1973 are subject to guidelines set up by the Oklahoma Water Resources Board. Data which included names and acres under irrigation and the annual amount of pumping were provided by the Oklahoma Water Resources Board. These data were reduced to pumping per acre and then distributed over the appropriate nodes. The heaviest irrigation found in the study area is in Garvin, Carter, and Johnston counties as is shown by the prior rights (Appendix O).

The prior rights in the Washita River alluvium in Grady, McClain, Garvin, Murray, Carter, and Johnston counties total 8,968 acre-feet per year. This averages out to approximately 0.93 acre-feet per acre per year distributed over 9,615 acres. The amount becomes 0.05 acre-feet per acre per year if the prior rights are distributed evenly over the total aquifer area (252.4 square miles). Applicable prior rights used in this study are shown in Appendix O.

Return flow from irrigation has been estimated at 15 to

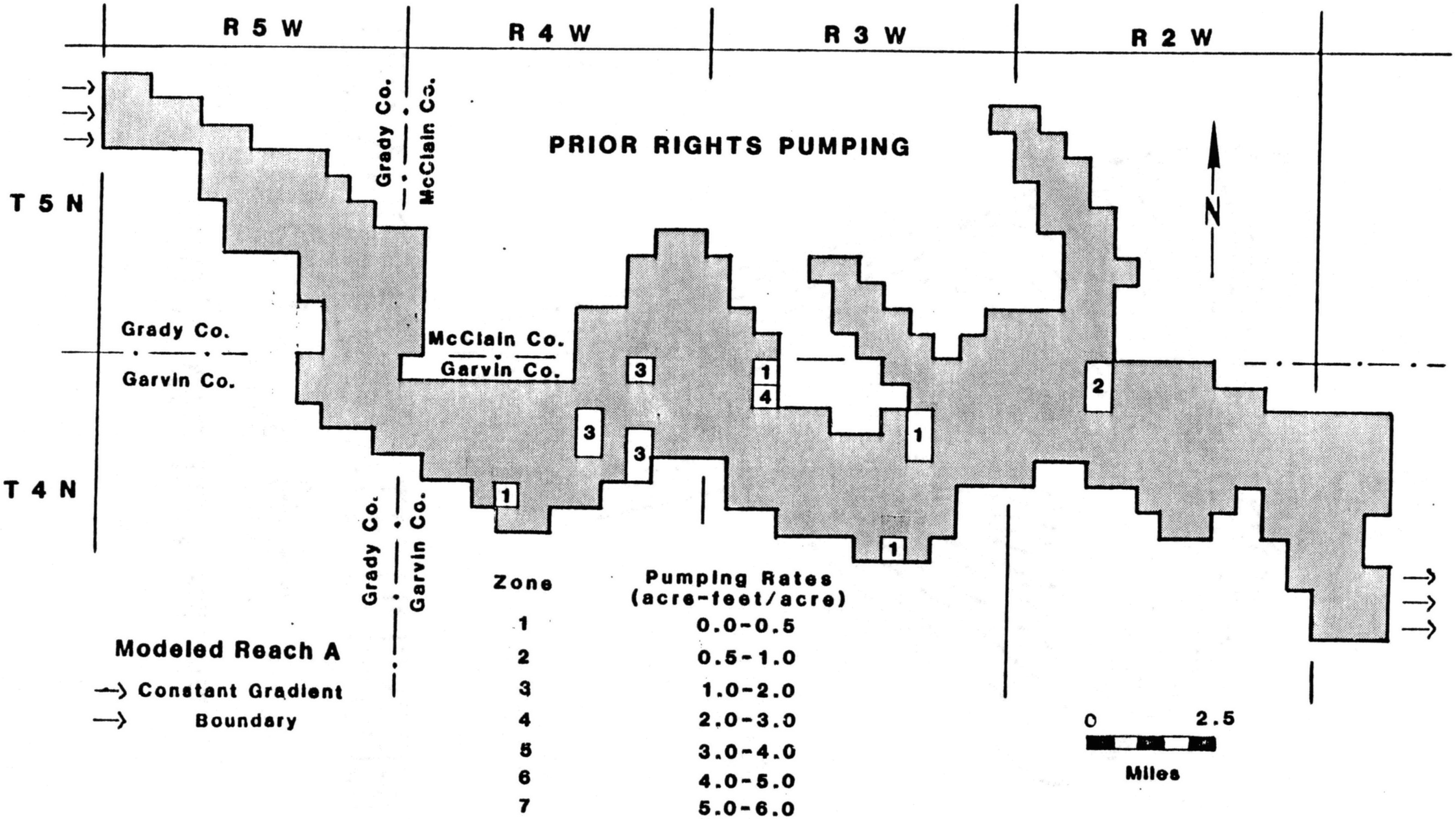


Figure 26. Distribution of Prior Appropriative Rights - Modeled Reach A

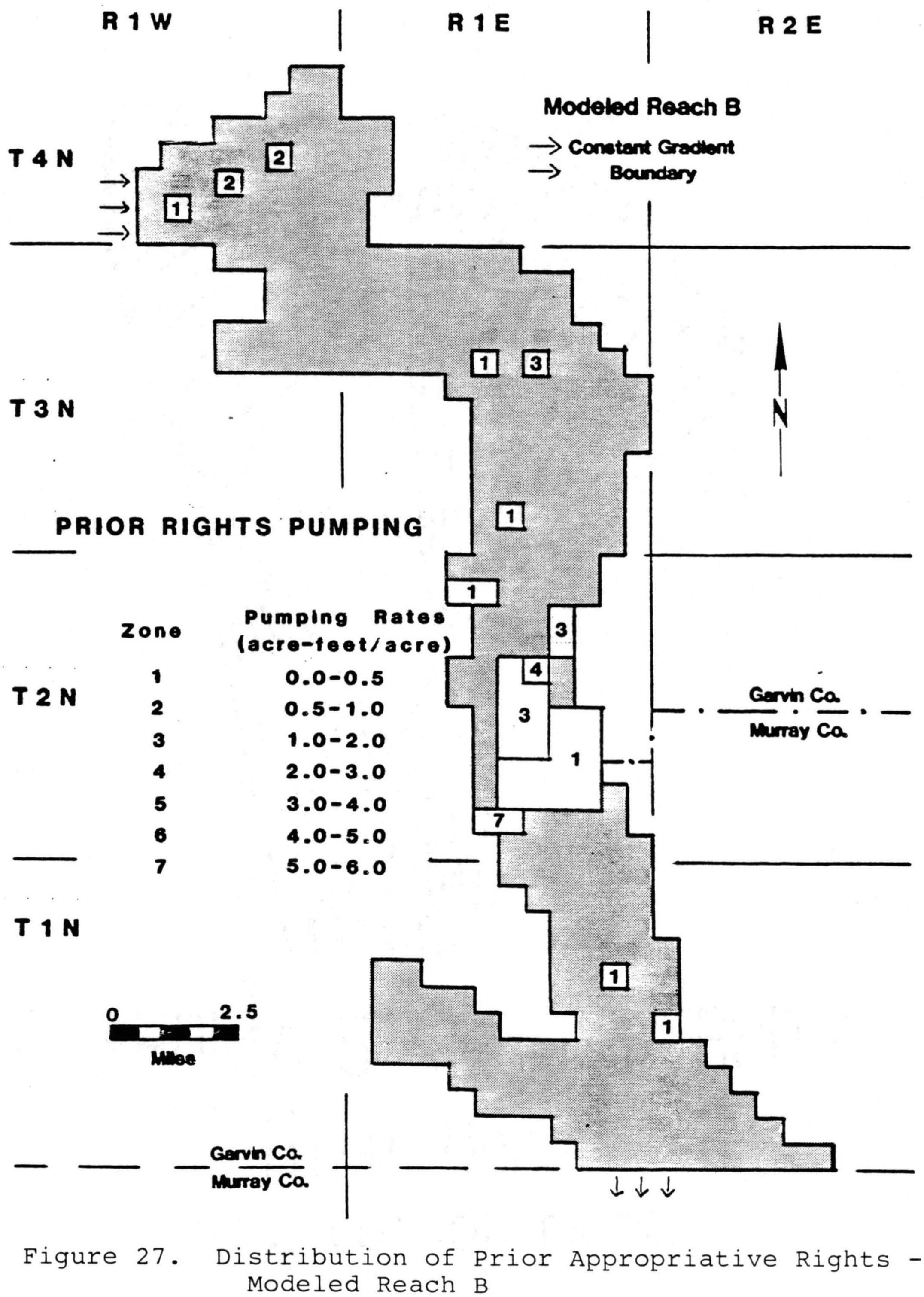


Figure 27. Distribution of Prior Appropriative Rights - Modeled Reach B

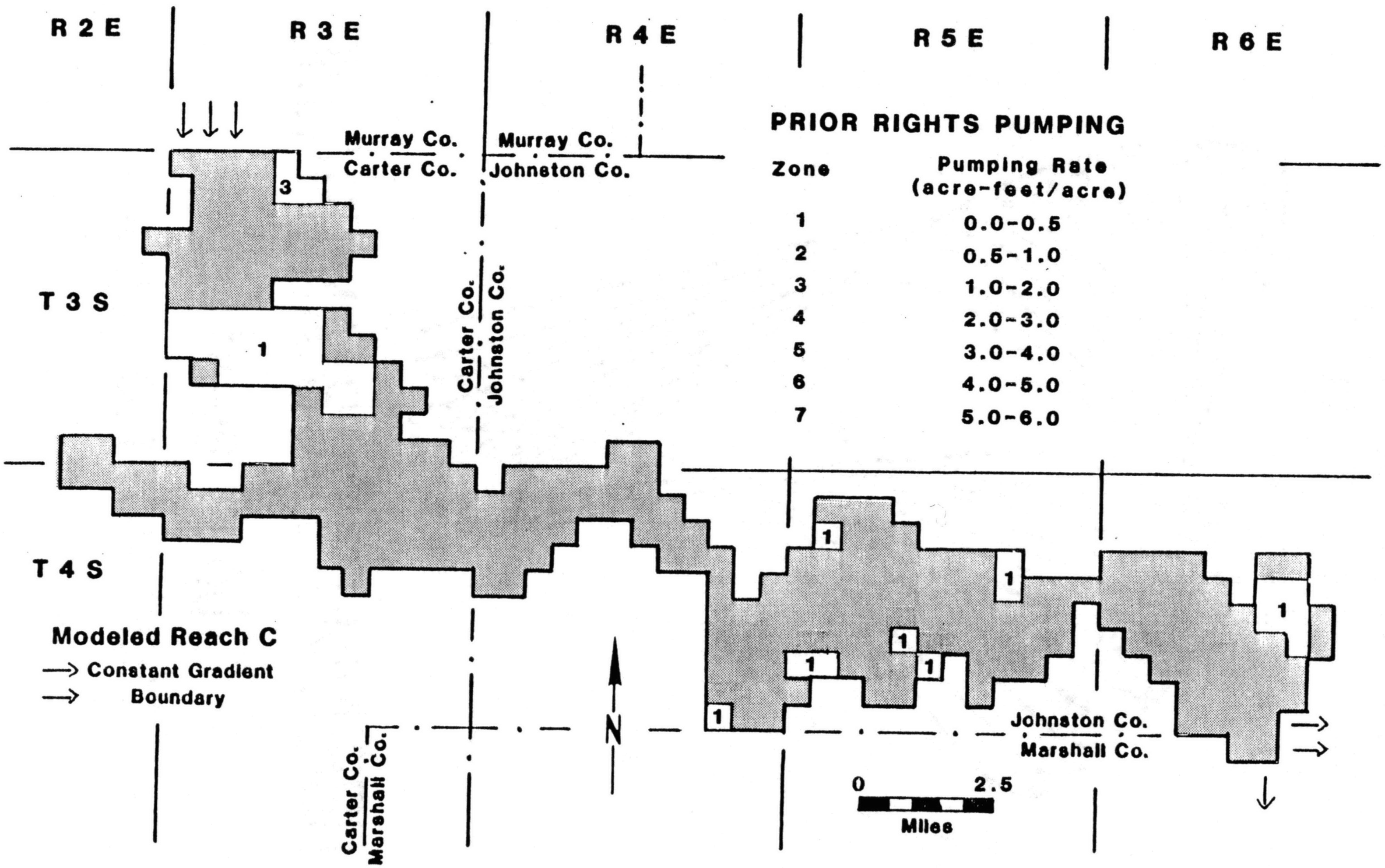


Figure 28. Distribution of Prior Appropriative Rights - Modeled Reach C

25 percent of pumping based on studies by the Oklahoma Water Resources Board, the United States Geological Survey, and others. A 15 percent return flow was used for the Washita River alluvium, based on water budget analyses and evapotranspiration estimates.

Ground-Water Quality

Various formations underlie the Washita River alluvium in the study area. These formations affect the quality of ground water found in the alluvium. Ten ground-water quality analyses from the alluvium are available in the Ardmore-Sherman Hydrologic Atlas (Hart, 1974). Total dissolved solids, ranging from 310 mg/l to 1,020 mg/l, average 319 mg/l. Each major constituent in the 10 analyses was averaged as follows; calcium, 95 mg/l; magnesium, 60 mg/l; sodium, 60 mg/l; bicarbonate, 44 mg/l; sulfate, 10 mg/l; and chloride, 50 mg/l. Analyses of the ground-water quality in the Washita River alluvium north and south of the Arbuckle Mountains are presented in Table II and are summarized graphically in Figure 29.

Due to the severely limited information on ground-water quality from formations underlying the Washita River alluvium, only broad, general conclusions could be made concerning the way these formations affect the water quality in the alluvium. Bedrock representing four geologic time periods were reported by Hart (1974) (Ordovician, Pennsylvanian, Permian, and Cretaceous). Rocks of

TABLE II

GROUND WATER QUALITY ANALYSES FROM ORDOVICIAN, PENNSYLVANIAN, PERMIAN, CRETACEOUS, AND QUATERNARY AGED MATERIAL

Ordovician

Ca	Mg	Na	HCO_3	SO_4	Cl	TDS
66.1	34.[illegible]	149.6	31.6	0.0	234.1	
66.1	30.[illegible]	4.4	33.3	3.4	10.6	
88.2	42.[illegible]	297.0	31.6	2.7	514.3	
70.1	40.[illegible]	11.0	34.4	0.3	10.6	
36.1	36.[illegible]	6.6	27.8	0.2	7.1	
70.1	29.[illegible]	11.0	34.4	0.1	3.5	
66	35	80	32	2	130	345

Pennsylvanian

Ca	Mg	Na	HCO_3	SO_4	Cl	TDS
30.1	14.[illegible]	1969.0	38.9	91.2	2536.1	
-	-	446.6	47.7	4.8	620.7	
-	-	204.6	44.4	3.4	17.7	
-	-	429.0	99.9	0.0	53.2	
14.0	6.[illegible]	33.0	55.5	17.2	99.3	
86.2	19.[illegible]	44.0	16.7	15.8	63.8	
44	13	570	51	22	564	1264

Permian

Ca	Mg	Na	HCO_3	SO_4	Cl	TDS
46.1	40.[illegible]	11.0	20.0	3.4	53.2	
40.1	1.[illegible]	121.0	50.0	147.5	397.3	
80.2	15.[illegible]	11.0	22.2	6.9	17.7	
100.2	46.[illegible]	2.2	16.7	20.6	46.1	
68.1	19.[illegible]	94.6	19.4	11.7	124.1	
60.1	29.[illegible]	35.2	13.3	2.1	106.4	
34.1	53.[illegible]	48.4	21.1	4.1	113.5	
28.1	27.[illegible]	28.6	18.3	1.4	24.8	
92.2	60.[illegible]	149.6	44.4	27.4	88.7	
436.9	38.[illegible]	1861.2	22.2	764.9	266.0	

TABLE II (Continued)

Permian (Continued)						
Ca	Mg	Na	HCO_3	SO_4	Cl	TDS
56.1	19.5	143.0	54.4	40.5	17.7	
144.3	81.5	66.0	47.2	49.4	35.5	
130.3	6.1	0.0	38.3	3.4	17.7	
102	34	198	30	83	99	546

Cretaceous						
Ca	Mg	Na	HCO_3	SO_4	Cl	TDS
60.1	40.1	11.0	36.1	4.8	17.7	
8.0	8.5	114.4	39.4	6.2	28.4	
34	24	63	38	6	23	89

Quaternary						
Ca	Mg	Na	HCO_3	SO_4	Cl	TDS
30.1	40.1	26.4	23.9	0.5	10.6	
80.2	104.6	22.0	50.0	1.4	17.7	
124.2	79.0	39.6	55.5	0.3	17.7	
112.2	65.7	44.0	58.3	1.8	60.3	
-	-	88.0	37.7	0.8	17.7	
124.2	63.2	35.2	31.1	2.0	106.4	
96.2	98.5	55.0	71.6	1.5	53.2	
68.1	45.0	184.8	44.4	1.5	46.1	
110.2	19.5	57.2	38.3	0.5	99.3	
110.2	29.2	44.0	27.8	4.3	70.9	
95	60	60	44	10	50	319

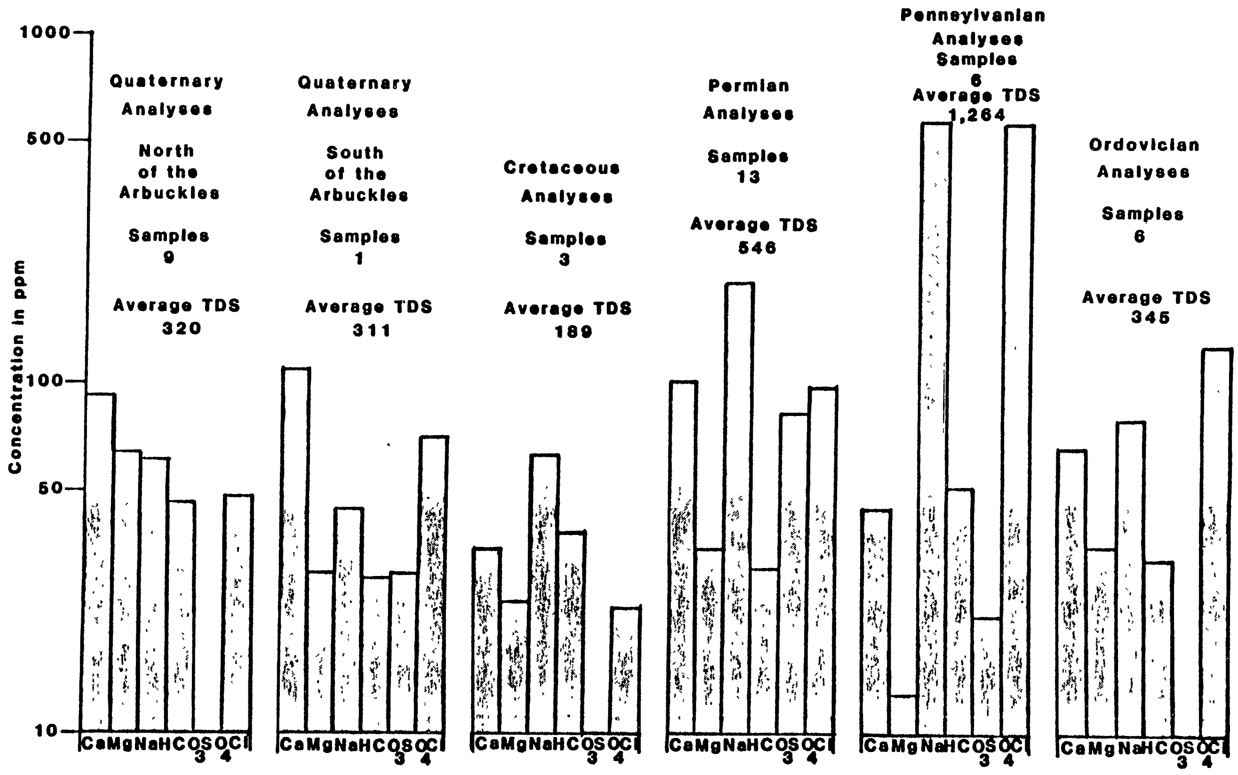


Figure 29. Ground-Water Quality Analyses of the Washita River Alluvium and of the Bedrock Units Underlying the Alluvium

Ordovician and Cretaceous age influence ground-water quality south of the Arbuckle Mountains. However, the analyses are in areas where streams empty into the Washita River southeast of any analyses made on ground-water quality of the alluvium. Therefore, no direct correlation between the effect of Ordovician and Cretaceous chemical constituents in the ground-water quality could be determined.

The drainage area north of the Arbuckles is underlain by Pennsylvanian and Permian aged rocks. Six analyses were combined and averaged for the Pennsylvanian and 13 analyses were averaged for the Permian. These analyses along with the analyses from Ordovician and Cretaceous aged rocks are presented in Table II and summarized graphically in Figure 29. Locations of the analyses are shown in Figures 30 and 31.

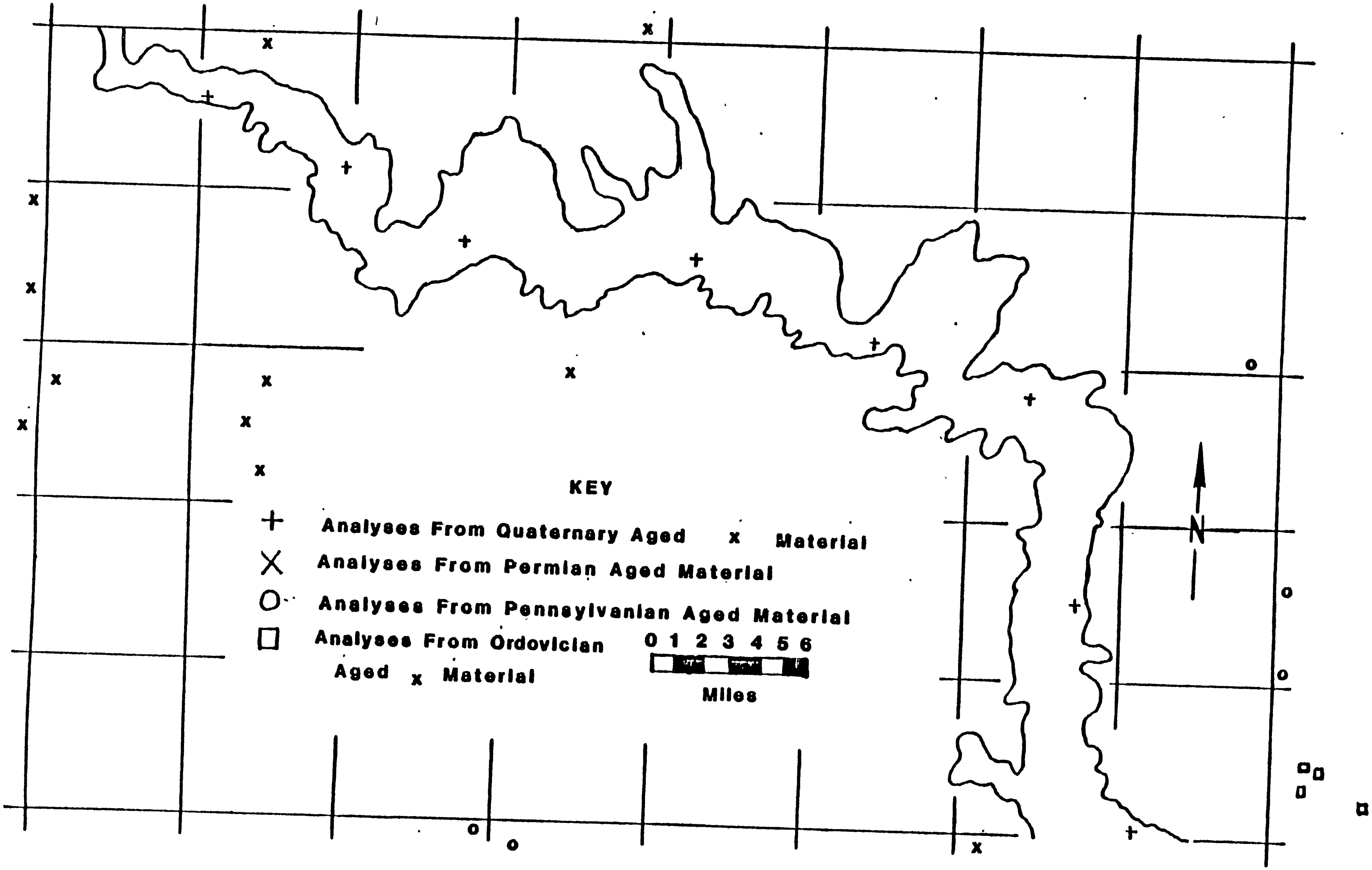


Figure 30. Location of Ground-Water Quality Analyses North of the Arbuckles

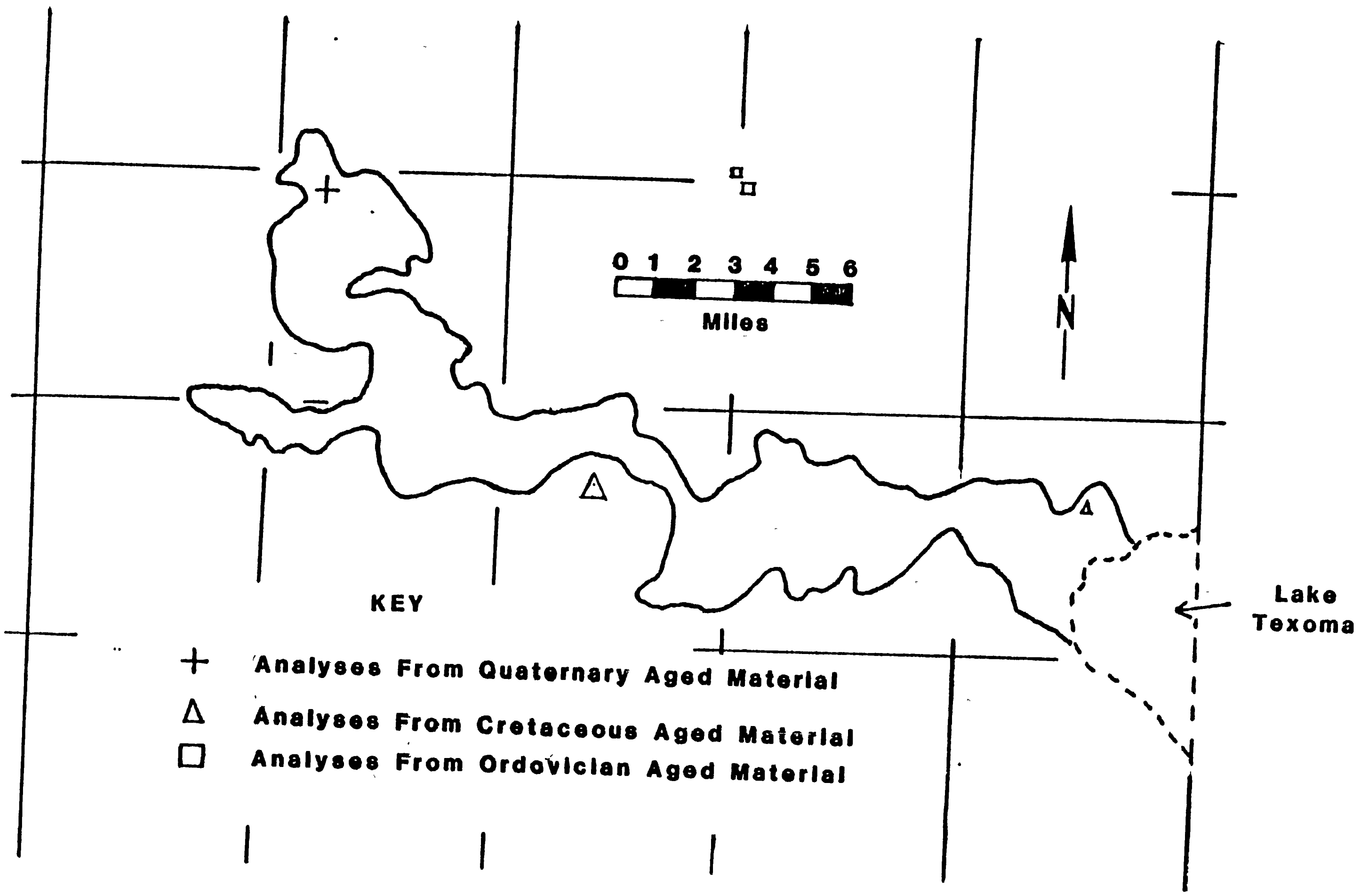


Figure 31. Location of Ground-Water Analyses South of the Arbuckles

CHAPTER V

FIELD METHODS

Geophysical Surveys

Before the final compilation of data to enter in the computer model was made, it was necessary to run geophysical (resistivity) surveys to fill in the data gaps in the study area. The author, with the assistance of a field assistant, ran resistivity surveys in the study area using a Bison Earth Resistivity Meter, Model 2350 in the summer of 1982 in order to determine water table and bedrock elevations.

A Wenner Configuration was used for the survey's four electrodes are spaced at equal intervals (a-spacing) along a line. The a-spacing was incrementally increasing from a starting point of five feet for each survey until the desired depth was reached. Figure 32 shows a typical Wenner configuration.

The resistivity measured is apparent resistivity and not true resistivity due to the nonuniform nature of the subsurface materials. The equation used for determining apparent resistivity follows (Bison, 1969):

$$pa = A(2\pi V/I)$$

where

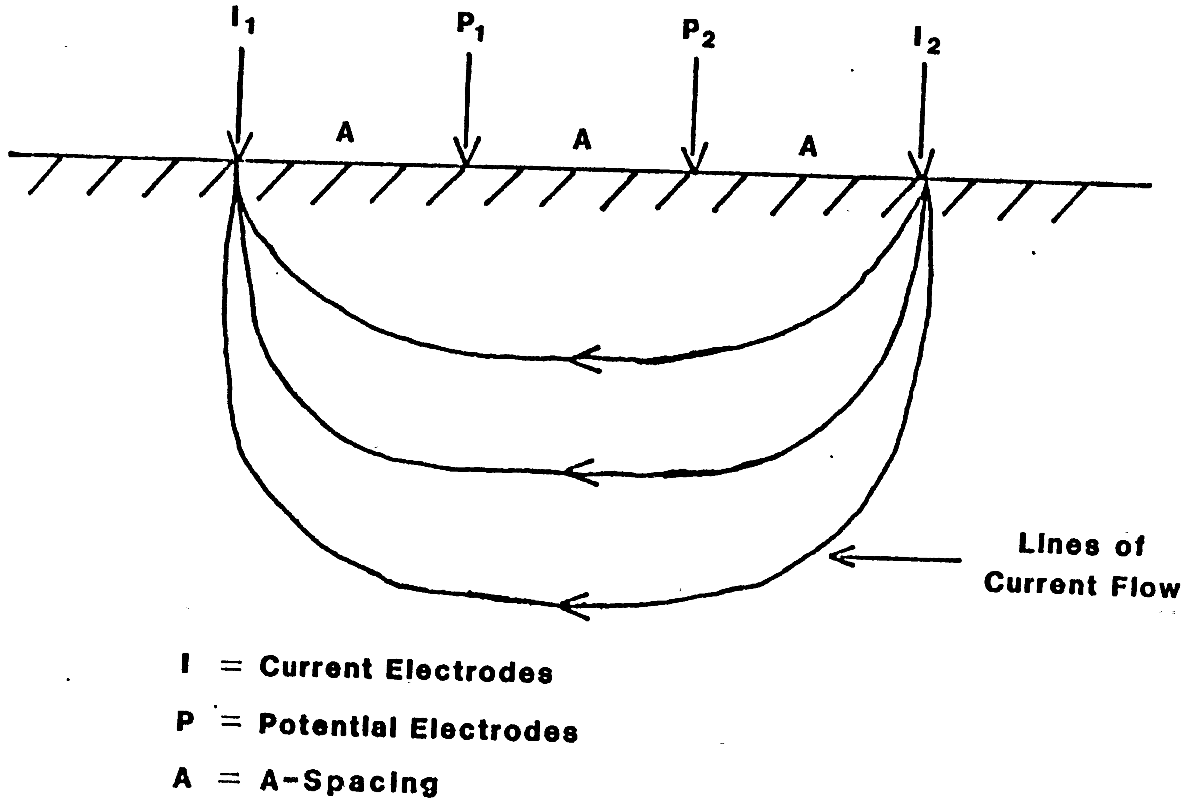


Figure 32. Wenner Configuration

pa = apparent resistivity in ohm/ft
A = a-spacing in feet
V = voltage in volts
I = current in milliamperes

After the apparent resistivity at each survey was measured and calculated (Table III), graphs were plotted for each station (apparent resistivity vs. depth). Figure 33 shows an example of a survey run in the study area with a corresponding geologic log. Resistivity graphs for the 36 surveys made in the study area are shown in Appendix S.

TABLE III

RESISTIVITY DATA FOR A STATION LOCATED IN T4NR3W SEC 17 CBCC

Tape					
Inside Electrode	Outside Electrode	A-Spacing (feet)	Dial (2 v/I)	Multiplier	Apparent Resistivity (ohm/ft)
2.5	7.5	5	113	0.1	56.5
5.0	15.0	10	479	0.01	47.9
7.5	22.5	15	324	0.01	48.6
10.0	30.0	20	249	0.01	49.8
12.5	37.5	25	202	0.01	50.5
15.0	45.0	30	171	0.01	51.3
17.5	52.5	35	146	0.01	51.0
20.0	60.0	40	132	0.01	52.8
22.5	67.5	45	119	0.01	53.5
25.0	75.0	50	108	0.01	54.0
27.5	82.5	55	101	0.01	55.5
30.0	90.0	60	914	0.001	54.8
32.5	97.5	65	808	0.001	54.3
35.0	105.0	70	775	0.001	54.3

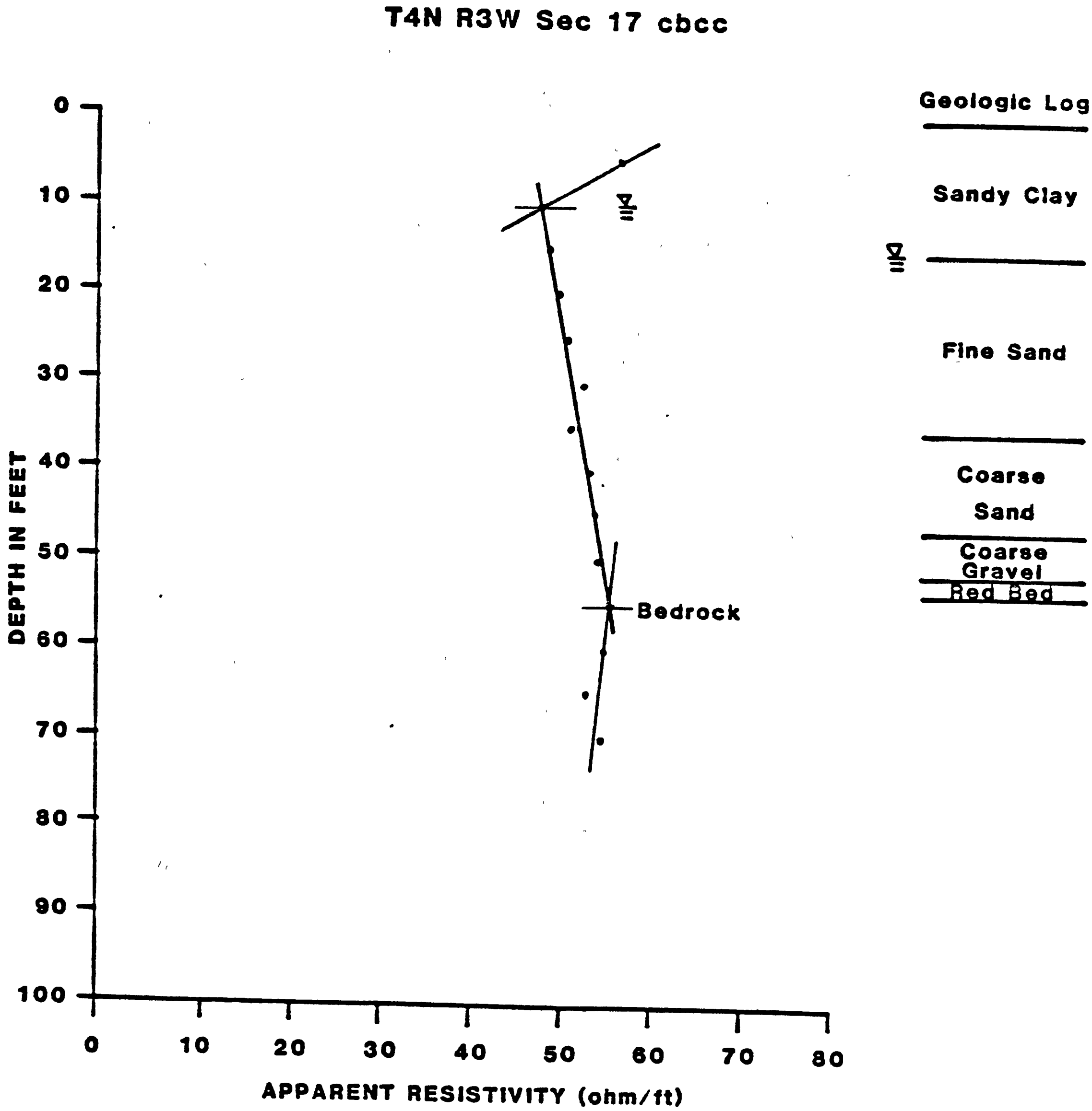


Figure 33. Graph of Apparent Resistivity

CHAPTER VI

COMPUTER MODELING

Part 1 - Simulation Procedure

General

The model used was originally written by Pinder (1970) and revised by Trescott, Pinder, and Larson (1976). It is a two-dimensional finite difference model with options for artesian, water-table, and combined aquifers. The water-table version was used to simulate the response of the aquifer to pumping stress over a 20-year period in the Washita River alluvium.

The finite difference method was used to approximate the ground water flow of an unconfined aquifer. This method divides the aquifer area into nodes with each node being represented by a finite difference approximation with an assigned value of permeability, storage coefficient, and net inflow. The aquifer then becomes a set of algebraic equations which are solved simultaneously using the Alternating Direction Implicit Procedure (ADIP). Head values in future time are determined by starting with known (initial) head values. As each time step is computed, the value is re-entered into the program by the computer until the final number of time steps desired is completed. Initial boundary conditions must also be specified.

Matrix Design

The aquifer boundaries and encompassing area were determined through use of topographic maps and through the Hydrologic Atlas of the Ardmore-Sherman Quadrangle (Hart, 1975). The aquifer was divided into three reaches based on location, computer grid limitations, and the consistency of the permeability values. Square nodes, one-half mile on a side, having a one-quarter mile square area (160 acres) were found to be sufficient to accomodate for an alluvial width which averaged two miles. A node grid which best fit the boundaries was constructed and is found in Figures 2, 3, and 4.

Boundary Conditions

The Washita River alluvium in the study area is primarily bounded by Permian bedrock on its sides and bottom. The permeability of the bedrock is quite low when compared to that of the alluvium, therefore the bedrock was assumed to be impermeable, or a no-flow boundary. Permeability and transmissivity values were assigned a value of zero at these boundary nodes.

Constant gradient nodes were placed where the river entered and exited the modeled reaches. They allow for subsurface inflow and outflow and can be calculated using the Darcy equation.

$$Q = mKI \text{ or } Q = TI$$

where

Q = the amount of inflow or outflow
m = saturated thickness of the adjacent node (set at the beginning of each time step)
K = permeability of the constant gradient mode
T = transmissivity of the constant gradient mode
I = selected change in head from constant gradient node to adjacent node (positive for inflow, negative for outflow)

The above equation is a simplification of $Q = k(Wm)\ dH/L$. When using a square node, the cross-sectional width (W) and the distance between node centers (L) are cancelled out.

Simulation Period

A water year was determined to be 360 days which was divided into 36 time steps of 10 days each. A time step is the period in which the computer readjusts the water-table elevations in response to recharge to discharge from the aquifer system. Each time step required a certain number of iterations to complete that time step. A maximum of 50 iterations was allowed for each time step. These iterations were performed until the differences of each subsequent iteration converged within an error factor of one-hundreth of a foot.

A four month pumping period (June-September) and an eight month non-pumping period (October-May) were set for each year. June to September represents the primary irrigation period (Figures 13 and 14). These were used during 20-year simulation runs and annual pumping was divided evenly over the four month pumping period.

Computer Runs

The actual modeling of the river alluvium was broken into several stages. First, the data and matrices were checked for errors. Data entry was double checked using a one-year calibration run. After all errors were corrected, a five-year calibration run was made. The five-year run was calibrated until the aquifer system fell within 10% of an idealized steady-state condition (no gain or loss by the system over five years). Calibration was completed when the system was found to be losing water at a rate less than 10% of ideal equilibrium. This allowed for a safer yield to be determined for the 20-year allocation/prior appropriative pumping runs.

Twenty-year allocation/prior appropriative pumping simulation runs were then made to determine the allocation in acre-feet per acre per year that would allow 50% of the aquifer to go dry over the 20-year period. A model was considered to be dry when its saturated thickness was 5.5 feet or less. Finally, 20-year prior appropriative pumping runs were made. These showed the effect of 20 years of pumping if only the prior rights were used. If a prior rate was found to be greater than an allocation rate at a certain node, then the prior rate was allowed to remain the same at that node.

Part 2 - Data Input

The data input format and the relevant options used in this study are listed below

Fixed Value:

1. Grid spacing in the X-direction (DELX)
2. Grid spacing in the Y-direction (DELY)
3. Number of runs in the model (DIML)
4. Number of columns in the model (DIMW)
5. Number of pumping periods in total simulation time (NPER)
6. Length of time steps in hours (DELT)
7. Number of days per period (TMAX)
8. Number if iterations per time step (ITMAX)

Adjustable Scalar:

1. Evapotranspiration rate (QET)
2. Allocation rate
3. Error criteria for convergence of mathematical model (ERR)

Pattern Matrix:

1. River node permeability (RATE)

Non-Uniform Matrix:

1. Land surface elevations (LAND)
2. Bedrock elevations (BOTTOM)
3. Water-table elevations (STRT)
4. Top of aquifer (TOP)
5. Prior appropriative pumping (WELL)
6. Constant gradient nodes (GRAD)
7.* Transmissivity (TRANS)

Uniform Matrix:

1. Specific yield (SY)
2.* Permeability (PERM)
3. Recharge rate (QRE)
4. Thickness of river bed (M)

Computer-Generated Non-Uniform Matrix:

1.* Permeability (PERM)
2.* Transmissivity (TRANS)
3. Saturated thickness
4. Water elevations in river (RIVER); set from STRT matrix

The asterick (*) marks those input parameters that were used in two of the categories above. It was necessary to enter permeability and the bedrock elevation as input parameters. As a result transmissivity values were generated by the computer. Transmissivity was later adjusted for calibration runs.

Defining Input Parameters

Surface Elevations (LAND). Surface elevations for each node were determined for each reach. Values of LAND for each node were obtained from topographic maps. Each node was represented by the average elevation of that node.

Bedrock Elevations (BOTTOM). Bedrock elevations or the bottom of the aquifer were determined through the use of drillers' logs obtained from the Oklahoma Water Resources Board, and through field investigations in the form of resistivity surveys by the author. The drillers' logs reported depth of well, lithological descriptions of materials encountered, casing size, perforation intervals, and gravel pack. Most logs also included well yield information such as duration, rate of pumping, and resultant drawdown. Examples of the determination of depth to bedrock using resistivity are found in Appendix S.

The bedrock elevations were averaged over each individual node. Contour maps of these elevations are found in Figures 34, 35, and 36.

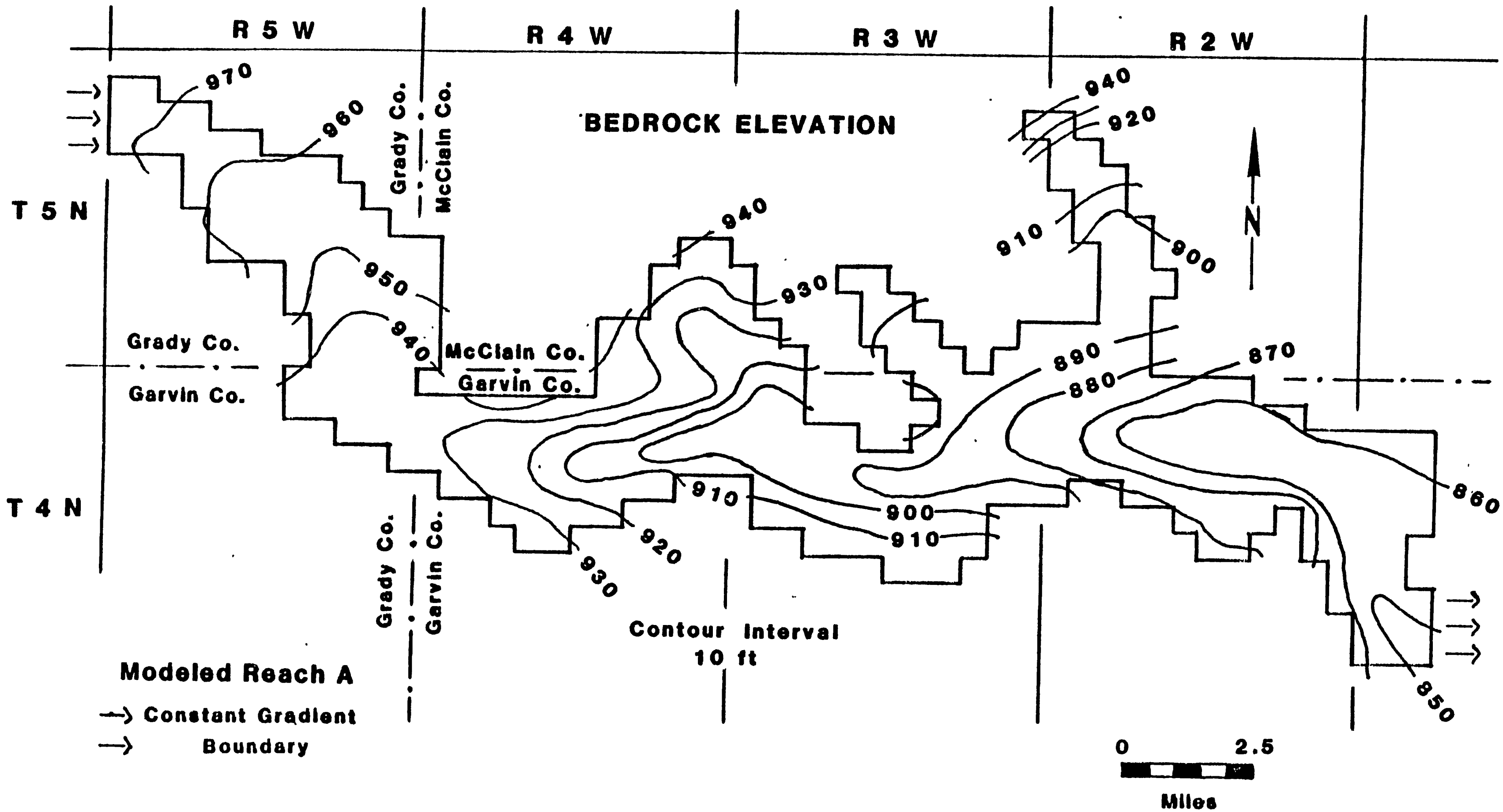


Figure 34. Bedrock Elevations - Modeled Reach A

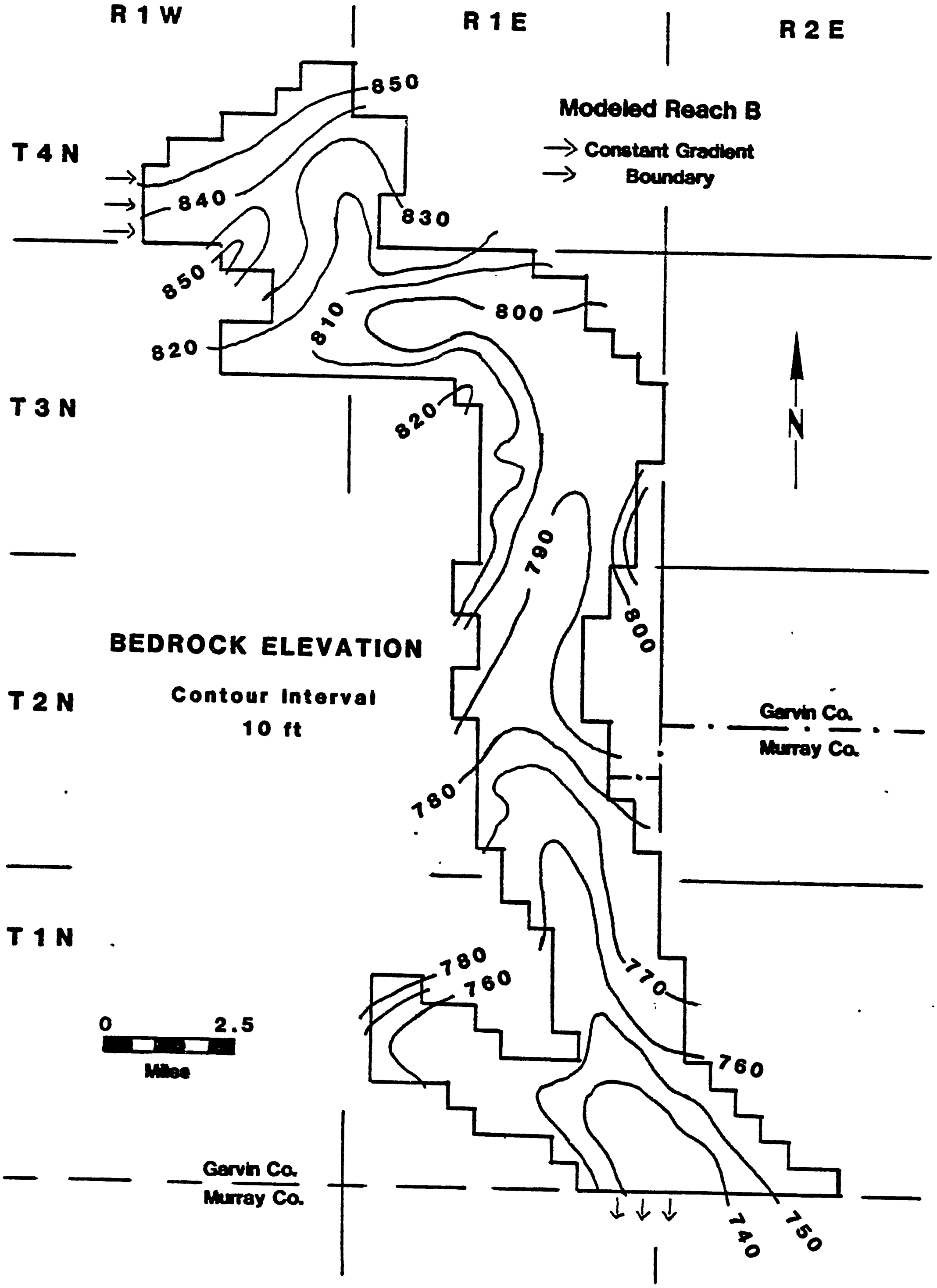


Figure 35. Bedrock Elevations - Modeled Reach B

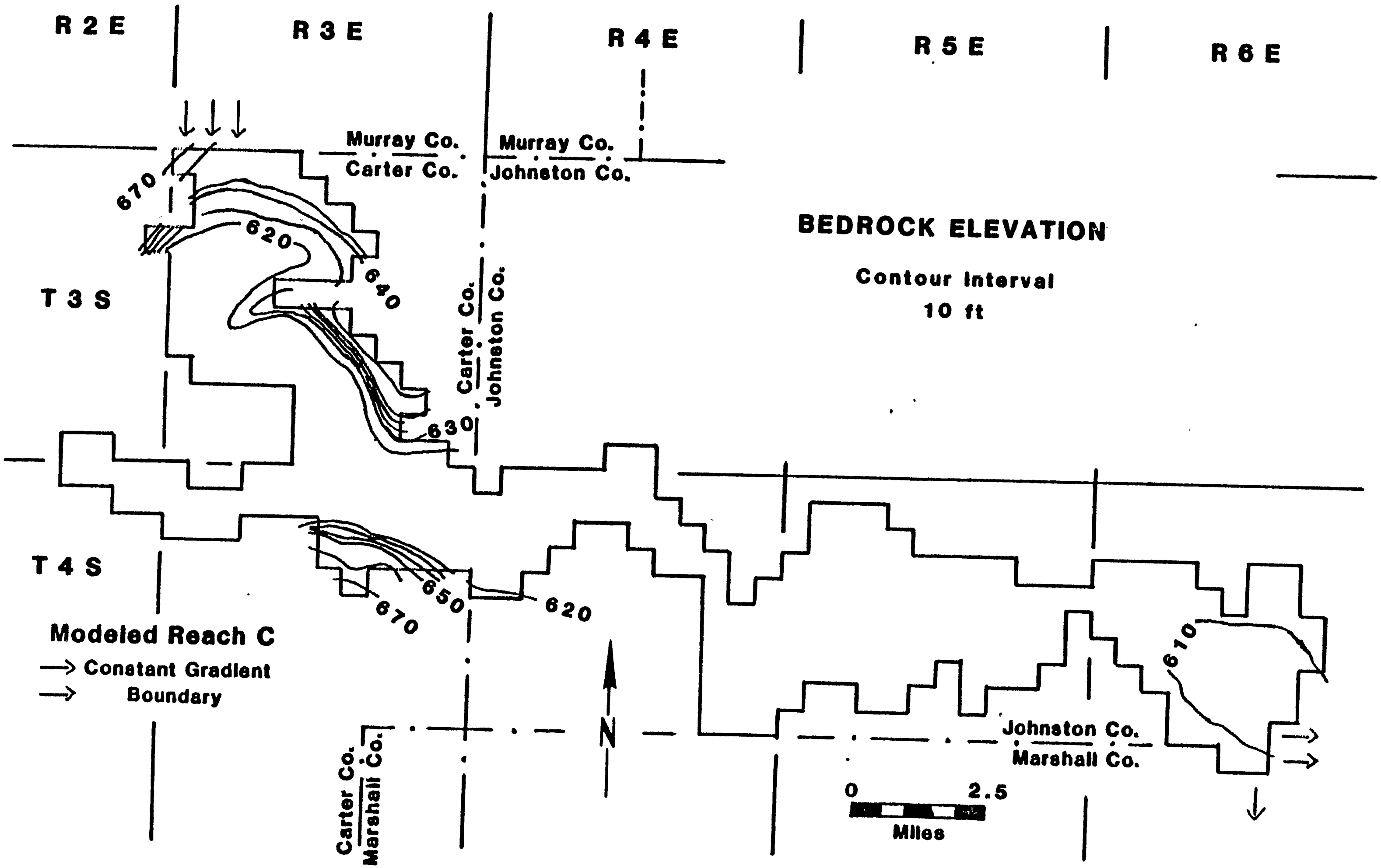


Figure 36. Bedrock Elevations - Modeled Reach C

Water-Table Elevations (STRT). The water-table elevations were also determined through drillers' logs and from resistivity surveys. The logs were recorded at the time the well was drilled, therefore the water levels cover a period of years. Because of this, water levels were averaged and contoured (Figures 37, 38, and 39). Information obtained from resistivity surveys were used to fill in data gaps in the area. The resulting water-table contour maps were assumed to represent a period where there was an approximate equilibrium between inflow and outflow.

Top of Aquifer (TOP). The top of the aquifer or bottom of the river elevations were determined from the water table elevations (STRT). The elevation of TOP must be below river bed thickness which must be set to at least one foot. Maps showing the configurations of the top of the aquifer for each reach are shown in Appendix H.

Prior Appropriative Pumping Rights (WELL). Final and tenative orders for prior rights pumping were obtained from the Oklahoma Water Resources Board. Only those well which were applicable to the study area were used. Applicable prior rights used in this study are shown in Appendix O.

Constant Gradient Nodes (GRAD). Grad nodes are placed along the inflow and outflow boundaries of the modeled reach. They are in the immediate vicinity of river and are determined from initial water-table elevations (STRT). The grad nodes represent the head change across the inflow

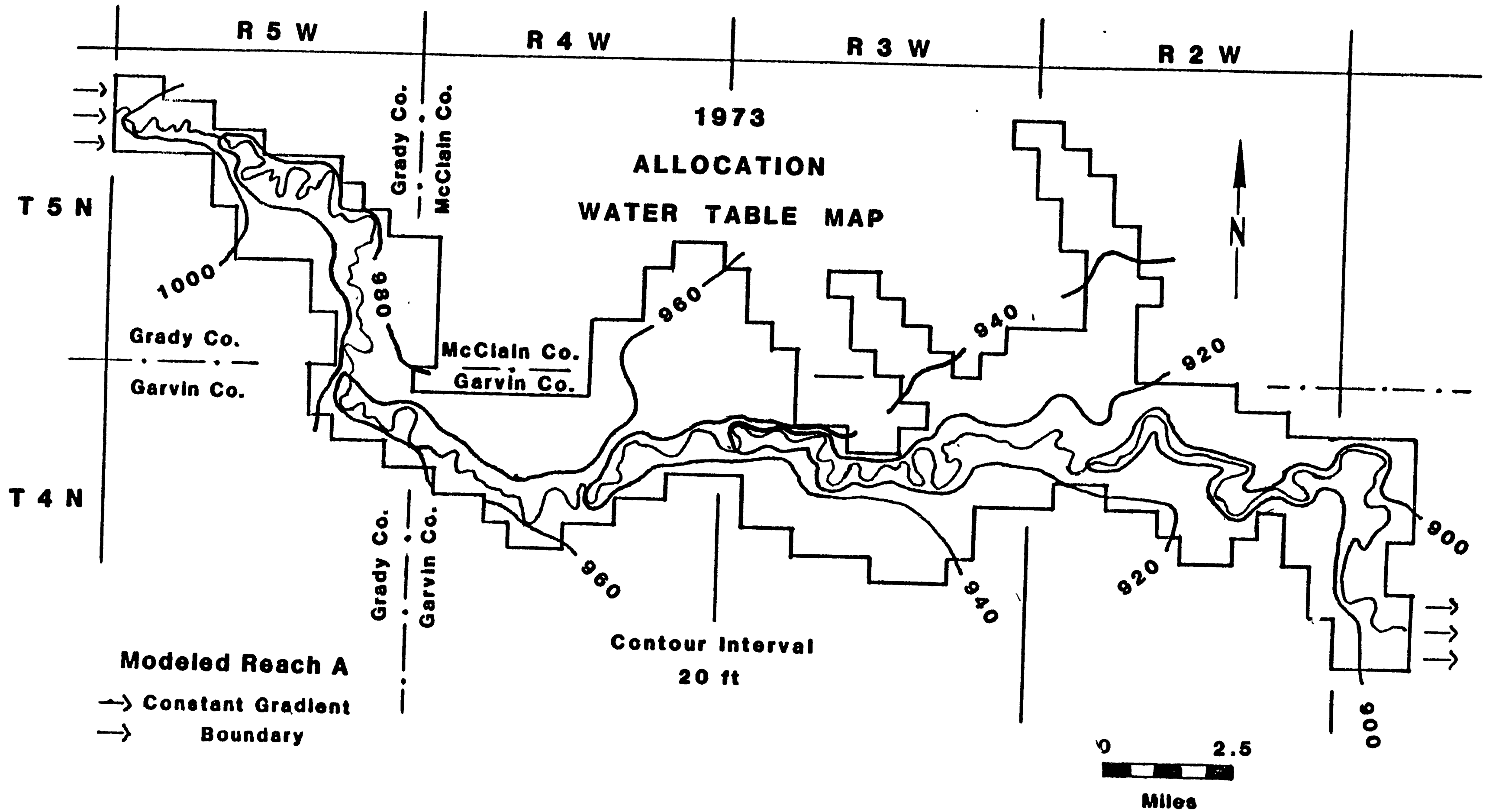


Figure 37. Allocation Water Table Map, 1973 - Modeled Reach A

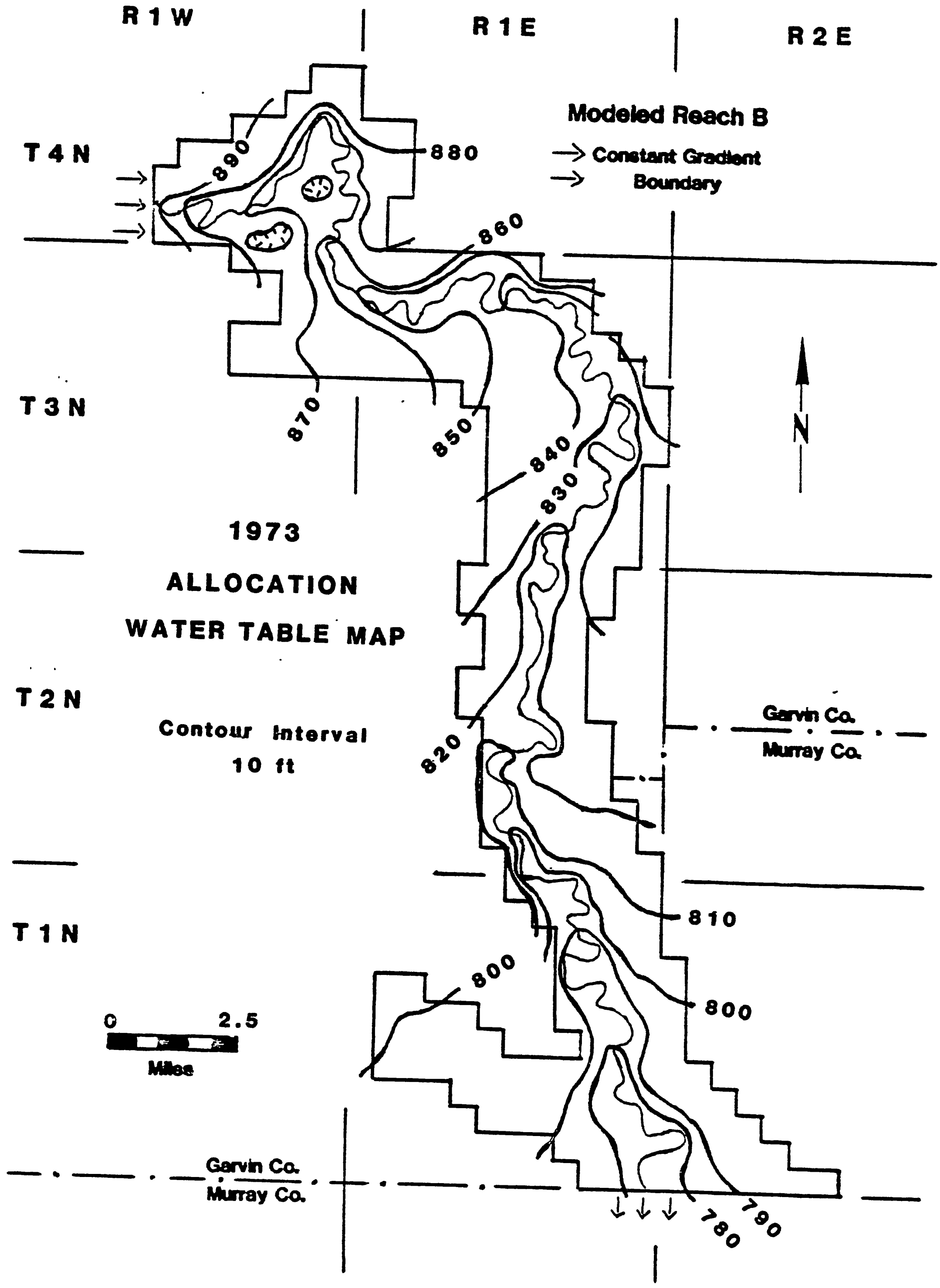


Figure 38. Allocation Water Table Map, 1973 - Modeled Reach B

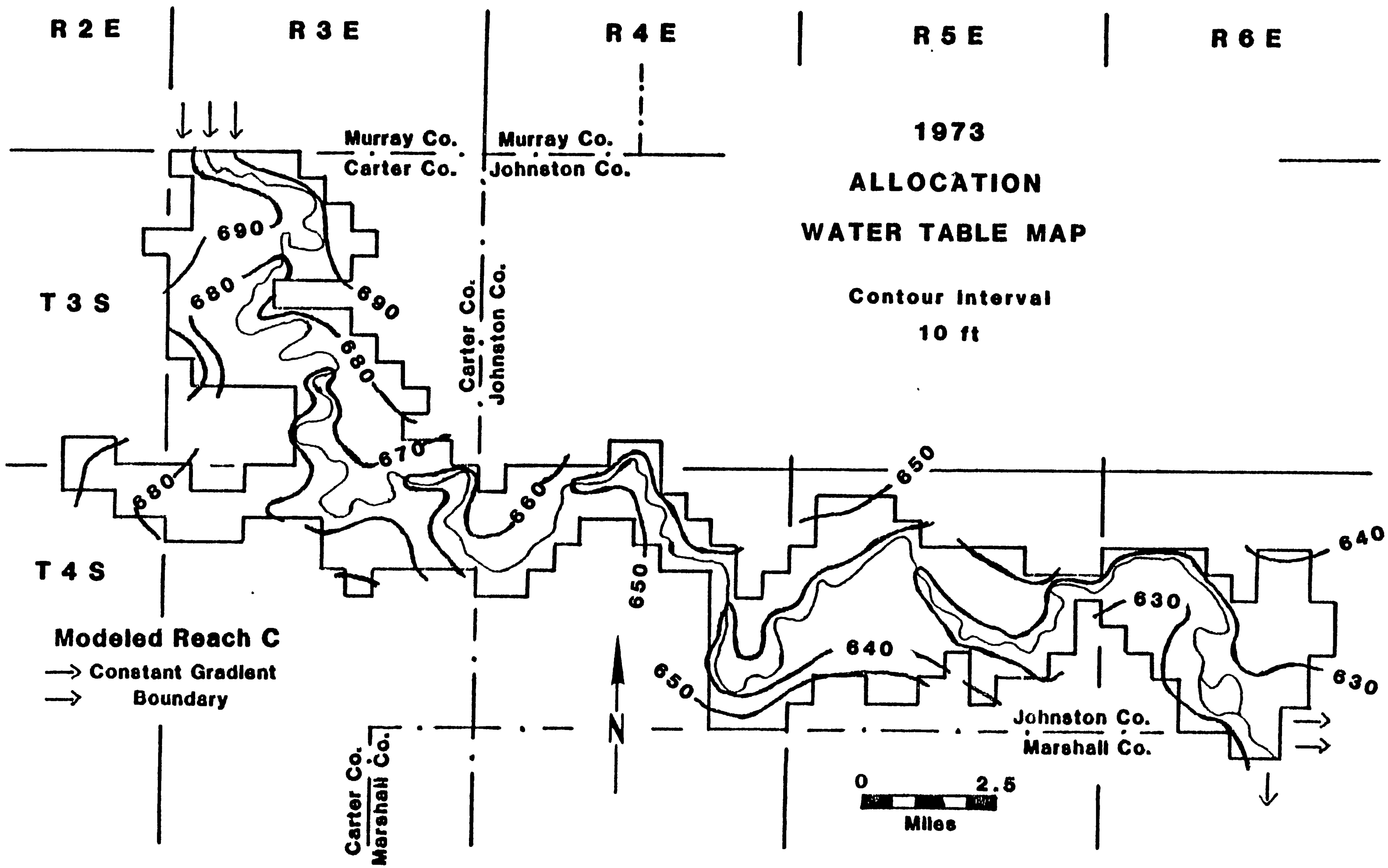


Figure 39. Allocation Water Table Map, 1973 - Modeled Reach C

(positive) and outflow (negative) boundaries. If an adjoining reach is a continuation of another reach, the inflow values of the second reach must be of equal magnitude and of opposite sign of the outflow values of the adjoining reach.

Permeability (PERM). Values of permeability are most easily determined through data derived from aquifer testing. However, aquifer test information was not available for the reaches within the study area. Therefore, two alternative methods were used to determine permeability (K).

Permeability (K) From Specific Capacity Data. Specific capacity can be determined from information found in drillers' logs. It is the number of gallons per minute a well can produce for each foot of drawdown. Walton (1970) relates a well's specific capacity to transmissivity through use of the following equation:

$$T = \frac{Q}{s}\left[264 \log\left(\frac{Tt}{2693 r_w^2 S}\right) - 65.5\right]$$

where

Q/s = specific capacity in gpm/ft
Q = discharge in gpm
s = drawdown in feet
T = coefficient of transmissivity in gpd/ft
S = coefficient of storage, fraction
r_w = nominal radius of well in feet
t = time after pumping started in minutes

A programmable version of the above equation was developed for a Texas Instruments hand-held calculator, Model 55. This program can be found in Appendix B. The program used an iterative process in which an estimated transmissivity value was entered into the right-hand side of the equation. The resulting "T" value was then put back into the equation. This process was repeated until the values on both sides of the equation were equal. The transmissivity value was then divided by the saturated thickness at the respective well to obtain an average permeability (K).

$$K = T/b$$

where

K = permeability in gpd/ft^2
T = transmissivity in gpd/ft
b = saturated thickness in feet

Walton's (1970) equation assumes 100% well efficiency. Based on conversations with Schipper (1983) and others, a 60% well efficiency was assumed to be a reasonable estimate of overall efficiency. This was accomplished by multiplying the specific capacity by a factor of 1.66.

Permeability From Geologic Logs. An alternative method was derived by Kent et al. (1973) using lithologic descriptions from drillers' logs to estimate permeability. All geologic logs available for the study area were subdivided into permeability classes based on grain size (Figure 40). Each permeability class was divided into low, middle, and high ranges. These classes are presented below.

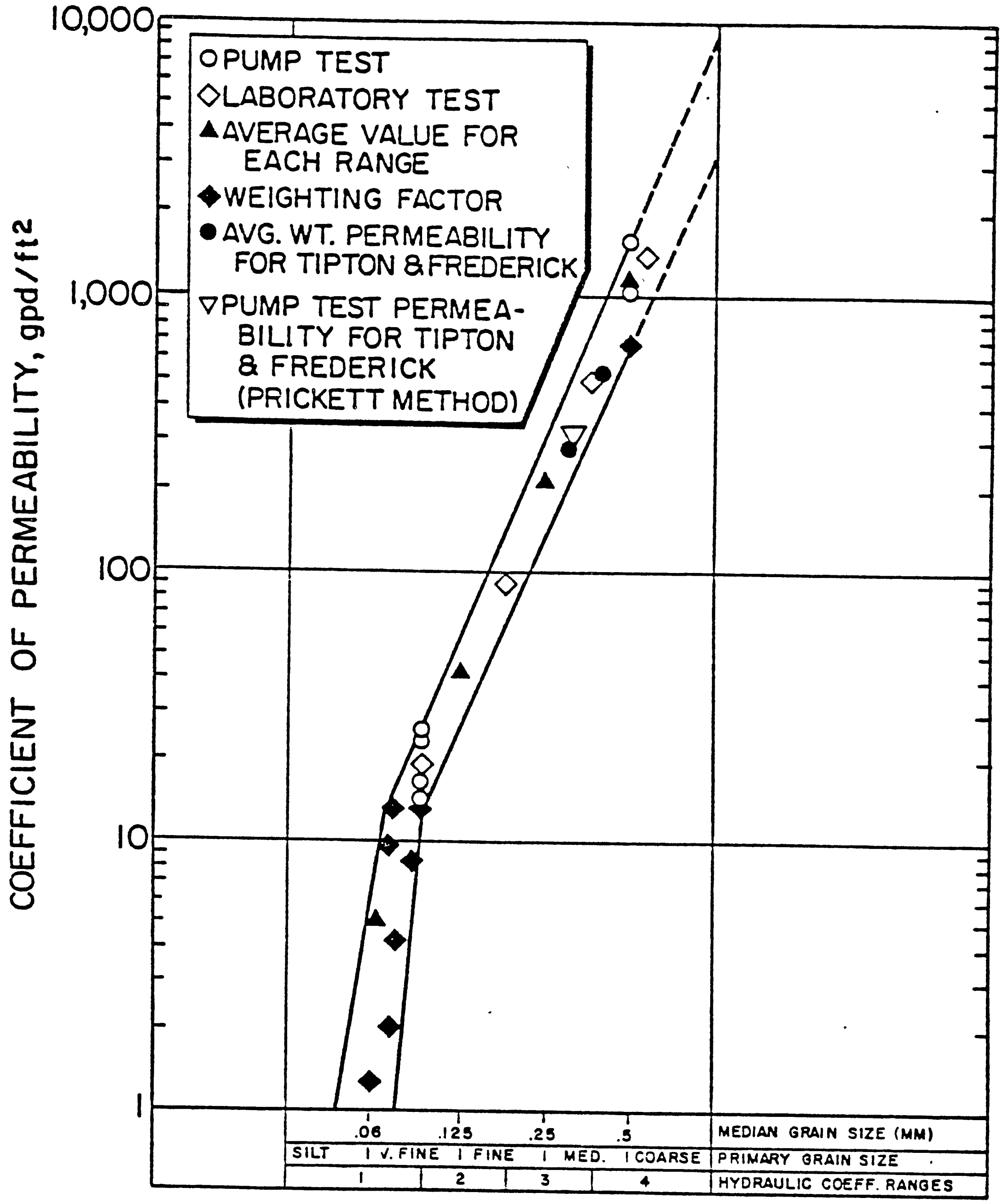


Figure 40. Coefficient of Permeability vs. Grain Size Envelope (after Kent et al., 1973)

Permeability Ranges (gpd/ft^2)

Class	Mean Grain Size (mm)	Low	Middle	High
1	0.6	- 1	1 - 1.5	1 - 5.0
2	0.125	1 - 20	1.5 - 3.0	5 - 50
3	0.25	20 - 140	30 - 210	50 - 300
4	0.50	140 - 1000+	210 - 1600+	300 - 2550+
5	0.19	10 - 300	15 - 500	25 - 800

Class 5 was created for those logs which did not differentiate the sand grain sizes.

Initially the lithologies of the saturated thickness from each geologic log were subdivided into their respective permeability ranges. The total saturated thickness for each range was then entered into a microcomputer program used on a Radio Shack Pocket Computer, Model TRS-80. This program is listed in Appendix C. It was based on an equation developed by Kent et al. (1973).

$$K_{wa} = \sum_{i=1}^{n} (A_i/A_t) K_i$$

where

K_{wa} : weighted average coefficient of permeability for total cross section
A_i : area of specific range
K_i : coefficient of permeability for specific range
A_t : total cross-sectional area

The program essentially worked on the principal that the saturated thickness of each range was divided by the overall saturated thickness and the resulting fraction was then multiplied by the permeability of each respective range.

This was done for each of the permeability ranges; low, middle, and high. The permeability of each range was found by summing the values from the respective classes. These three values were then summed and averaged to find the overall permeability. A hand calculated check of the computer derived value was made for well. An example of the check method is found in Table IV.

The class values of permeability were determined to be represented by the highest values of each respective permeability range. These values were arrived at by comparing permeability values derived from specific capacity data to those derived from the relationship developed by Kent et al. (1973). These values are compared in Table V and their locations are shown in Table VI. The permeability values derived from the specific capacity data more closely approximated permeability values from the upper part of the grain size envelope (Figure 40). Thus the range values used for determining permeabilities in the model were selected using the highest values of each range, with the exception of class 5.

Transmissivity (TRANS). Transmissivity was used in lieu of permeability in Modeled Reach B because of the lack of and inconsistency of permeability and saturated thickness data. Maps of transmissivity are shown in Appendix L.

Specific Yield (SY). Specific yield was determined through a relationship used by Kent (1978). Kent (1978)

TABLE IV

DETERMINATION OF PERMEABILTY FROM GEOLOGIC LOGS
LOCATION T4N, R2W, SEC 7, ACDA

Well Log	From (ft)	To (ft)	Saturated Thickness (b) in ft	Range	Percent of Total Saturated Thickness	Permeability (k) gpd/ft^2 Upper*	Middle*	Lower*
Surface	0	9	-	-	-			
Sand	9	19	6	5	11	16.5	11.0	7.7
Clay	22	32	10	1	19	0.95	0.285	0.19
Clay Muck	32	35	3	1	6	0.3	0.09	0.06
Clay, Red	35	39	4	1	7	0.35	0.105	0.07
Clay, Blue	39	41	2	1	4	0.2	0.06	0.04
Sand, Med.-Coarse	41	44	3	4	6	153.0	96.0	60.0
Sand, Coarse	44	46	2	4	4	102.0	64.0	40.0
Sand, Coarse, Rock	46	50	4	4	7	178.5	112.0	70.0
Clay	50	67	17	1	31	1.55	0.465	0.31
			Total 54		Total	555.45	348.035	218.39

*To obtain values of upper, middle, and lower permeability, percent total saturated thickness was multipled by the following:

$$\text{Total} = \frac{1121.875}{3} = 374 \text{ gpd/ft}^2$$

Range	Upper	Middle	Lower
1	5	1.5	1
2	60	40	30
3	300	210	140
4	2550	1600	1000
5	150	100	70

TABLE V

WATER WELL DATA

Location	Total Depth (ft)	Depth to Static Water Level (ft)	Test Yield (gpm)	Test Pumping Duration (hrs)	Test Pumping Drawdown (ft)	Specific Capacity (gpm/ft of Drawdown)	Transmissivity from Specific Capacity (gpd/ft)	Transmissivity from Specific Capacity SC*1.66 (gpd/ft)	Permeability from Specific Capacity (gpd/ft^2)	Permeability from SC*1.66 (gpd/ft^2)	Permeability from Geologic Log (gpd/ft^2)		
											Upper	Middle	Lower
1	60	6	-	-	-	-	-	-	-	-	23.45	14.41	9.94
2	85	17	200	10	70	2.86	2836.5	5019.2	41	74	25.35	15.75	11.36
3	82	24	350	4	70	5.0	4726.3	8392.0	81	145	60.0	40.0	29.0
4	68	17	90	2	50	1.8	1290.5	2347.2	25	46	183.0	124.2	85.4
5	66	17	100	2	30	3.33	2825.2	5059.1	52	103	31.1	19.23	13.42
6	85	24	125	2	75	1.67	1180.2	2149.7	18	35	178.6	112.04	71.58
7	83	24	500	4	66	7.57	7563.7	13377.2	128	227	150.0	100.0	70.0
8	81	24	650	3	60	10.83	10919.7	19300.8	198	339	-	-	-
9	84	24	140	2	70	2.0	1462.6	2654.9	35	44	183.15	113.40	70.93
10	85	14	200	4	70	2.86	2493.8	4455.6	36	63	-	-	-
11	56	24	70	4	40	1.75	1496.3	2677.6	50	84	50	32.04	22.39
12	56	24	90	2	40	2.25	1681.4	3045.5	56	95	533.1	336.4	213.5
13	84	20	190	6	55	3.45	3276.6	5815.9	51	91	-	-	-
14	83	17	365	4	70	5.21	5198.5	9195.1	79	139	-	-	-
15	87	25	200	8	49	4.08	3130.9	5656.8	51	91	1073.9	672.87	420.58
16	89	23	200	4	55	3.64	2799.1	5056.1	32	77	-	-	-
17	80	20	300	8	60	5.0	5175.7	7643.4	86	127	-	-	-
18	89	23	300	4	70	4.28	3958.7	5747.7	60	87	-	-	-
19	60	20	200	5	56	3.57	3321.5	5904.6	83	148	641.25	401.13	250.75
20	82	28	600	6	54	11.11	12229.3	21492.9	226	398	-	-	-
21	70	13	200	4	45	4.44	4128.0	7338.7	72	129	719.55	454.48	288.0
22	67	13	200	4	45	4.44	4128.0	7338.7	76	136	555.45	348.04	218.39

TABLE V (Continued)

Location	Total Depth (ft)	Depth to Static Water Level (ft)	Test Yield (gpm)	Test Pumping Duration (hrs)	Test Pumping Drawdown (ft)	Specific Capacity (gpm/ft of Drawdown)	Transmis-sivity from Specific Capacity (gpd/ft)	Transmis-sivity from Specific Capacity SC*1.66 (gpd/ft)	Permeability from Specific Capacity (gpd/ft^2)	Permeability from SC*1.66 (gpd/ft^2)	Permeability from Geologic Log (gpd/ft^2) Upper	Middle	Lower
23	37	14	-	-	-	-	-	-	-	-	707.4	445.6	281.46
24	49	26	-	-	-	-	-	-	-	-	699.15	439.83	277.26
25	46	21	60	24	20	3.0	3331.8	5852.4	95	234	476.0	368.0	231.4
26	75	12	1200	10	12	100.0	144222.2	249868.7	2289	3966	-	-	-
27	79	29	1000	6	12	83.3	112921.7	196209.2	2258	3924	891.2	559.62	351.3
28	72	27	-	-	-	-	-	-	-	-	537.1	357.37	212.56
29	70	20	-	-	-	-	-	-	-	-	541.5	340.45	214.8
30	62	22	590	12	20	29.5	38713.9	67376.2	968	1684	832.13	521.01	325.68
31	65	26	200	6	60	3.33	3147.3	5588.3	75	143	131.90	87.70	61.38
32	68	27	-	-	-	-	-	-	-	-	96.35	63.56	44.47
33	66	19	421	6	9	46.78	60025.8	104586.3	1277	2225	-	-	-
34	60	21	948	3.5	48	19.75	21831.4	38358.8	532	984	466.15	297.32	188.7
35	42	16	50	3	3	16.67	17735.0	31236.0	682	1201	-	-	-
36	32	10	-	-	-	-	-	-	-	-	60	40	29
37	-	10	60	3.0	20	-	-	-	-	-	-	-	-
38	-	10	75	3.75	20	-	-	-	-	-	-	-	-
39	46	13	38	-	0	-	-	-	-	-	493.55	309.92	195.31
40	36	13	32	-	0	-	-	-	-	-	1130.7	710.8	446.53
41	45	13	32	-	0	-	-	-	-	-	680.25	431.5	276.65
42	35	27	60	3	8	7.5	7204.5	12777.4	720	1597	2550.0	1600.0	1000.0
43	33	29	60	3	8	7.5	7204.5	12777.4	1201	3194	2550.0	1600.0	1000.0
44	45	19	350	4	10	35.0	41834.3	73169.0	1549	2814	2020.7	1271.96	796.64
45	45	19	300	4	10	30.0	35271.1	61747.2	1306	2375	1964.65	1232.35	770.23

TABLE VI

LOCATION OF WATER WELLS

Code	Location	Code	Location
1	NE N SE SW 25-5N-5W	24	SW NW SW 13-4N-1N
2	NW N SW SW 10-4N-4W	25	SE NW NE SE 27-4N-1W
3	NE S NE SE 10-4N-4W	26	NW NE SE SE 33-4N-1W
4	SW S SW NW 10-4N-4W	27	NE SE SW NE 13-3N-1W
5	NE S NE NE 10-4N-4W	28	SW NW NE SE 13-3N-1W
6	SE S SW SE 10-4N-4W	29	NE NW NE NE 12-3N-1W
7	SW N SE SE 10-4N-4W	30	NE NE SE NE 15-3N-1E
8	SE S SE SE 10-4N-4W	31	NE SE SW SW 4-3N-1E
9	SE N SW NW 11-4N-4W	32	NE NW SE SE 4-3N-1E
10	NE S NW NW 11-4N-4W	33	NW SE SW NW 18-3N-1E
11	NW S SE NE 15-4N-4W	34	NE SW NE NW 27-3N-1E
12	NE S SE NE 15-4N-4W	35	NE NW NW NW 16-3N-1E
13	? 10-4N-4W	36	SW SE 4-2N-1E
14	? 10-4N-4W	37	SE NW 23-2N-1E
15	SW N NE NW 5-4N-3W	38	SE NW 23-2N-1E
16	NW SW 5-4N-3W	39	NE NE NE NW 13-1N-1E
17	SW NW 5-4N-3W	40	SE SE NE NW 13-1N-1E
18	SW NW 5-4N-3W	41	NE NE NW 13-1N-1E
19	SW S SE NW 11-4N-3W	42	SE SW SW NW 19-1N-1E
20	SE NE 5-4N-2W	43	NW NW 19-1N-1E
21	NE S SW NE 7-4N-2W	44	SW NW SE SW 4-3S-3E
22	NE S SE NE 7-4N-2W	45	SE SW NW SE 4-3S-3E
23	SW N NE SW 13-4N-1W		

used grain size and permeability to modify Johnson's (1969) relationship between grain size and specific yield so that specific yield could be correlated with permeability data from the Washita River alluvium. Values of specific yield were determined from permeability for each modeled reach (Figure 41). Specific yield values were entered as both uniform and non-uniform matrices. The values used for each reach are listed below:

	Permeability gpd/ft^2	Specific Yield %
Upper modeled reach (A)	201	25.8
Middle modeled reach (B)	1047	30.0
Lower modeled reach (C)	2294	32.0
ENTIRE AREA (Average)		29.2

Part 3 - Calibration

Calibration is the balance of inflow and outflow within a modeled reach between measured and calculated data. It is accomplished through the reasonable adjustment of the initial input parameters so as to best approximate this balance. The principal component of inflow to the aquifer is recharge. The major components of outflow are pumpage by ground water wells and leakage in the form of ground-water discharge (base flow) to the river. Pumpage rates were obtained through prior appropriative rights and base flow was estimated through stream flow records. Recharge was initially estimated from base flow data. Recharge and leakage were both adjusted during calibration to best

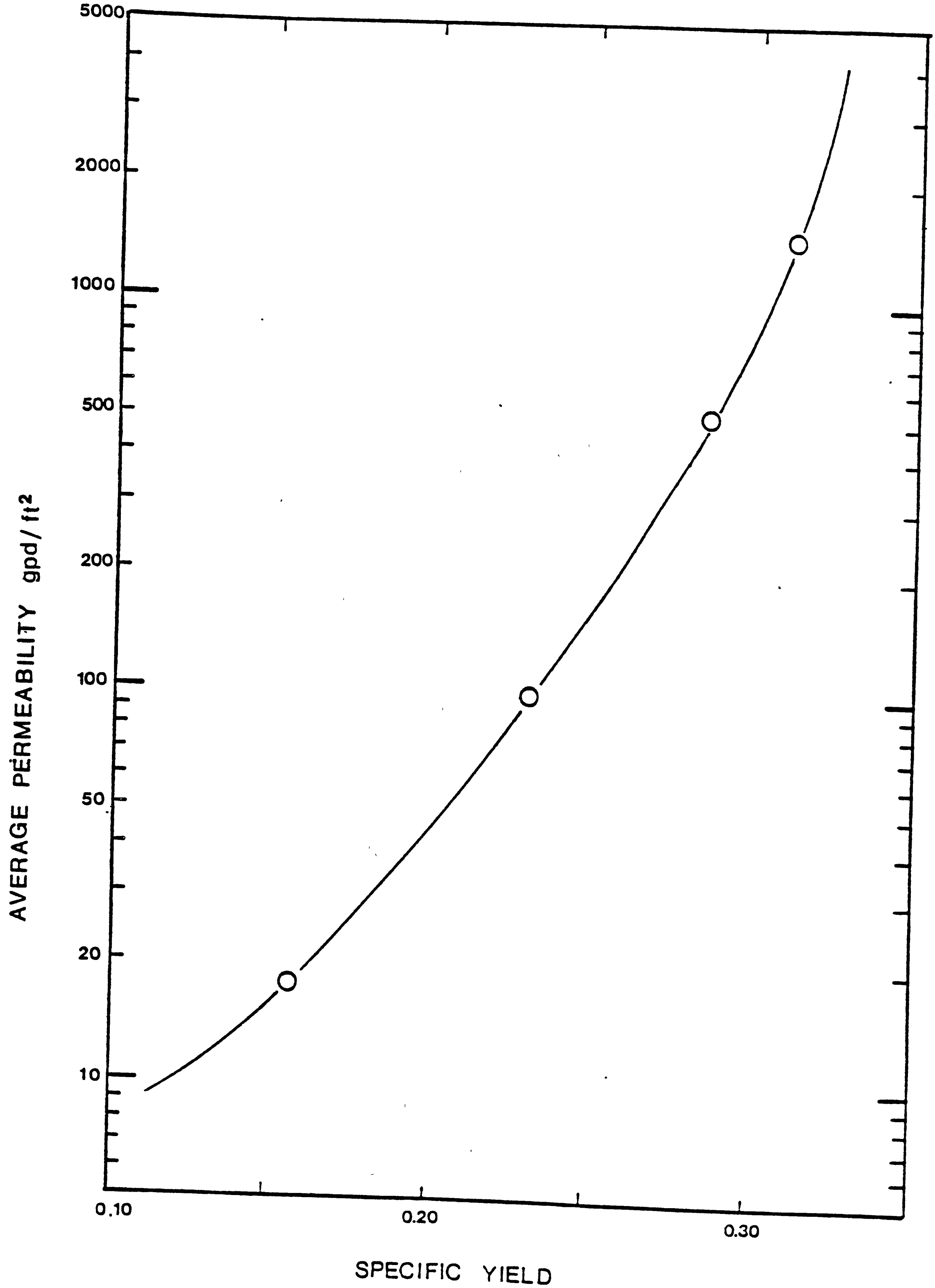


Figure 41. Relationship Between Permeability and Specific Yield (after Kent, 1978)

approximate the balance between inflow and outflow of the modeled reaches. After final calibration, calibrated values of recharge and leakage were used for their respective reaches.

<u>Recharge (QRE)</u>

Recharge, as stated earlier, is the principal source of inflow into the aquifer. It was assumed to occur as direct infiltration from precipitation and from upward leakage through the underlying bedrock less water loss by evapotranspiration. In an underdeveloped aquifer, net recharge and ground water discharge (base flow) would be in equilibrium, however, when pumping is imposed on the system, a net loss in ground-water storage occurs. Net recharge was assumed to be equal to ground-water discharge to the river (base flow) plus that being removed by pumping in order to fulfill the assumption that the system was in steady-state. Pumping was automatically adjusted within the model to reflect a 15% return flow to the aquifer.

Base flow was determined from stream flow records for Pauls Valley for a period extending from 1970 to 1979. Initially, the 10-year average of maximum, mean, and minimum flow was determined. Then the maximum, mean, and minimum flow (December-February, July-August) was determined. Although pumping and evapotranspiration do have an effect on base flow, the months of July and August did represent some of the lowest flow months. Also, several of the winter months, which are generally accepted as the best period for base flow measurements, had some of the highest flows because of low evapotranspiration and no pumping during this period. The monthly flow at Pauls Valley is shown in Figure 42. Mean base flow from the low flow months was 73.7 cfs and the minimum flow from these same months was 36.5 cfs.

Base flow was calculated using the following equation (Schipper, 1983):

$$\text{Base flow (cfs) from gauging station records} * \underbrace{\frac{714.14 \text{ acre-ft/yr}}{\text{cfs}}}_{\text{(conversion factor)}} * \frac{\text{area of modeled reach}}{\text{area of alluvium above gauging station}} = \text{Base flow ac-ft/yr for modeled reaches}$$

For the Pauls valley gaging station (Reach A):

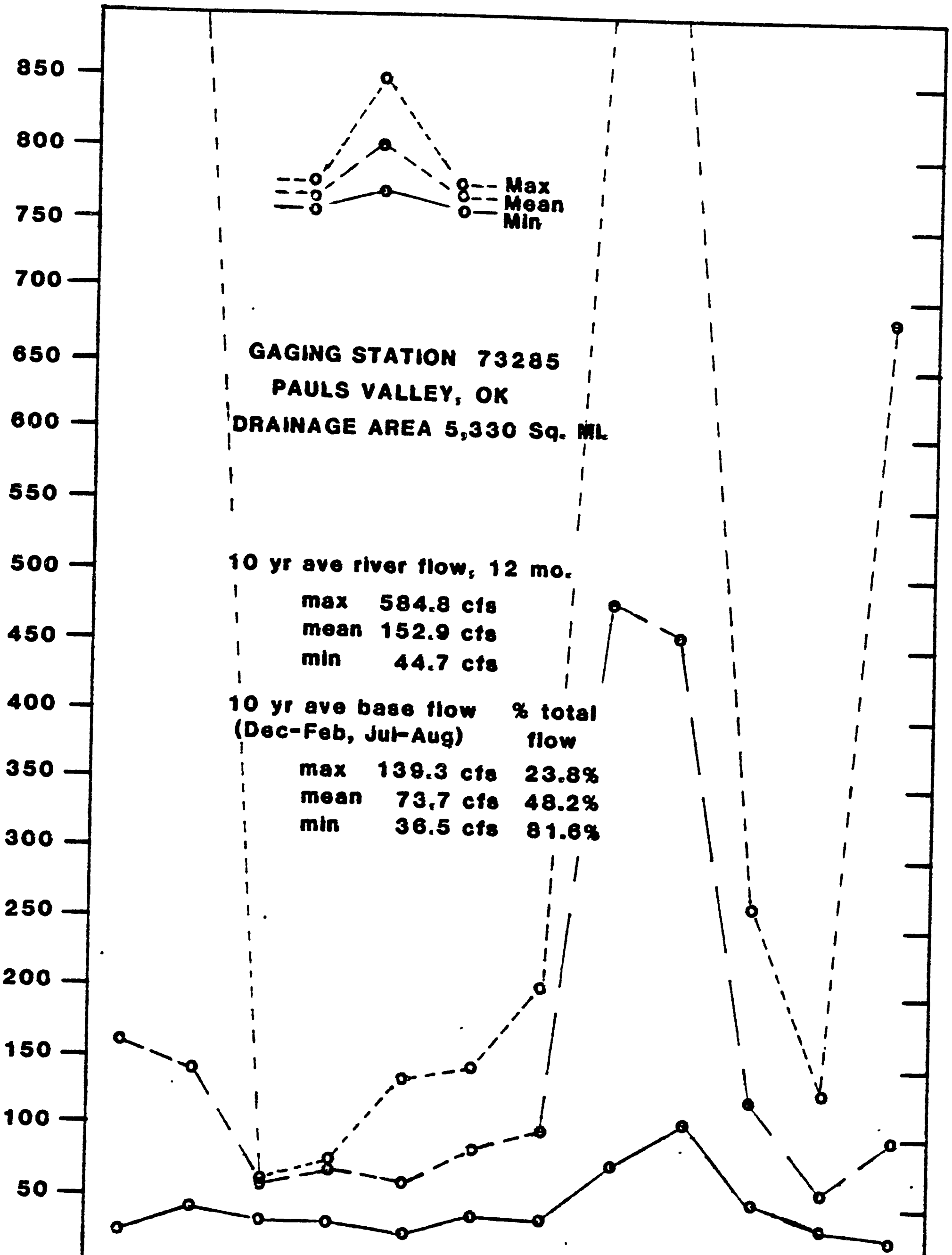
$$\underset{\text{mean base flow}}{73.7 \text{ cfs}} * 714.14 \frac{\text{ac-ft/yr}}{\text{cfs}} * \frac{55840 \text{ acres}}{65440 \text{ acres}} = 44911 \text{ ac-ft/yr OR } 62.9 \text{ cfs}$$

= mean base flow contributed by the modeled reach

An initial recharge rate for calibration purposes had to be calculated. This was accomplished by converting the mean base flow into net recharge through the use of the following equation.

$$\underset{\text{(in/yr)}}{\text{Net Recharge}} = \underset{(\text{in}^3/\text{yr})}{\text{Base flow rate}} \ / \ \text{basin area} \underset{(\text{in}^2)}{\text{of}} \text{ alluvium}$$

The base flow rate was converted into cubic inches per year



cfs	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Max	962	925	59.8	85	162	167	201	2,167	1,215	262	127	685
Mean	111	142	58.2	68.3	63	86.9	97.9	475	453	124	55.5	100
Min	25.9	44.4	33.4	34.8	31.2	38.3	35.4	76.2	107.8	48.8	34.5	25.7

Figure 42. Maximum, Mean, and Minimum Monthly Flows at Pauls Valley, Oklahoma Based on Ten Years of Records (1970-1979)

in the following manner:

$$44{,}911 \text{ ac-ft/yr} * 75.27*10^6 \text{ in}^3/\text{ac-ft} = 3.4*10^{12} \text{ in}^3$$

(base flow rate) (conversion factor)

Additionally, the area of alluvium in acres was converted to square inches:

$$65{,}440 \text{ acres} * 6.27*10^6 \text{ in}^2/\text{acre} = 4.10*10^{11} \text{ in}^2$$

(area of alluvium above gaging station) (conversion factor)

The substitution of the above values into the original equation

$$\underset{(\text{in/yr})}{\text{Net Recharge}} = \underset{(\text{in}^3/\text{yr})}{\text{Base flow rate}} \;/\; \underset{(\text{in}^2)}{\text{basin area of alluvium}}$$

gives

$$\text{Net Recharge} = 3.4*10^{12} \text{ in}^3 \;/\; 4.1*10^{11} \text{ in}^2 = 8.3 \text{ in/yr}$$

Final values of base flow and net recharge were found through calibration of the model.

Rate of Vertical Water Movement Through the Confined River Bed (RATE). An integral part of the calibration process is the determination of RATE. The rate is how slow or fast the water moves through the confining river bed. Initially, RATE is entered as a patterned matrix to indicate the course of the river by a series of one's. Then a RATE was determined for each river node. All the values of RATE were then averaged to find an initial value that could be used for the modeled reach. The final values of rate were determined through calibration. The equation used to determine the RATE at a river node follows:

RATE = Hydraulic Conductivity (River Width/Node Width) dL/m

where

Hydraulic Conductivity = that of the confining river bed
River Width = width of river at the node
Node Width = width of node
dL = change in head in the node
m = thickness of river bed

The above equation is a derivation of Darcy's equation.

Five-Year Calibration. Five-year calibration runs were made without pumping turned on from prior appropriative right owners. This was done to reflect steady-state conditions for the modeled reaches over a five-year period. The reasonable adjustment of a few input parameters was necessary to calibrate the model. Since the modeled flow was governed by Darcy's equation, saturated thickness, permeability, and the gradient towards the river could be altered within reasonable limits to allow the base flow to fall into the desired range.

The course of the river was entered as a separate matrix (RATE) as discussed earlier. River elevations (RIVER) were set equal to the initial water-table (STRT) elevation at each respective river node. These equations remain constant throughout time. If the water-table in the adjacent nodes drops, the gradient towards the river drops, and thus ground water flow towards the river decreases. If the water-table drops below the river elevation, there is no ground water flow to the river.

The combination of a shallow ground-water gradient with a fairly high "RATE", high permeability and/or transmissivity, and the course of the river with respect to the shape of the alluvium can cause the ground water to pile back away from the river into the aquifer system. In order to induce ground water flow towards the river, the drop-river option contained in the computer program was used. The drop-river option drops the river elevation by a set number of feet. This creates a steeper gradient and forces the ground water to flow towards the river. The drop-river option was used for each modeled reach.

Adjustments of recharge, rate, and drop-river were necessary to produce five-year calibration runs. The calibrated recharge rate was comparable to the recharge computed using base flow calculations. Final calibrations were attained when the mass balances of each modeled reach showed a net loss in stored ground water within a 10% error of steady-state conditions. A small loss in ground water storage was allowed to produce a safer allocation over a 20-year period.

Twenty-Year Calibration. Upon the completion of the five-year calibration runs, 20-year allocation runs were made for each modeled reach to determine the maximum allowable allocation for each reach. The maximum allowable allocation is that amount of water which can be pumped from the aquifer which will cause 50% of aquifer area to go dry after a 20-year period (July 1, 1973 - July 1, 1993). The aquifer was considered to be dry when the saturated thickness was 5.5 feet or less.

Both allocation and prior appropriative runs were made for the 20-year period starting July 1, 1973. Full allocation runs of two acre-feet per acre per year caused the aquifer to go dry after four to five years. The allocation had to be reduced for each modeled reach until the 50% dry area was achieved. Less than 5% dry aquifer area was calculated after 20 years of prior appropriative pumping.

Prior appropriative runs made for the modeled reaches showed that the ground water continued to flow into the river after 20 years. However, with the allocation runs, the river dried up within the first five years. Water table maps of both prior appropriative pumping and full allocation pumping after 20 years are shown in Figures 43 through 48.

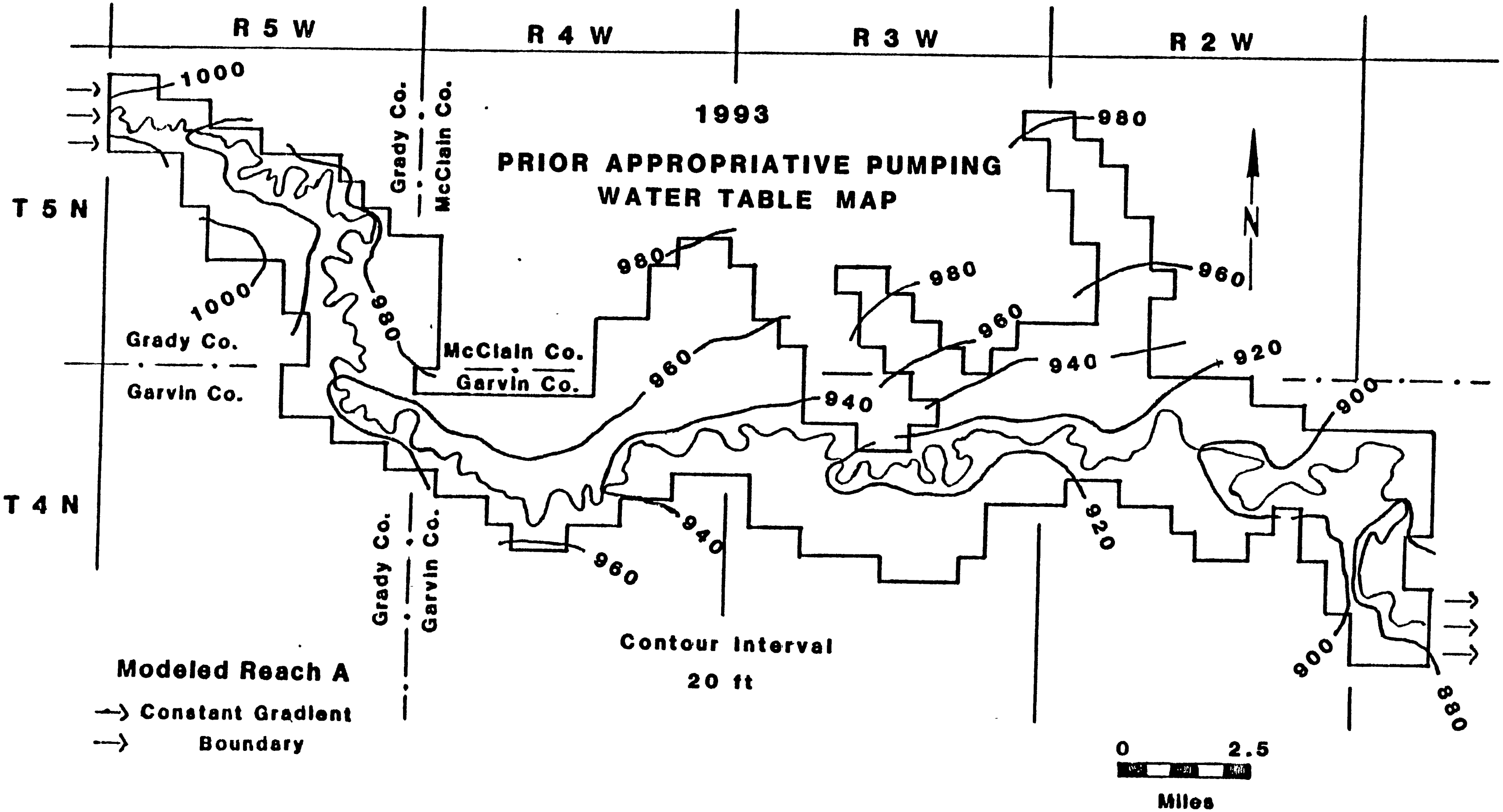


Figure 43. Prior Appropriative Pumping Water Table Map, 1993 - Modeled Reach A

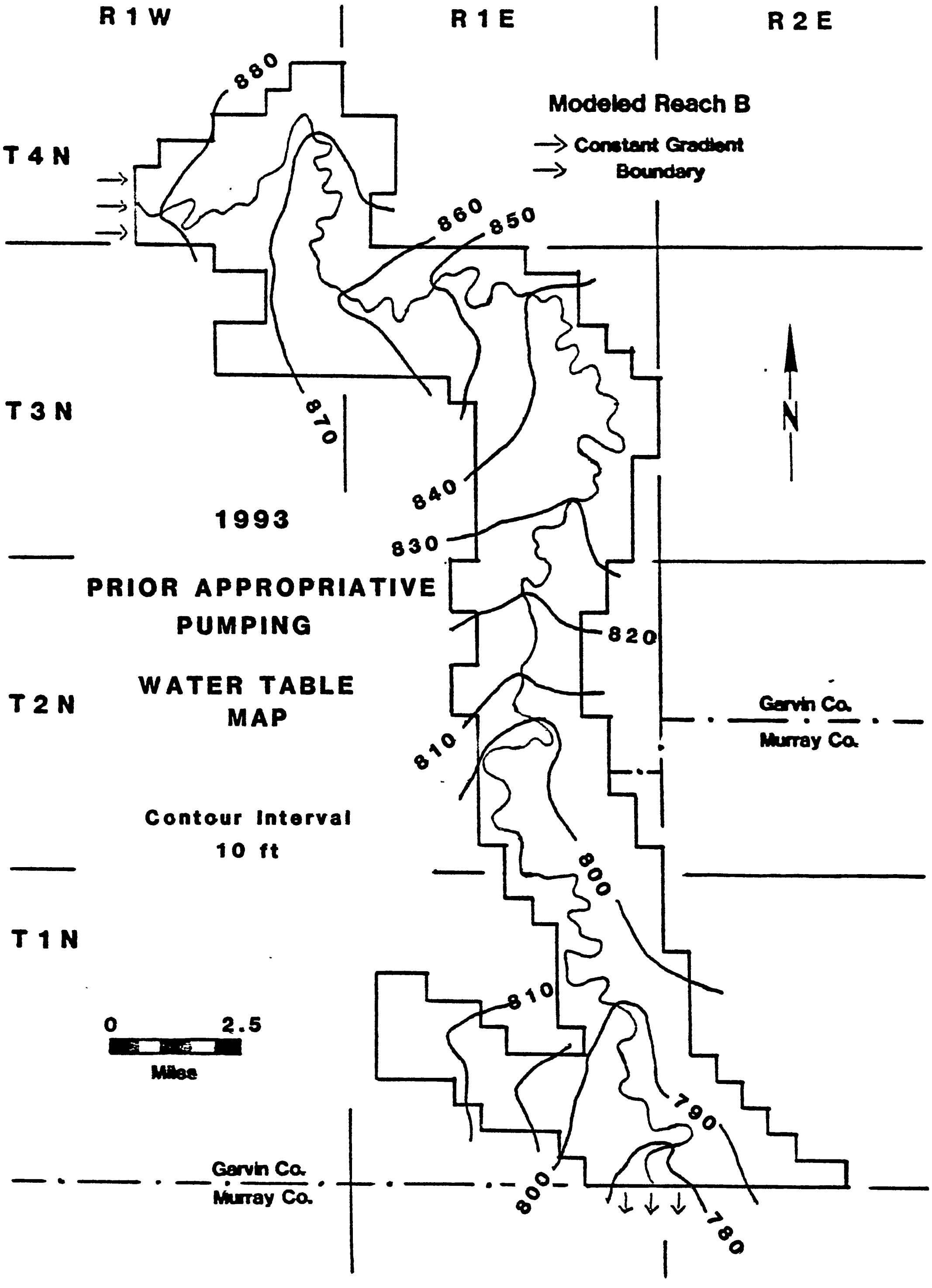


Figure 44. Prior Appropriative Pumping Water Table Map, 1993 - Modeled Reach B

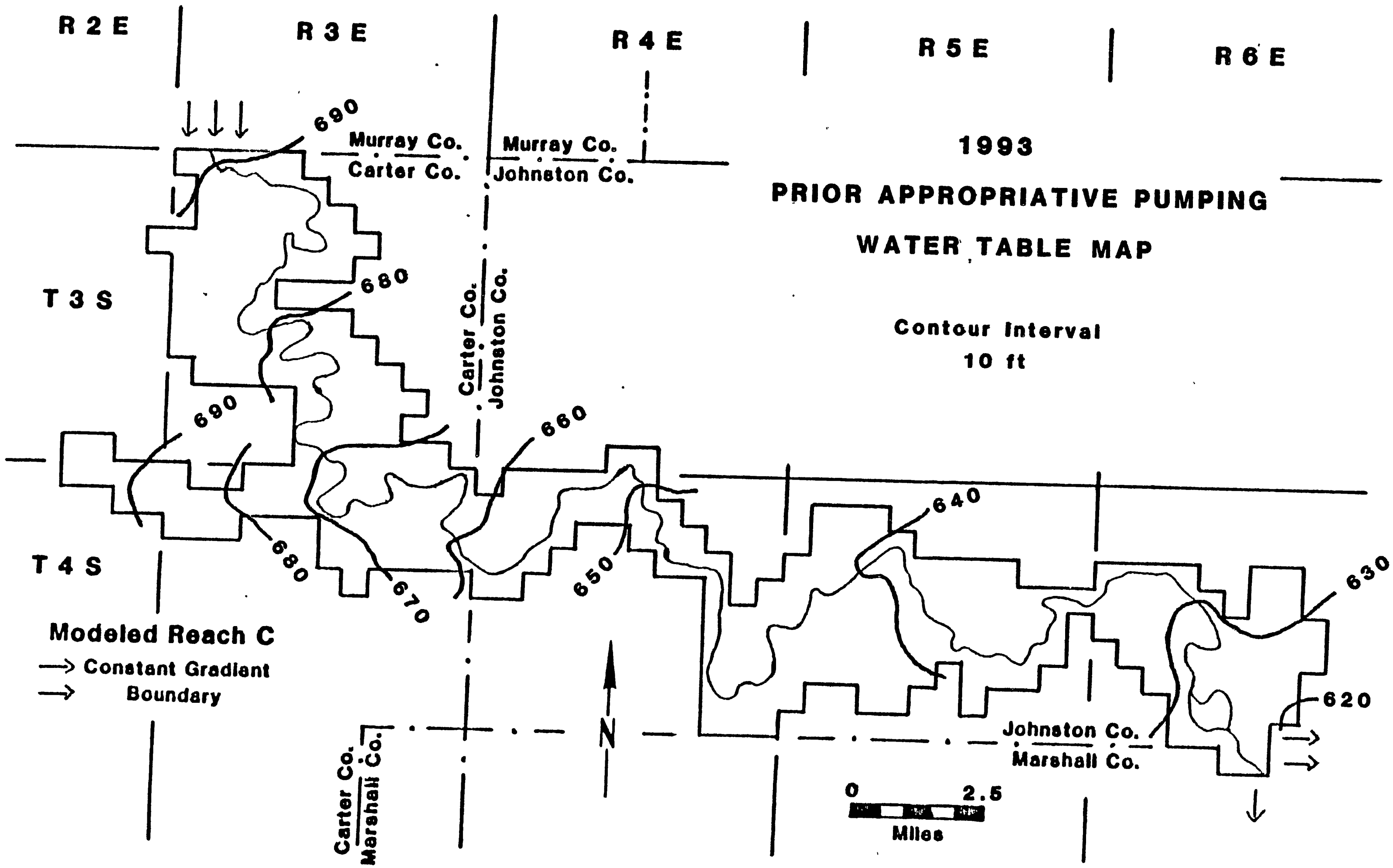


Figure 45. Prior Appropriative Pumping Water Table Map, 1993 - Modeled Reach C

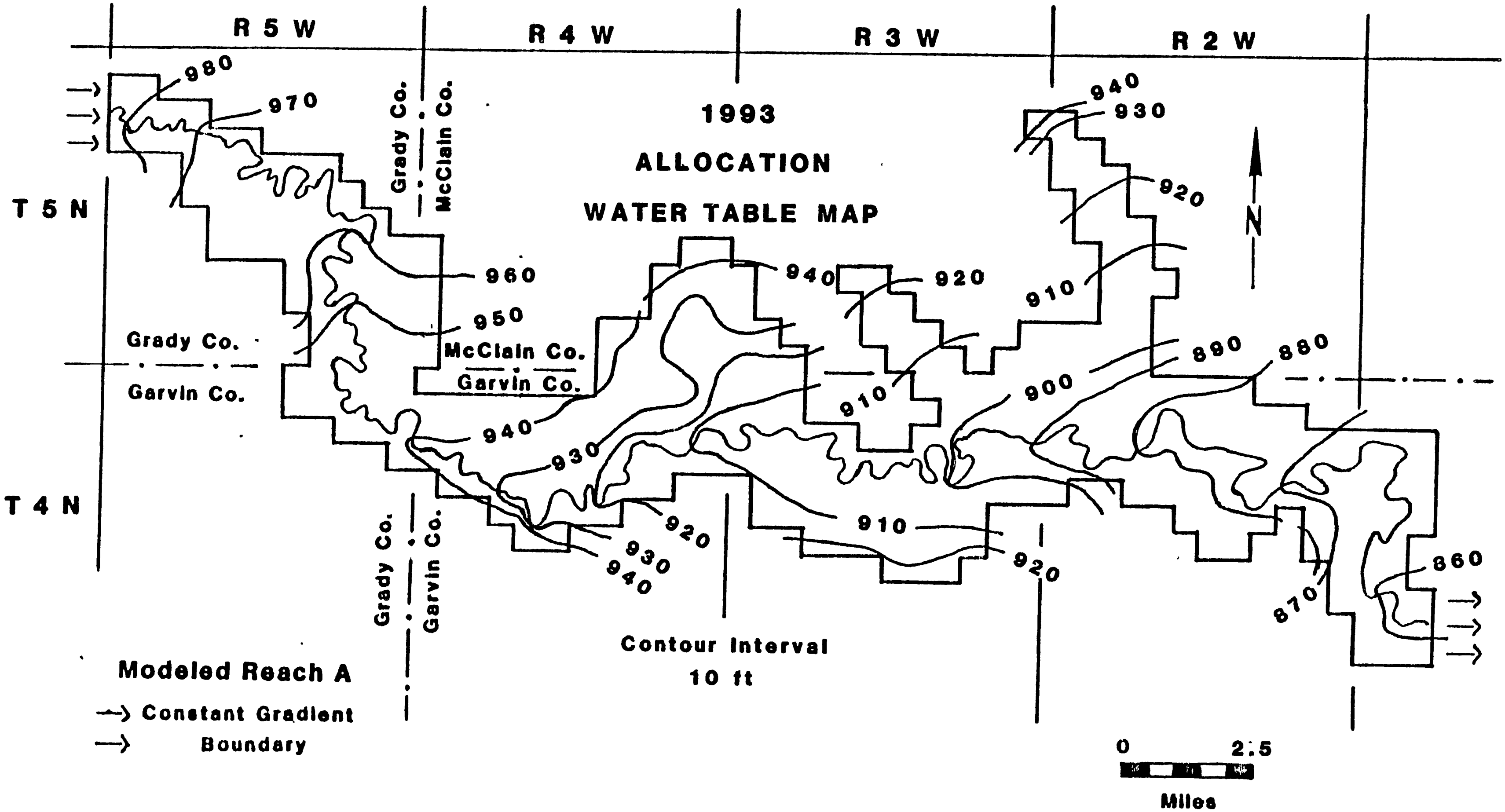


Figure 46. Allocation Water Table Map, 1993 - Modeled Reach A

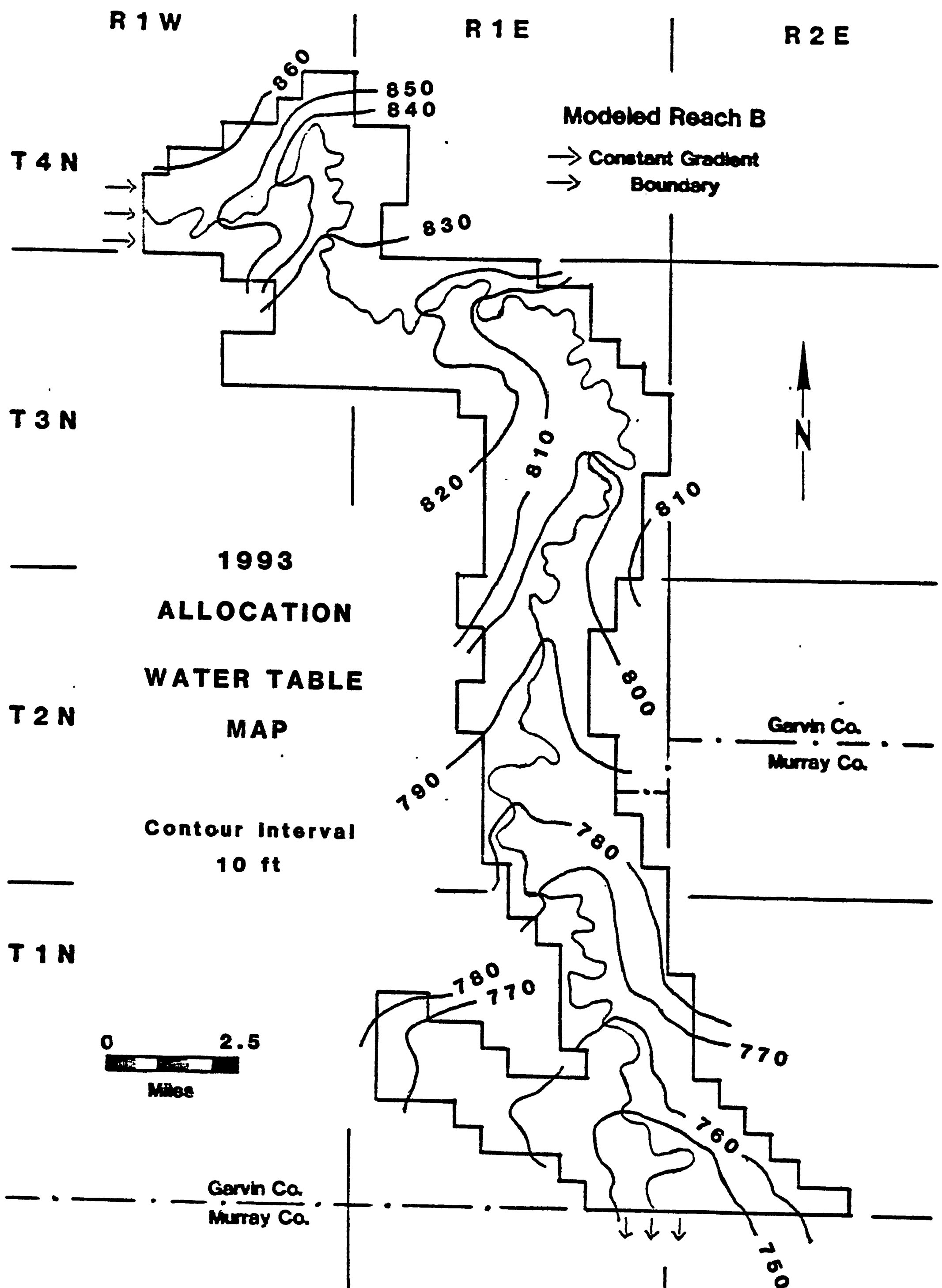


Figure 47. Allocation Water Table Map, 1993 - Modeled Reach B

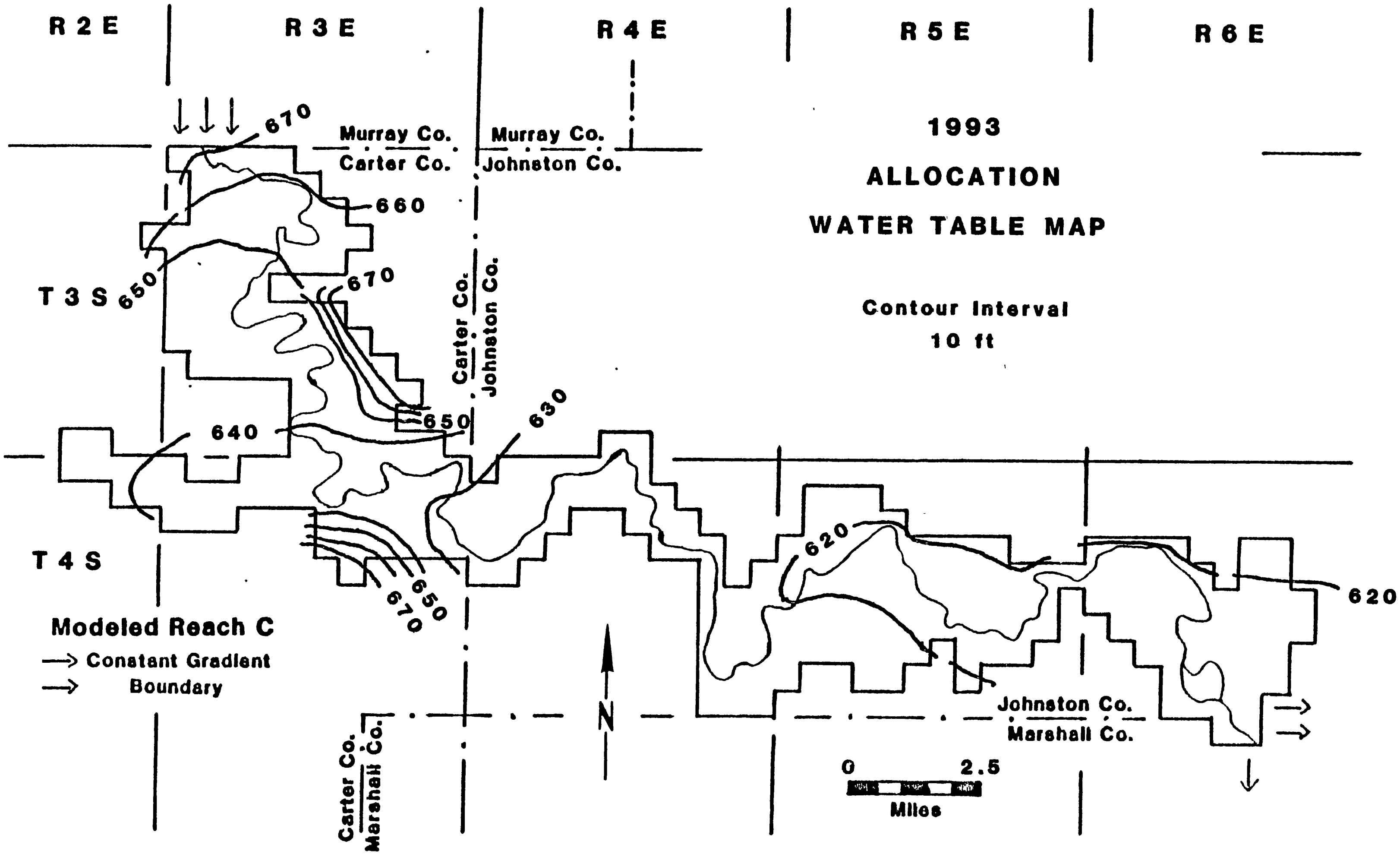


Figure 48. Allocation Water Table Map, 1993 - Modeled Reach C

CHAPTER VII

RESULTS

Allocation and Prior Appropriative Pumping

A final simulation of each modeled reach was made for the 20-year period extending from 1973 to 1993 for both allocation plus prior pumping and prior pumping.

Irrigation allocation rates were distributed over a four month pumping period (June - September). Pumping was assumed not to occur during the remaining eight months. The maximum allowable allocation rate was found by adjusting the amount of allocated pumping so that 50% of each modeled reach would go dry by the end of the simulation period. The aquifer was considered to be dry if the saturated thickness was 5.5 feet or less. This was done on a node by node basis. A maximum allowable allocation rate of 0.99 acre-feet per acre per year was calculated for the entire study area. This is equivalent to 159,905 acre-feet per year. Table VII shows the allocations of each modeled reach and the allocation for the entire area.

Twenty-year ground water budgets were determined for each modeled reach and for the entire area from the final computer allocation runs (Figures 49 through 52, and in Appendix E). The method used to complete these budgets was

TABLE VII

WEIGHTED AVERAGE ALLOCATION FOR THE TOTAL AQUIFER AREA INCLUDING ALLOCATION BY MODELED REACH

	Area, Modeled Reach (acres)	Total Area All Modeled Reaches (acres)	Fraction		% Total Area		Allocation by Modeled Reach (ac-ft/ac/yr)	Weighted Allocation (ac-ft/ac/yr)
Upper Modeled Reach (A)	55,200	161,520	55,200 / 161,520	=	34.2	*	0.882	0.30
Middle Modeled Reach (B)	51,840	161,520	51,840 / 161,520	=	32.1	*	1.14	0.36
Lower Modeled Reach (c)	44,480	161,520	44,480 / 161,520	=	27.5	*	1.20	0.33
					Net allocation for total aquifer area			0.99

	Allocation by Modeled Reach			Weighted Allocation
	Upper Reach	Middle Reach	Lower Reach	Total area, A, B, and C
Allocation ac-ft/ac/yr	0.882	1.14	1.20	0.99

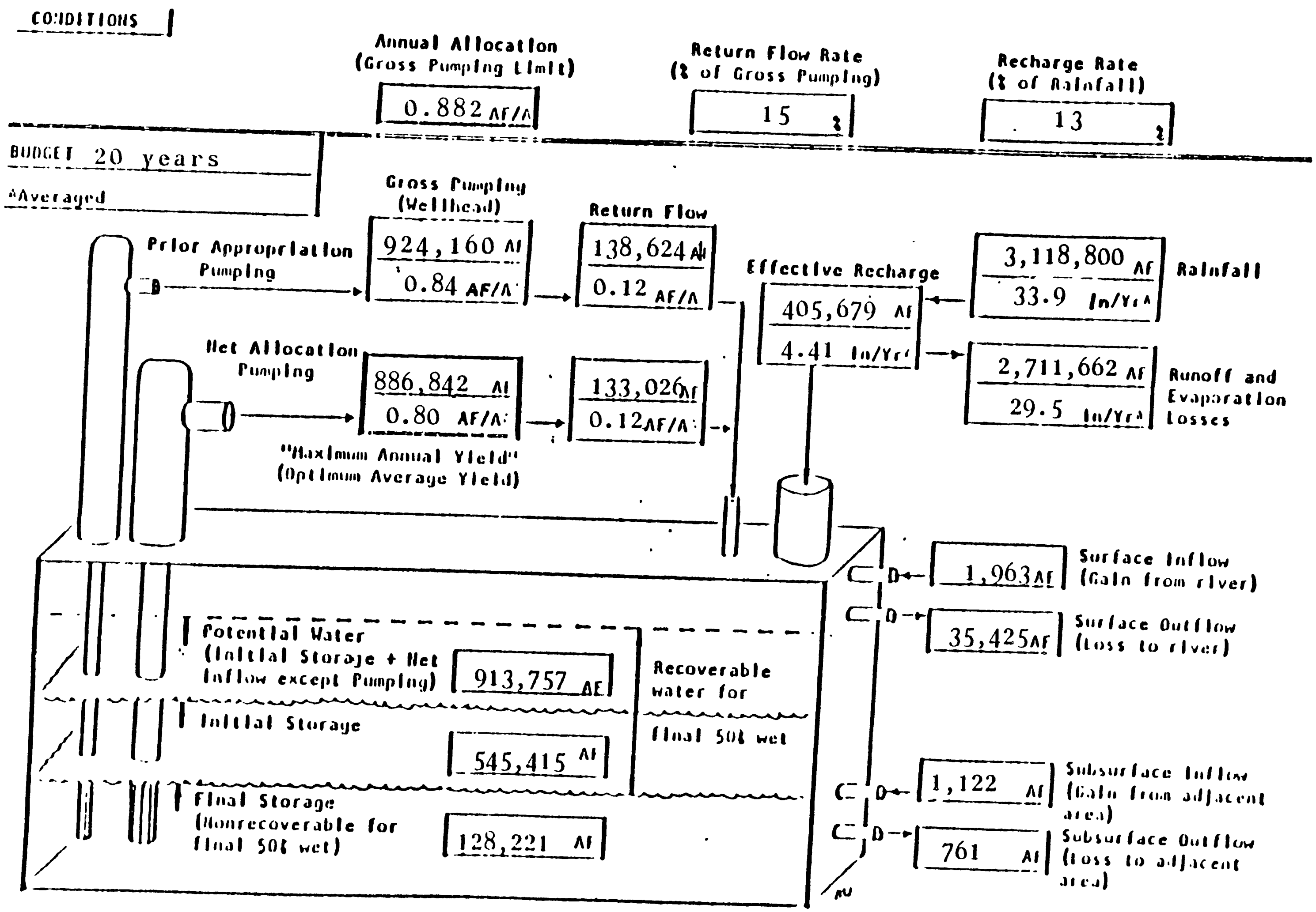


Figure 49. Ground-Water Budget - Modeled Reach A

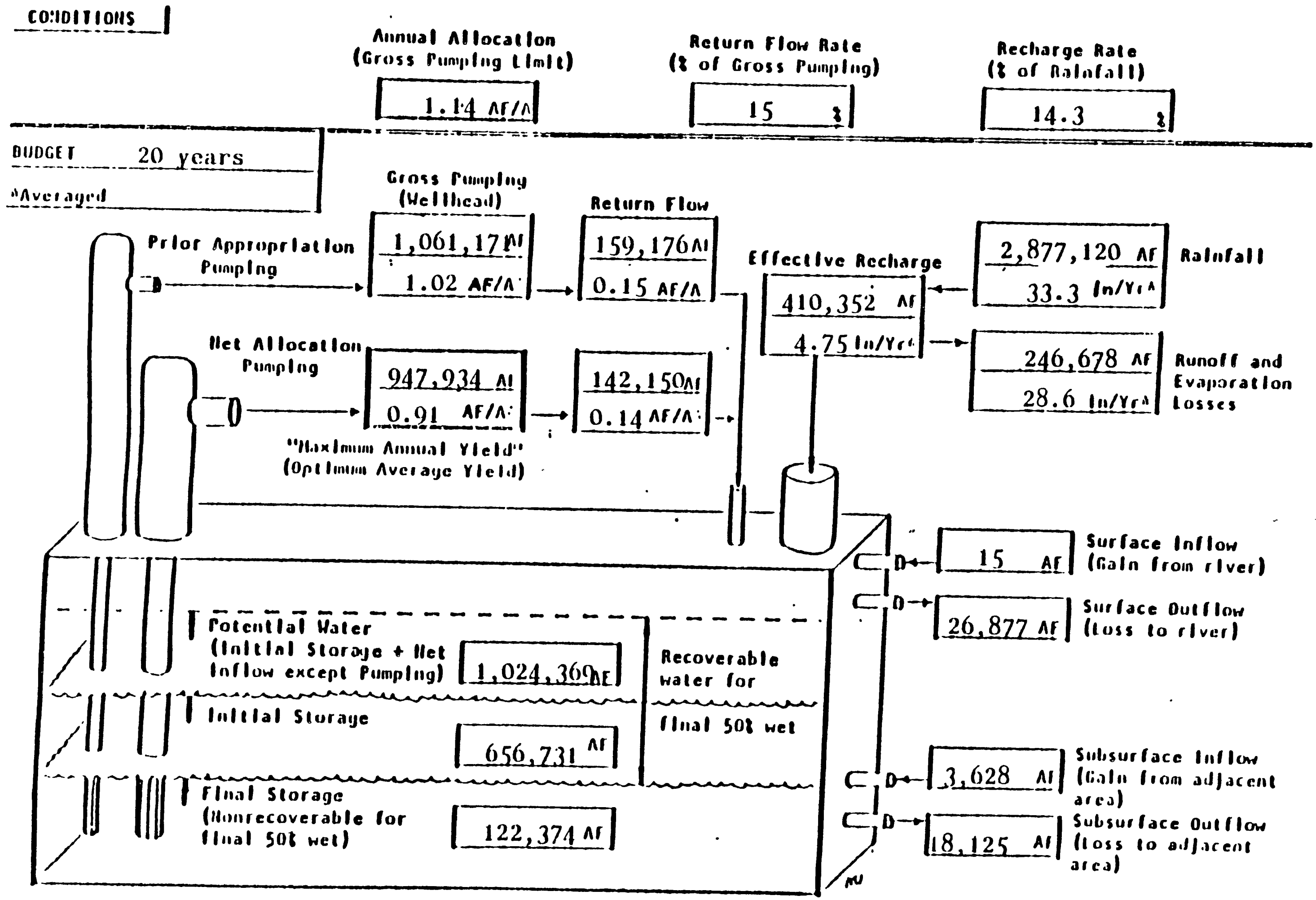


Figure 50. Ground-Water Budget - Modeled Reach B

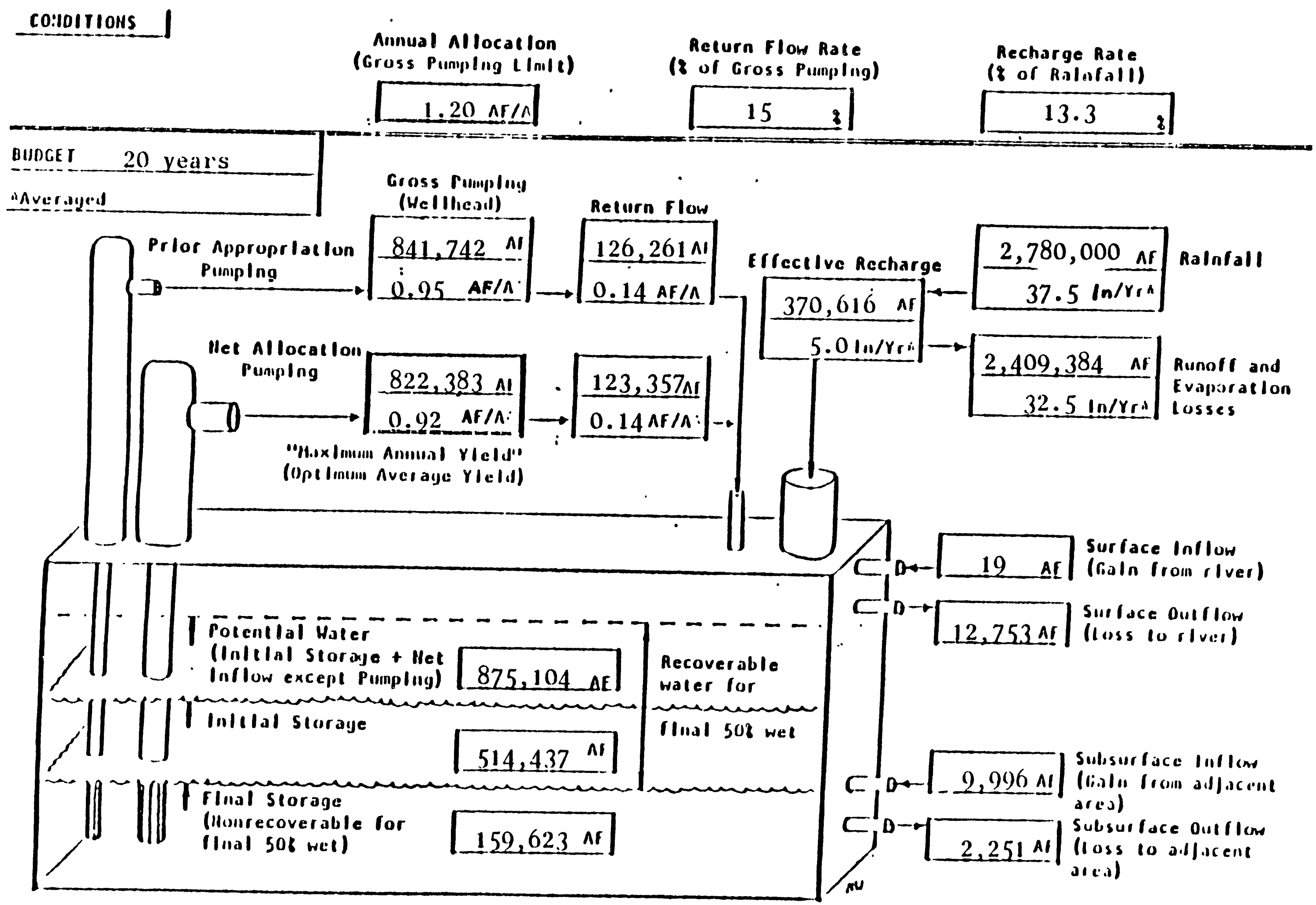


Figure 51. Ground-Water Budget - Modeled Reach C

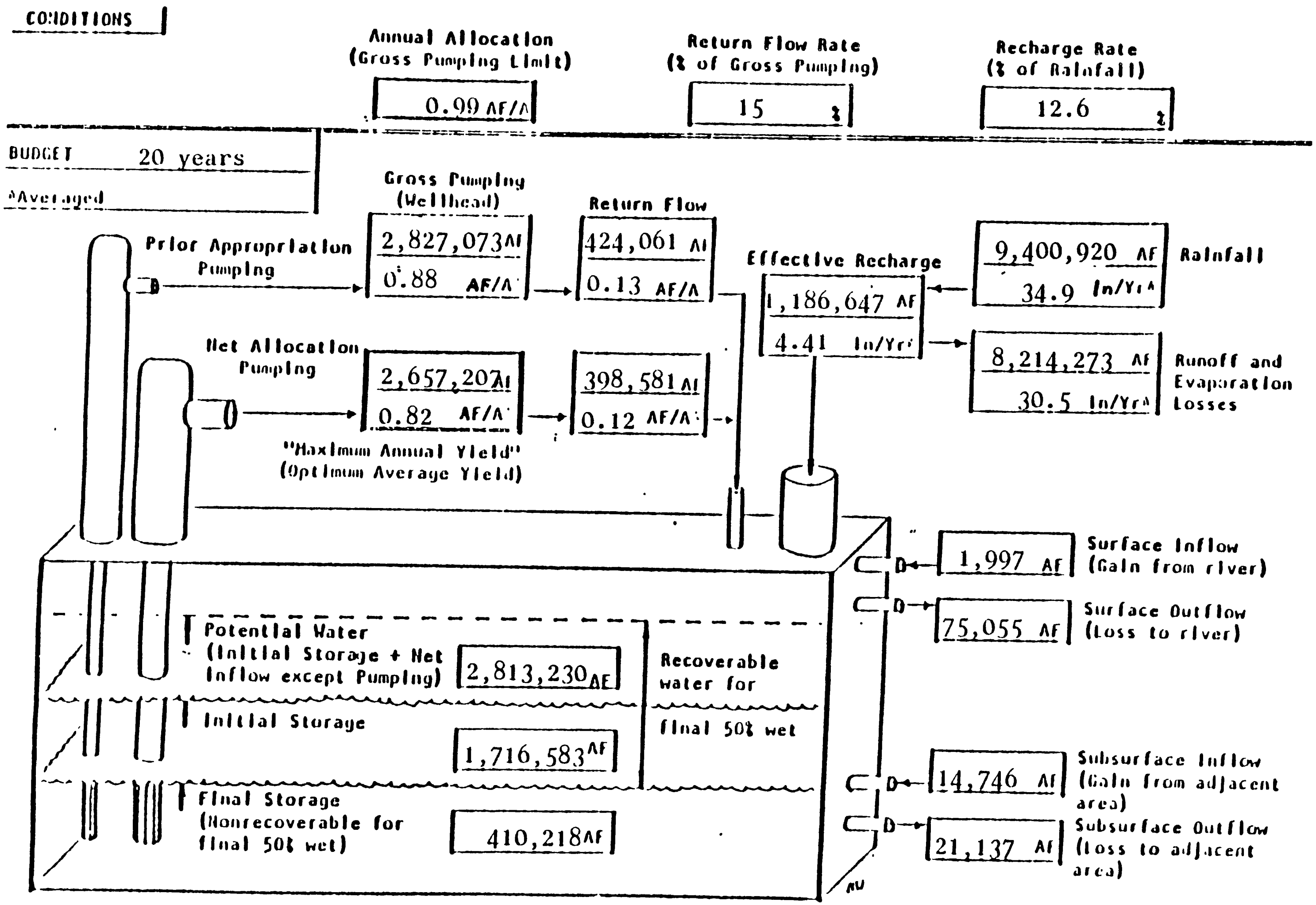


Figure 52. Ground-Water Budget, Total Aquifer Area (Modeled Reaches A, B, and C)

modified from the description by Schipper (1983) and is described in Appendix A. Additionally, mass balances for full allocation pumping and prior appropriative pumping for the period extending from July 1, 1973 to July 1, 1993 are shown in Appendixes F and P (Tables IX through XIV).

Computer generated data were typically produced as zoned maps. Simulated changes in allocation saturated thickness from 1973 and 1993 for each modeled reach are found in Figures 53 through 58. Allocation saturated thickness for 1978, 1983, and 1988 are found in Appendix J. Additional zoned maps include depth to water, transmissivity, prior rights distribution, and permeability. These are found in Appendixes M, L, N, and K, respectively.

Prior appropriative pumping shows little to no change in saturated thickness from 1973 to 1993. Saturated thickness maps of changes caused by prior appropriative pumping for 1973 and 1993 are shown in Figures 59 through 64. Modeled Reach A shows that none of its aquifer area went dry after 20 years of prior appropriative pumping (Figure 60). Reaches B and C showed less than 1% dry after 20 years of pumping (Figures 62 and 64).

Full allocation pumping simulations produced a 50% dry aquifer area for each modeled reach after 20 years of pumping. Modeled Reach A shows a few dry nodes in the western portion of the reach after 10 years of pumping. The development of the western portion of the reach as the primary dry area continued through 1993 (Figure 56).

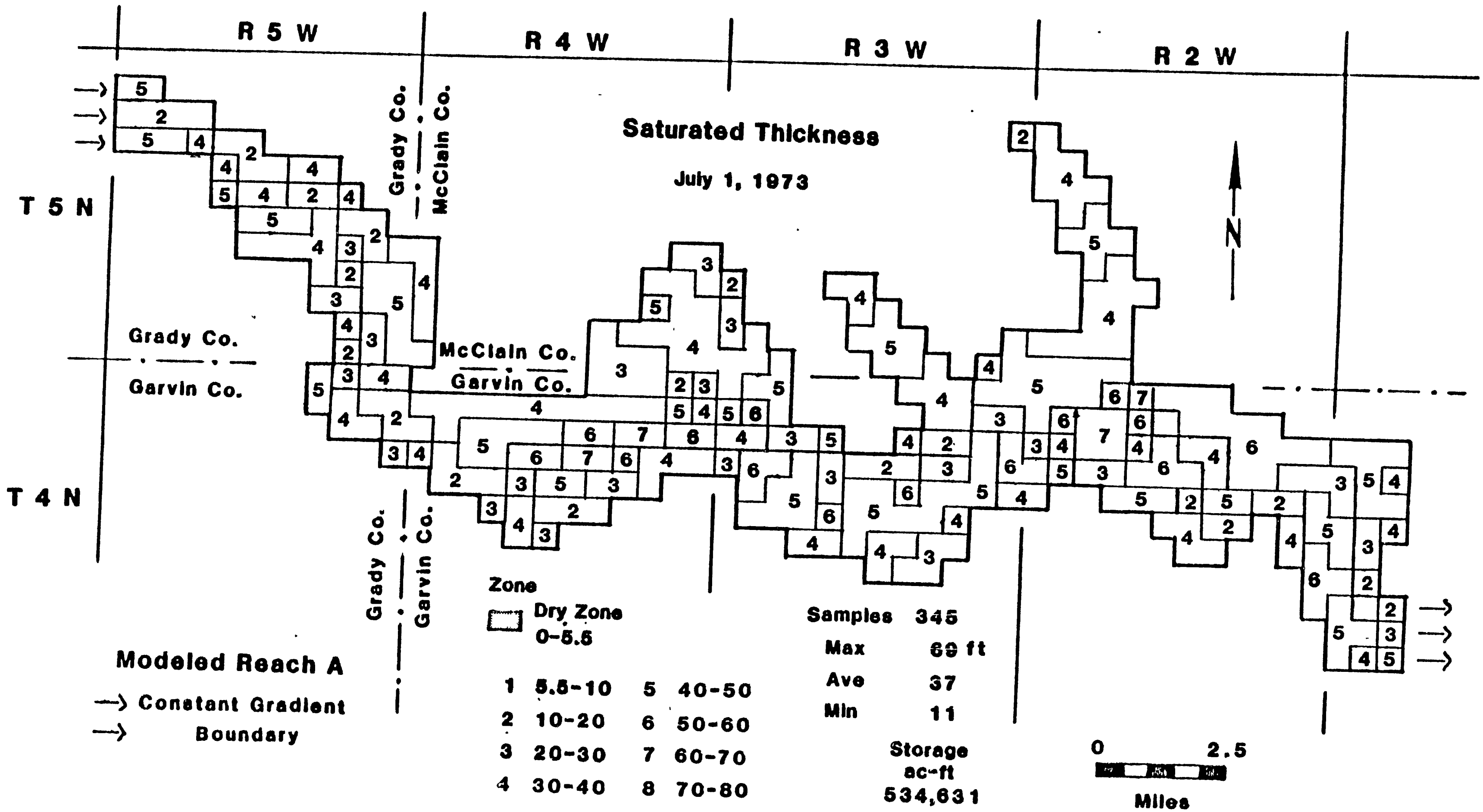


Figure 53. Allocation Saturated Thickness Map, 1973 - Modeled Reach A

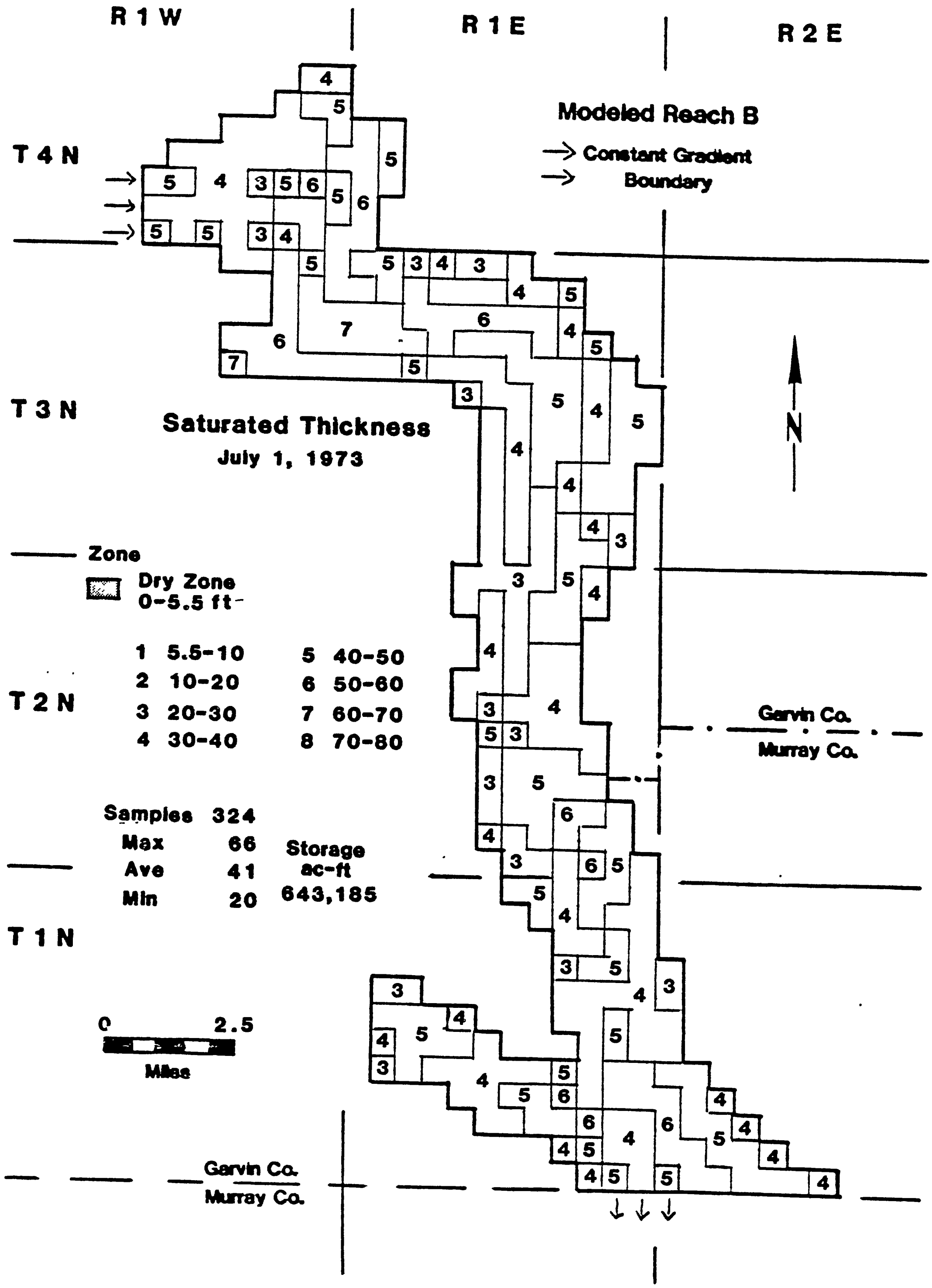


Figure 54. Allocation Saturated Thickness Map, 1973 - Modeled Reach B

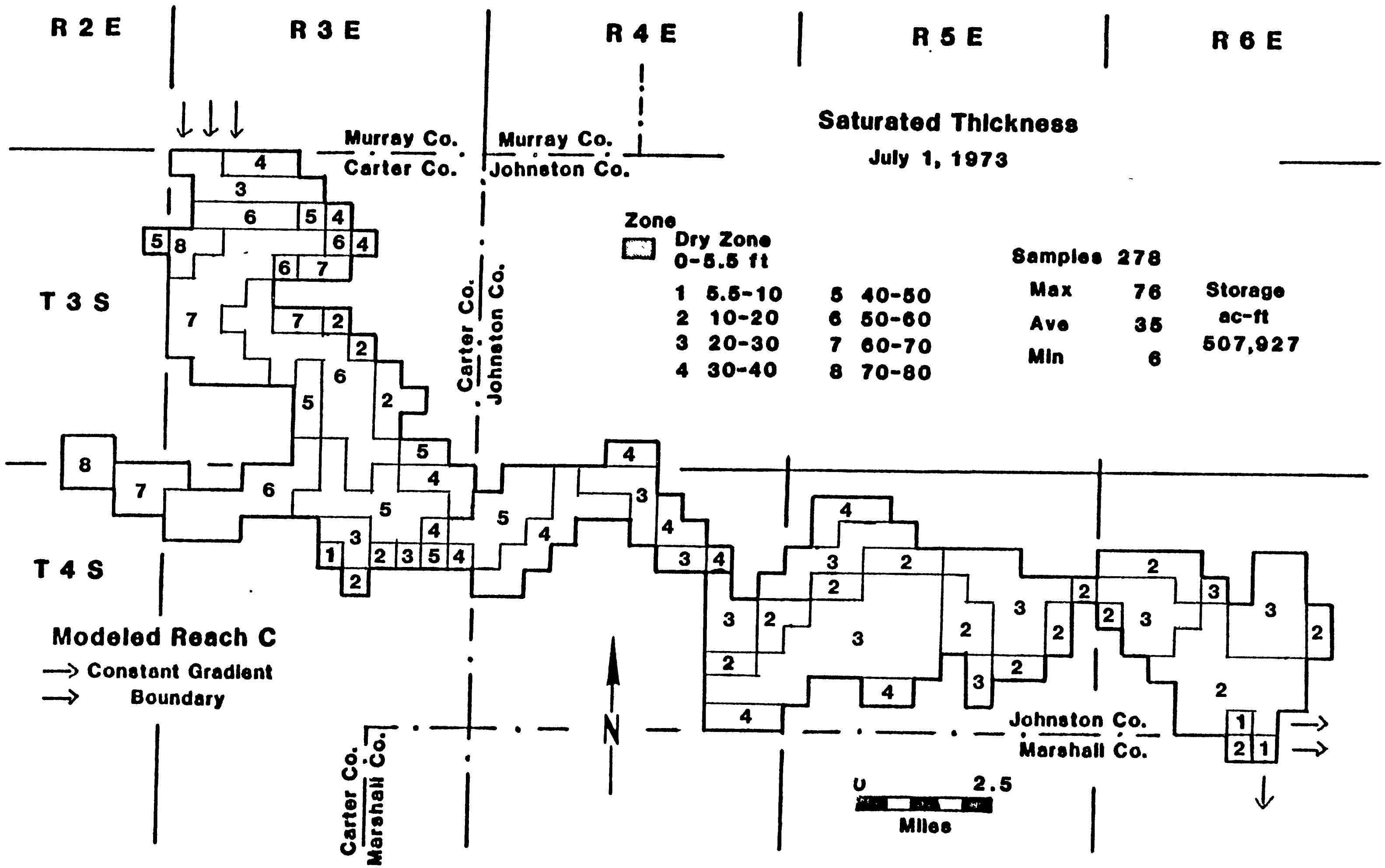


Figure 55. Allocation Saturated Thickness Map, 1973 - Modeled Reach C

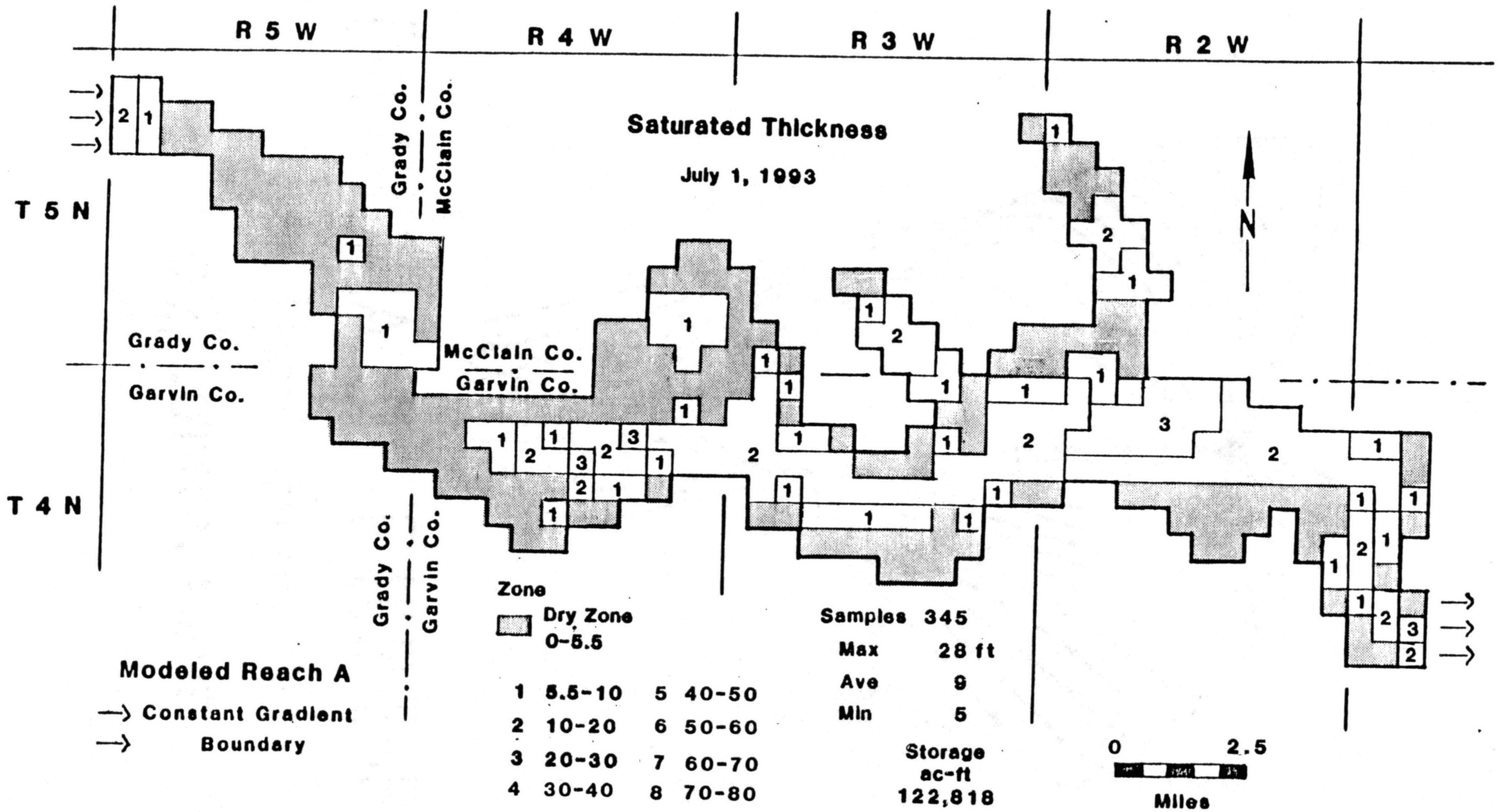


Figure 56. Allocation Saturated Thickness Map, 1993 - Modeled Reach A

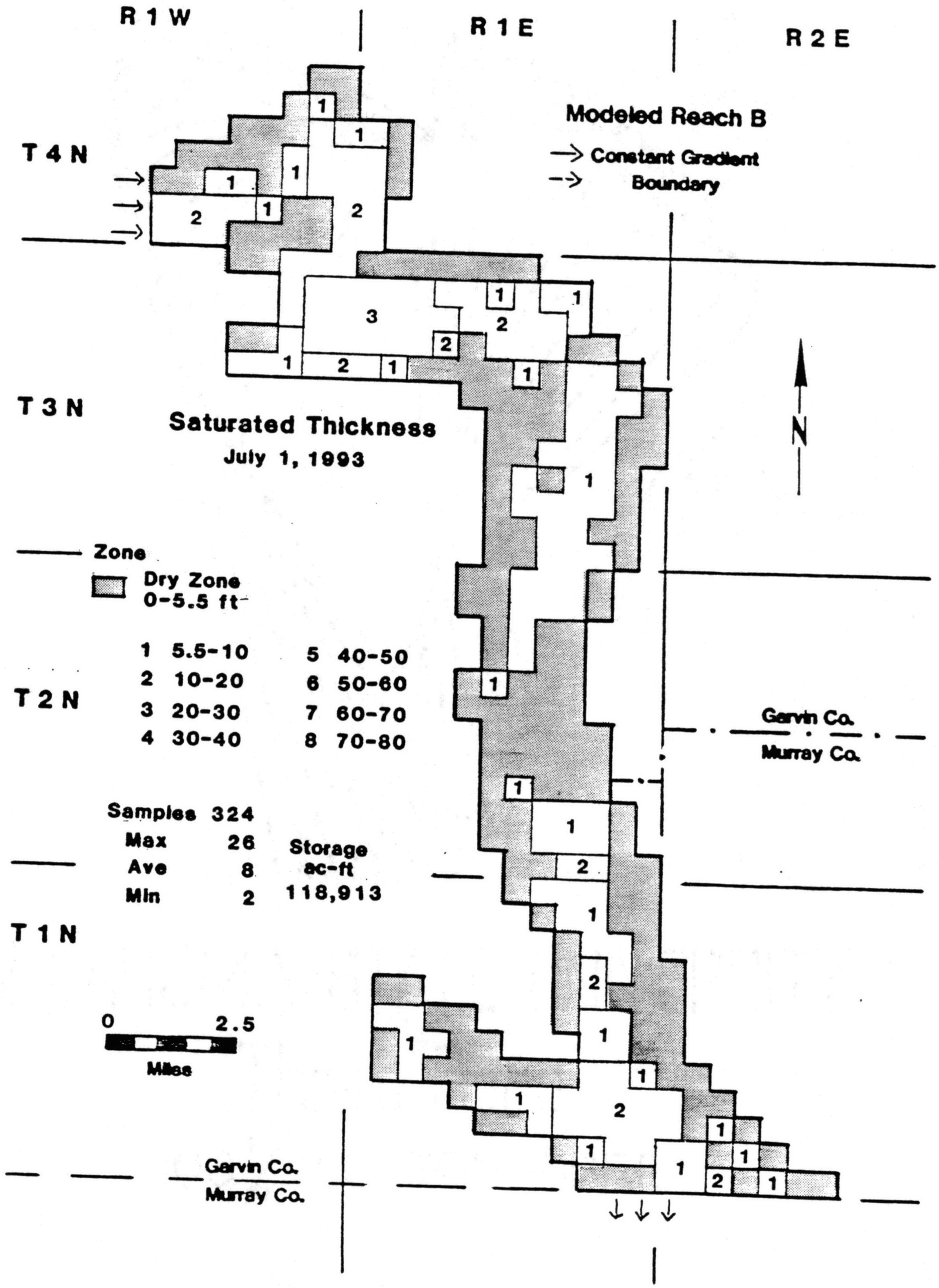


Figure 57. Allocation Saturated Thickness Map, 1993 - Modeled Reach B

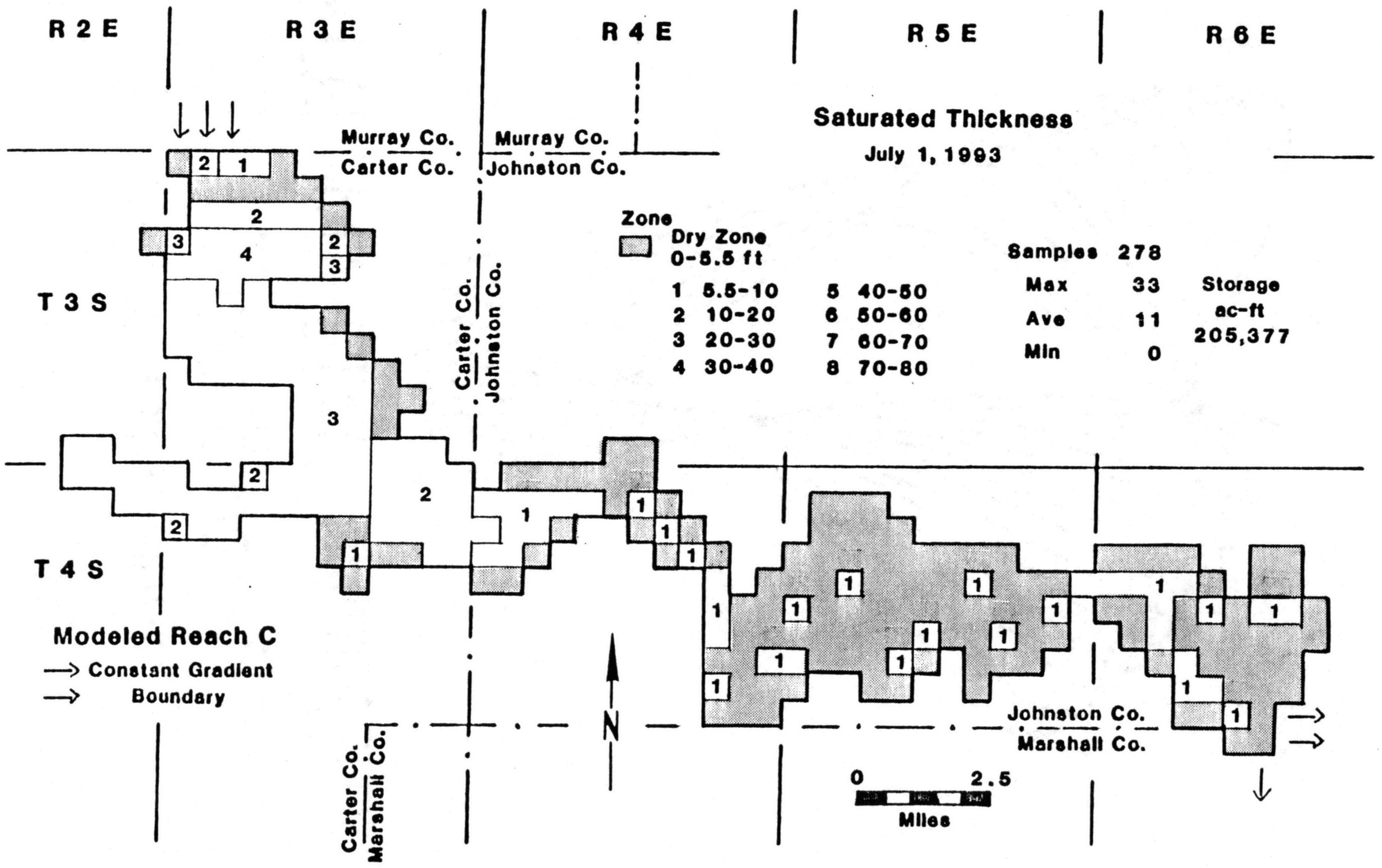


Figure 58. Allocation Saturated Thickness Map, 1993 - Modeled Reach C

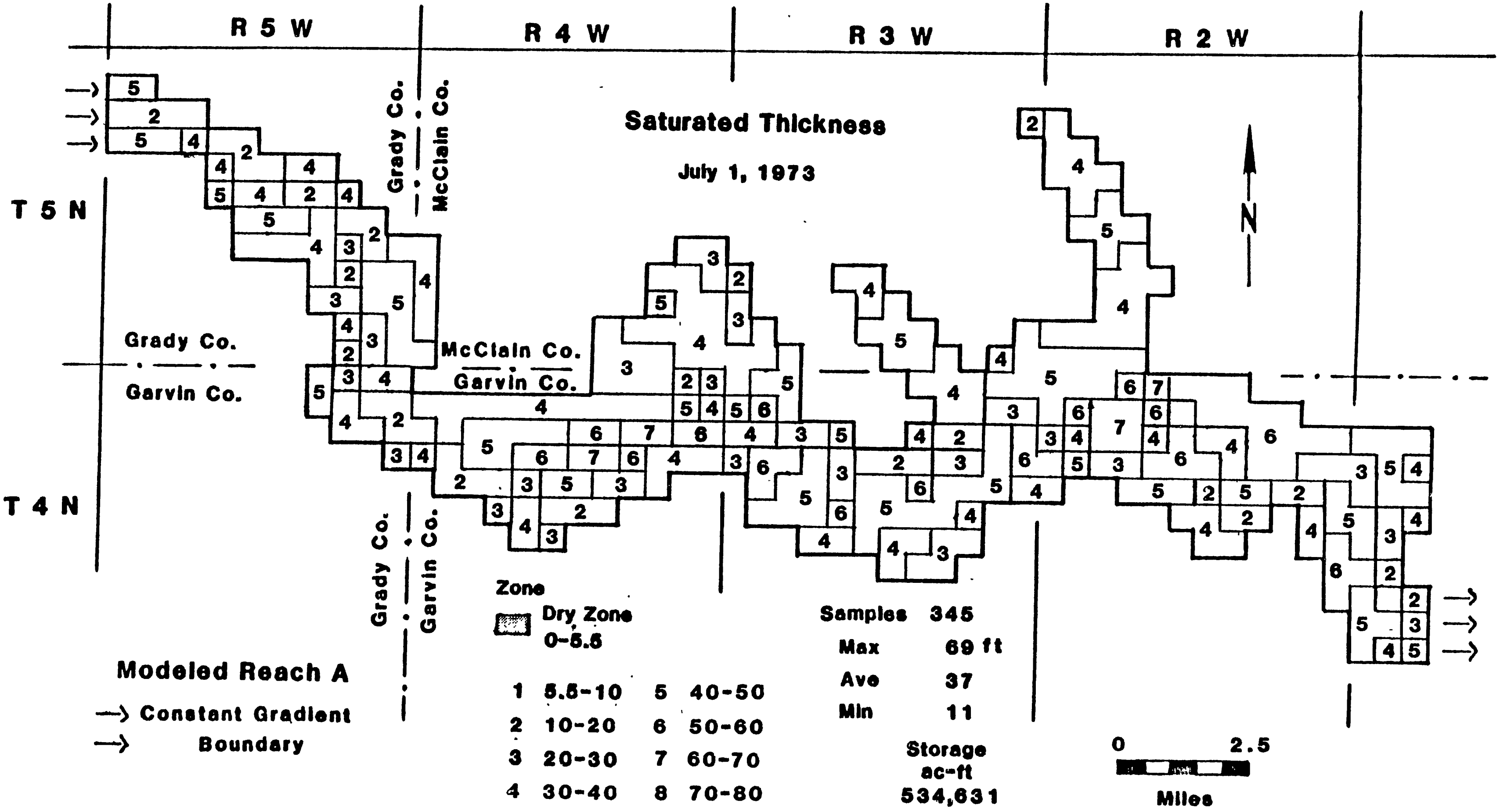


Figure 59. Prior Appropriative Saturated Thickness Map, 1973 - Modeled Reach A

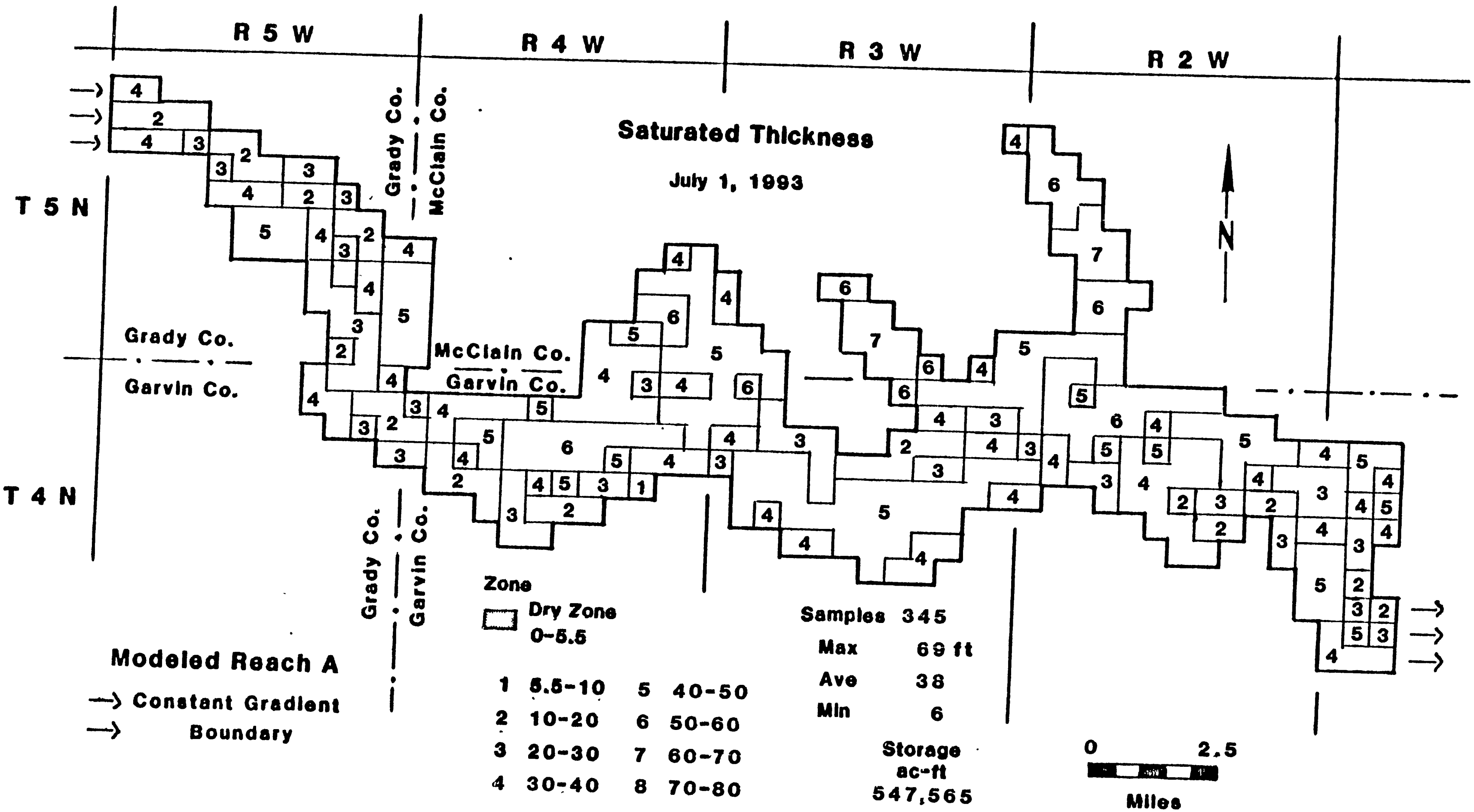


Figure 60. Prior Appropriative Saturated Thickness Map, 1993 - Modeled Reach A

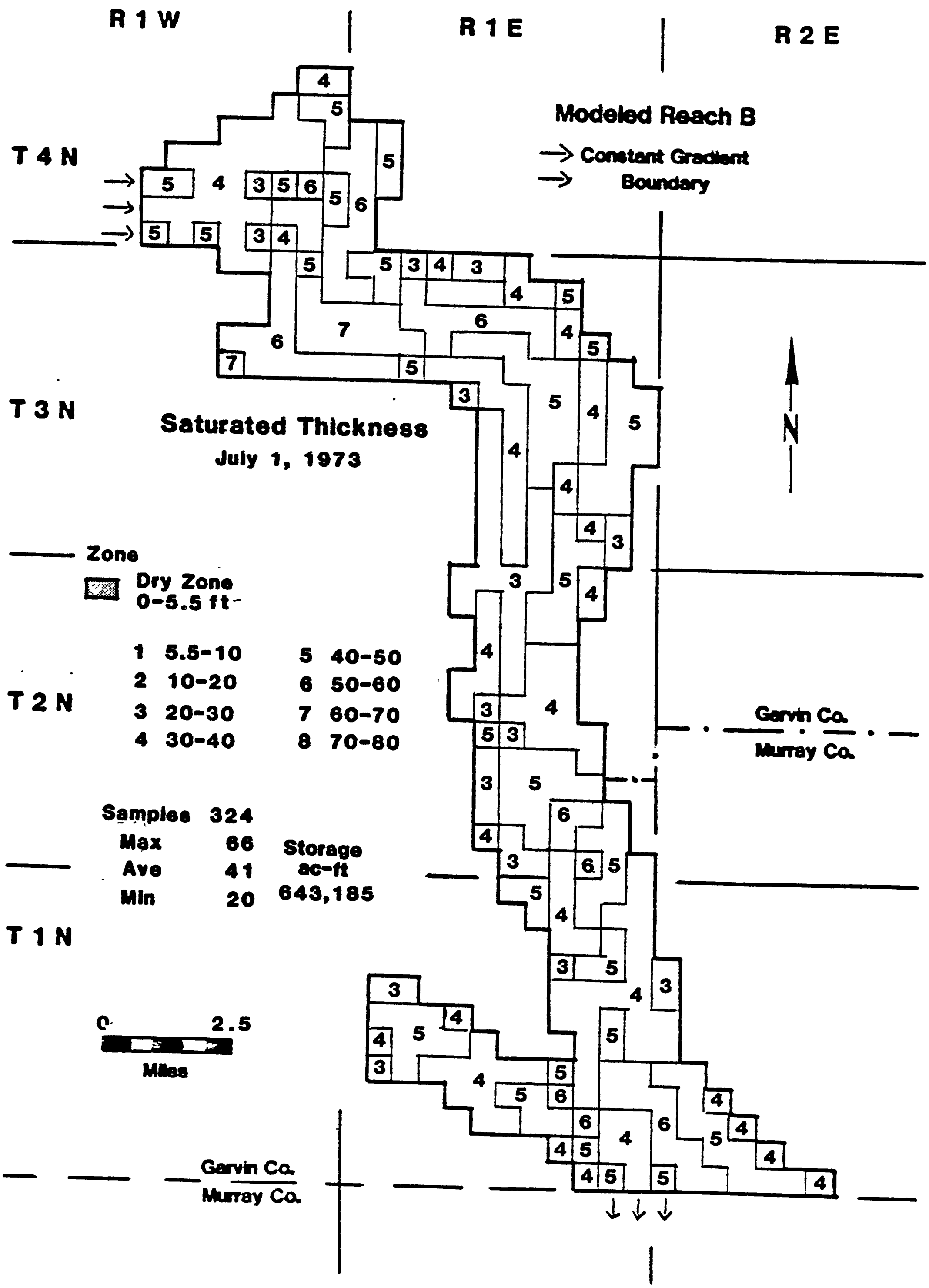


Figure 61. Prior Appropriative Saturated Thickness Map, 1973 - Modeled Reach B

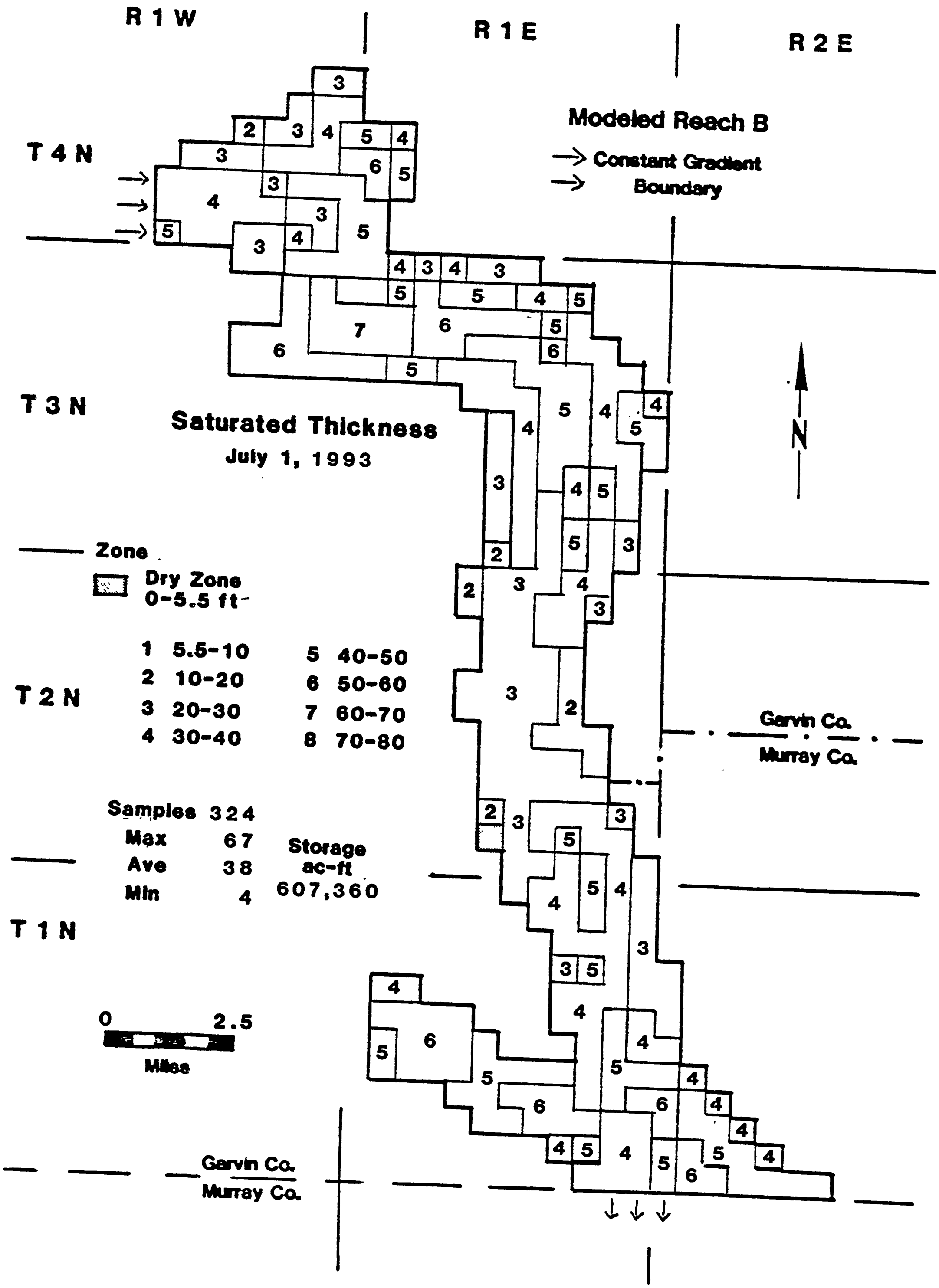


Figure 62. Prior Appropriative Saturated Thickness Map, 1993 - Modeled Reach B

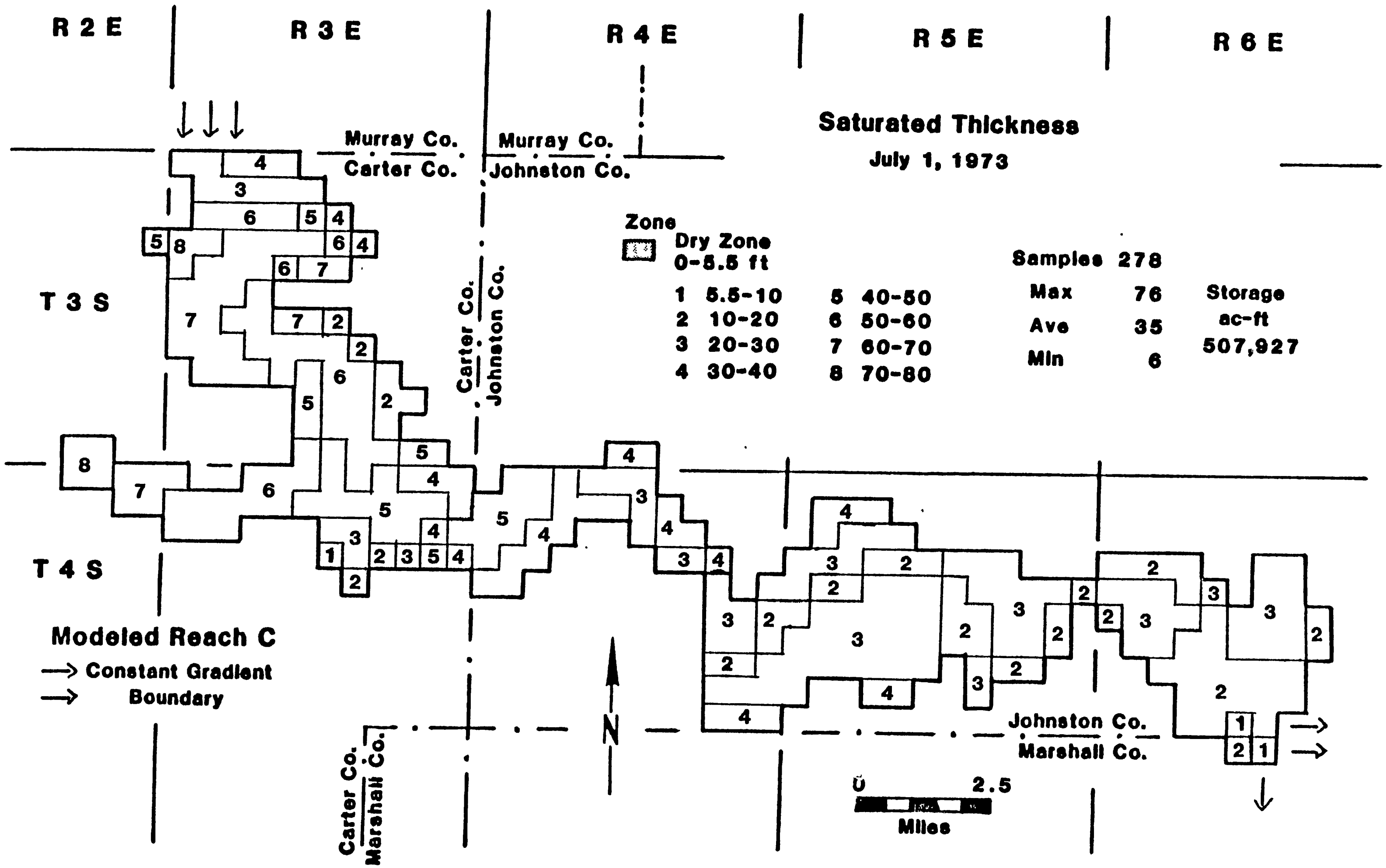


Figure 63. Prior Appropriative Saturated Thickness Map, 1973 - Modeled Reach C

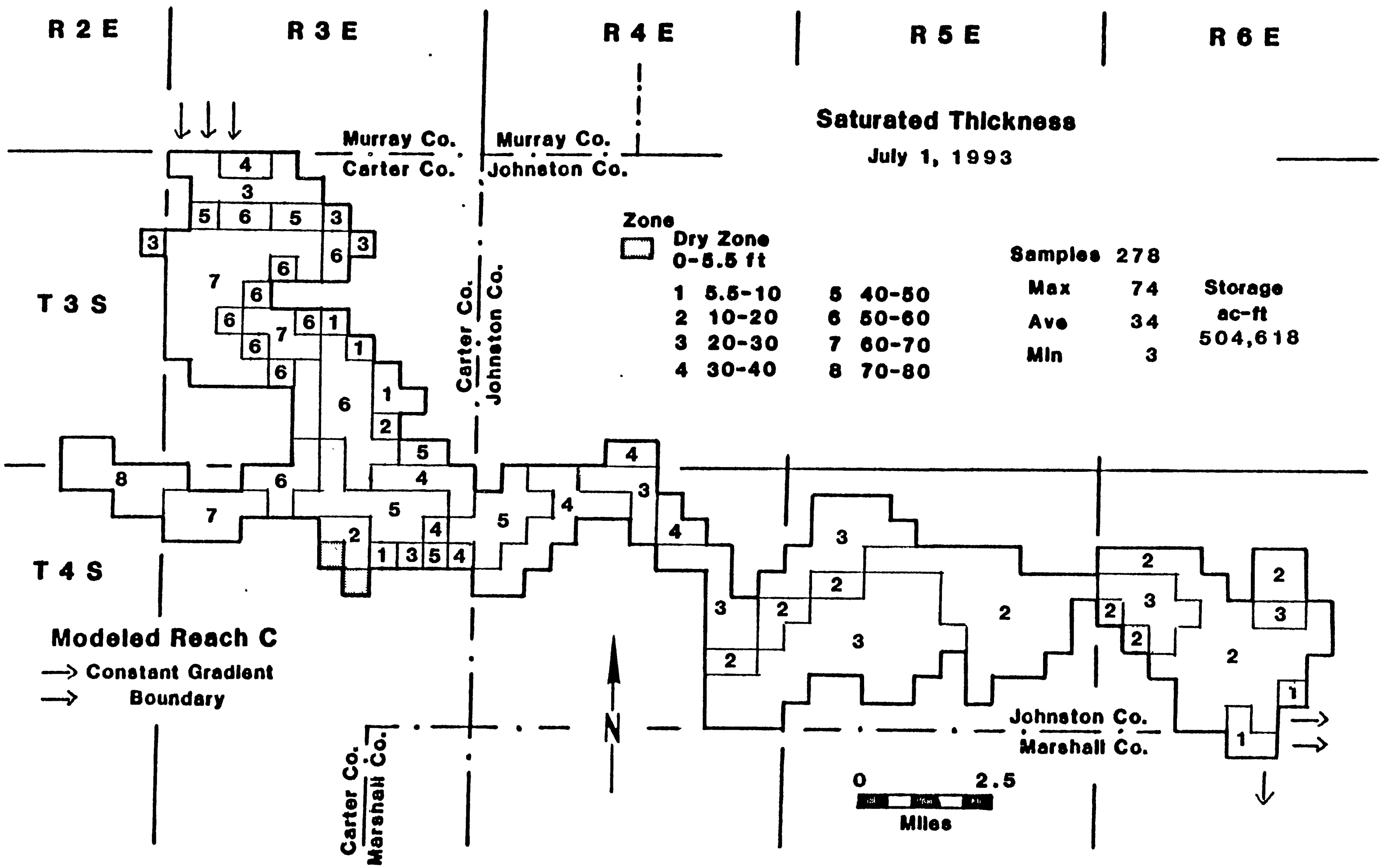


Figure 64. Prior Appropriative Saturated Thickness Map, 1993 - Modeled Reach C

Modeled Reach B shows scattered dry areas after 10 years of pumping. A trend develops in 1988 with the center portion of the reach going dry and this area continues to expand through 1993. Figure 57 shows the center portion of the reach as dry as well as the border nodes as being dry. Modeled Reach C shows the development of a few dry nodes through 1978 and then a drastic increase of dry areas occurs in 1983. The saturated thickness map of 1993 (Figure 58) shows that the eastern two-thirds of Reach C is essentially dry. The dry zones for both prior appropriative and full allocation pumping are probably attributable to low transmissivity in those areas.

The percent dry aquifer area of the modeled reaches in five year increments for both prior appropriative and full allocation pumping is shown in Table VIII.

Maps showing bedrock contours, full allocation and prior appropriative pumping water table contours, and the configuration of the top of the aquifer are shown in Appendices I, J, Q, and H.

Water Quality

Ground water quality in the alluvium is affected by the chemical composition of the underlying formations. Permian aged rocks underlie most of the study area north of the Arbuckle Mountains and appear to have the greatest effect on the ground water quality. The prominent rock types underlying the alluvium south of the Arbuckles are

Cretaceous aged rocks. No conclusions could be drawn on the influence of these rock types on the ground-water quality in the alluvium because of the location of the analyses. However, analyses of ground water in the alluvium south of the Arbuckles showed that the water quality was actually better than the analyses for the alluvium located north of the Arbuckles. This is contrary to the belief that the water quality should deteriorate south of the Arbuckle Mountains.

TABLE VIII

PERCENT DRY AQUIFER AREA IN FIVE YEAR INCREMENTS

	Prior Appropriative Pumping			Full Allocation Pumping		
Year	Modeled Reach A	Modeled Reach B	Modeled Reach C	Modeled Reach A	Modeled Reach B	Modeled Reach C
1973	0	0	0	0	0	0
1978	0	0	0.4	0	0.3	5.4
1983	0	0	0.7	2.3	8.3	33.8
1988	0	0	0.7	18.3	27.8	44.6
1993	0	0.3	0.7	50.7	50.9	50.4

Analyses of surface water quality at two gaging stations in the study area; Alex and Durwood, showed that the river water was of slightly worse quality than that of the alluvium. A depletion in aquifer thickness caused by 20-years of pumping would probably induce river recharge into the alluvium. Additionally, an increase in the amount of upward leakage from the bedrock may occur as the result of a lower head in the alluvium. Although most of the analyses of total dissolved solids from water in the river and the underlying bedrock do not exceed the limit set by the Oklahoma Water Resources Board for irrigation (5,000 mg/l), several of the analyses do. With the additional flow from river recharge it is possible that alluvial ground-water quality would deteriorate over 20 years of pumping.

CHAPTER VIII

CONCLUSIONS

Interpretations of the relationships found within the aquifer were based on collected data, field investigations, and published reports. The conclusions made are only as good as this raw data and the assumptions made by the author. The assumptions used in modeling the Washita River alluvium are as follows:

1. The aquifer is considered to be isotropic and homogeneous even though horizontal and vertical changes do occur in the aquifer composition.
2. The Washita River is considered to be a gaining stream.
3. The bedrock bounding the aquifer on its sides and bottom is considered to be impermeable. Therefore, vertical leakage is not assumed to be a component of ground water recharge.
4. Net recharge, permeability, and storage coefficient values are considered to be constant throughout the simulation period.

Based on the correlation of collected data, field investigations, published reports, and the above assumptions, the following aquifer properties were determined:

Aquifer Area, 252.4 square miles = 161,520 acres

Average Thickness, 65 feet

Average Saturated Thickness (1973), 38 feet

Specific Yield, 29.2

Average Transmissivity (1973), 43,123 gpd/feet

Well Yields:	Minimum	< 100 gpm
	Average	280 gpm
	Maximum	1,200 gpm

Average Precipitation, 34.9 inches/year

Effective Recharge, 4.41 inches/year

Recharge Rate (% of rainfall), 12.6%

Total Prior Rights, 8,968 acre-feet/year

Average Prior Right Over Entire Study Area, 0.05 acre-feet/year

Average Dissolved Solids from Alluvium, 319 mg/l

Conclusions established after final 20-year simulation runs of allocation plus prior appropriative pumping and prior appropriative pumping are as follows:

1. The maximum allowable allocation rate for the entire study area is 0.99 acre-feet/acre. This is equivalent to 159,905 acre-feet/year. Allocations by reach are: Reach A, 0.882 acre-feet/acre; Reach B, 1.14 acre-feet/acre; and Reach C, 1.20 acre-feet/acre.
2. The final projected saturated thickness and transmissivity after 20 years of full allocation plus prior appropriative pumping was 9.4 feet and 11,715 gpd/ft, respectively. The saturated thickness represents a 75% reduction of the initial (1973)

saturated thickness.

3. Prior appropriative pumping showed little to no change in saturated thickness after 20 years of pumping. This suggests that initially the aquifer was near a steady-state condition.

4. Initially, the volume of water in the aquifer (July 1, 1973) was 1,716,583 acre-feet; the final storage as of July 1, 1993 is 410,218 acre-feet.

Recommendations for Future Work

1. Chemical analyses of ground water by wells need to be developed in the field study area. The major constituents used to determine water quality, calcium, magnesium, sodium, bicarbonate, sulfate, and chloride need to be recorded at each well. Analysis should be performed on a weekly basis to document changes in ground water quality during wet and dry periods.

2. Surface water analyses need to be greatly expanded. All major water quality constituents need to be recorded. Analysis should also be made on a weekly basis.

3. Ground water level measurements need to be made in the study area on a regular basis. A series of wells should be established in the study area and measurements should be made monthly. This would allow for change in the amount of ground water storage to be calculated over any period of time.

4. Aquifer tests should be made at the completion of

each well into the alluvium. Observation wells should also be completed in conjunction with the primary (pumping) wells to ensure the accuracy of values reported.

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APPENDIXES

APPENDIX A

PROCEDURE FOR COMPLETING A 20-YEAR GROUND-WATER BUDGET

Procedure to complete a 20-year ground water budget "plumbing diagram" for a modeled area:

Obtain the 20-year mass balances for both prior and allocation runs. Create a table such as the one shown in Table IX. Table IX is representative of Modeled Reach B. Figure 65 is an example water budget diagram coded with numbered blocks. Figure 66 is a filled in version of the water budget and represents Reach B. Computer-generated statistics and the allocation mass balance for Modeled Reach B, that were used to complete the water budget are shown in Figures 67 and 68, respectively. The procedure used to complete the water budget follows.

Water Budget Completion Procedure

Δ = change from 1973-1993; values from Δ column are used in a 20 year budget
Box 1-5 values are taken from Figure
Box 6 is total area minus width of river times length of node times number of river nodes
Box 7 is annual irrigation allocation (Table IX)
Box 8 is the assigned return flow rate (Figure 67)
Box 9 is Box 7 * return flow rate (Box 8)
Box 10 is Box 7-Box 9
Box 11 is the average rainfall in inches/year
Box 12 is (Box 11÷12) * 20 years * total area (Box 5)
Box 13 is taken from mass balance (Table IX)
Box 14 is (Box 13*12÷20)÷total area (Box 5)
Box 15 is Box 14÷Box 11
Box 16 is Box 12-Box 13
Box 17 is Box 11-Box 14
Box 18 is allocation E.T. from mass balance (Table IX)
Box 19 is (Box 18*12÷20)÷Box 5
Box 20-23 are from mass balance (Table IX)
Box 24 is allocation pumping from mass balance (Table IX)
Box 25 is Box 24÷(1-Box 10)
Box 26 is Box 25-Box 24
Box 27 is prior pumping from mass balance (Table IX)
Box 28 is Box 27÷(1-Box 10)
Box 29 is Box 28-Box 27
Box 30 is Box 25-Box 28

Box 31 is Box 26-Box 29
Box 32 is Box 24-Box 27
Box 33 is the corresponding box above÷20: (Box 24÷20; Box 25÷20, Box 26÷20; Box 27÷20; Box 28÷20; Box 29÷20; Box 30÷20; Box 31÷20; Box 32÷20)
Box 34 is Box 33÷Box 5
Box 35 is final storage, 1993 for modeled area taken from program statistics
Box 36 is initial storage, 1973 for modeled area taken from program statistics
Box 37 is Box 35÷Box 24
Box 38 is Box 37÷Box 26
Box 39 is Box 24÷Box 37
Box 40 is Box 27÷Box 37
Box 41 is Box 32÷Box 37
Box 42-45 are taken from program statistics

TABLE IX

EXAMPLE MASS BALANCE
(VALUES FOR MODELED REACH B USED AS AN EXAMPLE)

	Allocation			Allocation		
	1973 Time Step 3 0.08 years	1993 Time Step 3 20.08 years		1973 Time Step 3 0.08 years	1993 Time Step 3 20.08 years	
Outflow						
Pumping	-1279	-903274	-901995	-1279	-97490	-96211
Leakage	-255	-27132	-26877	-255	-320423	-320168
Gradient	-144	-18269	-18125	-144	-29963	-29819
E.T.	-9	-13	-4	-9	-5781	-5772
Total	-1688	-948688	-947001	-1688	-453657	-451970
Inflow						
Leakage	0	15	15	0	3	3
Gradient	25	3653	3628	25	5059	5034
Recharge	1710	412062	410352	1710	412062	410352
Total	1734	415730	413995	1734	417124	415389
Net	46	-532958	-533006	46	-36533	-36581

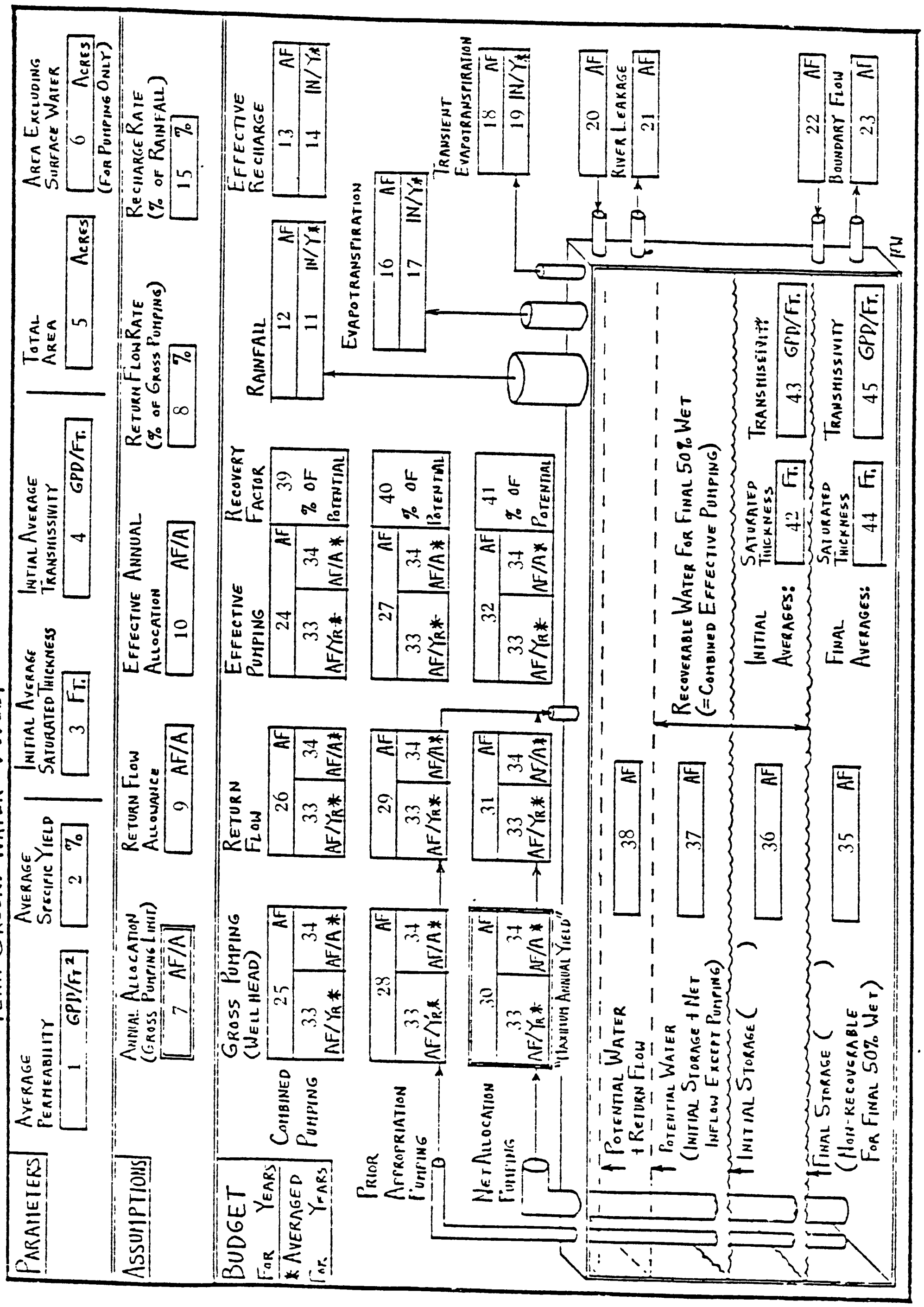


Figure 65. Flow Diagram for Ground-Water Budget

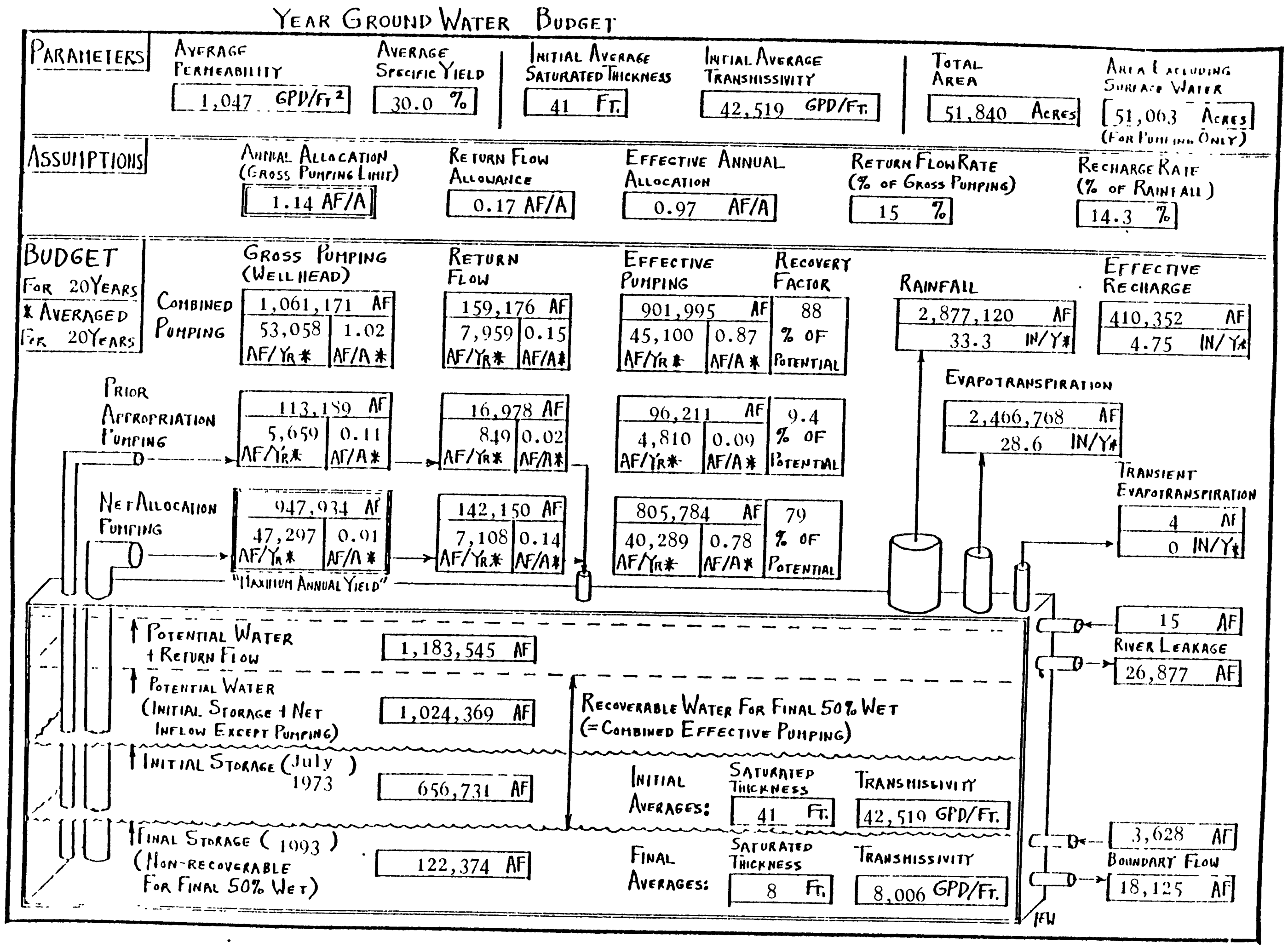


Figure 66. Ground-Water Budget for Modeled Reach B

```
               AREA: SCWB
                RUN: A830725.2308
          NODE AREA:      160 ACRES
     PUMPING PERIOD:      0.33 (FRACTION OF YEAR)
   RETURN FLOW RATE:       15 PERCENT
   NET PUMPING RATE:       85 PERCENT
```

JULY 1, 1973:

	NON-RIVER	RIVER	STUDY AREA	BOUNDARY	ALL NODES	
NUMBER OF NODES:	260	64	324	6	330	
NUMBER OF DRY NODES:						
PERCENT DRY:						PERCENT
AREA:	41600	10240	51840	960	52800	ACRE
PERMEABILITY:	1047	1047	1047	1047	1047	GPD/FT2
SPECIFIC YIELD:	30.0	30.0	30.0	30.0	30.0	PERCENT
SATURATED THICKNESS:	43	36	41	47	41	FEET
TRANSMISSIVITY:	44617	33998	42519	49246	42641	GPD/FT
RECHARGE:	4.75	4.75	4.75	0.00	4.66	IN/YR
TOTAL PUMPING:	11613	3736	15348	0	15348	AF/YR
STORED WATER:	531804	111381	643185	13546	656731	AF

DATA FROM:
A830725.2308 RUN 20YR,ALLOC1 14,RIVER-10.,RATE=9.265E-9,QRE-4.75IN/YR

```
               AREA: SCWB
                RUN: A830725.2308
          NODE AREA:      160 ACRES
     PUMPING PERIOD:      0.33 (FRACTION OF YEAR)
   RETURN FLOW RATE:       15 PERCENT
   NET PUMPING RATE:       85 PERCENT
```

JULY 1, 1993:

	NON-RIVER	RIVER	STUDY AREA	BOUNDARY	ALL NODES	
NUMBER OF NODES:	260	64	324	6	330	
NUMBER OF DRY NODES:	146	19	165		165	
PERCENT DRY:	56.2	29.7	50.9		50.0	PERCENT
AREA:	41600	10240	51840	960	52800	ACRE
PERMEABILITY:	1047	1047	1047	1047	1047	GPD/FT2
SPECIFIC YIELD:	30.0	30.0	30.0	30.0	30.0	PERCENT
SATURATED THICKNESS:	7	9	8	12	8	FEET
TRANSMISSIVITY:	7629	9535	8006	12583	8089	GPD/FT
RECHARGE:	4.75	4.75	4.75	0.00	4.66	IN/YR
TOTAL PUMPING:	124448	31677	156125	2791	158915	AF/YR
STORED WATER:	90937	27976	118913	3461	122374	AF
CHANGE IN STORAGE:	-440868	-83405	-524272	-10084	-534357	AF

	GROSS PUMPING	RETURN FLOW	NET PUMPING
MAXIMUM ALLOCATION:	1.14	0.17	0.97 AF/A

DATA FROM:
A830725.2308 RUN 20YR,ALLOC1 14,RIVER-10.,RATE=9.265E-9,QRE=4.75IN/YR

Figure 67. Computer Generated Statistics From Twenty-Year Allocation Simulations For Modeled Reach B

Time Step No. 3

MASS BALANCE Years 0.08

TYPE OF FLOW	CURRENT RATE (ACRE FT/YR) INFLOW	OUTFLOW	CUMULATIVE (ACRE FT) INFLOW	OUTFLOW
PUMPING	0.	-15572.	0.	-1279.
LEAKAGE	0.	-5438.	0.	-255.
CONSTANT FLUX	297.	-1753.	25.	-144.
EVAPOTRANS.		-107.		-9.
RECHARGE	20818.	0.	1710.	0.
TOTAL	21116.	-22871.	1734.	-1688.
NET INFLOW	-1755.		47.	
STORAGE INCR.	-1754.		47.	
ERROR	-1.		-0.	
PERCENT ERROR	-0.00%		-0.01%	

Time Step No. 3

MASS BALANCE Years 20.08

TYPE OF FLOW	CURRENT RATE (ACRE FT/YR) INFLOW	OUTFLOW	CUMULATIVE (ACRE FT) INFLOW	OUTFLOW
PUMPING	0.	-111889.	0.	-903274.
LEAKAGE	0.	0.	15.	-27132.
CONSTANT FLUX	104.	-321.	3653.	-18269.
EVAPOTRANS.		0.		-13.
RECHARGE	20818.	0.	412062.	0.
TOTAL	20922.	-112210.	415730.	-948688.
NET INFLOW	-91289.		-532959.	
STORAGE INCR.	-91286.		-532892.	
ERROR	-3.		-67.	
PERCENT ERROR	-0.01%		-0.02%	

Figure 68. Computer Generated Mass Balances From Twenty-Year Allocations for Modeled Reach B

APPENDIX B

MICROCOMPUTER PROGRAM FOR DETERMINING TRANSMISSIVITY

The following is a program written for a Texas Instrument Model 55 to determine transmissivity. The equation used is from Walton (1970).

$$T = \frac{Q}{s}\left[264\log\left(\frac{Tt}{2693 r_w^2 S}\right) - 65.5\right]$$

where

T = coefficient of transmissivity in gpd/ft
Q/s = specific capacity in gpm/ft
Q = discharge in gpm
s = drawdown in feet
S = coefficient of storage, fraction
r_w = nominal radius of well in feet
t = time after pumping started in minutes

The program

```
2nd Rst
2nd Lrn
*
STO 2
÷
STO 7
÷
STO 3
x²
÷
STO 4
=
Log
*
STO 6
-
STO 5
=
*
STO 1
=
R/S
Rst
Lrn
2nd Rst
```

where

STO 1 = specific capacity (Q/s)
STO 2 = time (t)
STO 3 = radius of well in feet (r_w)

STO 4 = coefficient of storage (s)
STO 5 = 65.5
STO 6 = 264
STO 7 = 2693

The values in STO musts be entered as STO 1, STO 2, STO 3, etc. These values will be retained as storage.

After the program and STO values have been entered, a transmissivity value needs to be entered. Any value may be entered. After punching in "T" hit R/S. This will enter "T" into program and start the program. Re-enter resulting "T" by pushing R/S key again. Repeat this process until the "T" entered is equivalent to the "T" outputed.

The division of the final "T's" for each well by the saturated thickness at the respective well is equivalent to the permeability at that site.

$$K = T/b$$

where

K = permeability in gpd/ft^2
T = transmissivity in gpd/ft
b = saturated thickness in feet

APPENDIX C

MICROCOMPUTER PROGRAM FOR DETERMINING A WEIGHTED K (PERMEABILITY)

The following is a program written for a Radio Shack TRS-80 Pocket Computer to determine weighted K (permeability). The program was written by J. Michael Monsil and is as follows:

```
  5:  For O=1 to 2
  6:  Beep 2:  Pause "Weighted K Program":  Next O
  7:  Beep 1:  Pause "Yes=+1  No=-1:
      Beep 1:  Pause "Yes=+1  No=-1
 11:  Input "Change K constants?", D:  If D<0 go to 20
 12:  Beep 1:  Pause "Input Class K Constants":
               Pause "Input Class K Constants"
 13:  Input "Class 1K=" jw:  Input "Class 2K=" jx:
      Input "Class 3K=" jy
 14:  Input "Class 4K=" jz
 20:  Input A=0:  B=0:  C=0:  D=0:  E=0:  F=0:  G=0:
            H=0:  I=0:  J=0:  K=0:  M=0:  N=0:  O=0:
 30:  Input "Total Well Depth=" jA:  Input "Depth to
      Water=" jB:  C=A-B
 40:  If C<10 Pause "Sat thick outside range!":  Go to
      30
 50:  If C>250 Pause "Sat thick outside range!":  Go to
      30
 60:  Input "Any class 1?" jD:  If D<0 Go to 100
 70:  Input "Enter ?Thickness" jE
 75:  Input "Any More?" jD
 80:  If D<0 Go to 100
 90:  Input "Enter Thickness" jD:  E=E+F:  Go to 75
100:  Input "Any Class 2?" jD:  If D<0 Go to 140
110:  Input "Enter Thickness" jH
120:  If D>0 go to 140
130:  Input "Enter Thickness" jI:  H=H+I:  Go to 115
140:  Input "Any Class 3?" jD:  If O<0 Go to 180
150:  Input "Enter Thickness" jK
155:  Input "Any More?" jD
160:  If D<0 Go to 180
170:  Input "Enter Thickness" jL:  K=K+L:  Go to 155
180:  Input "Any Class 4?" jD:  If D<0 Go to 210
190:  Input "Enter Thickness" jL
195:  Input "Any More?" jD:  Go to 205
200:  Input "Enter Thickness" jG:  J=J+G:  Go to 195
205:  If D<0 Go to 200
210:  M=E+H+K+J:  If M=C Go to 270
215:  For O=2 to 3
220:  Beep 2:  Pause "Error!"
225:  Next O
230:  Pause "Check Figures":  Pause "Check Figures"
240:  Print "Press Enter to Continue"
250:  Print "Well Depth=" jA:  Print "Water Depth =" jB:
      Print "Total Class 1=" jE
255:  Print "Total Class 2=" jH:  Print "Total Class
```

```
     3=" jK:  Print "Total Class 4=" jJ
260: Beep 2:  Pause "Start over Turkey!"; Go to 20
270: N=((E/M*W)+((H/M)*X)+((K/M)*Y)+((J/M)*Z)
280: Beep 2:  Pause "Weighted K=" jN:  Beep 1:  Pause
     "Weighted K=" jN
290: Input "Got it?" jD:  If D<0 Go to 280
300: Input "Another?" jD:  If D>0 Go to 20
310: Beep 2:  Pause "You owe Mike a Beer!": Pause
     "Bye, Bye!":  End
```

APPENDIX D

COMPUTER USER'S MANUAL

I. Acquisition and Definition of Parameters

Obtain all initial information through logs held by the OWRB, U.S.G.S., or field observations. The following parameters are necessary for use of the Trescott groundwater model computer program.

1. Water-Table Elevation (STRT)
2. Permeability (PERM) or Transmissivity (T)
3. Bedrock Elevation (BOTTOM)
4. Specific Yield (SY)
5. Top of Aquifer (TOP)
6. Course of River (RATE)
7. Thickness of River Bed (M)
8. Surface Elevation (LAND)
9. Recharge Rate (QRE)
10. Prior Rights Pumping (WELL)
11. Gradient Nodes (GRAD)

Definition of Parameters

<u>Water Table Elevation (STRT)</u>

Units: Feet

Water table elevation can be determined through drillers logs and water level measurements. Both can be obtained through the OWRB and the U.S.G.S. An example of a STRT matrix is shown in Figure 69.

<u>Permeability and Transmissivity (PERM/T)</u>

Units: PERM = FT/S
T = FT2/S

Permeability may be determined in two ways--through specific capacity data or through the use of drillers logs. Examples of permeability matrices are shown in Figure 70.

STRT

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	0	0	0	0	0	0	0	0	0	0
R2	0		Grad 851	Grad 849	Grad 855					0
R3	0		850	R 848	851	853	856	860		0
R4	0		849	849	R 847	850	852	858		0
R5	0		849	845	845	R 844	847	853		0
R6	0		843	R 839	R 840	845	845	846		0
R7	0		R 838	840	841	841	840	843		0
R8	0		841	R 837	R 836	R 835	R 834	838		0
R9	0					Grad 829	Grad 828	Grad 833		0
R10	0	0	0	0	0	0	0	0	0	0

Figure 69. Example of Water Table Elevation

PERM

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	0	0	0	0	0	0	0	0	0	0
R2	0		Grad 210	Grad 210	Grad 210					0
R3	0		210	210	210	210	210	210		0
R4	0		210	210	210	210	210	210		0
R5	0		210	210	210	210	210	210		0
R6	0		185	185	185	185	185	185		0
R7	0		185	185	185	185	185	185		0
R8	0		185	185	185	185	185	185		0
R9	0					Grad 185	Grad 185	Grad 185		0
R10	0	0	0	0	0	0	0	0	0	0

If varying perms then enter in gpd/ft^2 and convert to (ft/s) with multiplier.

Figure 70. Example of Permeability

PERM (gpd/ft^2)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	0	0	0	0	0	0	0	0	0	0
R2	0		Grad 1	Grad 1	Grad 1					0
R3	0		1	1	1	1	1	1		0
R4	0		1	1	1	1	1	1		0
R5	0		1	1	1	1	1	1		0
R6	0		1	1	1	1	1	1		0
R7	0		1	1	1	1	1	1		0
R8	0		1	1	1	1	1	1		0
R9	0					Grad 1	Grad 1	Grad 1		0
R10	0	0	0	0	0	0	0	0	0	0

Use multiplier times perm if constant to convert to (ft/s).

Figure 70. Continued

Determination of Permeability Using Specific Capacity Data

Specific capacity data can be obtained through well records at the OWRB. This information is then substituted into the following equation from Walton (1970):

$$T = \frac{Q}{s}\left[264 \log\left(\frac{Tt}{2693 r_w^2 S}\right) - 65.5\right]$$

where

Q/s = specific capacity in gpm/ft
Q = discharge in gpm
s = drawdown in feet
T = coefficient of transmissivity
S = coefficient of storage, fraction
r = nominal radius of well in feet
t = time after pumping started in minutes

The selection of "T" on the right-hand side of the equation depends on the other variables. The resulting "T" can then be substituted back into the equation until the equation balances itself. This technique is further discussed and documented in Appendix B.

The transmissivity is then divided by the saturated thickness at the corresponding well to obtain permeability

$$K = T/m$$

where

K = permeability in gpd/ft2
T = transmissivity in gpd/ft
m = saturated thickness in feet

Determination of Permeability Using Drillers Logs

Drillers logs need to be analyzed based on their varying lithologies. Each log is divided into grain size ranges as described by Kent (1973). The total saturated thickness is determined for a specific log and this is used to determine the weighted K's for each range. These in turn are summed and averaged and an overall K is determined for the particular well.

Bedrock Elevation (BOTTOM)

Units = Feet

Bedrock elevations can be determined through drillers logs and well records maintained by the OWRB and the U.S.G.S. An example of a BOTTOM matrix is shown in Figure 71.

Specific Yield (SY)

No Units

Specific Yield is determined through correlation with permeability. This can be performed automatically in the model using a predetermined type curve. For more information refer to Schipper (1982) and the text of this thesis. An example of specific yield is shown in Figure 72.

Top of the Aquifer (TOP)

Units = Feet

Top is defined as the top of the impermeable boundary below the river. The elevation of "TOP" must be below river bed thickness (M) which is at least one foot. An example of a TOP matrix is shown in Figure 73.

BOTTOM

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	0	0	0	0	0	0	0	0	0	0
R2	0		Grad 806	Grad 804	Grad 810					0
R3	0		805	803	806	808	811	815		0
R4	0		804	804	802	805	807	813		0
R5	0		804	800	800	799	802	808		0
R6	0		798	794	795	800	800	801		0
R7	0		793	795	796	796	795	798		0
R8	0		796	792	791	790	789	793		0
R9	0					Grad 784	Grad 783	Grad 788		0
R10	0	0	0	0	0	0	0	0	0	0

Figure 71. Example of Bottom

SY

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	0	0	0	0	0	0	0	0	0	0
R2	0		Grad 0.30	Grad 0.30	Grad 0.30					0
R3	0		0.30	0.30	0.30	0.30	0.30	0.30		0
R4	0		0.30	0.30	0.30	0.30	0.30	0.30		0
R5	0		0.30	0.30	0.30	0.30	0.30	0.30		0
R6	0		0.30	0.30	0.30	0.30	0.30	0.30		0
R7	0		0.30	0.30	0.30	0.30	0.30	0.30		0
R8	0		0.30	0.30	0.30	0.30	0.30	0.30		0
R9	0					Grad 0.30	Grad 0.30	Grad 0.30		0
R10	0	0	0	0	0	0	0	0	0	0

Figure 72. Example of Specific Yield

TOP

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	0	0	0	0	0	0	0	0	0	0
R2	0									0
R3	0			846						0
R4	0				845					0
R5	0					842				0
R6	0			837	838					0
R7	0		836							0
R8	0			835	834	833	832			0
R9	0									0
R10	0	0	0	0	0	0	0	0	0	0

Figure 73. Example of Top

Course of the River (RATE)

RATE is initially used to mark the river pattern. The number "1" should be entered at the nodes which represent the river. An example of a RATE matrix is shown in Figure 74.

Thickness of the River Bed (M)

Units = Feet

M is the thickness of the impermeable material below the river. M must be at least 1 foot thick and is assigned at the RATE nodes.

Surface Elevation (LAND)

Units = Feet

Surface elevations are obtained from topographic maps. An example of a LAND matrix is shown in Figure 75.

Recharge Rate (QRE)

Units = in/yr

The determination of recharge is one of the more complex computations due to its variability. Precipitation records must first be obtained for the study area. A 30-year coverage is preferable. Then maximum mean and minimum rainfalls for each station in the study area must be determined. The duration (in months) needs to be determined. These are the months of minimum flow. The maximum, mean, and minimum rainfall for these months also needs to be determined.

Determine the number of acres between gaging stations

RATE

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	0	0	0	0	0	0	0	0	0	0
R2	0									0
R3	0			1						0
R4	0				1					0
R5	0					1				0
R6	0			1	1					0
R7	0		1							0
R8	0			1	1	1	1			0
R9	0									0
R10	0	0	0	0	0	0	0	0	0	0

Figure 74. Example of Rate

LAND

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	O*	O	O	O	O	O	O	O	O	O
R2	O		Grad 868	Grad 866	Grad 872					O
R3	O		867	865	868	870	873	877		O
R4	O		866	866	864	867	869	875		O
R5	O		866	862	862	861	864	870		O
R6	O		860	856	857	862	862	863		O
R7	O		855	857	858	858	857	860		O
R8	O		858	854	853	852	851	855		O
R9	O					Grad 846	Grad 845	Grad 850		O
R10	O	O	O	O	O	O	O	O	O	O

Figure 75. Example of Land

and the total number of acres in the study area that applies for the recharge being determined. Recharge can then be determined through the following equation:

$$\text{base flow from gaging station record} * 714.14\ \underline{\text{ac-ft/yr}} * \frac{\text{area of modeled reach (ac)}}{\text{area of alluvium above gaging station (acres)}}$$

$$= \text{base flow (ac-ft/yr) for modeled reach} \qquad (1)$$

$$\text{Ex:}\quad 73.7 * 714.14\ \underline{\text{ac-ft/yr}} * \frac{55840}{65440} = 44911\text{ac-ft/yr} \qquad (2)$$

Ac-ft/yr needs then to be converted to in/yr. This is done in the following manner:

$$\text{Area of alluvium above gaging station)acres} * 6.27E6\text{in}^2/\text{ac} = \text{area (in}^2) \qquad (3)$$

$$\text{Ex:}\quad 65440 * 6.27E6\ \text{in}^2 = 4.1E11\text{in}^2$$

Also

$$\text{ac-ft/yr (from e.g. \#2)} * 75.27E6\text{in}^3 = \text{recharge in in}^3/\text{yr}$$

$$\text{Ex:}\quad 44911\ \text{ac-ft/yr} * 75.27E6\text{in}^3/\text{ac-ft} = 3.38E12\text{in}^3/\text{yr}$$

Combining the two above equations

$$= \text{in}^3/\text{yr}/\text{in}^2 = \text{in/yr}$$

$$\text{Ex:}\ \frac{3.38E12\text{in}^3/\text{yr}}{4.1E11\text{in}^2} = \frac{3.38E12\text{in}^3}{4.1E11\text{in}^2/\text{yr}} = 8.25\ \text{in/yr}$$

The resulting number is net recharge in inches per year. However, for south central Oklahoma, previous studies showed that the above value ran approximately 75% higher than values normally used. Fine tuning of net recharge was achieved through calibration which is discussed later.

Prior Rights Pumping Rates (WELL)

Units = ac-ft/yr

Final and tentative orders for all counties in Oklahoma can be obtained through the OWRB. It is necessary then to obtain the prior rights which apply to your study area. If the prior rights cover more than one node, it is necessary to equally divide them among the area covered.

Ex: 325 ac-ft covering 480 acres (3 nodes)
325/3 = 108.33

The numbers must be whole numbers; therefore they must be split up so that the numbers will equal 325. The most logical conclusion:

Two nodes = 108
One node = 109

An example of WELL is shown in Figure 76.

Gradient Nodes (GRAD)

Grad nodes represent the head change going into the aquifer and going out of the aquifer. Grad nodes are done for each reach and are placed in the immediate vicinity of the river. Where the water enters the reach is considered inflow, the values are positive. Where water leaves is outflow the values are negative. Values for grad nodes are obtained by adding water table elevations at the adjacent nodes which would directly affect the grad nodes. The grad nodes are immediately outside of the aquifer boundary. An

WELL

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	0	0	0	0	0	0	0	0	0	0
R2	0									0
R3	0									0
R4	0				.50					0
R5	0									0
R6	0						40			0
R7	0			60						0
R8	0									0
R9	0									0
R10	0	0	0	0	0	0	0	0	0	0

Figure 76. Example of Prior Rights (entered as acre-feet/year)

example of a GRAD matrix is shown in Figure 77.

If an adjoining reach is a continuation of another reach, then the inflow values of the second reach must be of equal magnitude and of opposite signs to the outflow values of the above reach.

Grad nodes must also be entered into the following matrices in order for the model to run:

1. LAND (Figure 75)
2. STRT (Figure 69)
3. BOTTOM (Figure 71)
4. T/PERM (Figure 70)

II. Additional Parameters

A. Error Criteria for Closure

1. Usually 0.01

B. Evapotranspiration Rate

1. Determined from previous studies and through average weighting of ET values in the area concerned

C. Width of node in X - direction

D. Width of node in Y - direction

III. FAIR

Follow logon procedures until the READY prompt is received, at this point FAIR begins *-

1. Type "Fair" <Return>

2. Machine response:
   Enter the file name: (For library enter area name)
   a. Type area name
      Ex: SCWA.CNTL <Return>

GRAD (Reach 1)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	0	0	0	0	0	0	0	0	0	0
R2	0		+1	+1	+4					0
R3	0									0
R4	0									0
R5	0									0
R6	0									0
R7	0									0
R8	0									0
R9	0					-6	-6	-5		0
R10	0	0	0	0	0	0	0	0	0	0

Figure 77. Example of Gradient Nodes

GRAD (Reach 2)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
R1	0	0	0	0	0	0	0	0	0	0
R2	0					+6	+6	+5		0
R3	0									0
R4	0									0
R5	0									0
R6	0									0
R7	0									0
R8	0									0
R9	0									0
R10	0	0	0	0	0	0	0	0	0	0

Figure 77. Continued

3. Machine response:
   For library enter member name
   a. Type member name
      Ex: BOTTOM <Return>
      -* Member names listed in #7 below.*-

4. Machine response:
   Has file been created (Y,N)?
   a. Answer "Y" if file name from above has already been created--"N" otherwise

5. Machine response:
   Linesize?
   a. Enter one of the following:
      1) "0" if using IBM terminal
      2) "80" if using Televideo (TVI) terminal
      3) "132" if using a Decwriter

6. Machine response:
   Choose Area
   a. Several matrix sizes will be listed. Select the most appropriate area and type the corresponding number.
   b. If none of the areas defined fit your area, type "0". The machine will then ask for the number of rows and columns. Enter the appropriate numbers.

7. Machine response:
   Choose Matrix Format

```
0  Other  (8F10,0.01)         7  Rate  (20F4,Blank)
1  Strt   (20F4,Blank)        8  River (20F4,Blank)
2  S      (20F4,Blank)        9  M     (20F4,Blank)
3  T/Perm (20F4,Blank)       10  Land  (8E10,9999)
4  Bottom (20F4,Blank)       11  QRE   (20F4,Blank)
5  SY     (20F4,Blank)       12  Well  (20F4,Blank)
6  TOP    (8F10,9999)
Matrix?
```

   -* The form above is defined as
        matrix (format,fill)
      where format is the Fortran format code and fill is the default value for the data
   a. Type appropriate number in

8. Machine response:
   File (New,old)?
   a. Type "new" if this is the initial entry of the matrix data. Type "old" otherwise (that is, if the matrix exists and is to be modified).

9. Machine response:
   Time: Loading Tables and Matrix
   Time: Tables and Matrix Loaded
   R1C1
   b. This puts the user at row 1, column 1 (R1C1) of the matrix.
   Note: User should have previously prepared data by row and column.

10. Type row and column wanted.
   Ex: R10C5
   a. User can either hit return or place a comma after the column and continue entering data
      Ex: R10C5,928,932,930, ,940 <Return>
      Blank indicates no data at a node
   b. This format can be continued until the end of the row <Return>
   c. Machine response:
      Will be the same row but one column further.

11. Continue processing by row and column.

12. Make sure to type "S" (save) every 10 minutes or so. This will enable user to save the data up to that point.
   a. After saving, continue with the formats listed in #10.

13. To end type "Z".
   a. This will save the data and return user to READY mode.

14. If you need to break out of the matrix hit "Break" key.
   a. Machine will respond with "!"
   b. Hit <Return>.
   c. Machine will respond with "Abort?"
   d. Type "Yes"
   e. Machine will respond with "Unload Matrix?"
   f. Type "Yes" if you want to save the material entered so far, type "No" if you want to delete the material.
   g. Machine response:
      READY
   h. Type whatever is applicable at this point.

IV. Control File Setup

The files described below control the Trescott model simulations by using Print/Plot commands, options, and macros (utility programs). The Print/Plot package is documented in the manual, "Users Manual for the Print/Plot Package" (Witz, 1982). The macros are described in the companion manual, "Users Manual for the Print/Plot Macro Preprocessor" (Witz, 1982). Documentation for the actual Trescott program is found in the manual, "Users Manual for Ground Water Model One" (Witz, 1982).

The files are set up for a "standard 20-year simulation described as follows:

1. The simulation begins June 1 of the year.

2. The pumping periods are four months "on" and eight months "off." The "on" pumping period begins July 1 of the year.

3. Time is measured in ten-day time steps with 36 time steps per year (360 days per year).

Master copies of all files mentioned are found in the Partitioned Data Set (PDS) U11236A.PPM.CNTL. To copy members of this PDS, use the following TSO formant:

COPY 'U11236A.PPM.CNTL (member)' dsn.CNTL (member)
where:

member is one of the file names listed below, and dso is the PDS name that contains all the input matrices.

The following files must be copied into the PDS for the area being modeled:

SIMIN and SIMJOB

and must then be modified to correctly represent the area.

SIMJOB is the file that is submitted for batch processing. The necessary changes for SIMJOB are as follows:

1. Change all $-codes as indicated in Table X. Certain $-codes may appear more than once in the file. Each occurrence must be changed the same.

2. Set the desired Priont Plot Macro (PPM) options as indicated in Table XI.

3. Set "CLASS" and "TIME" in line 3 of the file according to the length of the run.
   For example:
   A. For a simulation run of 1 year use,
      CLASS=A,TIME=(0,40).
      This will give the job a maximum of 40 seconds of CPU time.
   B. For a simulation run of 2 to 5 years use,
      CLASS=K,TIME=(5,00)
      This will give the job a maximum of 5 minutes of CPU time.

TABLE X

SIMJOB EDIT OPTIONS

Code	Example	Description
$JOBNAME	U11832B	Any 8 letter name: usually same as userid except first letter.
$IN	JWP	User's initials (Must be 3 characters).
$NAM	SCWA	Unique 4 letter area identifier.
$RM	J	Single alphabetic character to indicate window for output (Basement of Math Sciences)
$USERID	U11832B	Dataset prefix; use TSO USERID assigned to user.
$MATRICES	----	All matrices to be included must be listed here in the form indicated (Variables read as constants do nnot need to be listed).
$TITLE	ANY TEXT	Description of run (Maximum length of 57 characters).
$USER	JIM	User's name: usually first name
$ALLOC	0.882	Allocation pumping rate (Use 0.0 for prior only).
$ACNODE	130	Node area in acres.
$NET	0.85	Net pumping rate = 1.0 - return flow rate.

TABLE XI

SIMJOB PPM OPTIONS

Code	Action if On (< for on, # for off)
LAYERED	Read and write layer permeability data.
LAYER TRACE	Write additional layer data.
PERM PATTERN	Permeability matrix is a pattern. Values are set in SIMPP.
PERM GPD/FT2	Permeability matrix is in gpd/ft^2 (rather than ft/sec).
RIVER	Read and write river data (TOP, RATE, RIVER, and M).
RAISE RIVER	River and STRT increased by RPARM 4 at river nodes.
NO RIVER INFLOW	Flow from river to aquifer suppressed. Flow from aquifer to river is allowed.
PERIOD RIVER	Flow to and from river suppressed during odd (wet) periods. Period lengths are set in SIMPP.
RECH PATTERN	Recharge matrix is a pattern. Values are set in SIMPP.
RECH IN/YR	Recharge matrix is in in/yr (rather than ft/sec).
PERIOD RECH	Recharge suppressed during even (dry) periods. Period lengths are set in SIMPP.
READ RECH	Read recharge matrix from file FT18F001. JCL must be included for file FT18F001.
PRIOR MULT	Prior pumping matrix multiplied by RPARM 5.
READ CONST WELL	Read a matrix for non-periodic pumping.

TABLE XI (Continued)

Code	Action if On (< for on, # for off)
CONST WELL AF/A	Constant well matrix is in af/a (rather than cfs).
NEW ALLOC CITY	Where prior is zero, allocation is added to constant well matrix.
ALLOC AT PRIOR ONLY	Allocation will be added only where prior is nonzero.
READ GRAD	Read constant gradient matrix.
SHORT RUN	Stop after one period.
RUN 1 YEAR	Stop after 1 year.
RUN 2 YEARS	Stop after 2 years.
RUN 3 YEARS	Stop after 3 years.
RUN 4 YEARS	Stop after 4 years.
RUN 5 YEARS	Stop after 5 years.

C. For a full 20 year simulation run use, CLASS=L,TIME=(60,00).
This will give the job a maximum of 60 minutes of CPU time and will not be run until after 6 PM.
(TIME may need to be altered depending on the complexity and size of the simulation area.)

4. If any of the followin options are used:
PERM PATTERN
PERIOD RIVER
RECH PATTERN
PERIOD RECH
then SIMPP must also be copied from the master and the following Job Control Language (JCL) change must be made:
&PPMLIB must be changed to &SECLIB on the following line,
```
//SIMPP DD DISP=SHR,DSN=&PPMLIB(SIMPP)   (STO)
```
so that the line looks like,
```
//SIMPP DD DISP=SHR,DSN=&SECLIB(SIMPP)   (STO)
```

SIMIN controls the input to the simulation run. Changes necessary for a standard run are shown in Table XI. All $-codes are to be altered as indicated.

SIMPP controls Print Plot operations that allow for pattern Permeability, pattern Recharge, periodic Recharge, periodic River. If SIMPP is to be altered, copy SIMPP is indicated. Alter the JCL in SIMJOB as indicated. Make the necessary changes to SIMPP as documented in Table XII.

Four data sets are needed for the output from the simulation. These data sets may be created by using the clist ALSIM. ALSIM will request the following parameters:

SECT - the 4 character file name for the reach. Equivalent to $NAME in Table X.

DSN - a 3 character descriptive file name usually of the form AYYMMDDB where,
A - subreach designation. Usually subreach 1 -> A, subreach 2 -> B, subreach C -> C, etc.
YY - last 2 digits of current year.
MM - numeric equivalent of the current month.

TABLE XII

SIMPP EDIT OPTIONS

Code	Units	Description
$PERM1	ft/sec*	Permeability value for pattern = 1.
$PERM2	ft/sec*	Permeability value for pattern = 2.
$PERM. . .		
$RECH1	ft/sec**	Recharge value for pattern = 1.
$RECH2	ft/sec**	Recharge value for pattern = 2.
$RECH. . .		
$REON	-----	First time step to turn on recharge.
$REOF	-----	First time step to turn off recharge.
$RION	-----	First time step to turn on river.
$RIOF	-----	First time step to turn off river.
$R1TM	-----	Number of time steps in "on" cycle.
$R2TM	-----	Number of time steps in "off" cycle.

* gpd/ft^2 if <PERM GPD/FT2 option is used in SIMJOB.

** in/yr if <RECH IN/YR option is used in SIMJOB.

DD - date.
B - character to indicate the run of the day. For instance, first run -> A, second run -> B, etc.

For calibration, designate the DSN as A000000A to be used as a master output file. When the output needs to be saved for future reference, allocate the files with the current year, month, and day as described above and copy from the master (A000000A) using ALSIM.

The files created and their data characteristics are:

FILE	RECEM	LRECL	BLKSIZE	GRACE
AYYMMDDB.F00	V B A	137	7448	TR(10,10)
AYYMMDDB.F05	F B	80	7440	TR(5,5)
AYYMMDDB.F06	VBA	137	7448	TR(10,10)
AYYMMDDB.F20	V B S	20000	6160	TR(20,20)

These files must be created before SIMJOB is submitted.

V. Calibration

Calibration is by far the most challenging and least exact part of computer modeling. If the reasonable adjustment of the initial input parameters so as to best approximate real life conditions.

A. One-Year Calibration

1. A one-year run is made to check to see if all parameters are correctly entered.

2. Before making this run, check for certain things

   a. M=-1 if a water-table aquifer
      M=+1 if a confined (artesian) aquifer
   b. Make sure STRT is below LAND and at least 6-7 feet above BOTTOM
   c. Make sure TOP is below river elevation STRT
   d. Make sure all matrices have been entered correctly. This includes having gradient nodes in the following matrices:

LAND
STRT
BOTTOM
T/PERM
SY

B. Five-Year Calibration

1. Five-year calibration runs are made with no pumping so as to approximate steady state conditions as closely as possible.

2. Parameters directly used to calibrate:
   a. Drop-River
   b. Rate = Leakage (outflow)
   c. Recharge (QRE) (inflow)

   Drop-River is used to induce groundwater flow to the river. Rate is used to increase or decrease leakage (outflow) and recharge is used to increase or decrease inflow. All three of these parameters must be simultaneously adjusted until a five-year run can be made where steady-state conditions are closely approximated. The user wants to come as close to a steady condition as possible without creating a gaining system. Net storage after five year calibration runs should be ≤ 0.

3. Problems to check for
   a. Drop-river must not be so large as to force TOP below BOTTOM.
   b. Large pumping in narrow reaches can cause groundwater to flow improperly through that certain part of the reach. Transmissivity and STRT must be adjusted to force the water downstream.
   c. Along tributaries, water must be allowed to flow through more than one node when connecting to the main aquifer. Sometimes it becomes necessary to add nodes to keep the water from piling up in the tributary.
   d. The shape of the matrix is important: extraneous nodes are undesirable because they create problems.
   e. There can be no more than 7 feet head change between nodes. Greater head changes between nodes cause the program to react eratically.
   f. Bottom may be too jagged for the model and may have to be smoothed somewhat.

C. Twenty-Year Run

1. Allocations are picked; usually 1 and 2 ac-ft/hr and are plugged into the run.
   a. From these the user can tell where to aim his or her efforts to obtain >50% aquifer dry after 20 years.
   b. It may be necessary after the first 20 year runs to re-calibrate the five year runs so that a 20-year run can be completed.

2. Problems here are the same as in the one and five year runs.

APPENDIX E

TWENTY-YEAR GROUND-WATER BUDGETS FOR MODELED REACHES A, B, AND C, AND FOR THE TOTAL AQUIFER AREA

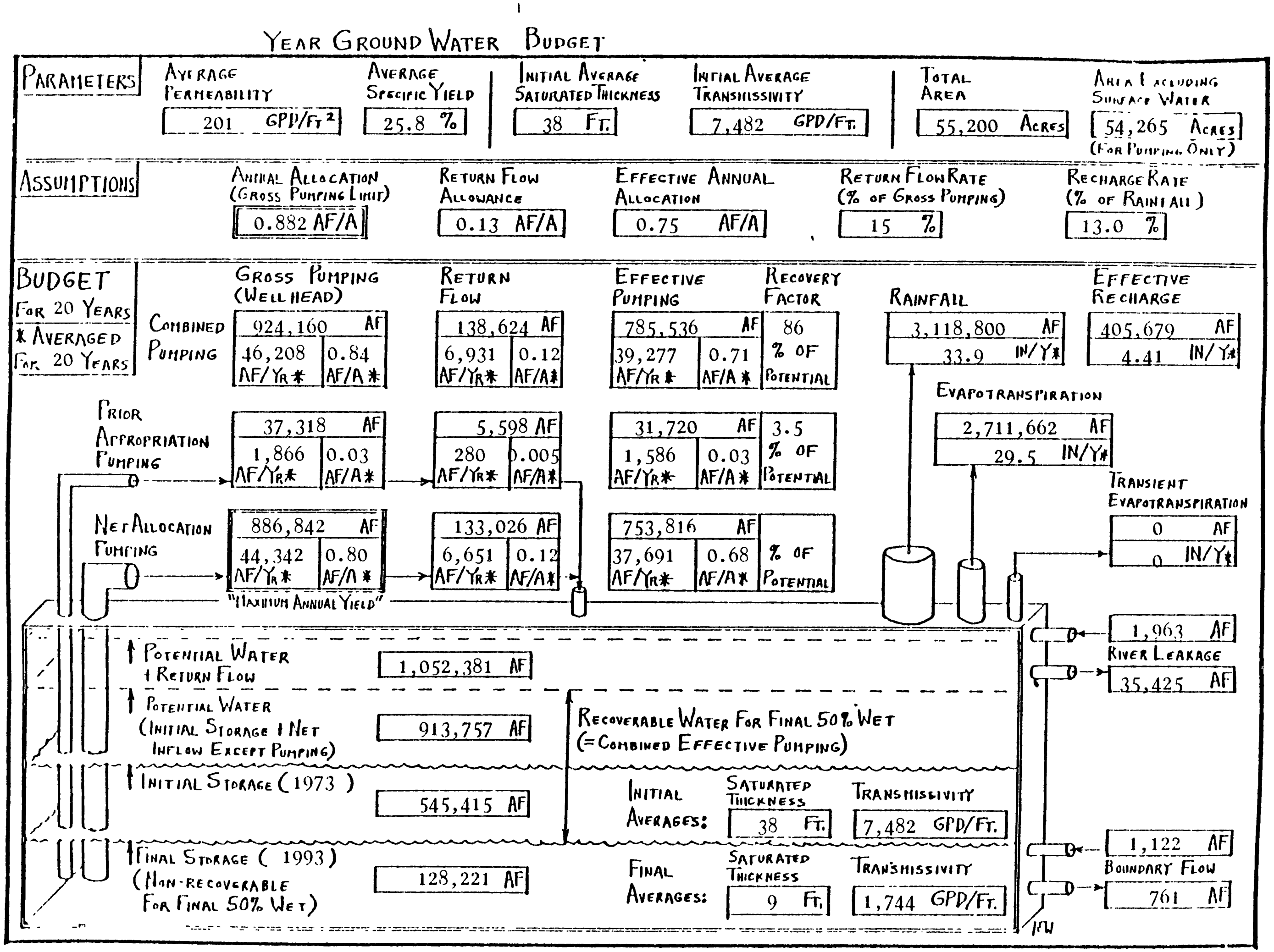


Figure 78. Ground-Water Budget for Modeled Reach A

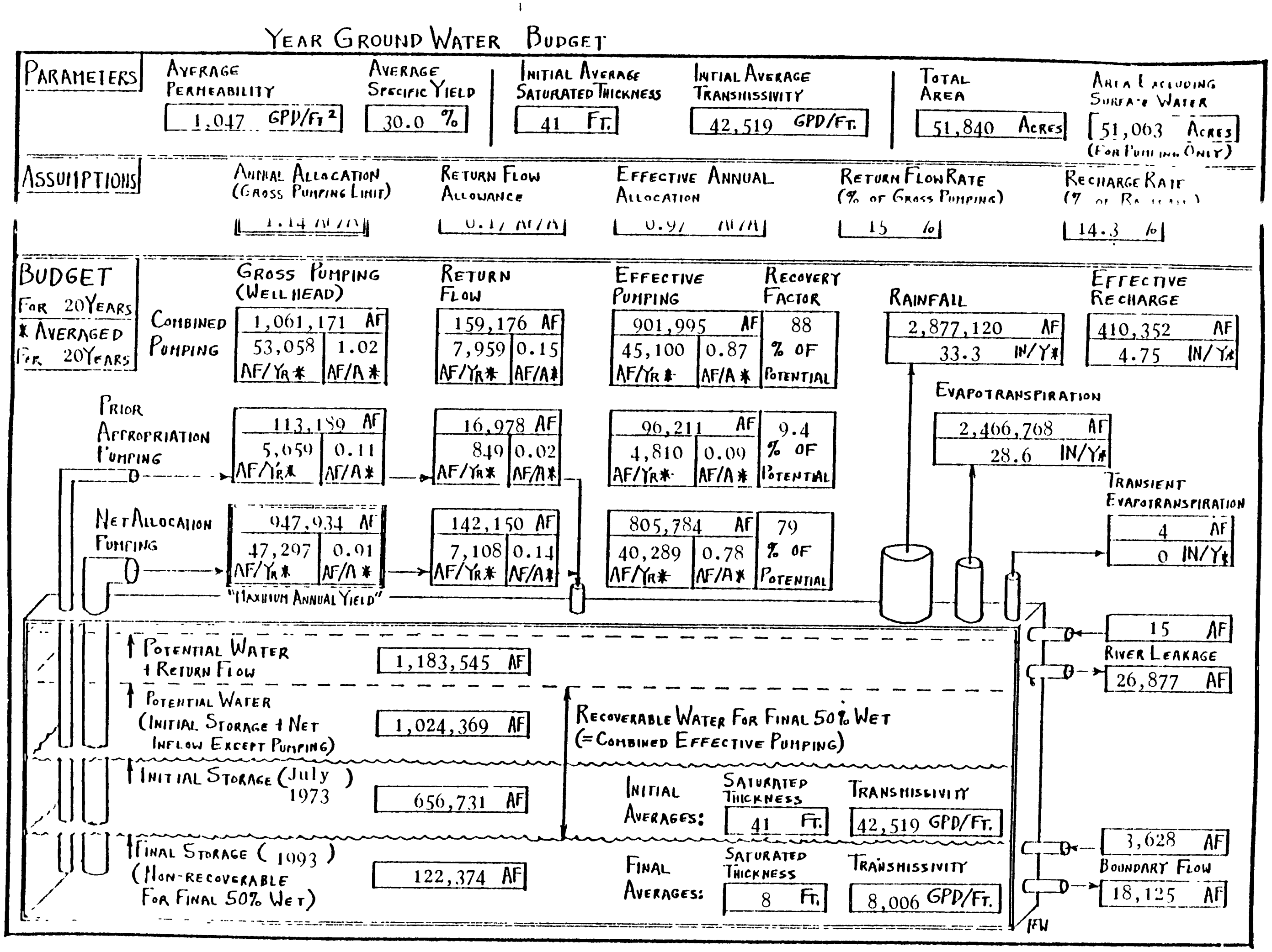


Figure 79. Ground-Water Budget for Modeled Reach B

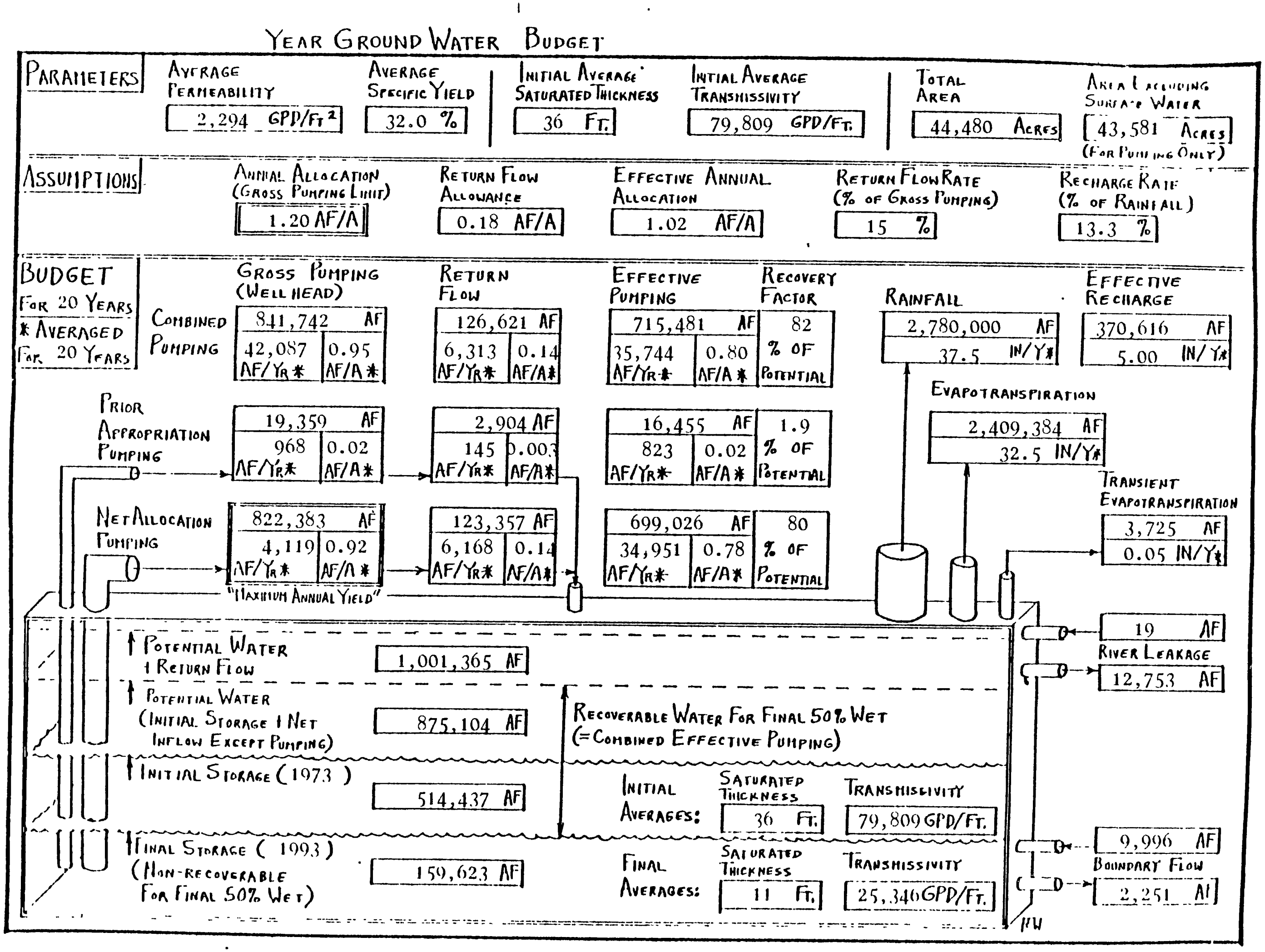


Figure 80. Ground-Water Budget for Modeled Reach C

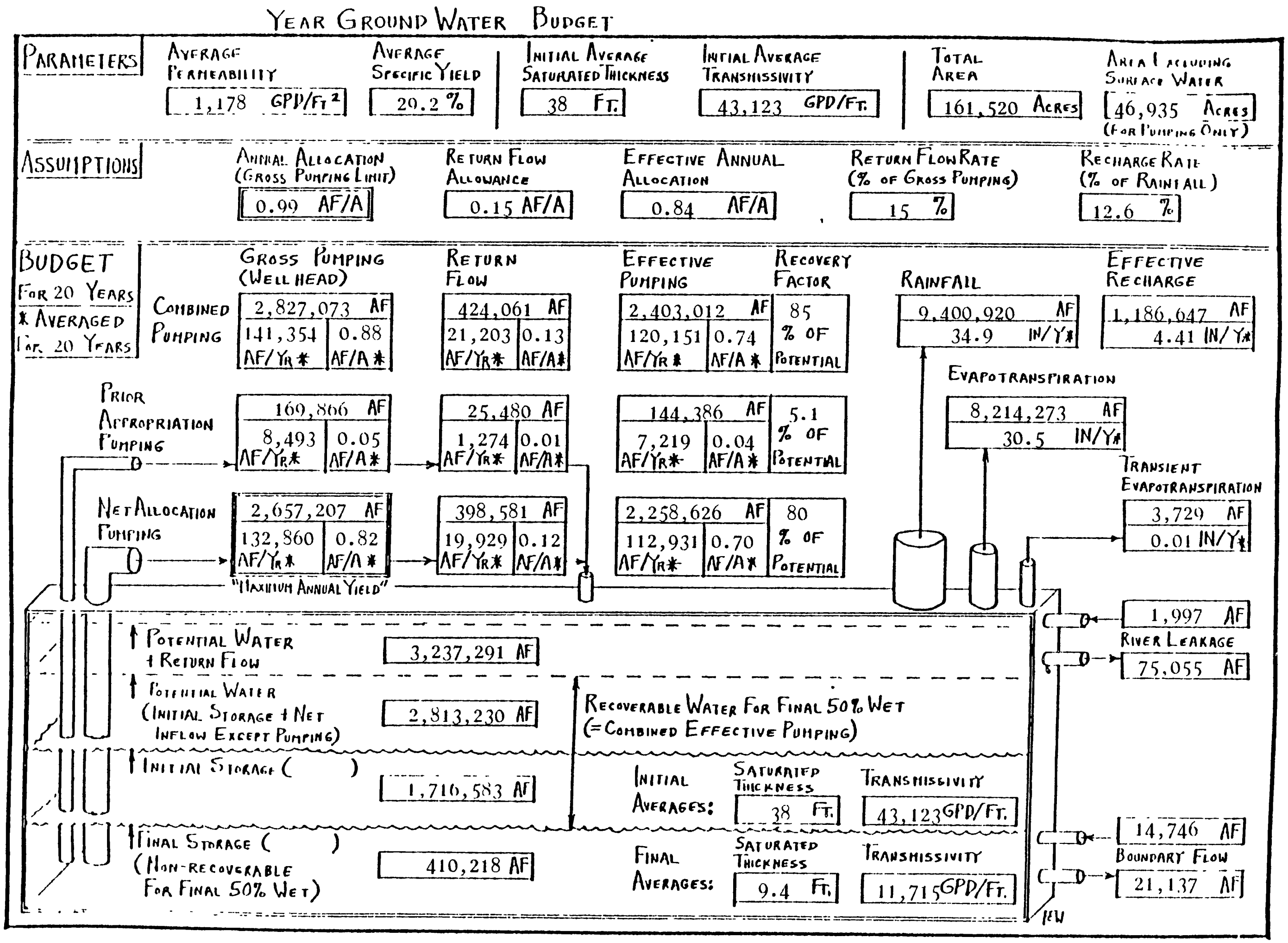


Figure 81. Ground-Water Budget for the Total Aquifer Area (Modeled Reaches A, B, and C

APPENDIX F

MASS BALANCE OF FULL ALLOCATION PUMPING

FROM JULY 1, 1973 TO JULY 1, 1993 FOR

MODELED REACHES A, B, AND C

TABLE XIII

MASS BALANCE OF FULL ALLOCATION PUMPING FROM JULY 1, 1973 TO JULY 1, 1993 (Modeled Reach A)

	Average Annual (acre feet)		Twenty Year Total (acre feet)	
	Inflow	Outflow	Inflow	Outflow
Recharge	20,581	0	407,369	0
Pumpage	0	-123,323	0	-785,945
River Leakage	0	0	1,963	-37,593
Subsurface Flow	39	-28	1,129	-765
Evapotranspiration				
TOTALS	20,620	-123,351	410,461	-824,303
Net Storage		-102,731		-413,842

Irrigation allocation for Upper Modeled Reach is 48,686 ac-ft/yr or 0.882 ac-ft/ac/yr

TABLE XIV

MASS BALANCE OF FULL ALLOCATION PUMPING FROM JULY 1, 1973 TO JULY 1, 1993 (Modeled Reach B)

	Average Annual (acre feet)		Twenty Year Total (acre feet)	
	Inflow	Outflow	Inflow	Outflow
Recharge	20,818	0	412,062	0
Pumpage	0	-111,889	0	-903,274
River Leakage	0	0	15	-27,132
Subsurface Flow	104	-321	3,653	-18,269
Evapotranspiration		0		-13
TOTALS	20,922	-112,210	415,730	-948,688
Net Storage		-91,289		-532,959

Irrigation allocation for Middle Modeled Reach is 59,098 ac-ft/yr or 1.14 ac/ft/ac/yr.

TABLE XV

MASS BALANCE OF FULL ALLOCATION PUMPING FROM
JULY 1, 1973 TO JULY 1, 1993
(Modeled Reach C)

	Average Annual (acre feet)		Twenty Year Total (acre feet)	
	Inflow	Outflow	Inflow	Outflow
Recharge	18,803	0	372,160	0
Pumpage	0	-106,797	0	-715,687
River Leakage	0	0	19	-12,994
Subsurface Flow	285	-91	10,061	-2,270
Evapotranspiration		0		-4,322
TOTALS	19,088	-106,888	382,240	-735,273
Net Storage		-87,800		-353,033

Irrigation allocation for Lower Modeled Reach is 53,376 ac-ft/yr or 1.20 ac-ft/ac/yr

APPENDIX G

ALLOCATION WATER TABLE MAPS FOR JULY 1, 1973 AND JULY 1, 1993 FOR MODELED REACHES A, B, AND C

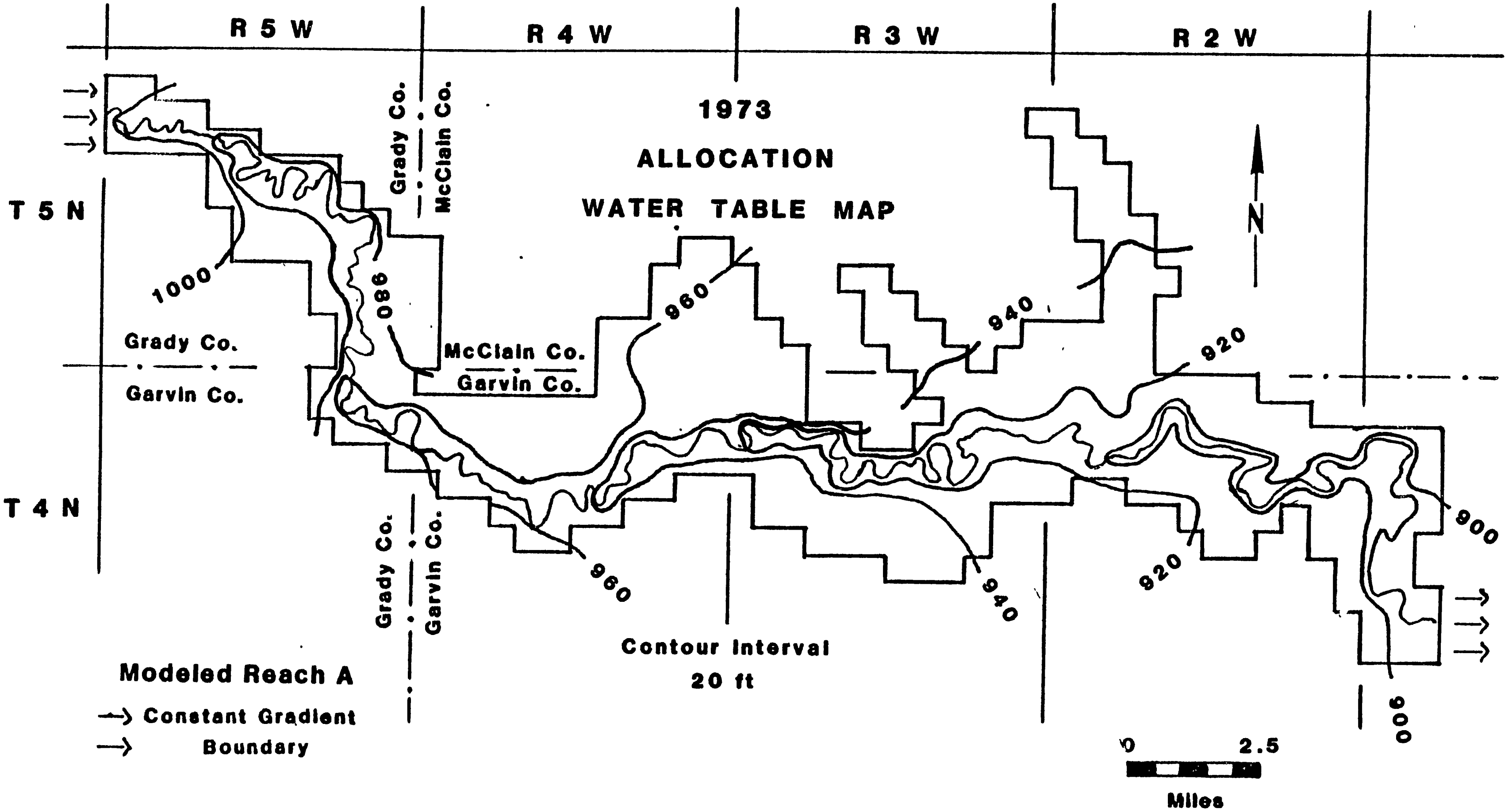


Figure 82. Allocation Water Table Map, 1973 - Modeled Reach A

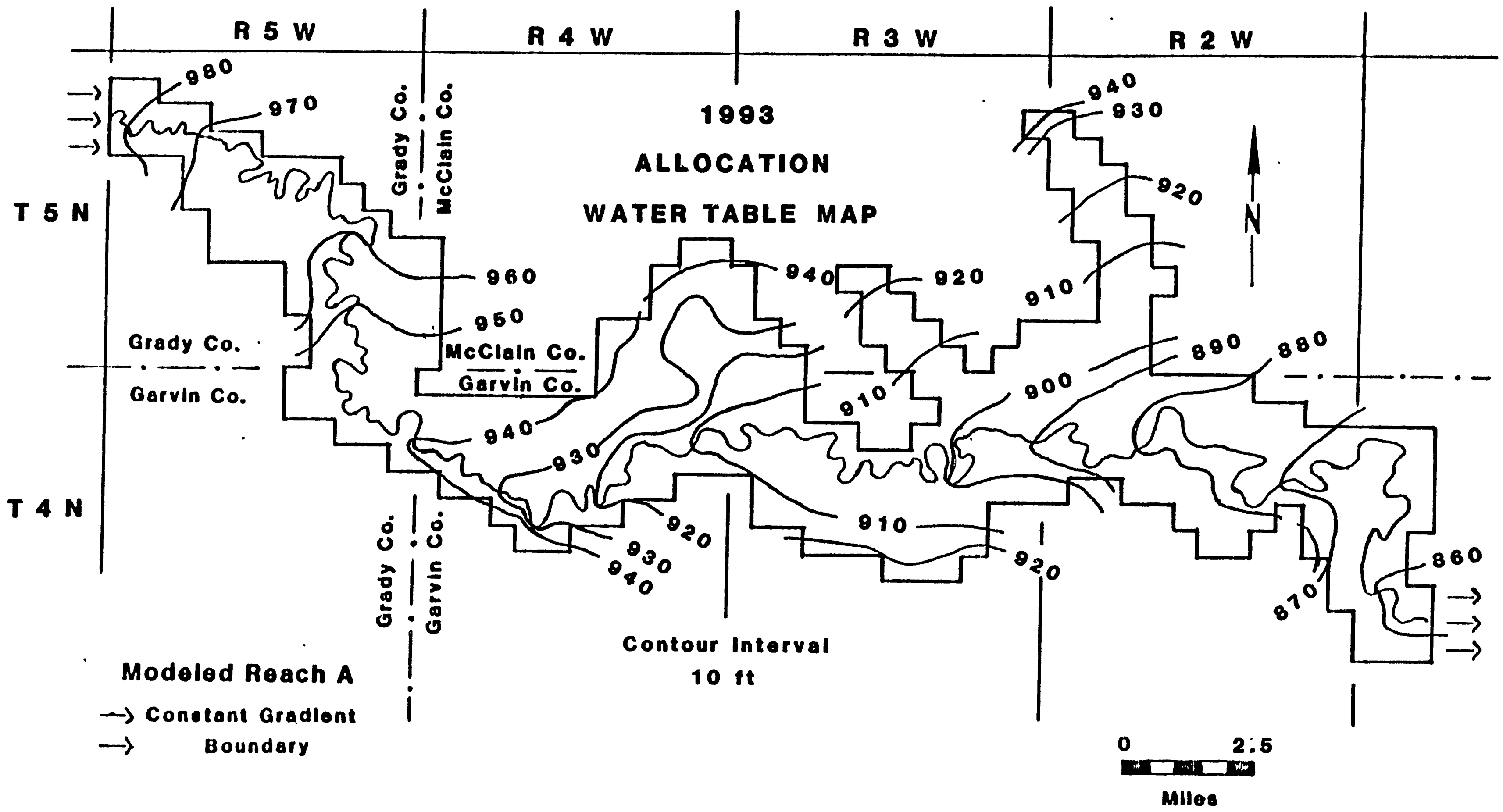


Figure 83. Allocation Water Table Map, 1993 - Modeled Reach A

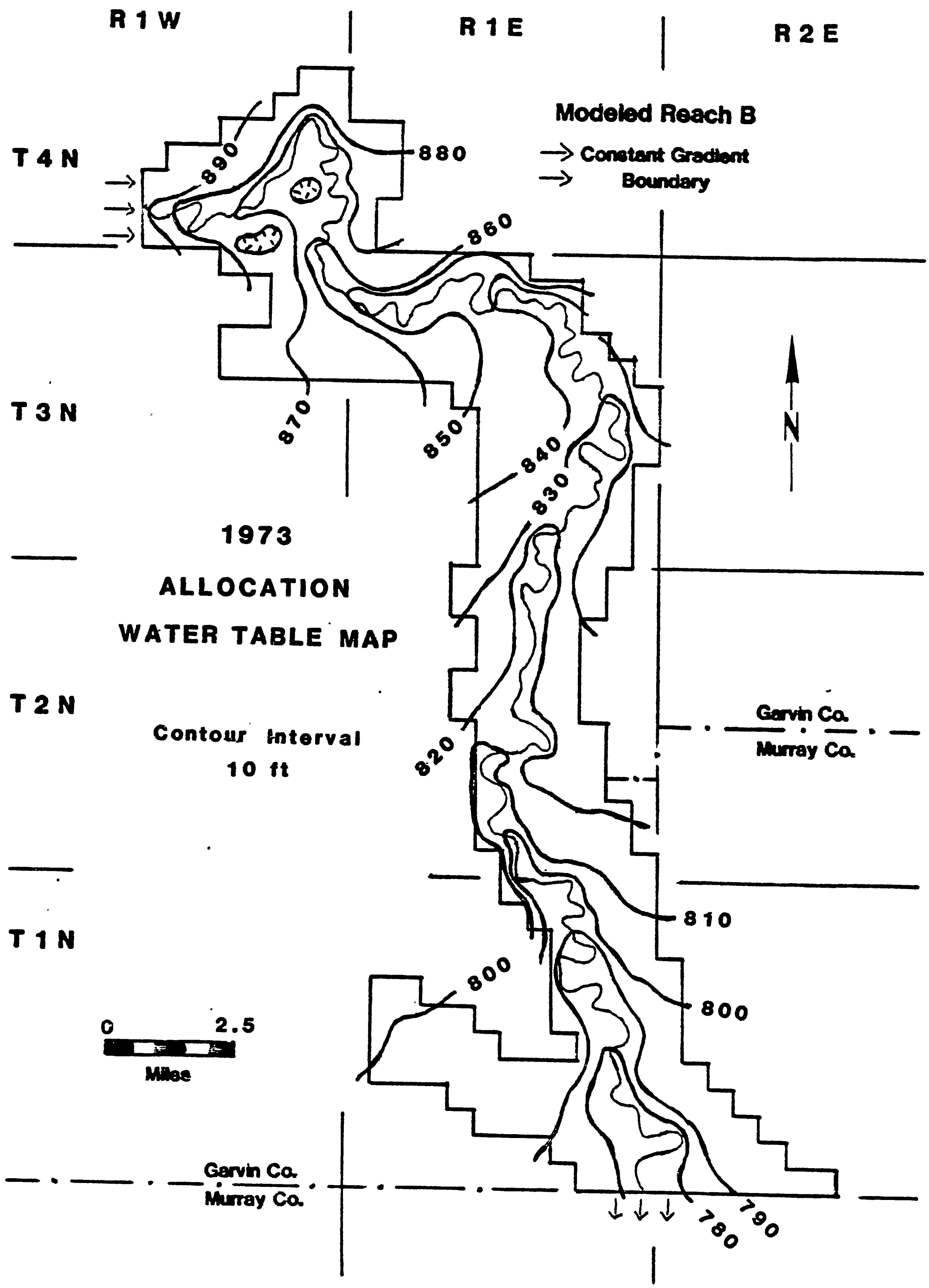


Figure 84. Allocation Water Table Map, 1973 - Modeled Reach B

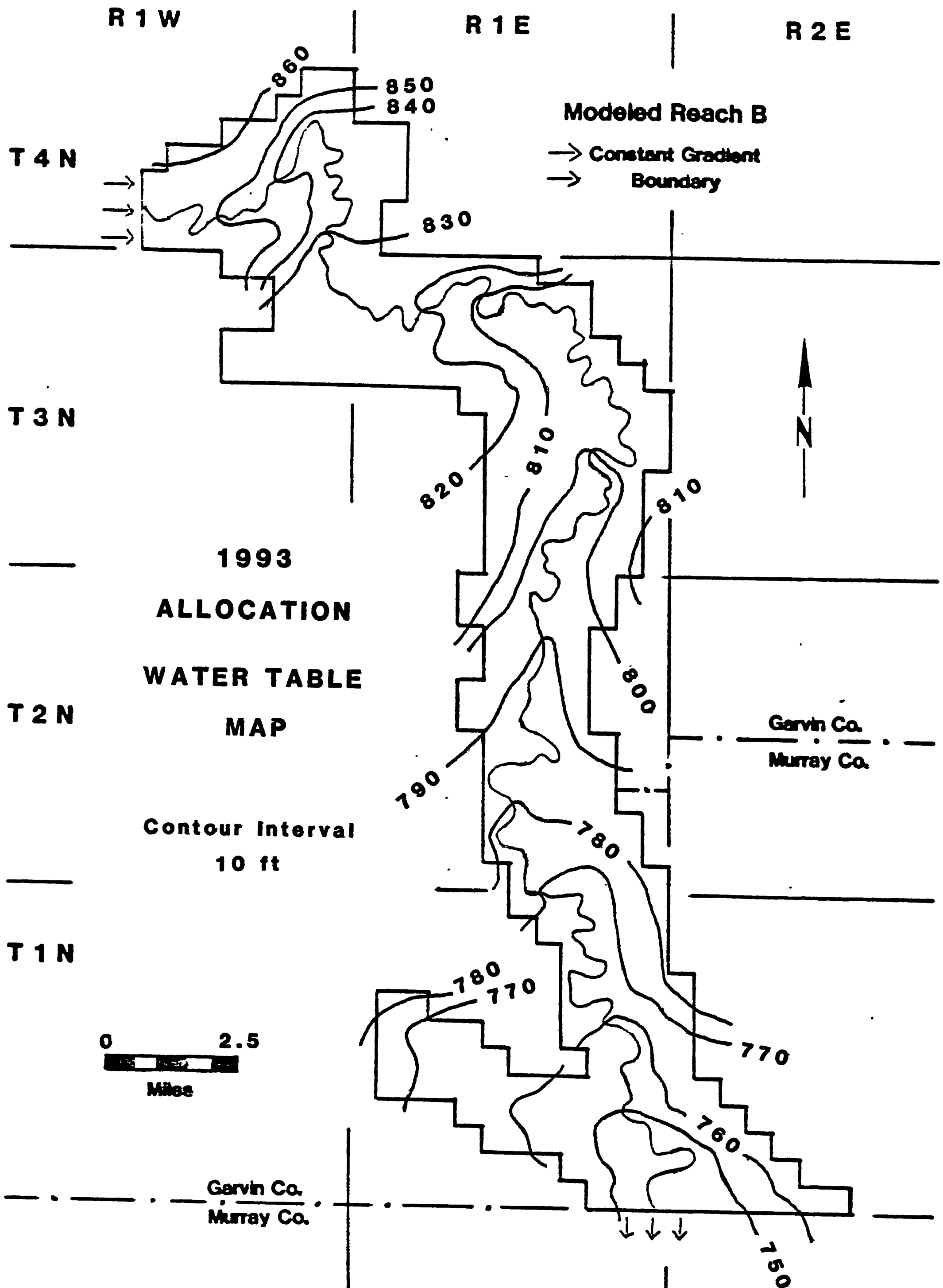


Figure 85. Allocation Water Table Map, 1993 - Modeled Reach B

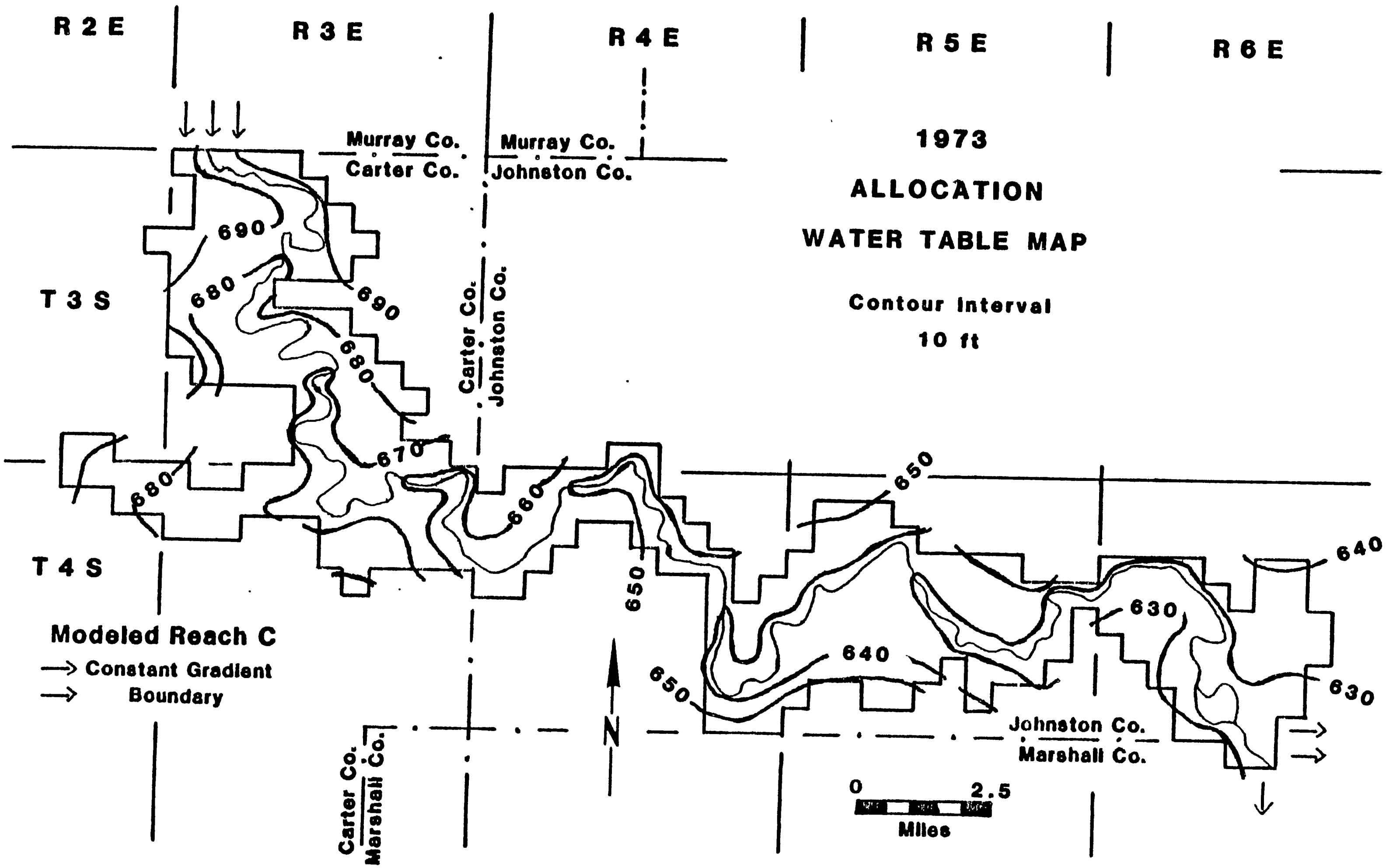


Figure 86. Allocation Water Table Map, 1973 - Modeled Reach C

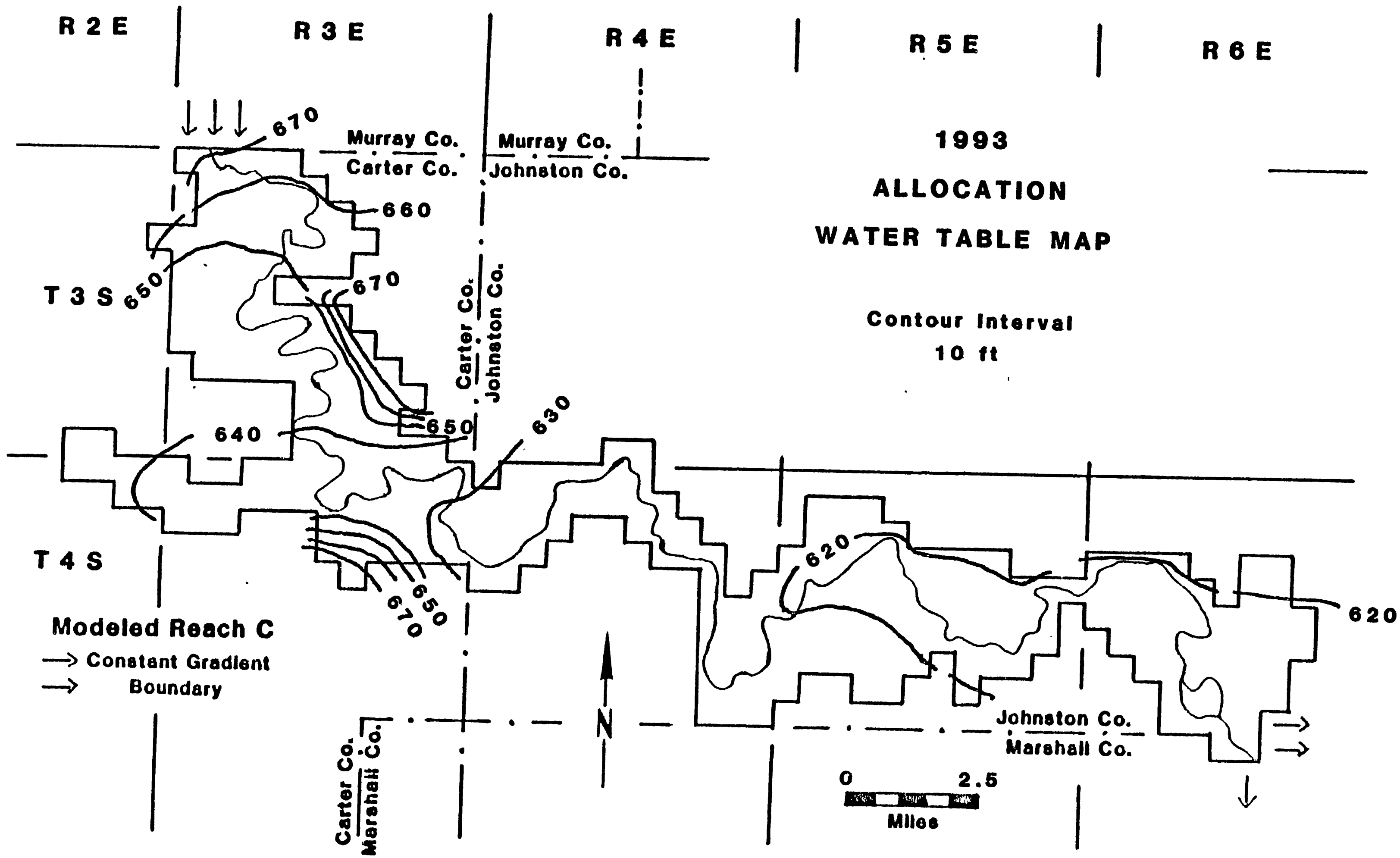


Figure 87. Allocation Water Table Map, 1993 - Modeled Reach C

APPENDIX H

CONFIGURATION OF TOP FOR MODELED REACHES A, B, AND C

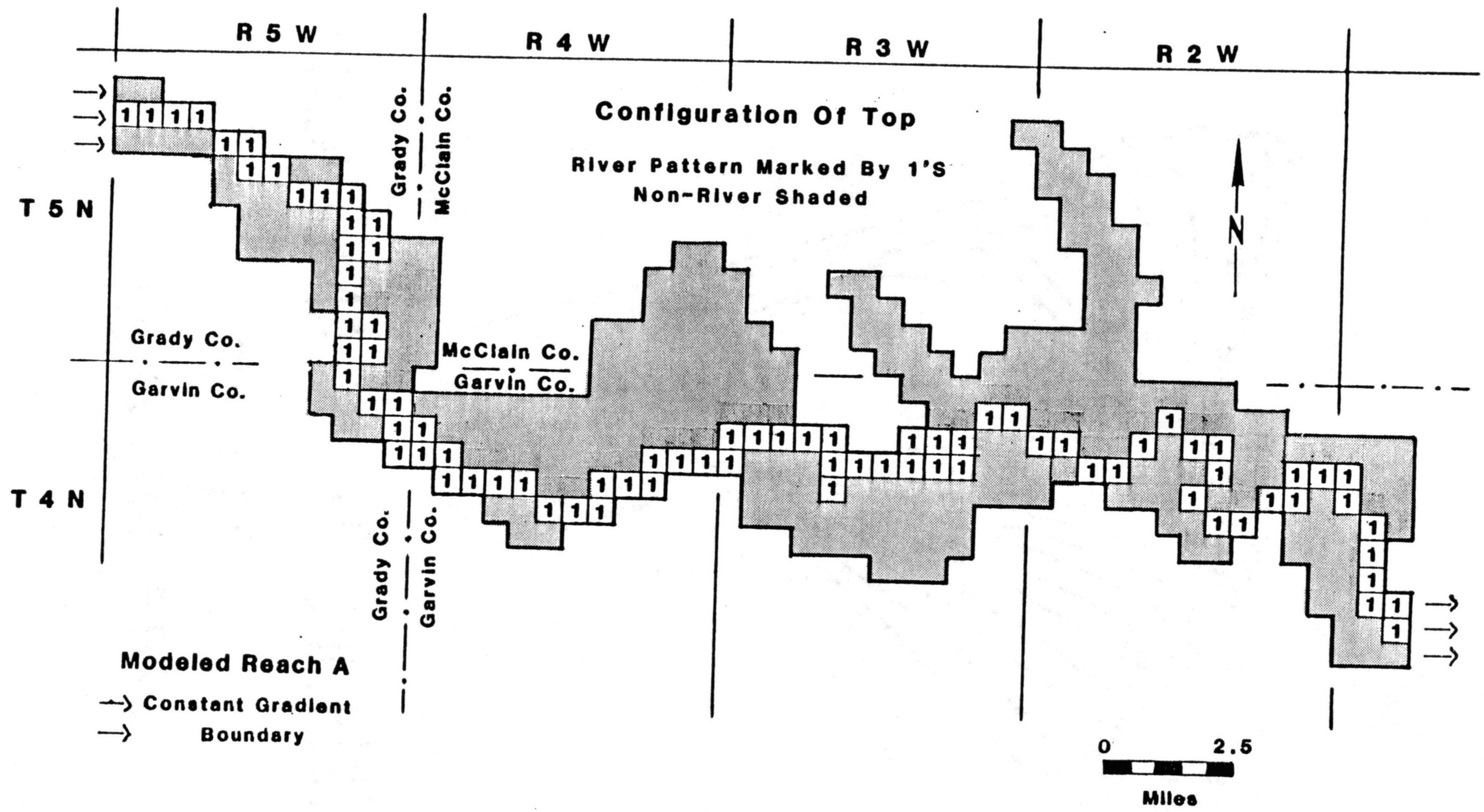


Figure 88. Configuration of Top - Modeled Reach A

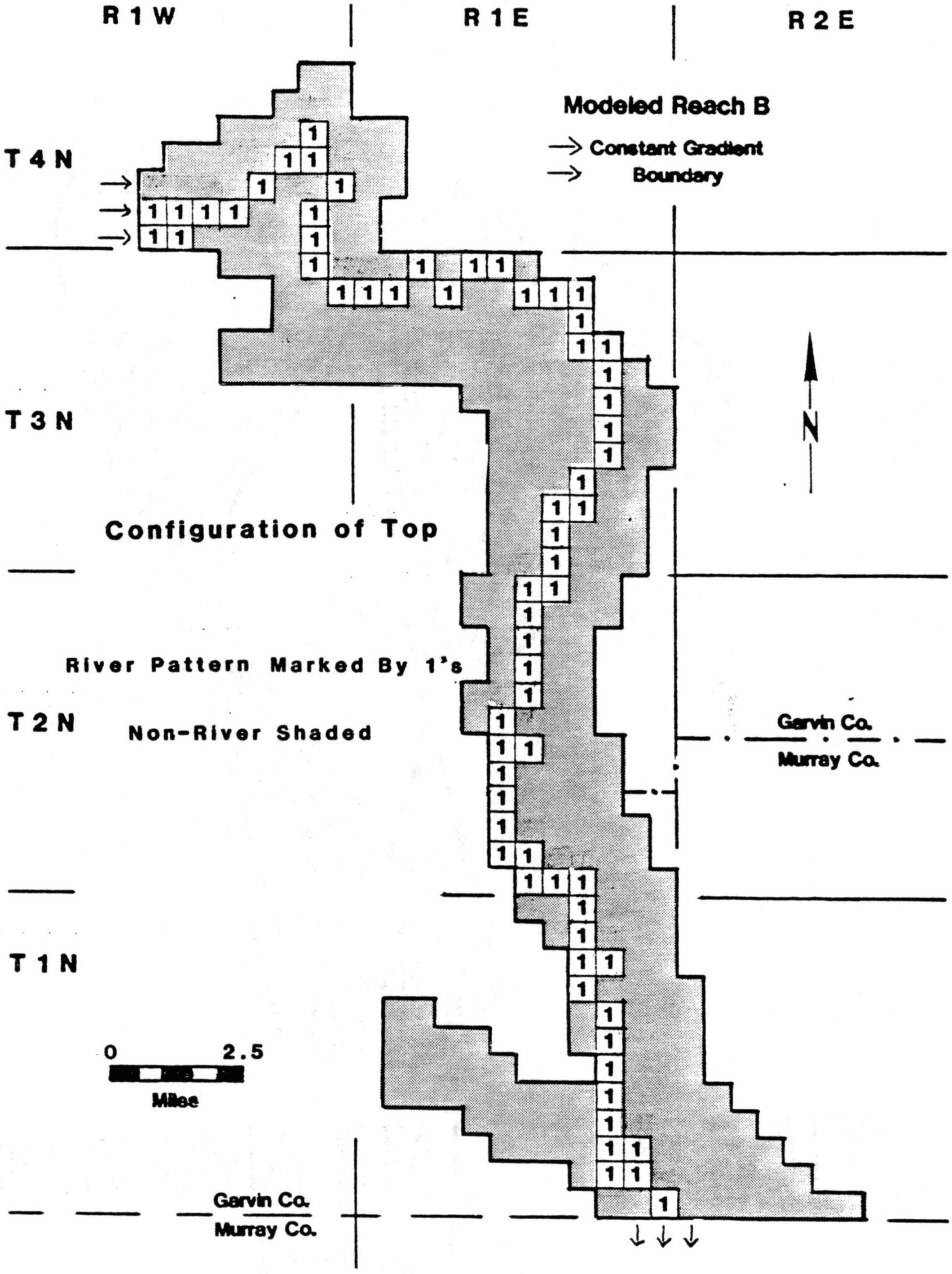


Figure 89. Configuration of Top - Modeled Reach B

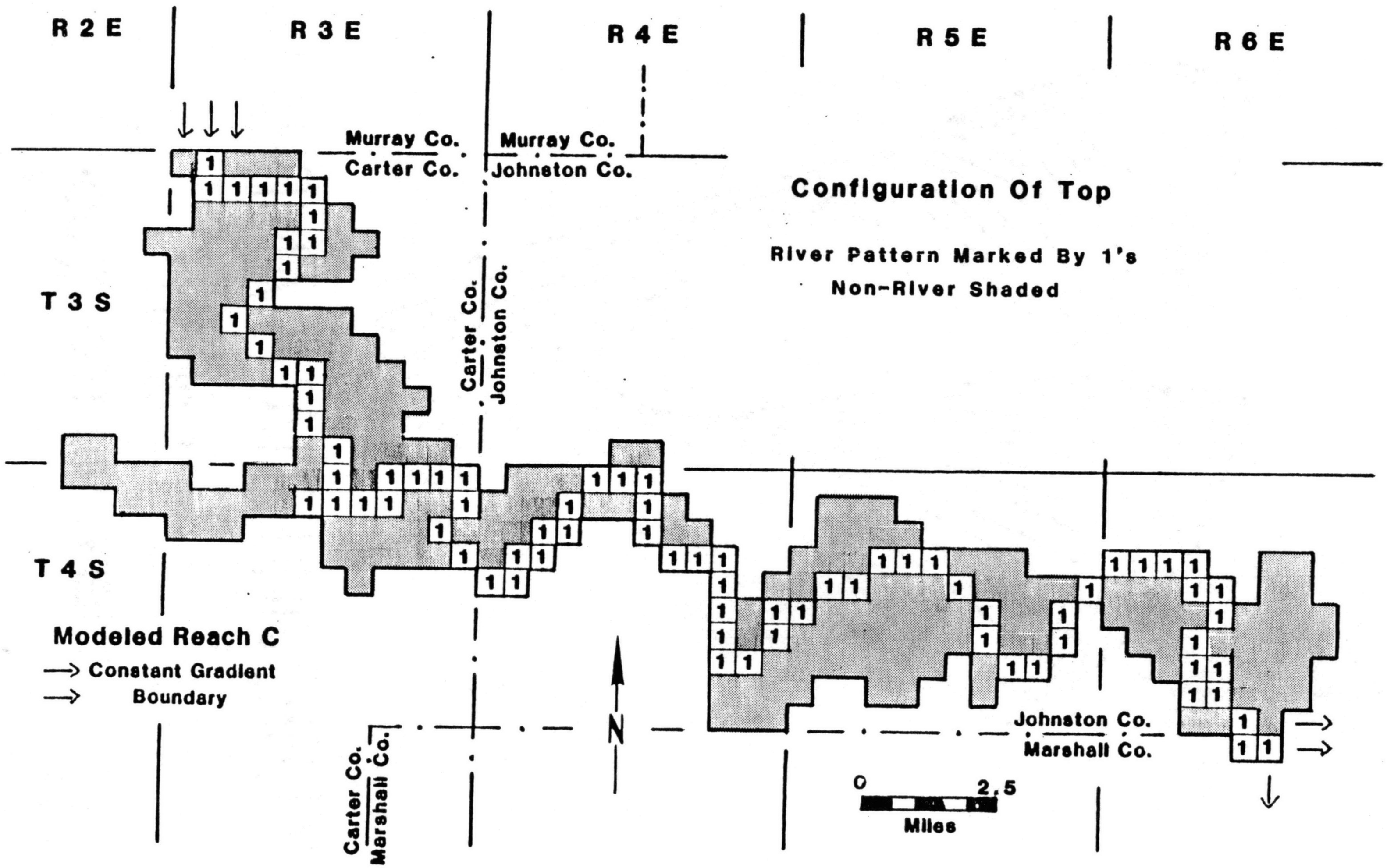


Figure 90. Configuration of Top - Modeled Reach C

APPENDIX I

BEDROCK ELEVATIONS, MODELED REACHES A, B, AND C

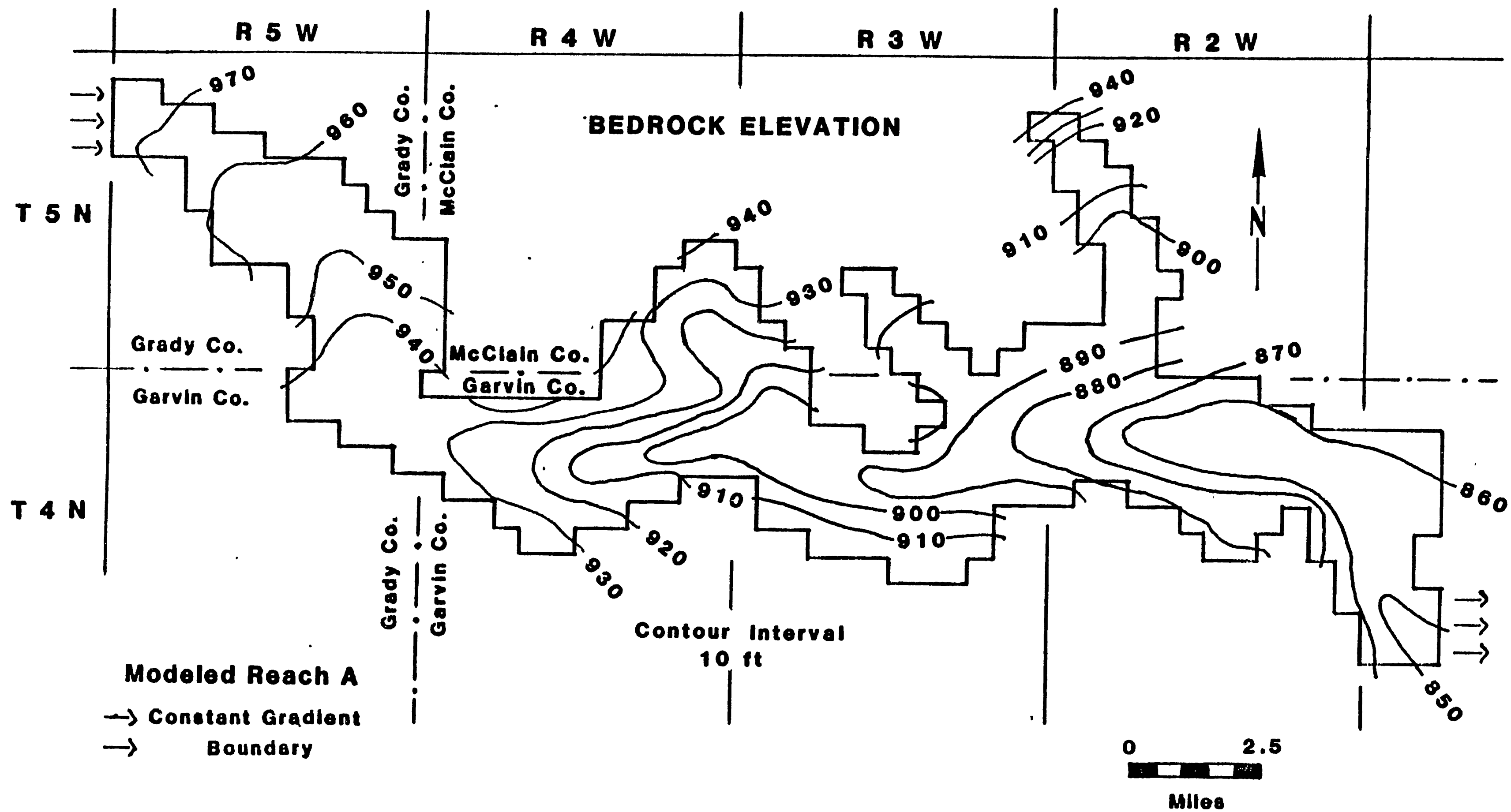


Figure 91. Bedrock Elevations - Modeled Reach A

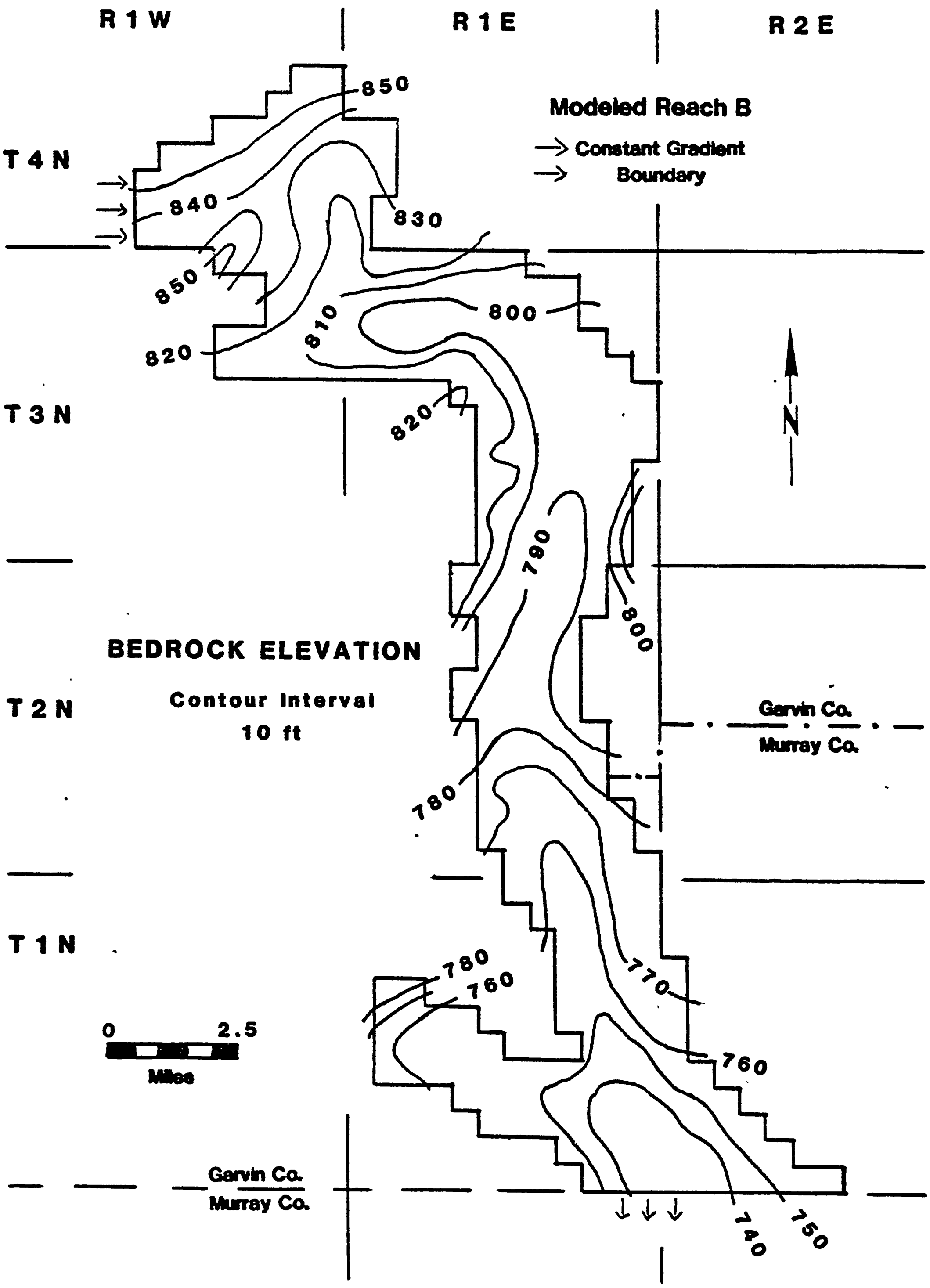


Figure 92. Bedrock Elevations - Modeled Reach B

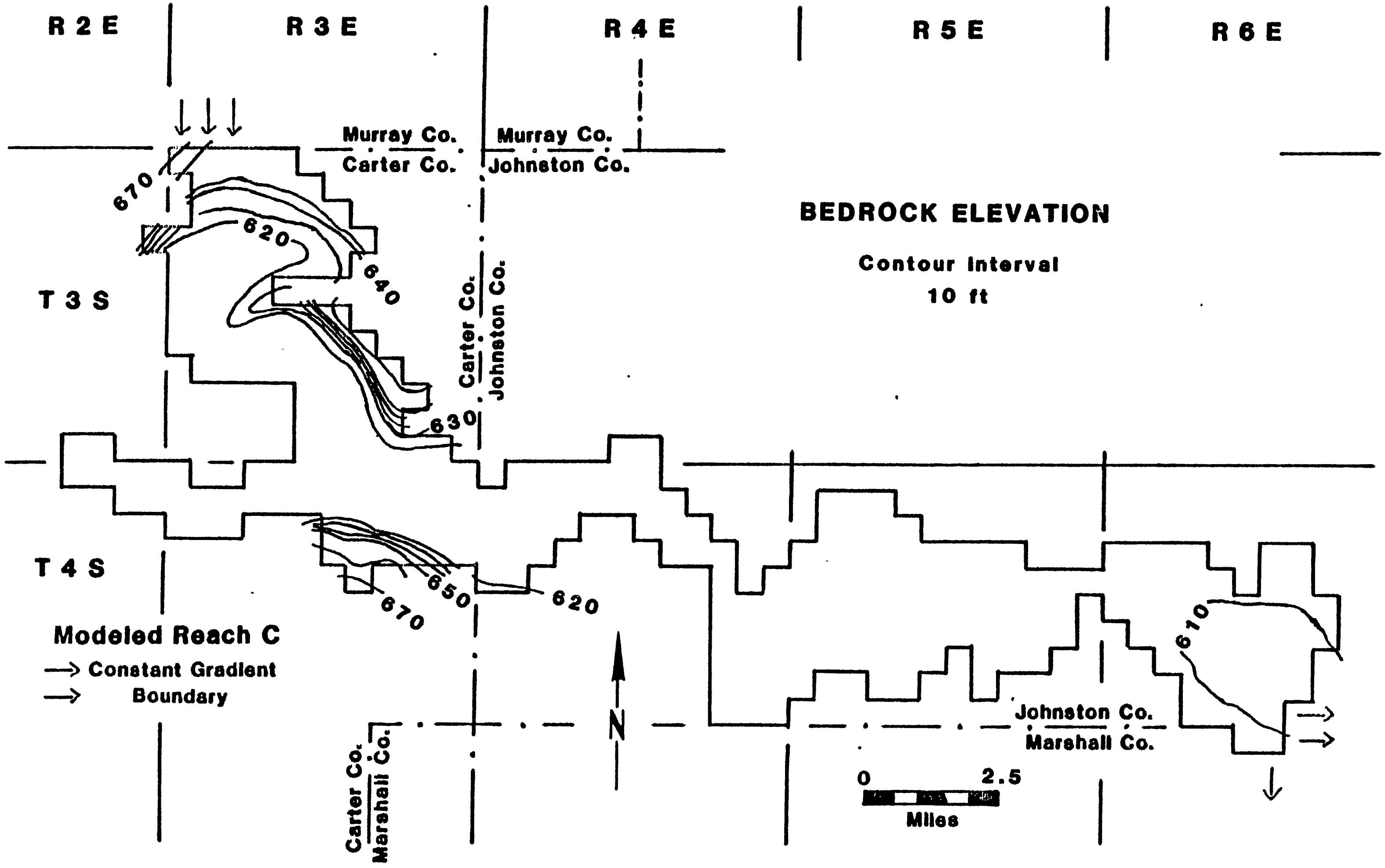


Figure 93. Bedrock Elevations - Modeled Reach C

APPENDIX J

ALLOCATION SATURATED THICKNESS MAPS FOR JULY 1, 1973, 1978, 1983, 1988, AND 1993 FOR MODELED REACHES A, B, AND C

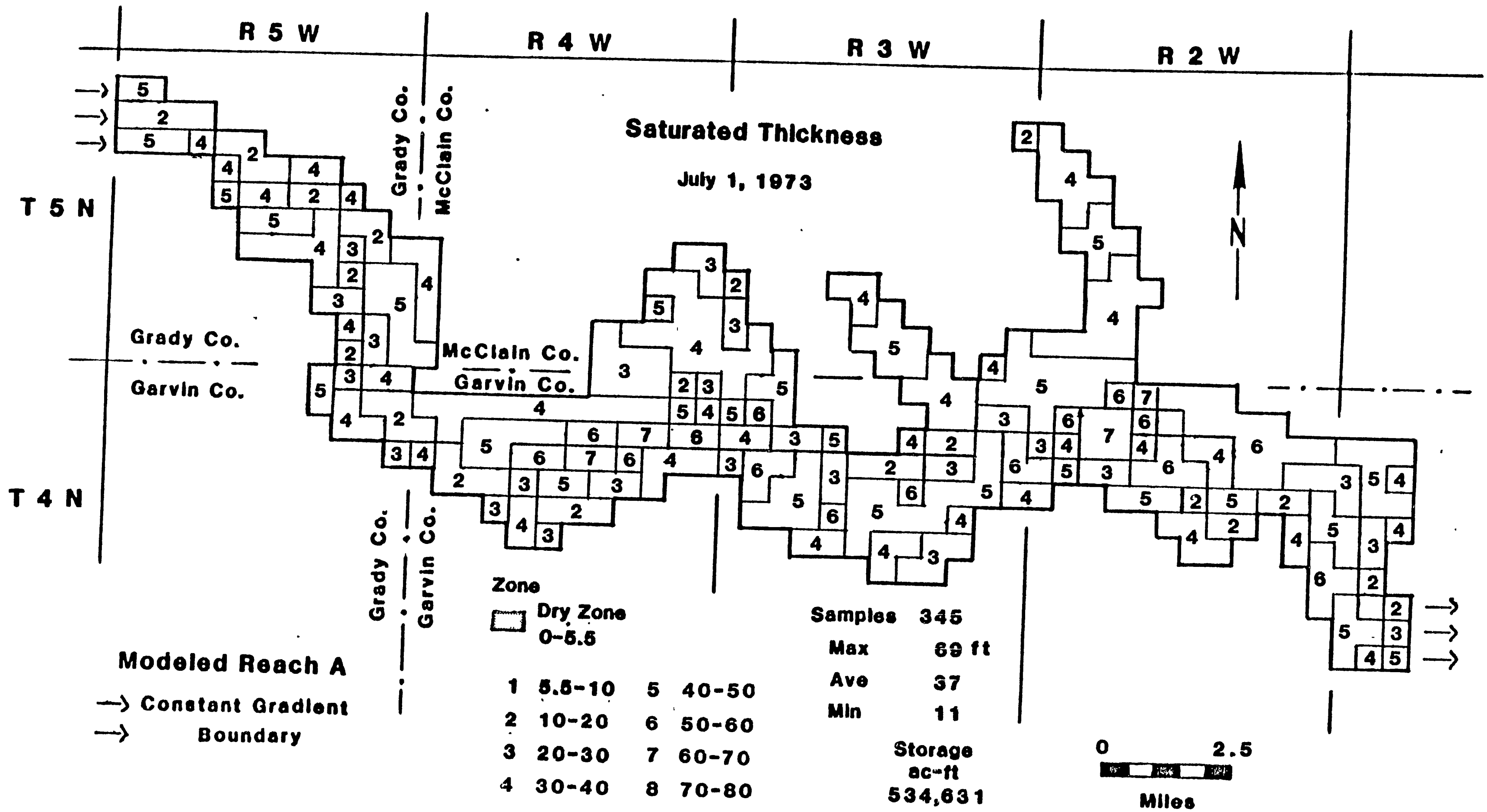


Figure 94. Allocation Saturated Thickness Map, 1973 - Modeled Reach A

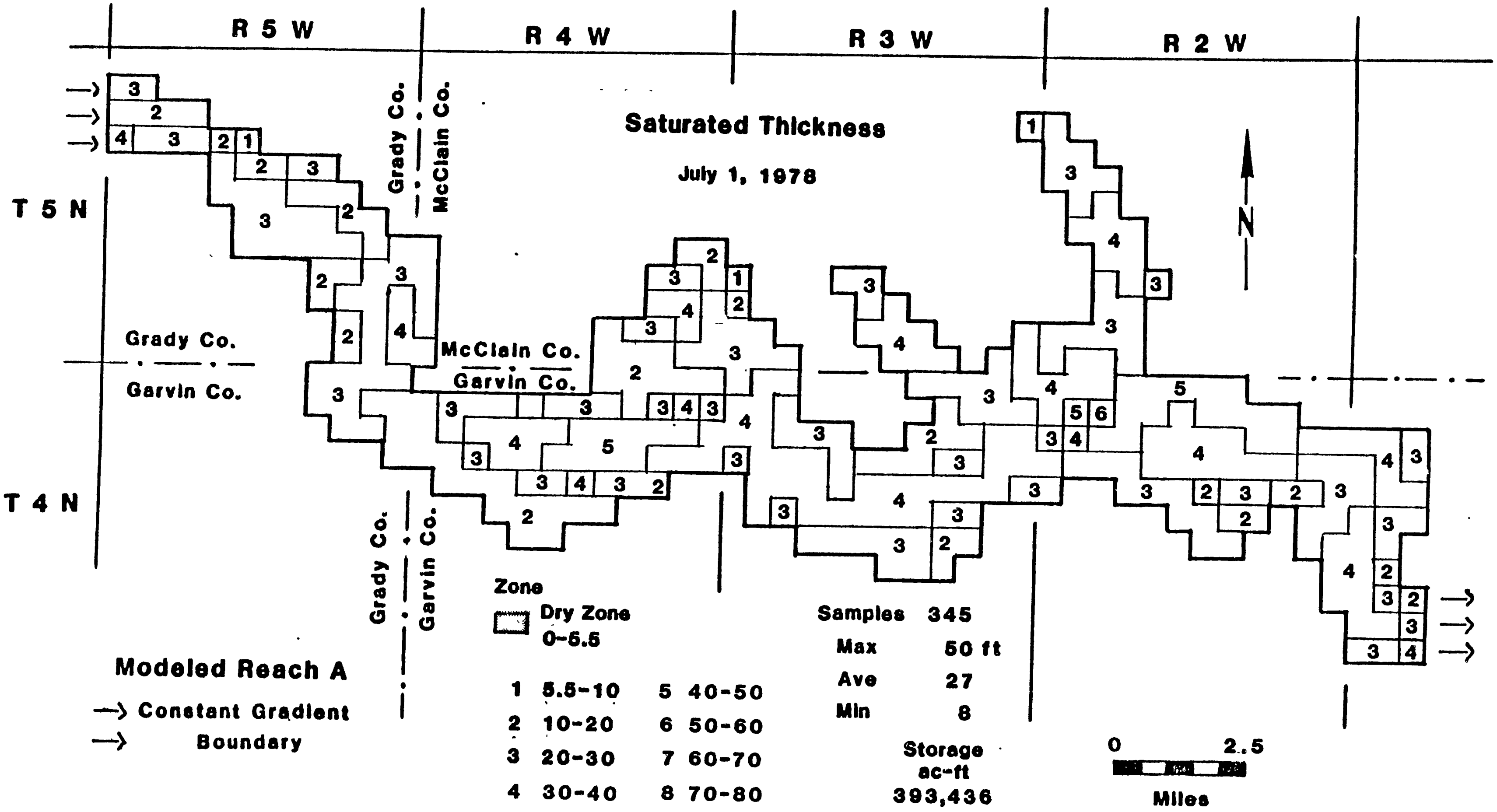


Figure 95. Allocation Saturated Thickness Map, 1978 - Modeled Reach A

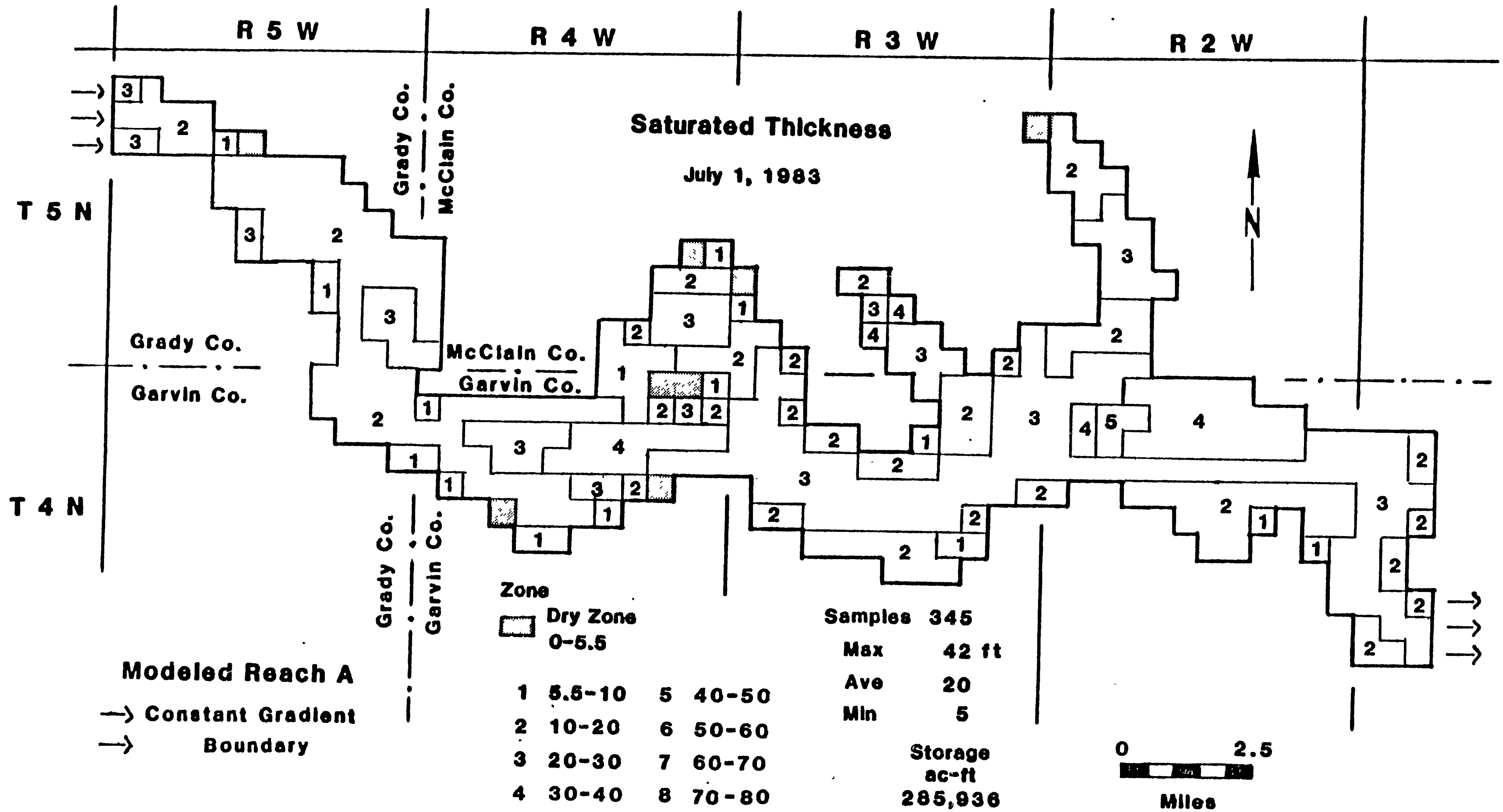


Figure 96. Allocation Saturated Thickness Map, 1983 - Modeled Reach A

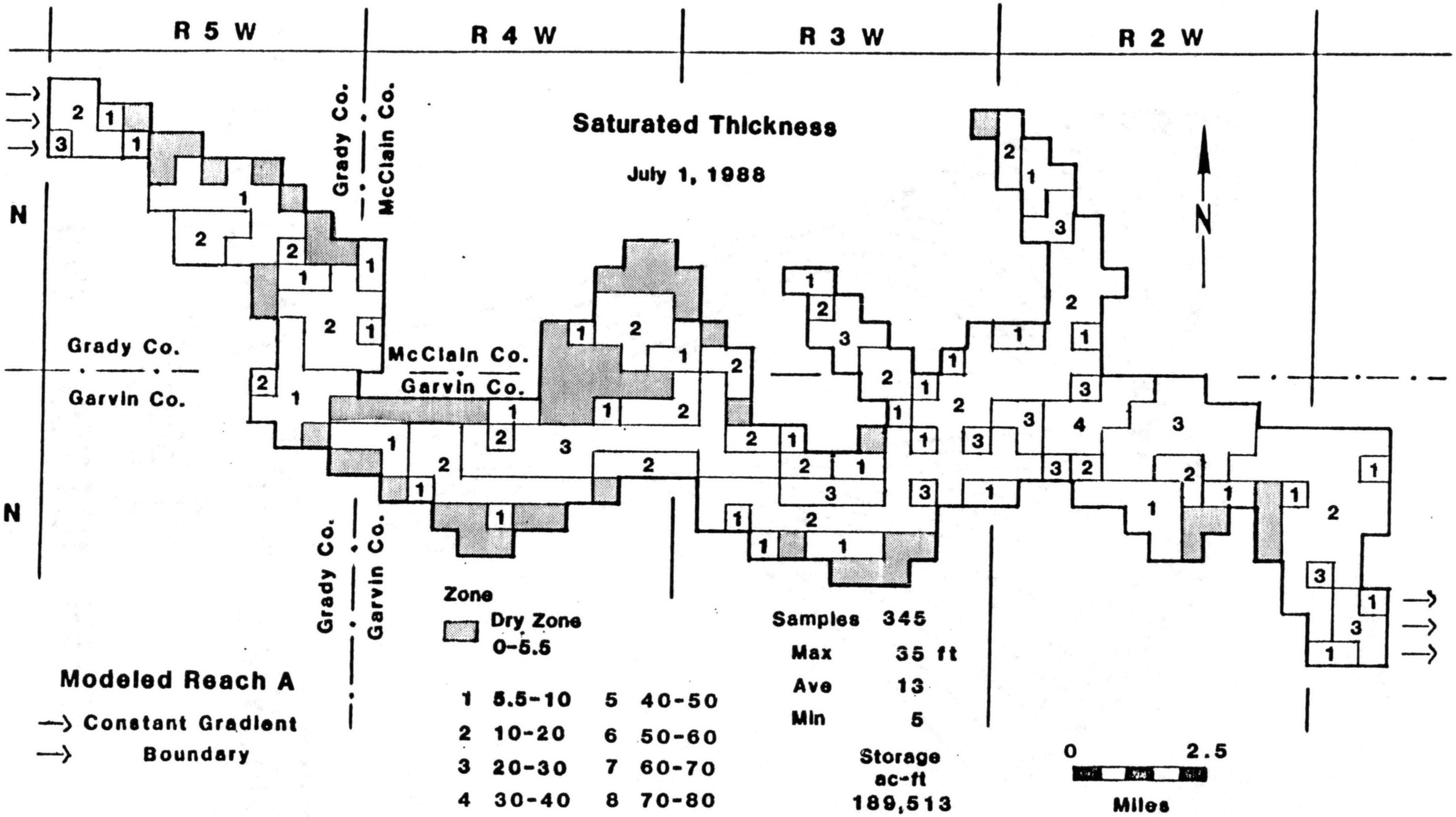


Figure 97. Allocation Saturated Thickness Map, 1988 - Modeled Reach A

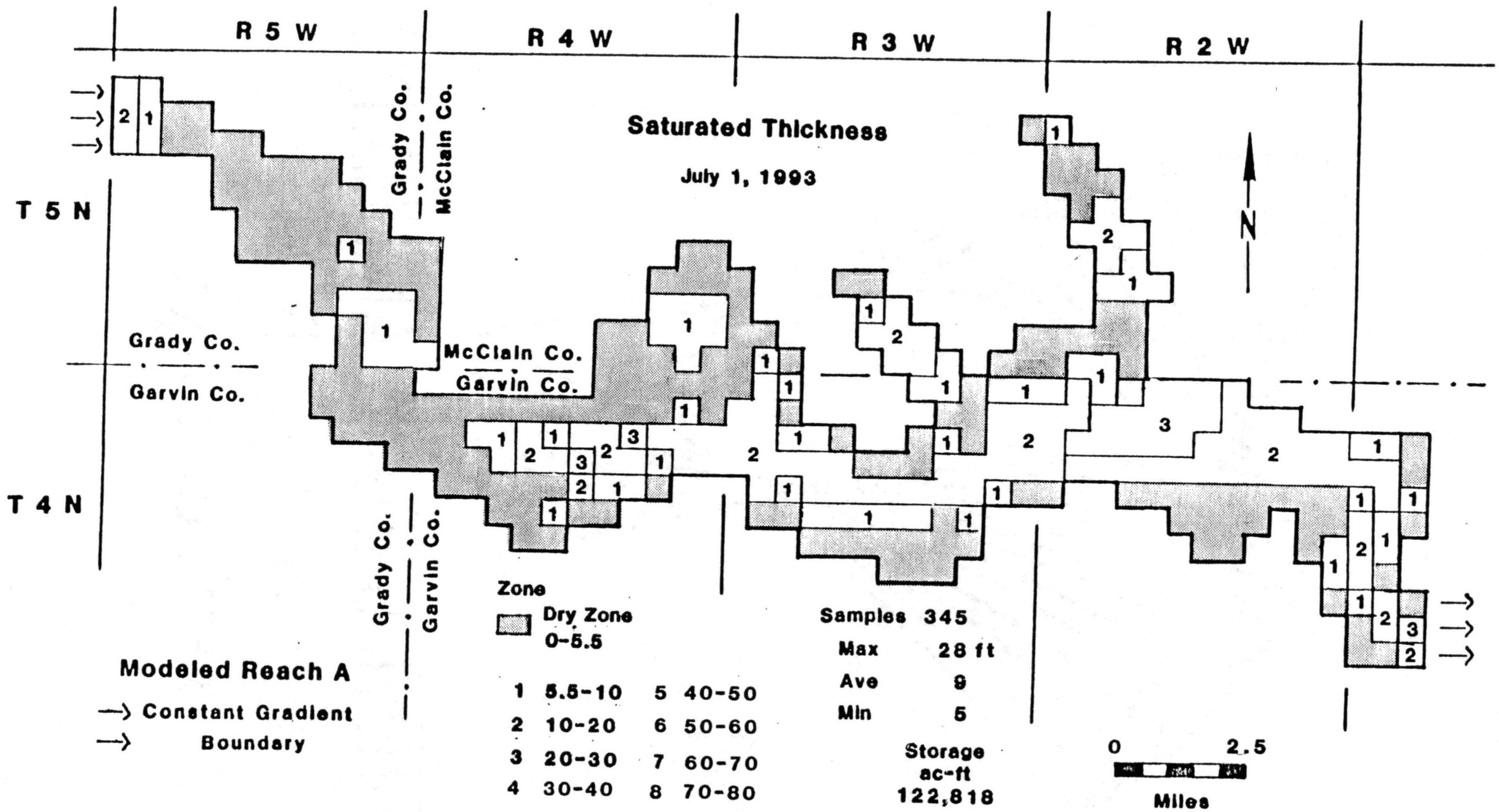


Figure 98. Allocation Saturated Thickness Map, 1993 - Modeled Reach A

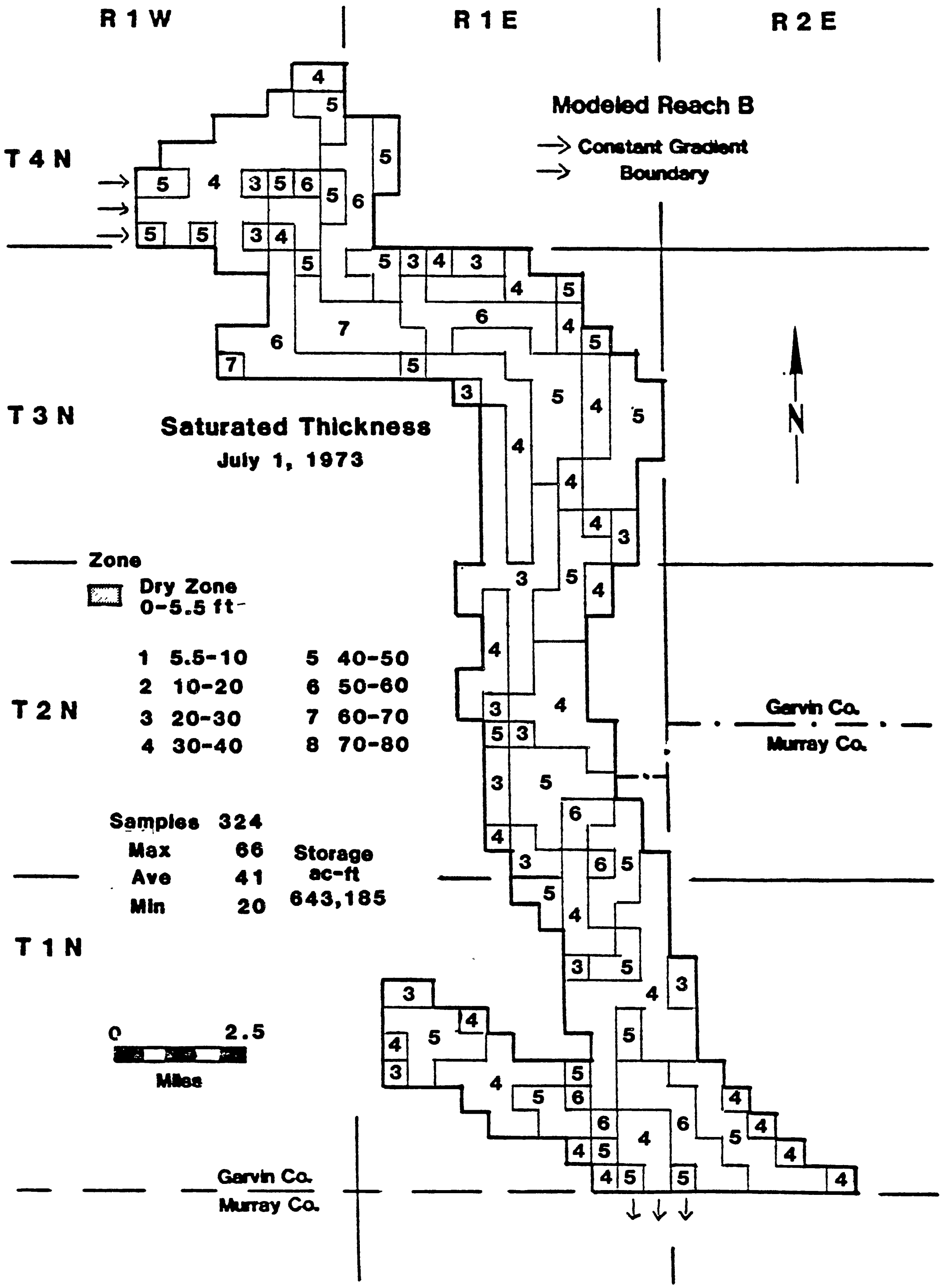


Figure 99. Allocation Saturated Thickness Map, 1973 - Modeled Reach B

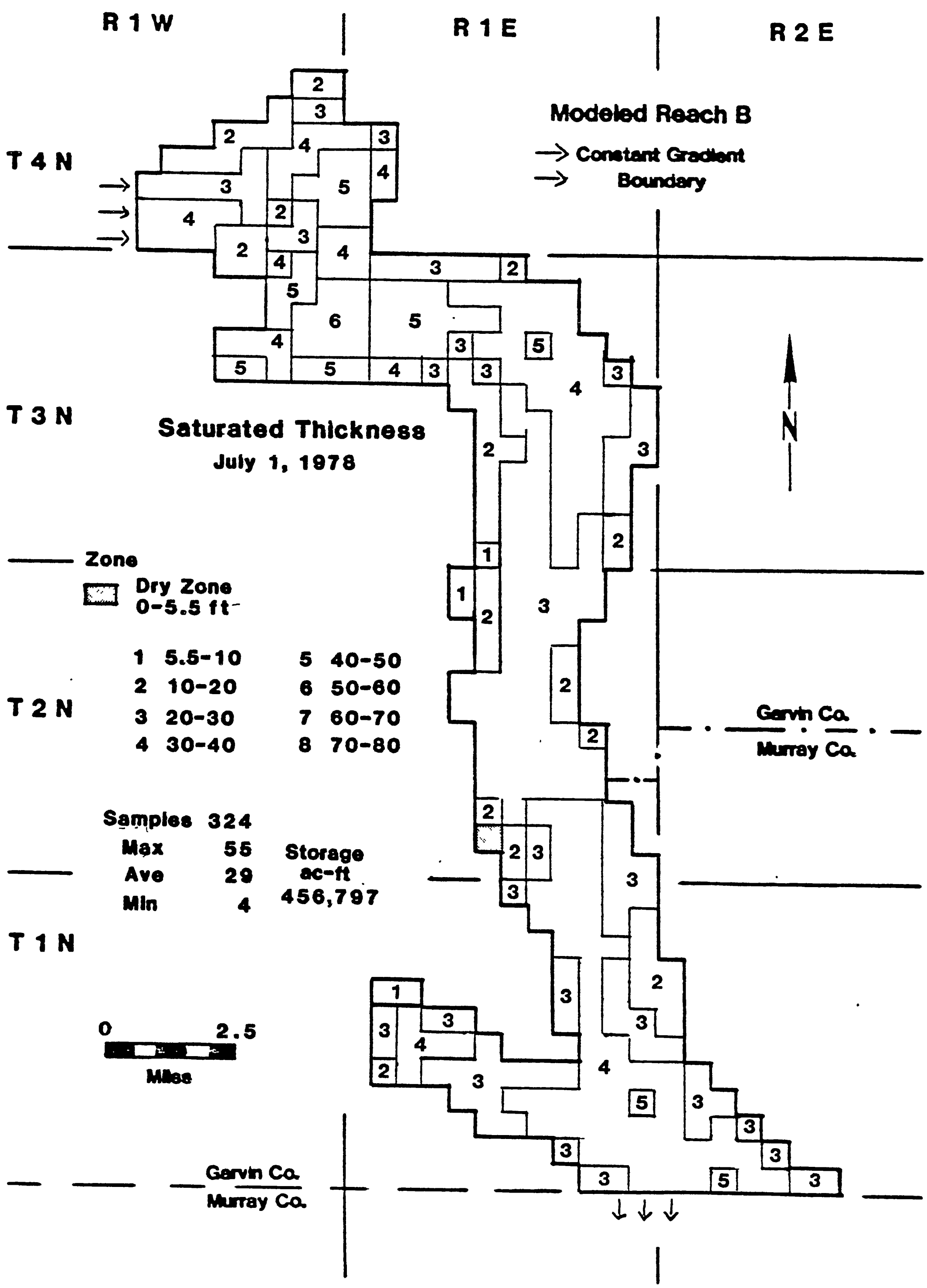


Figure 100. Allocation Saturated Thickness Map, 1978 - Modeled Reach B

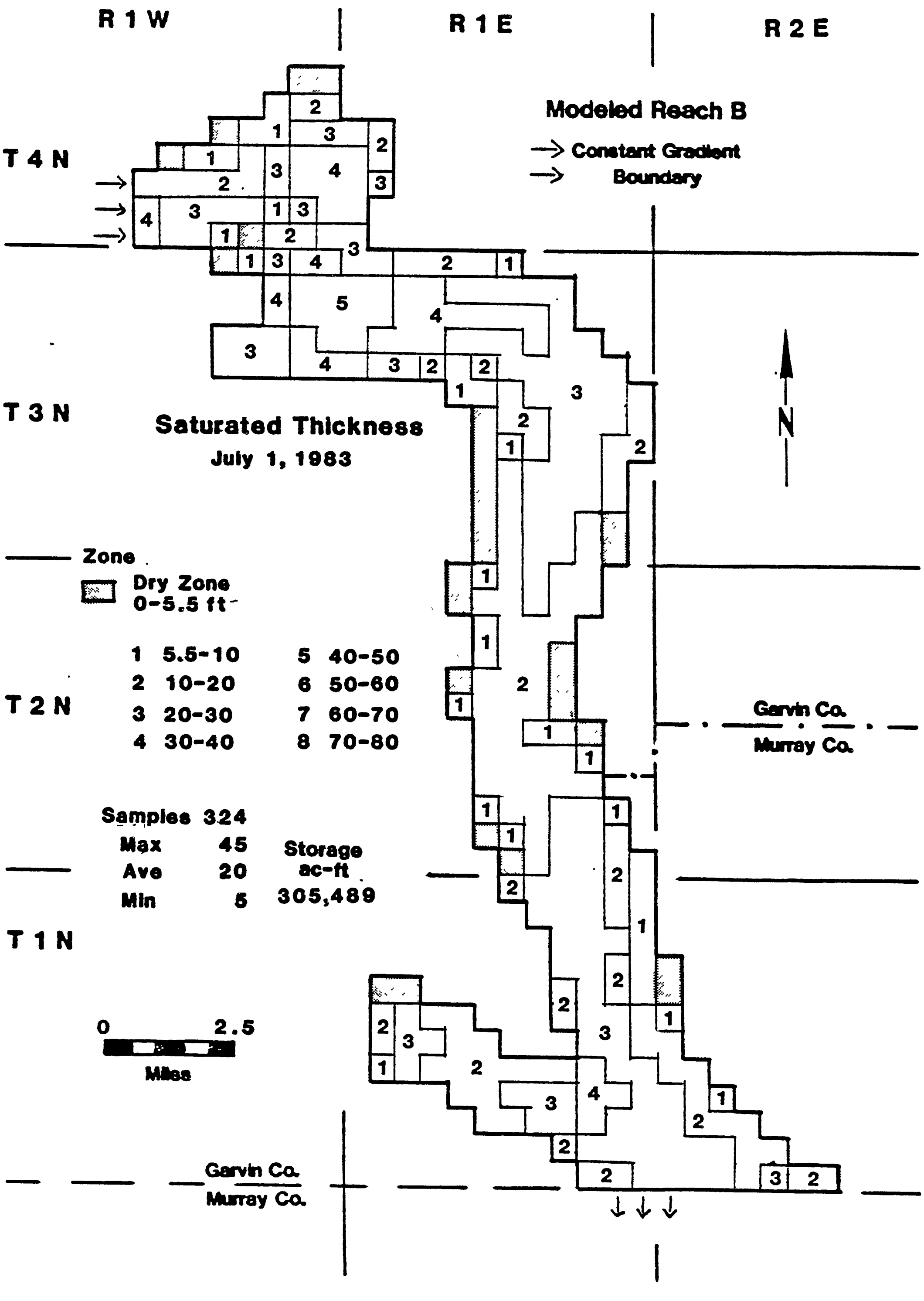


Figure 101. Allocation Saturated Thickness Map, 1983 - Modeled Reach B

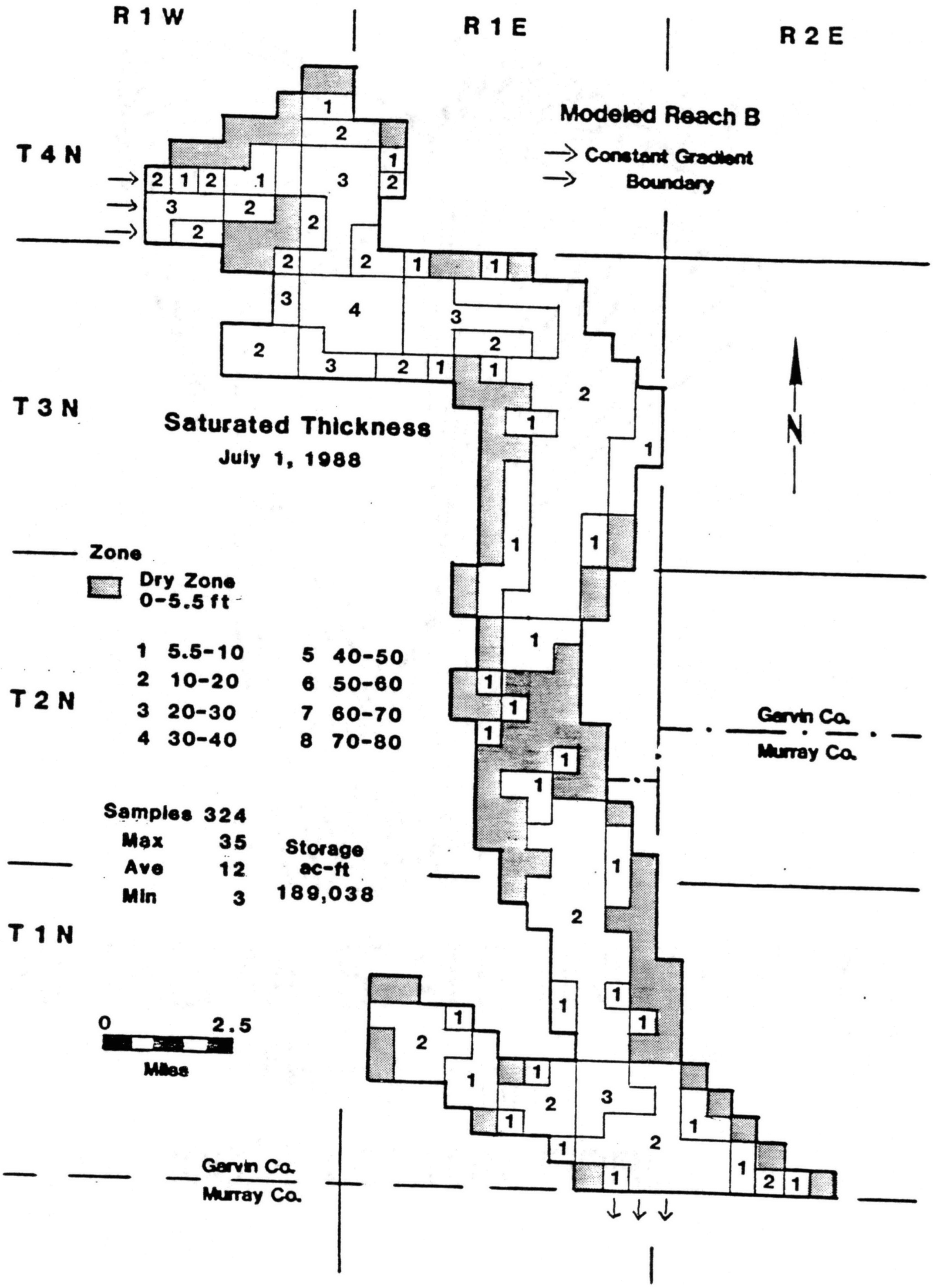


Figure 102. Allocation Saturated Thickness Map, 1988 - Modeled Reach B

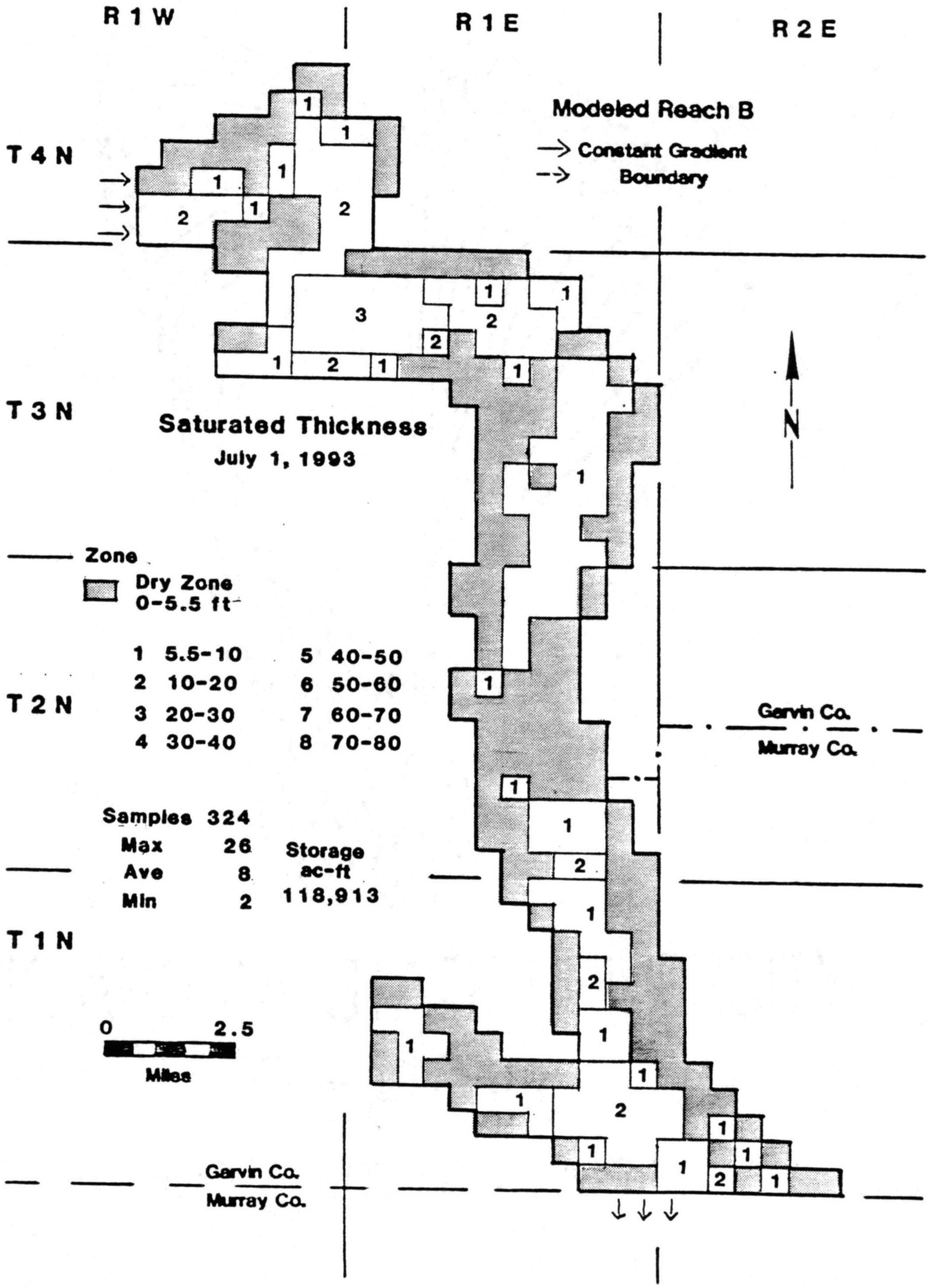


Figure 103. Allocation Saturated Thickness Map, 1993 - Modeled Reach B

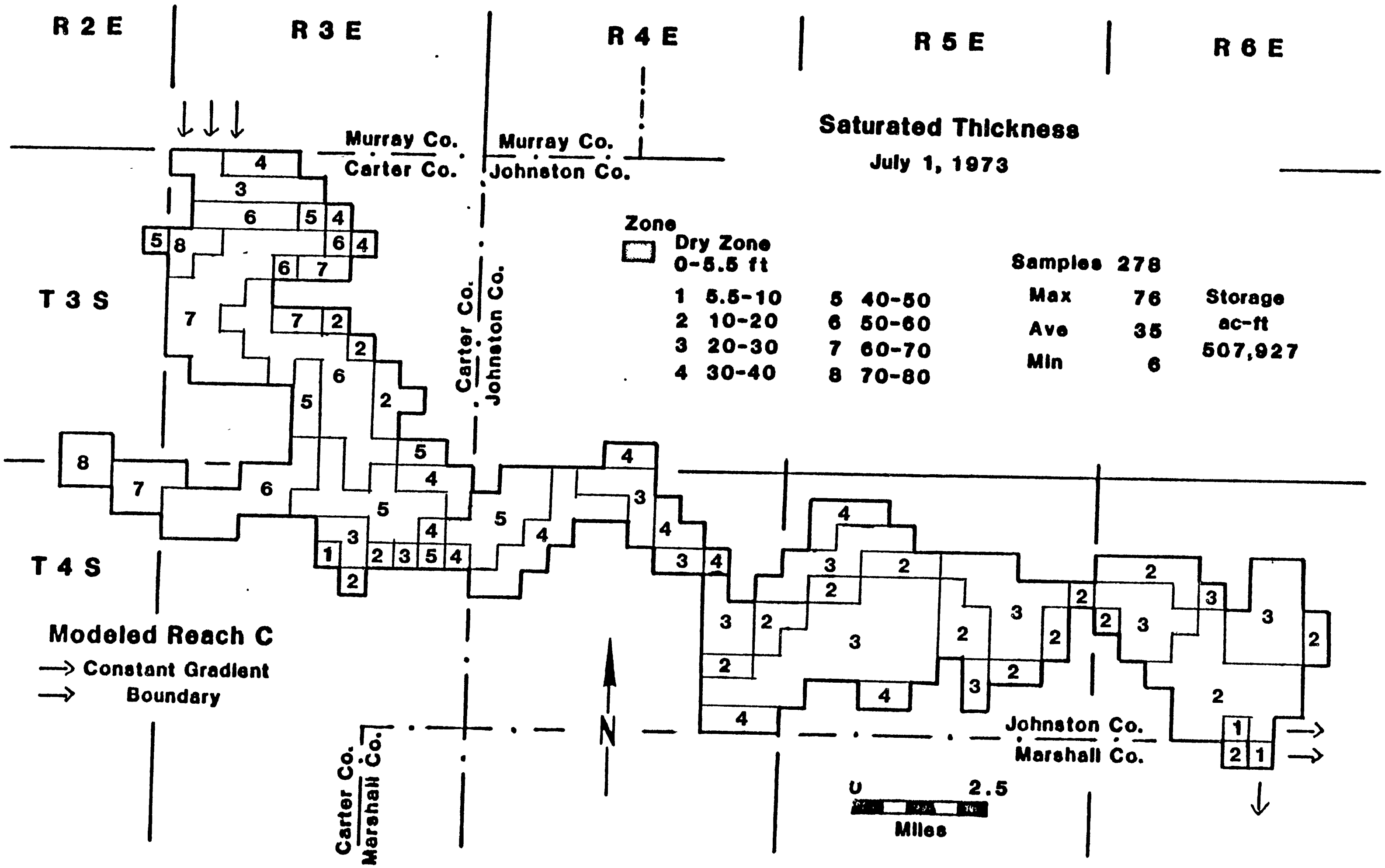


Figure 104. Allocation Saturated Thickness Map, 1973 - Modeled Reach C

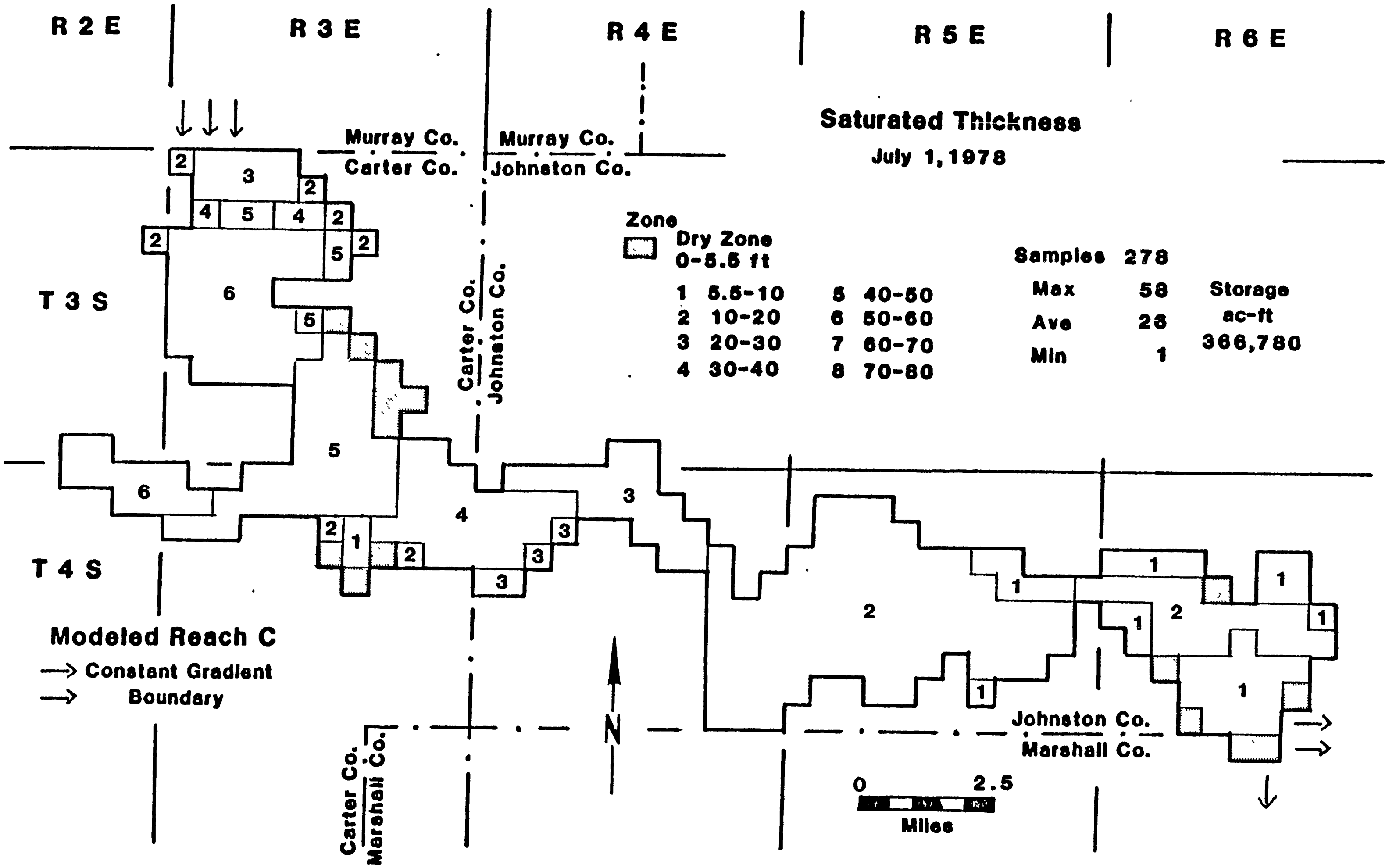


Figure 105. Allocation Saturated Thickness Map, 1978 - Modeled Reach C

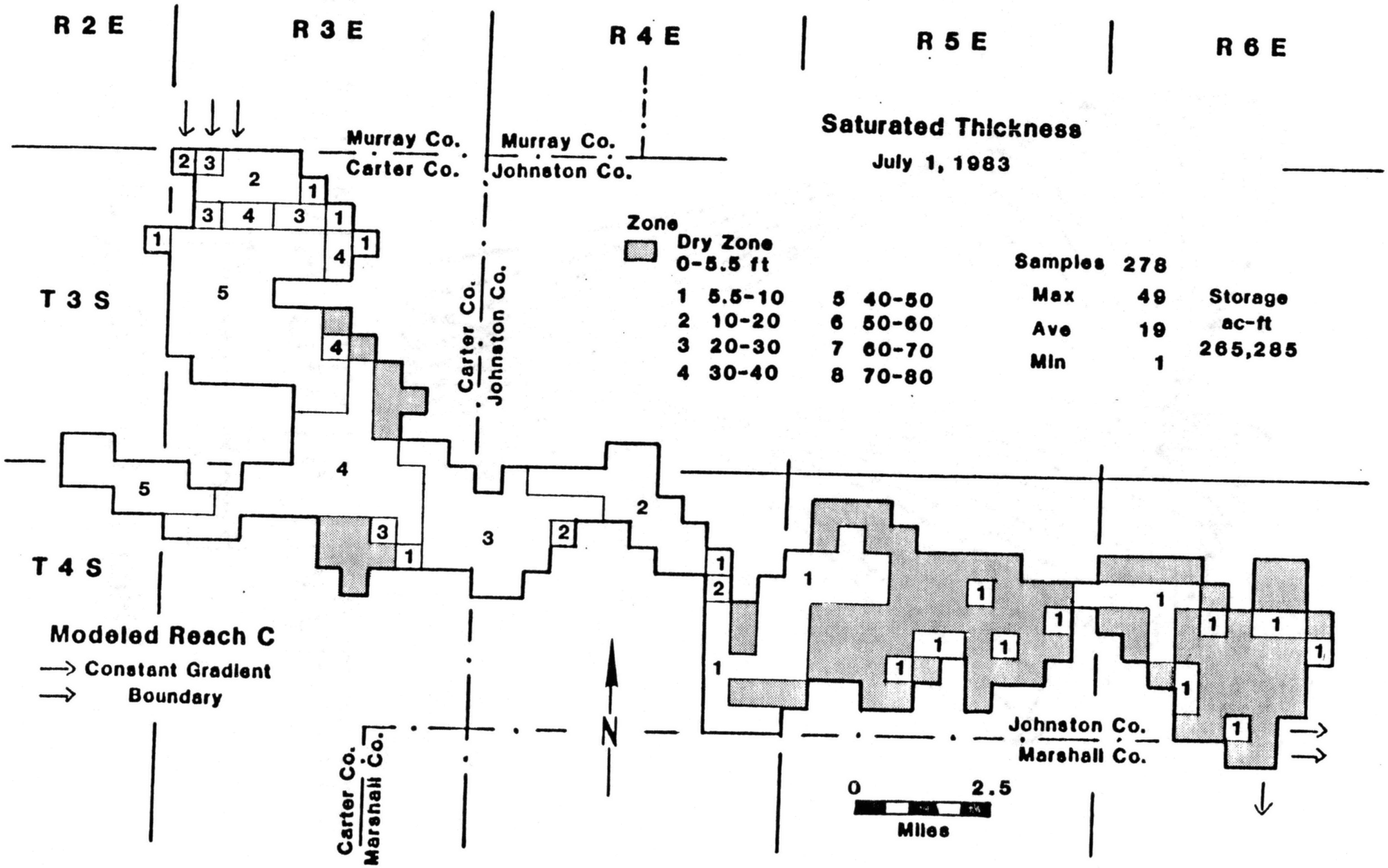


Figure 106. Allocation Saturated Thickness Map, 1983 - Modeled Reach C

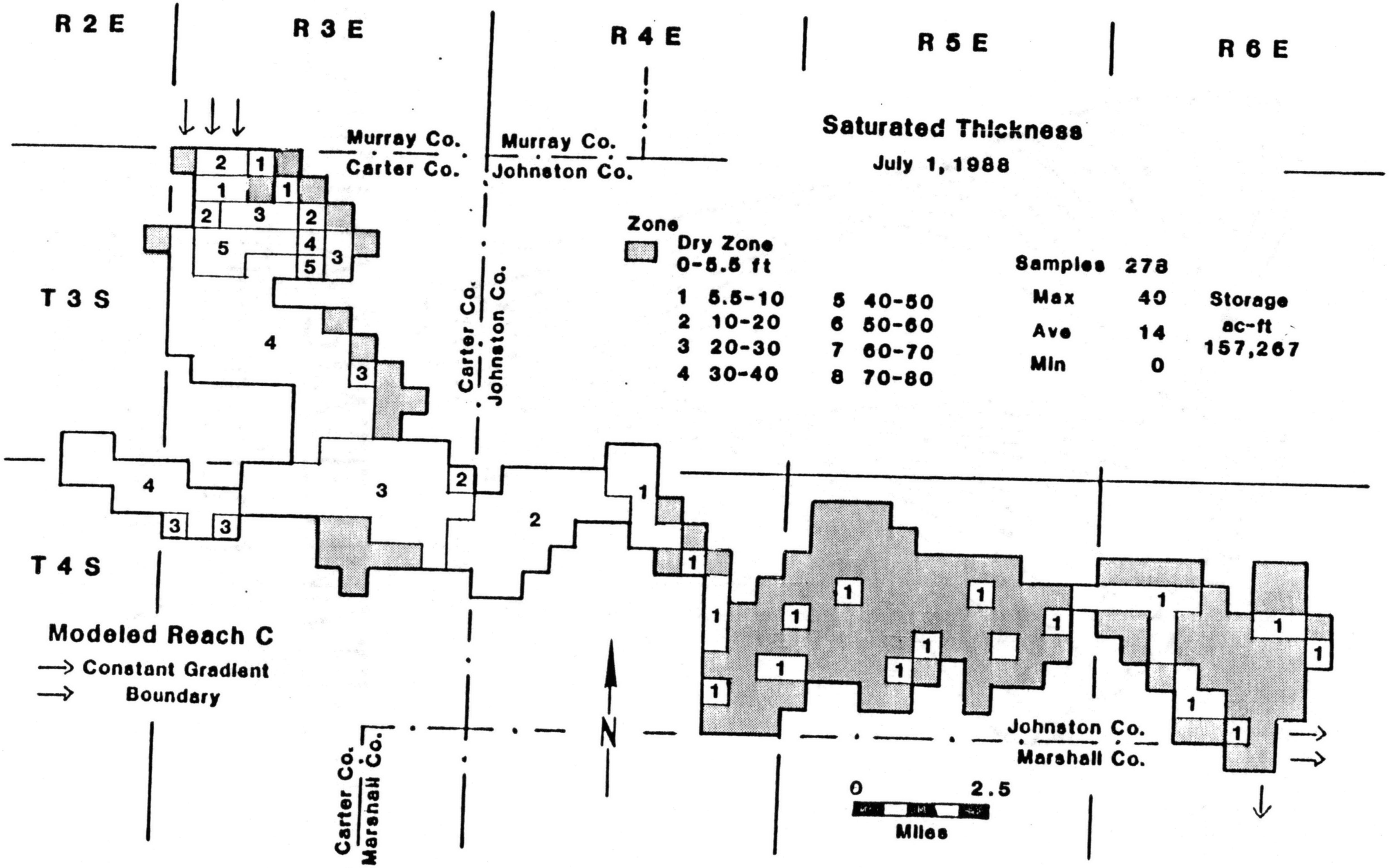


Figure 107. Allocation Saturated Thickness Map, 1988 - Modeled Reach C

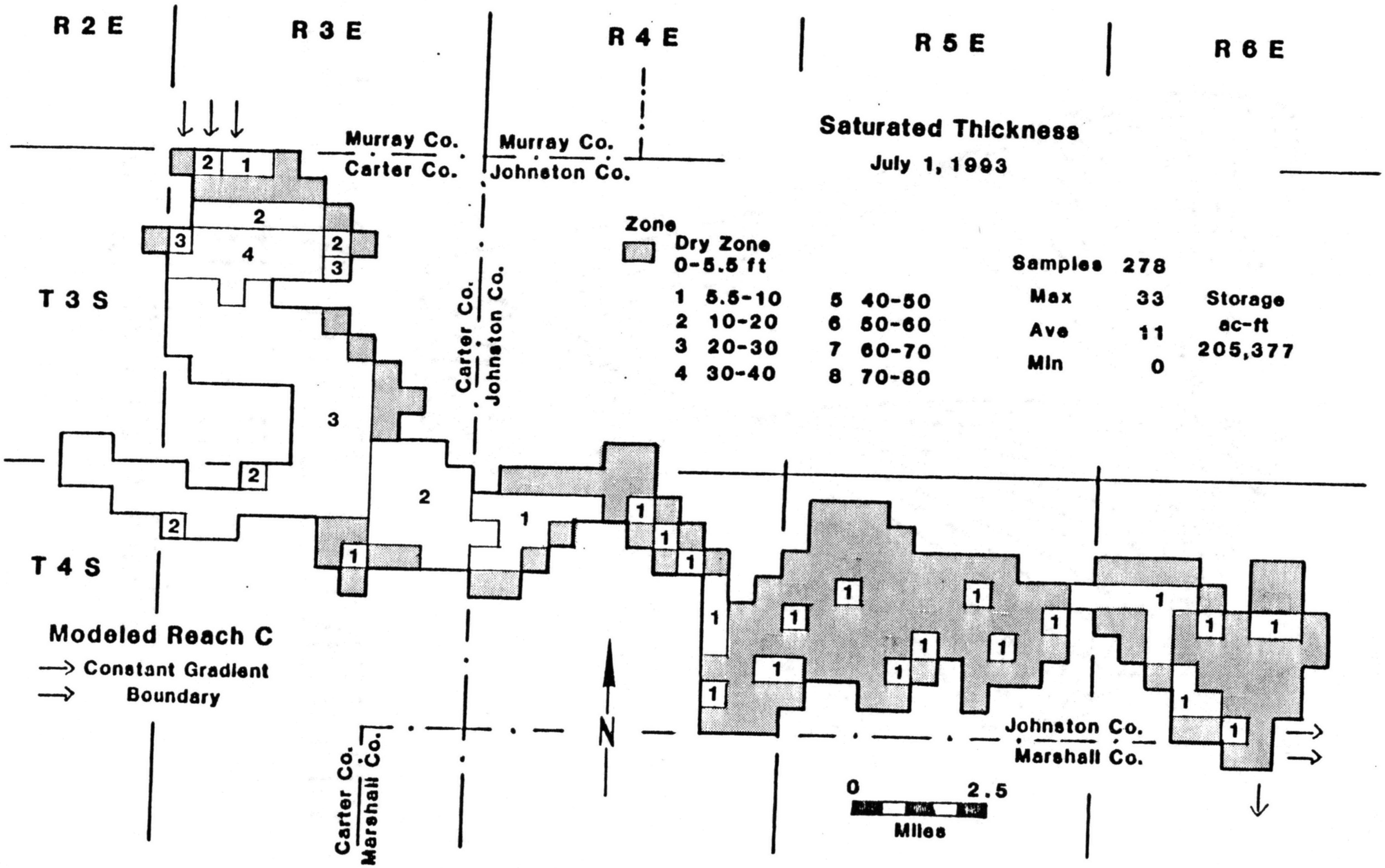


Figure 108. Allocation Saturated Thickness Map,l 1993 - Modeled Reach C

APPENDIX K

HYDRAULIC CONDUCTIVITY MAPS FOR

MODELED REACHES A, B, AND C

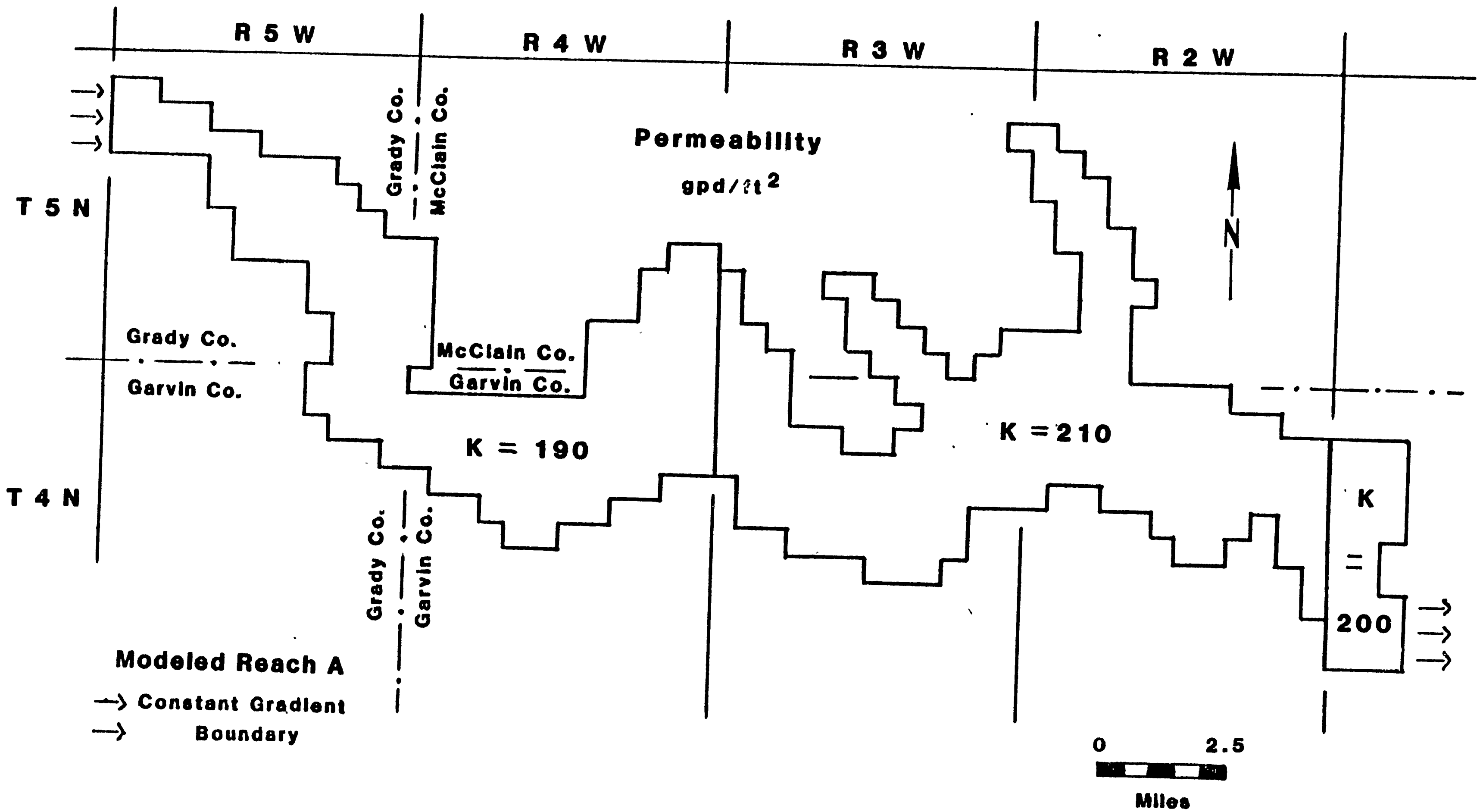


Figure 109. Hydraulic Conductivity Map - Modeled Reach A

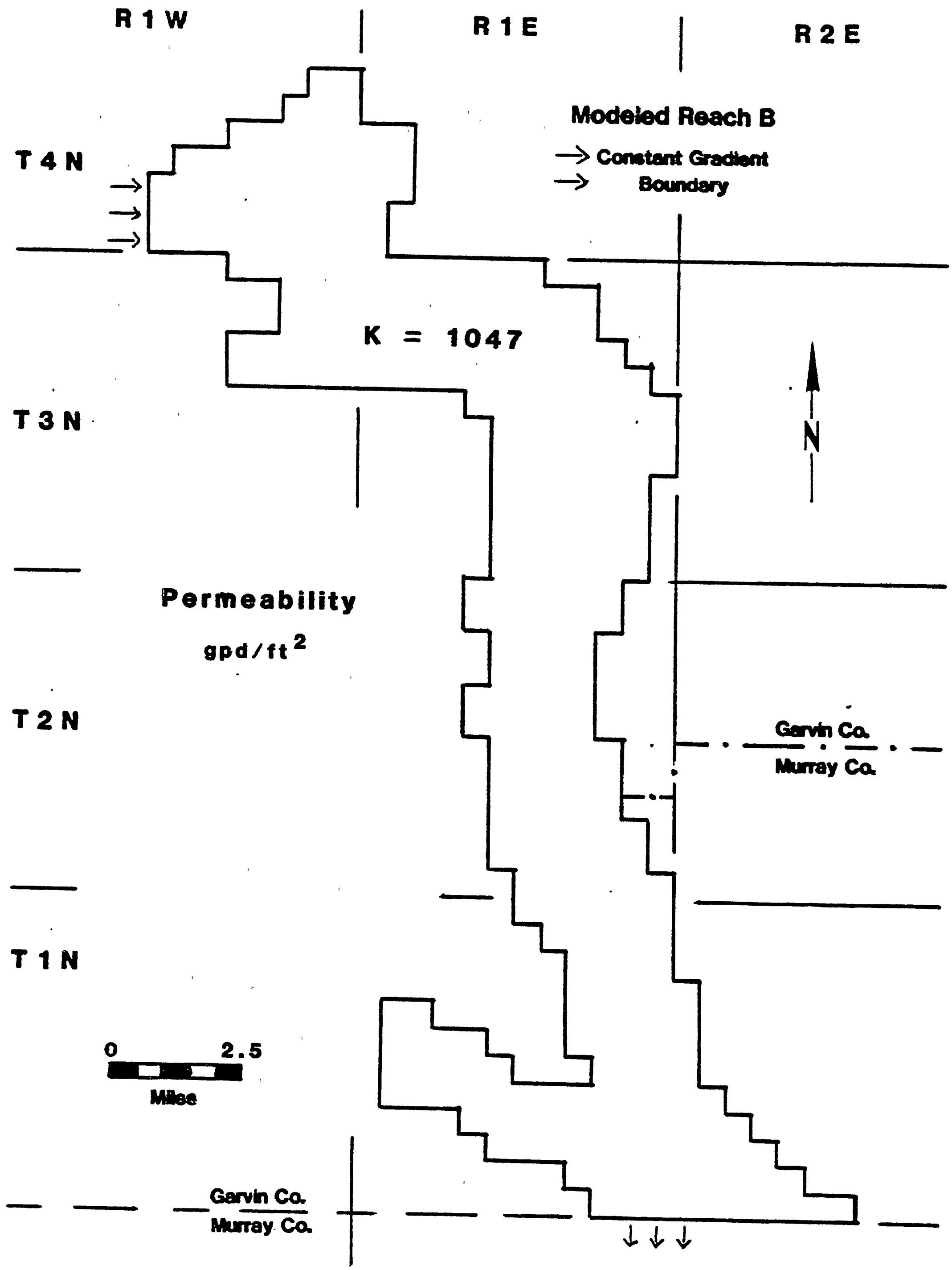


Figure 110. Hydraulic Conductivity Map - Modeled Reach B

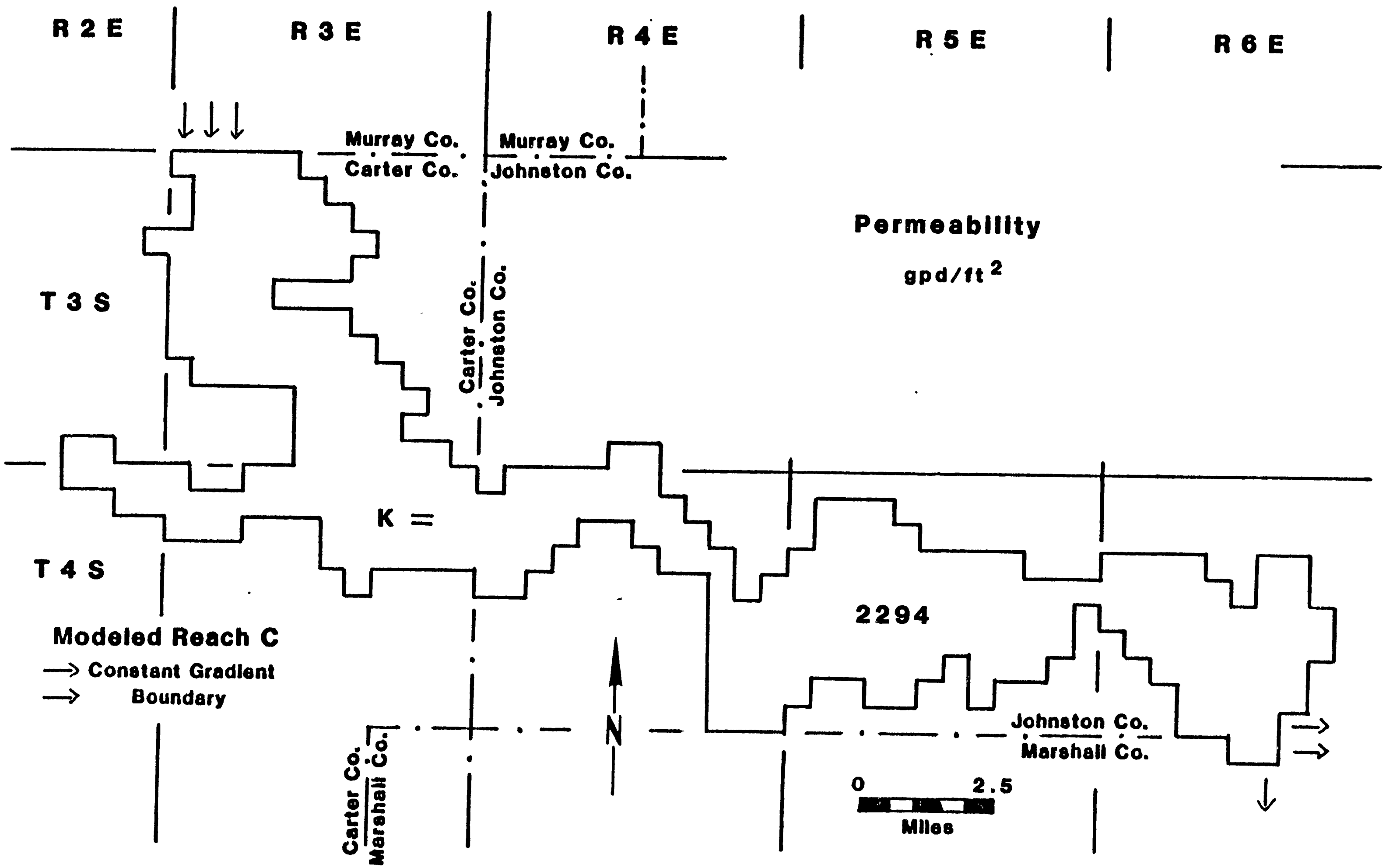


Figure 111. Hydraulic Conductivity Map - Modeled Reach C

APPENDIX L

TRANSMISSIVITY MAPS FOR JULY 1, 1973 AND JULY 1, 1993 FOR MODELED REACHES A, B, AND C

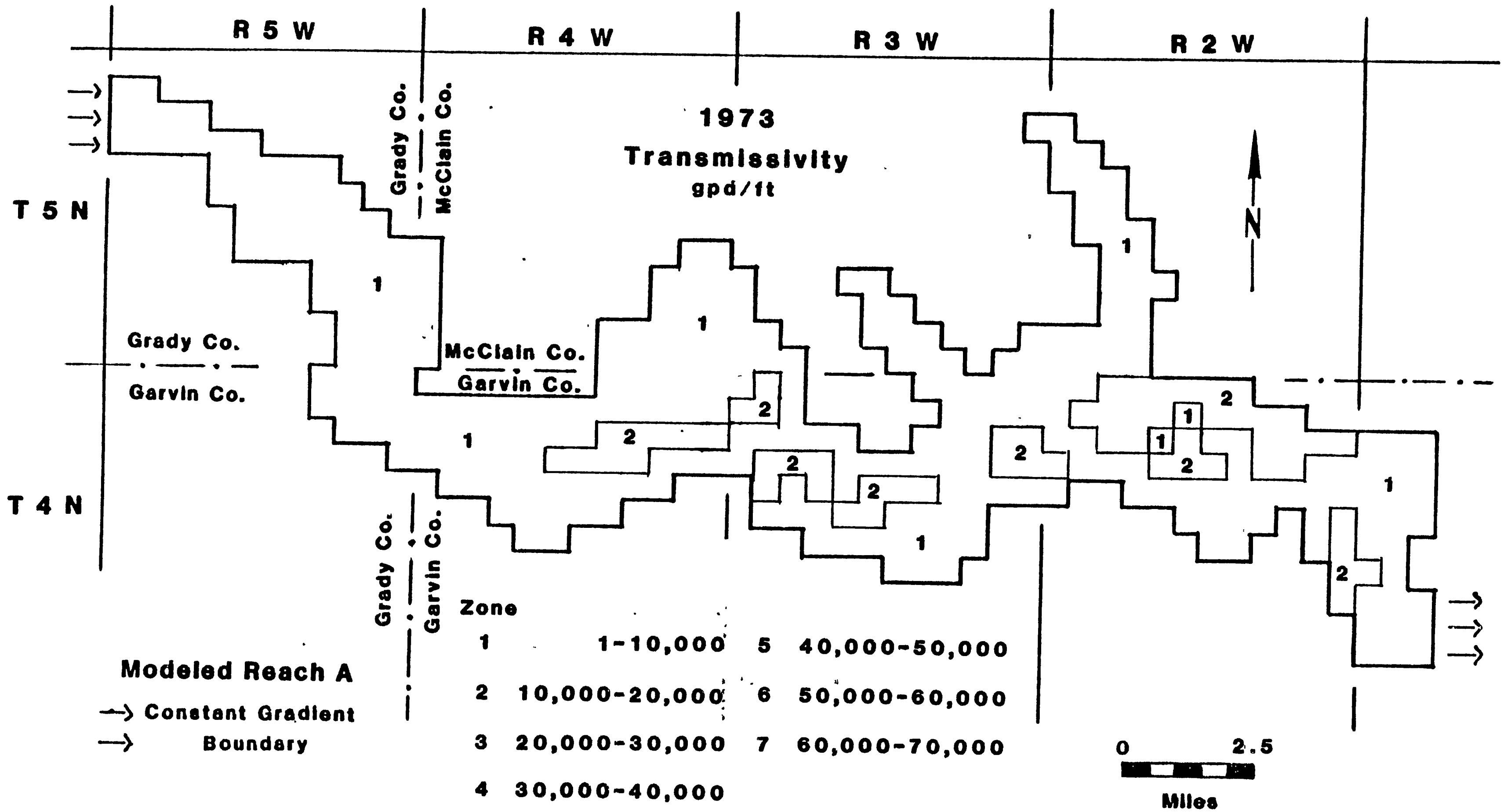


Figure 112. Transmissivity Map, 1973 - Modeled Reach A

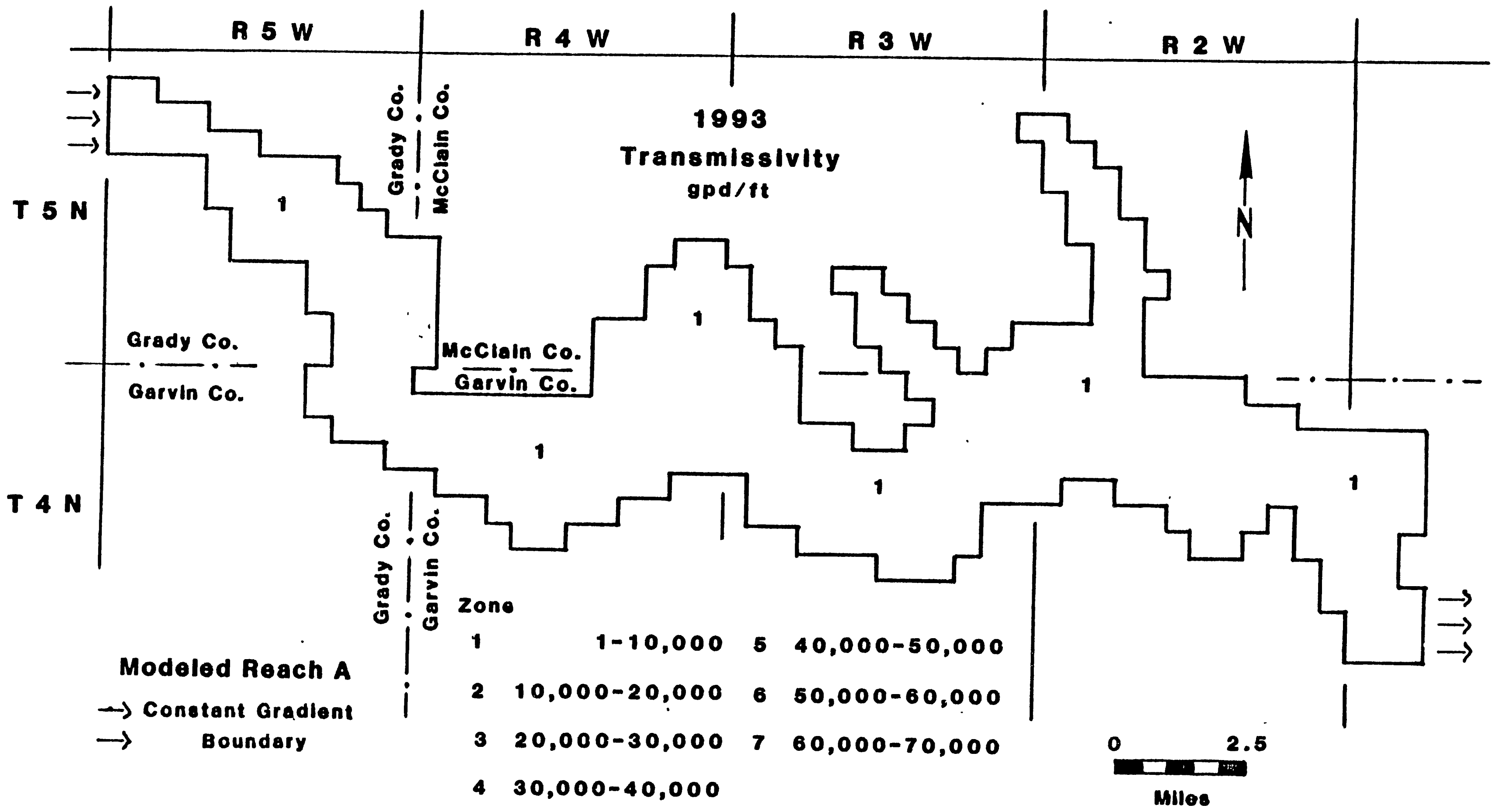


Figure 113. Transmissivity Map, 1993 - Modeled Reach A

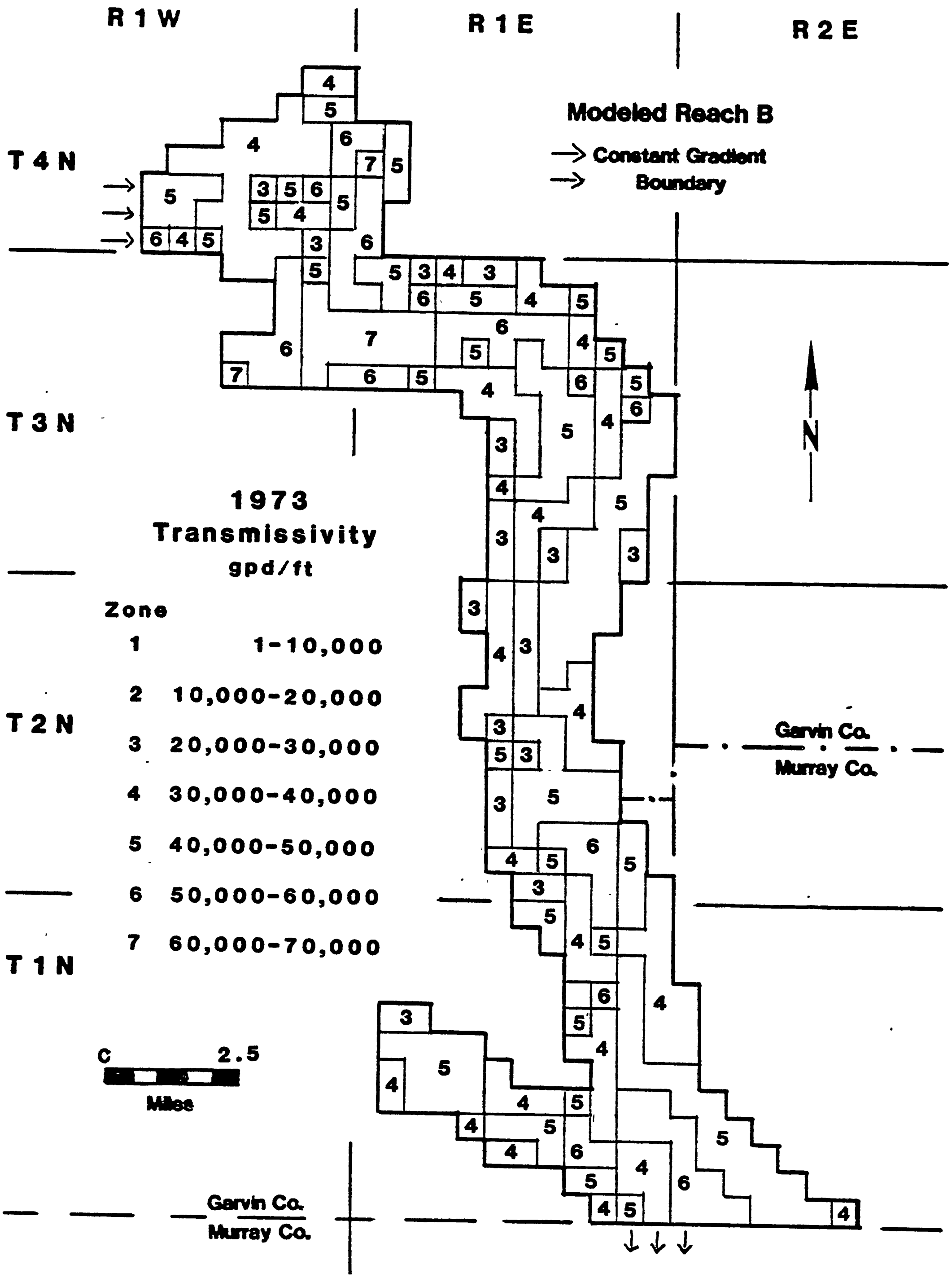


Figure 114. Transmissivity Map, 1973 - Modeled Reach B

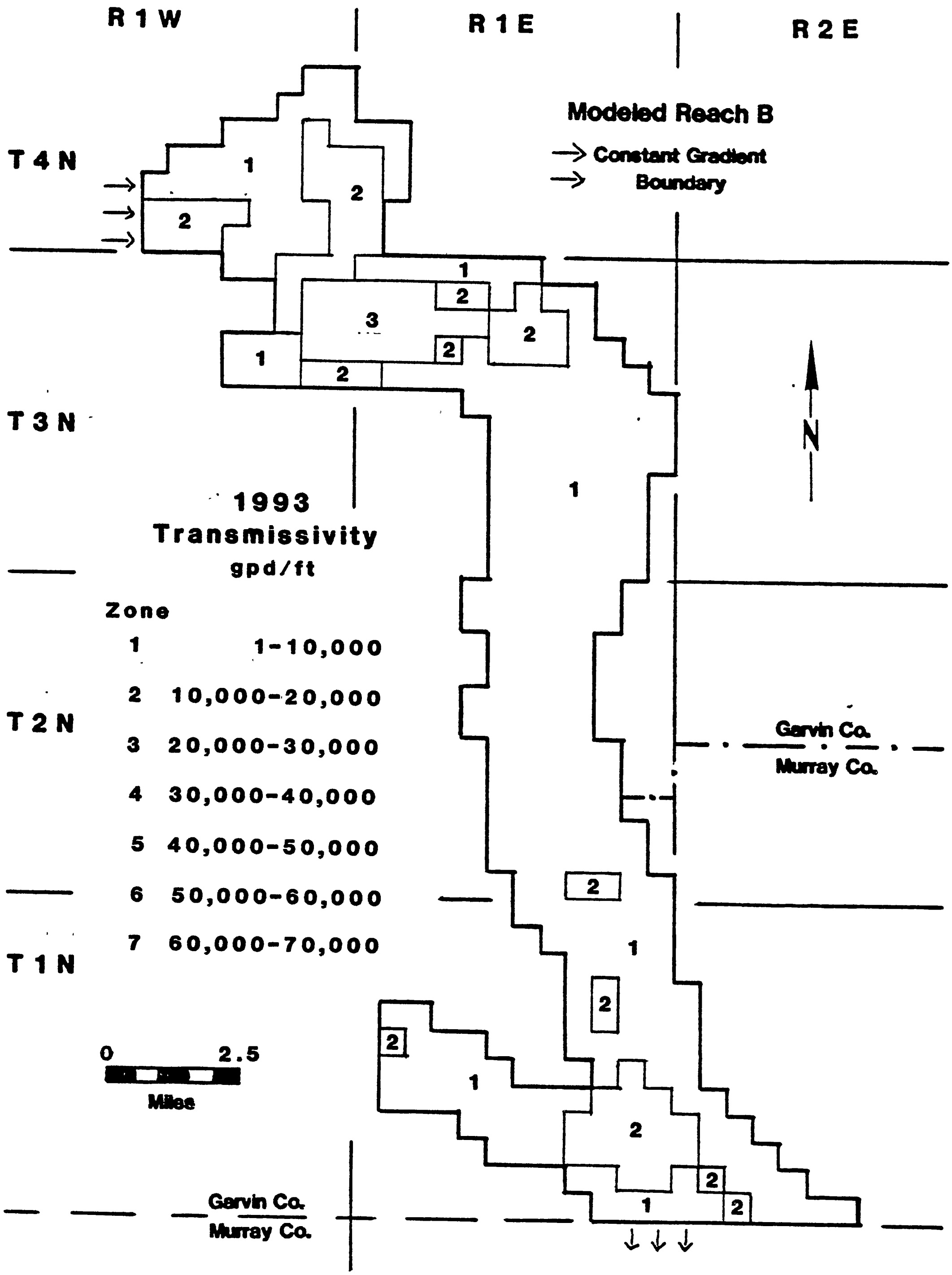


Figure 115. Transmissivity Map, 1993 - Modeled Reach B

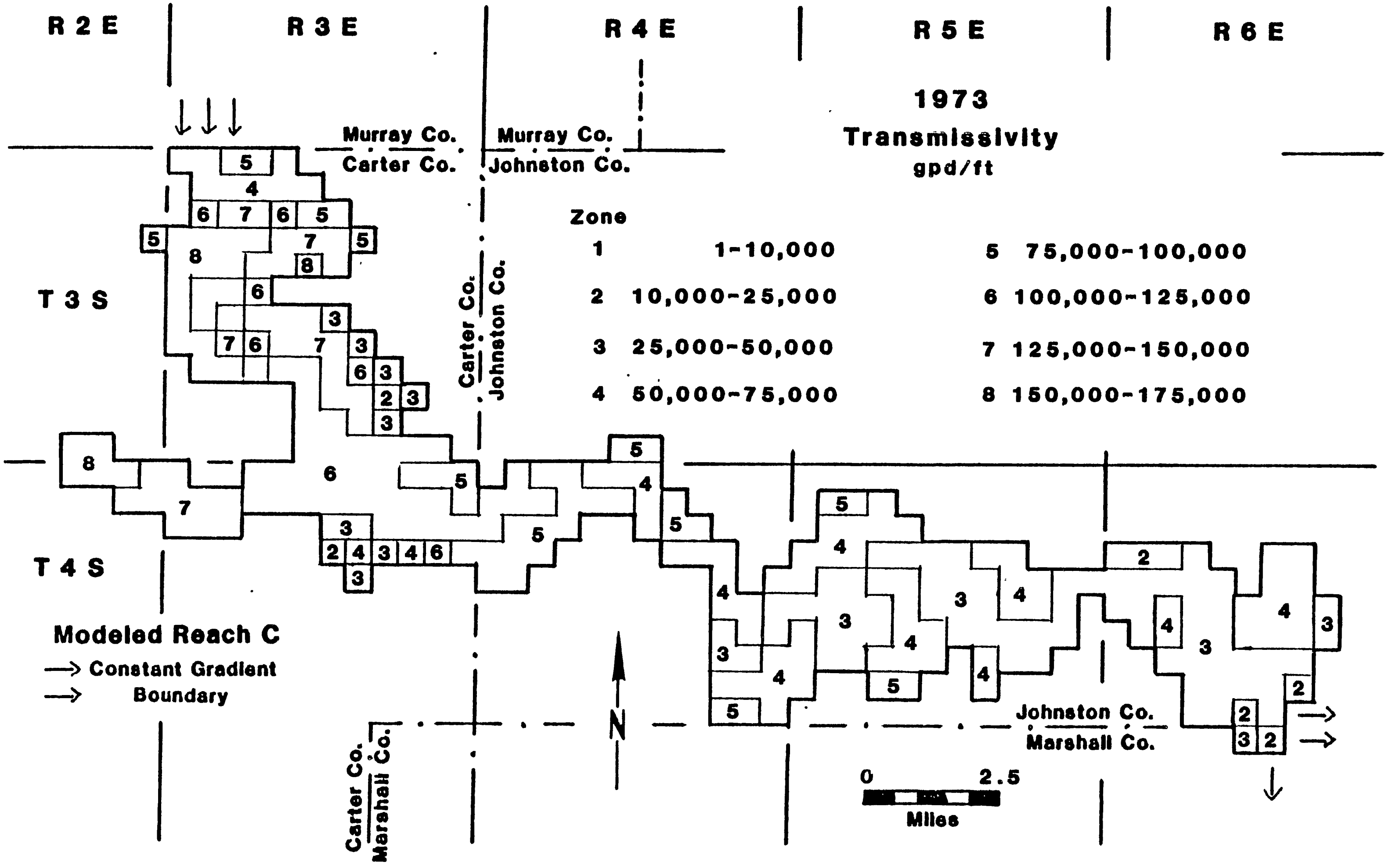


Figure 116. Transmissivity Map, 1973 - Modeled Reach C

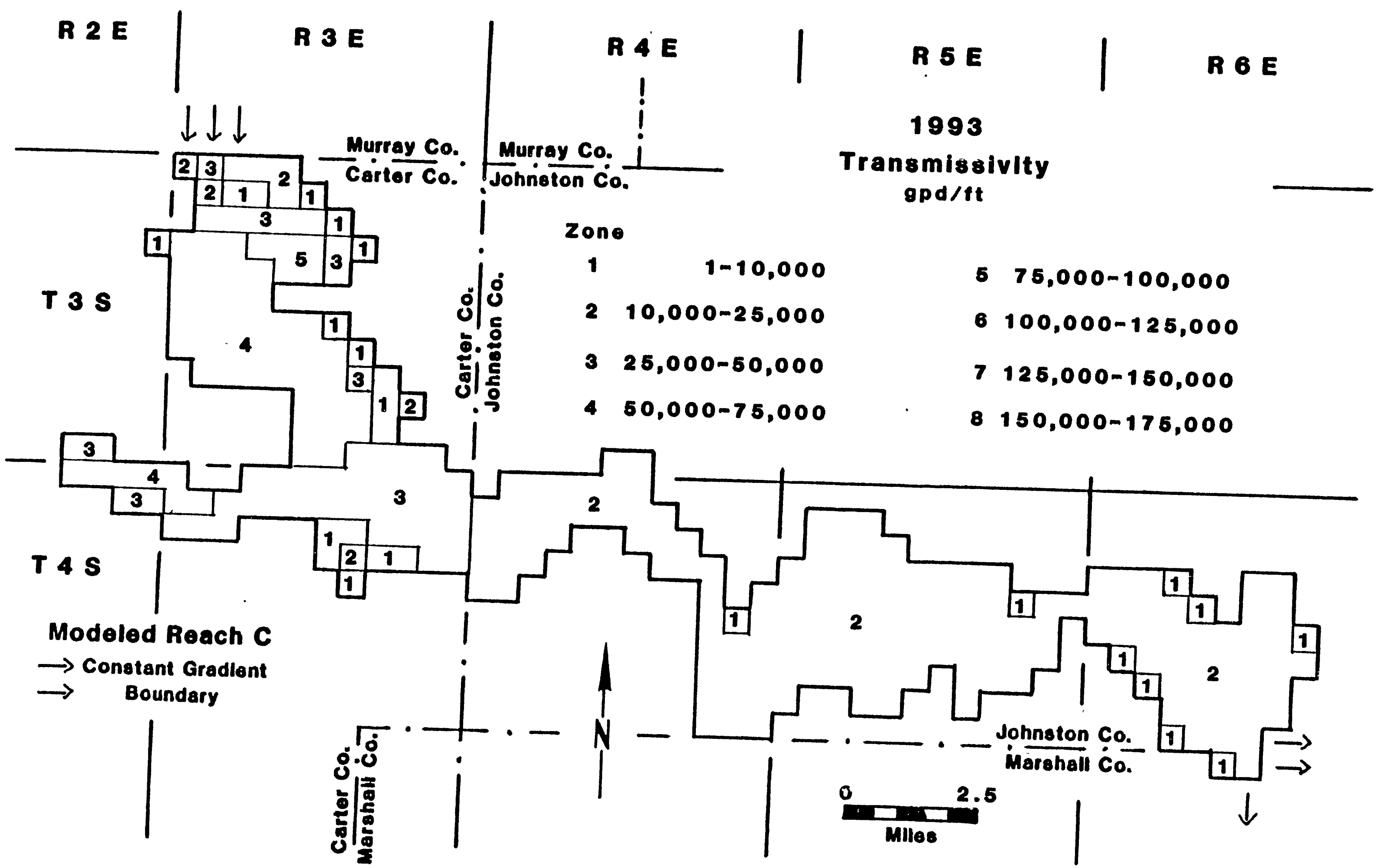


Figure 117. Transmissivity Map, 1993 - Modeled Reach C

APPENDIX M

DEPTH TO WATER, JULY 1, 1973 AND
JULY 1, 1993 FOR MODELED
REACHES A, B, AND C

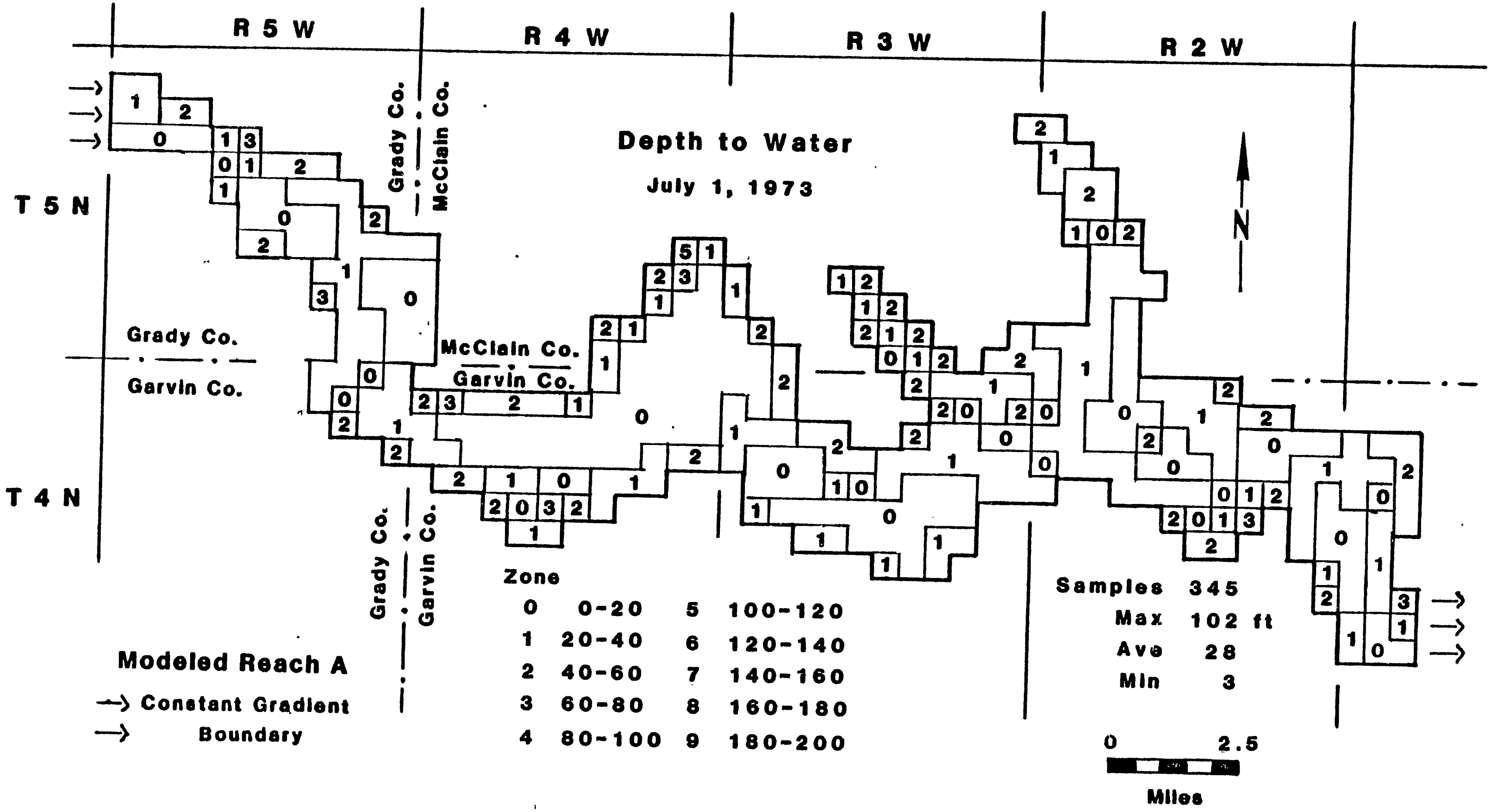


Figure 118. Depth to Water, 1973 - Modeled Reach A

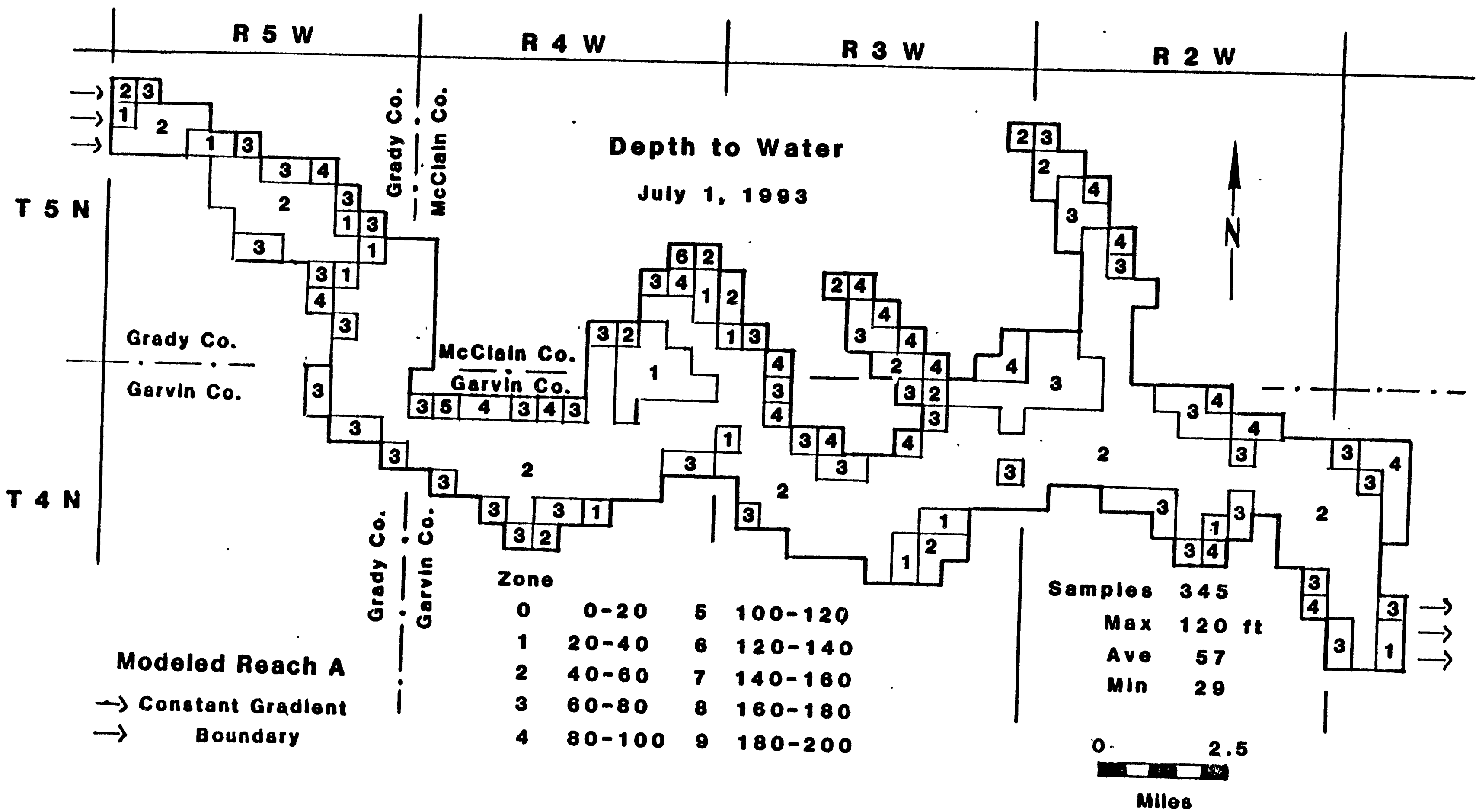


Figure 119. Depth to Water, 1993 - Modeled Reach A

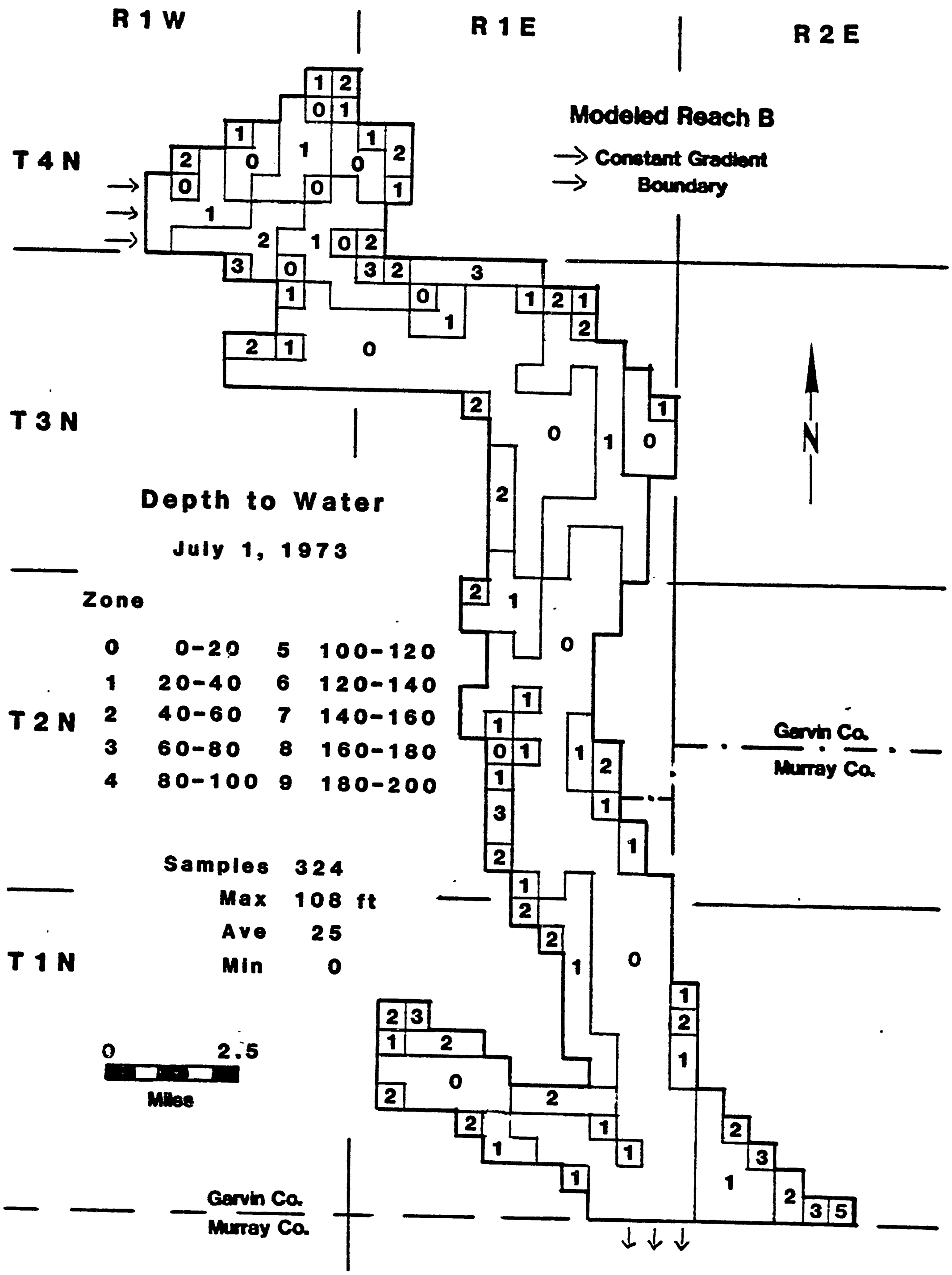


Figure 120. Depth to Water, 1973 - Modeled Reach B

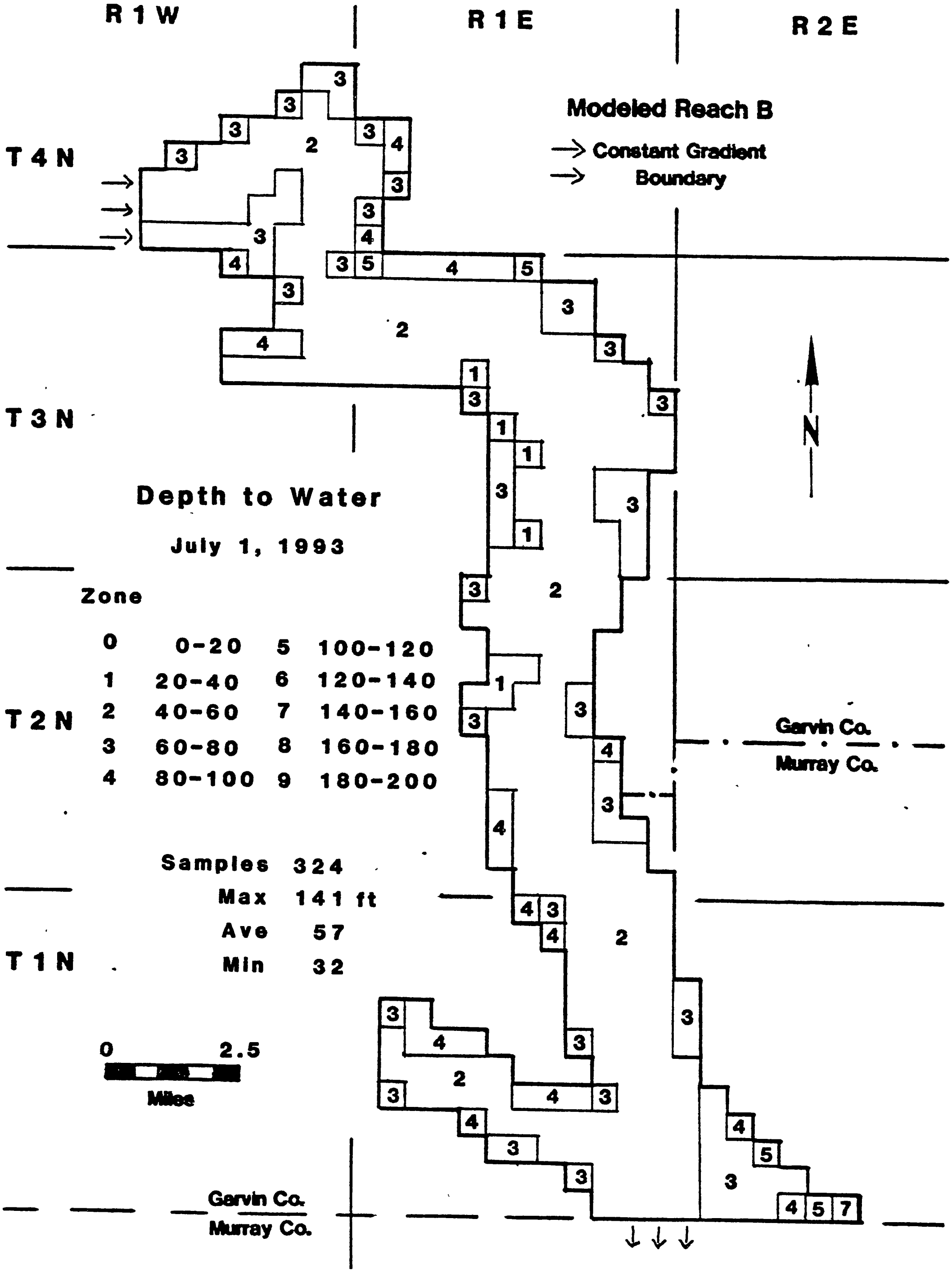


Figure 121. Depth to Water, 1993 - Modeled Reach B

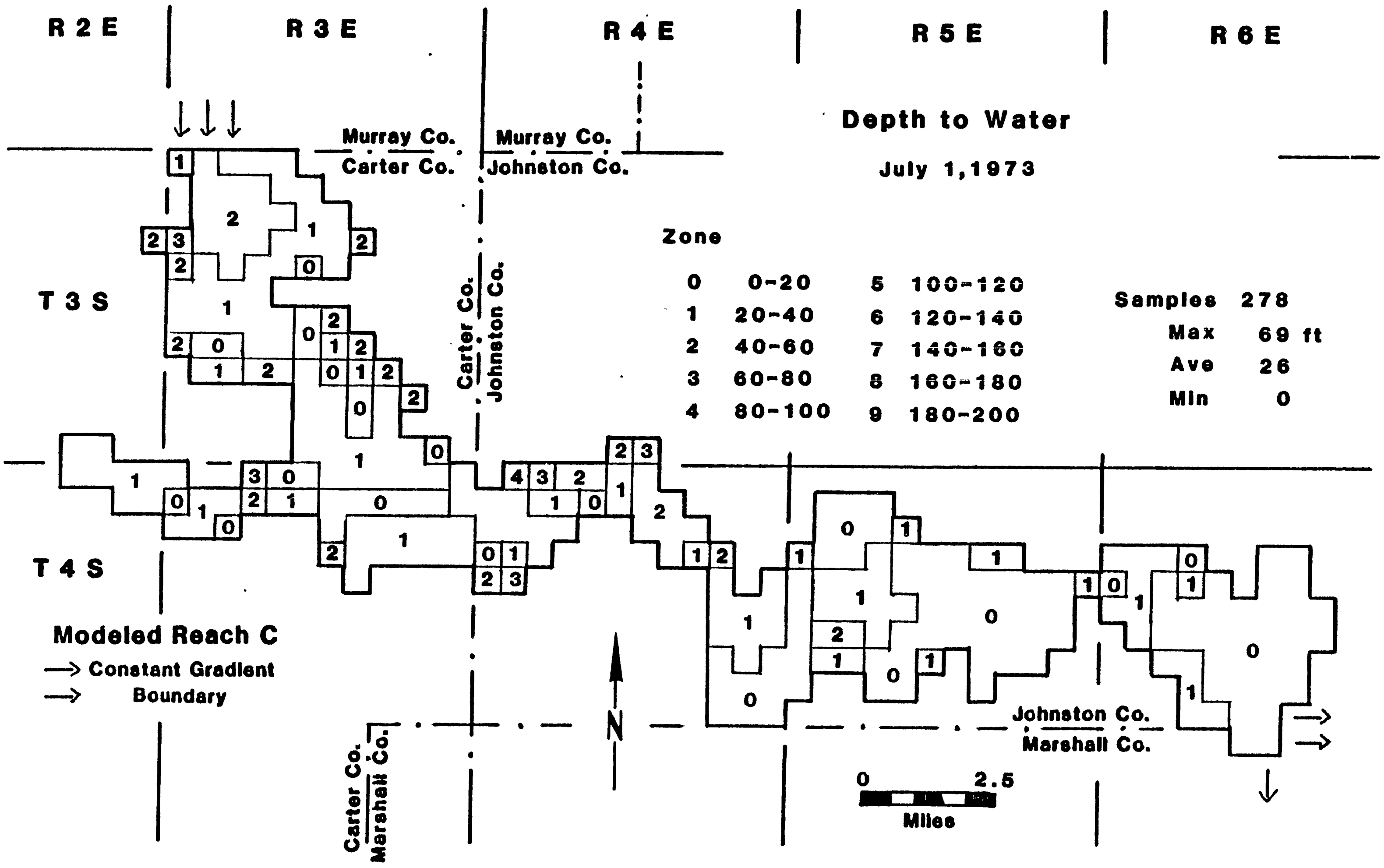


Figure 122. Depth to Water, 1973 - Modeled Reach C

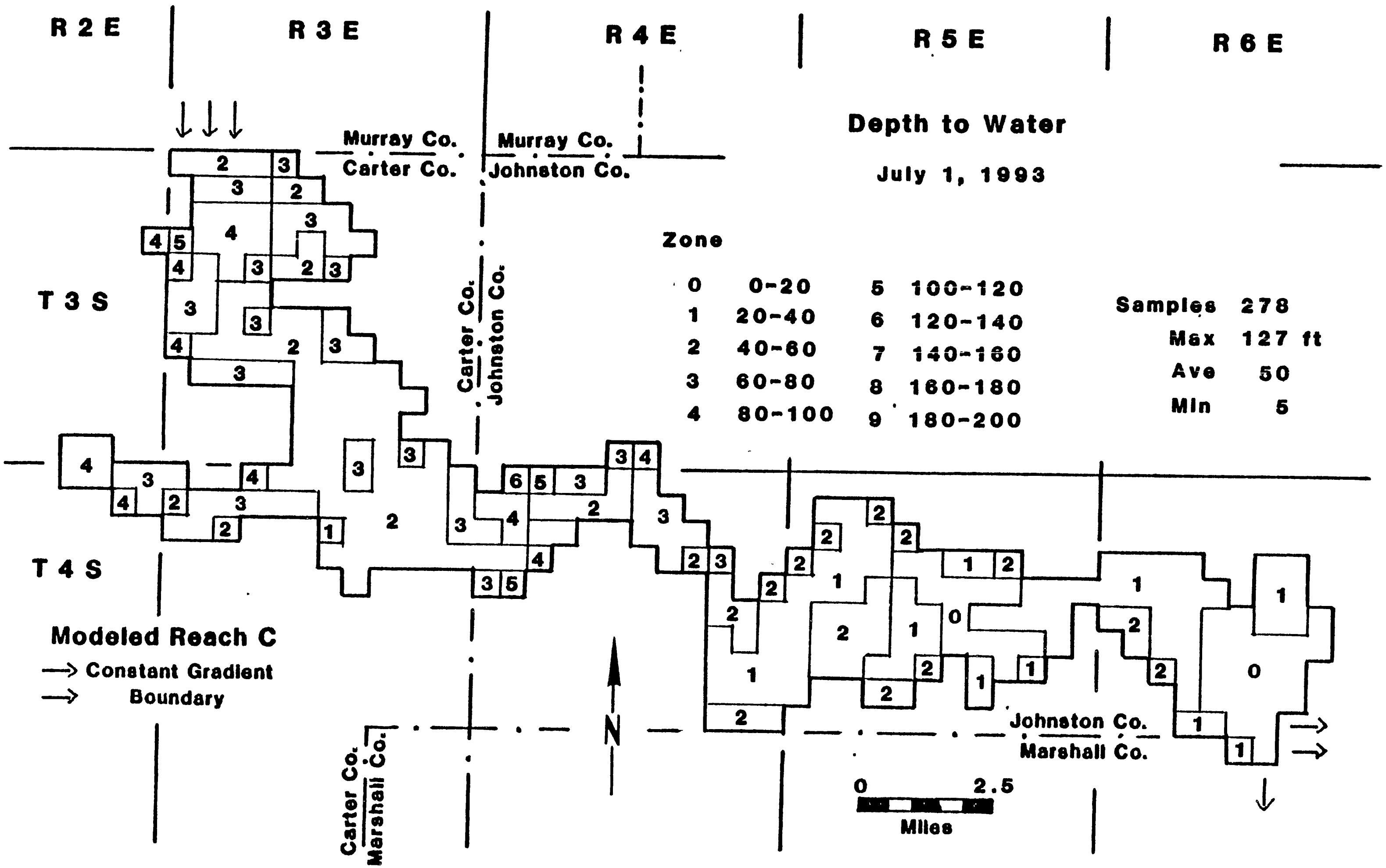


Figure 123. Depth to Water, 1993 - Modeled Reach C

APPENDIX N

DISTRIBUTION OF PRIOR RIGHTS FOR
MODELED REACHES A, B, AND C

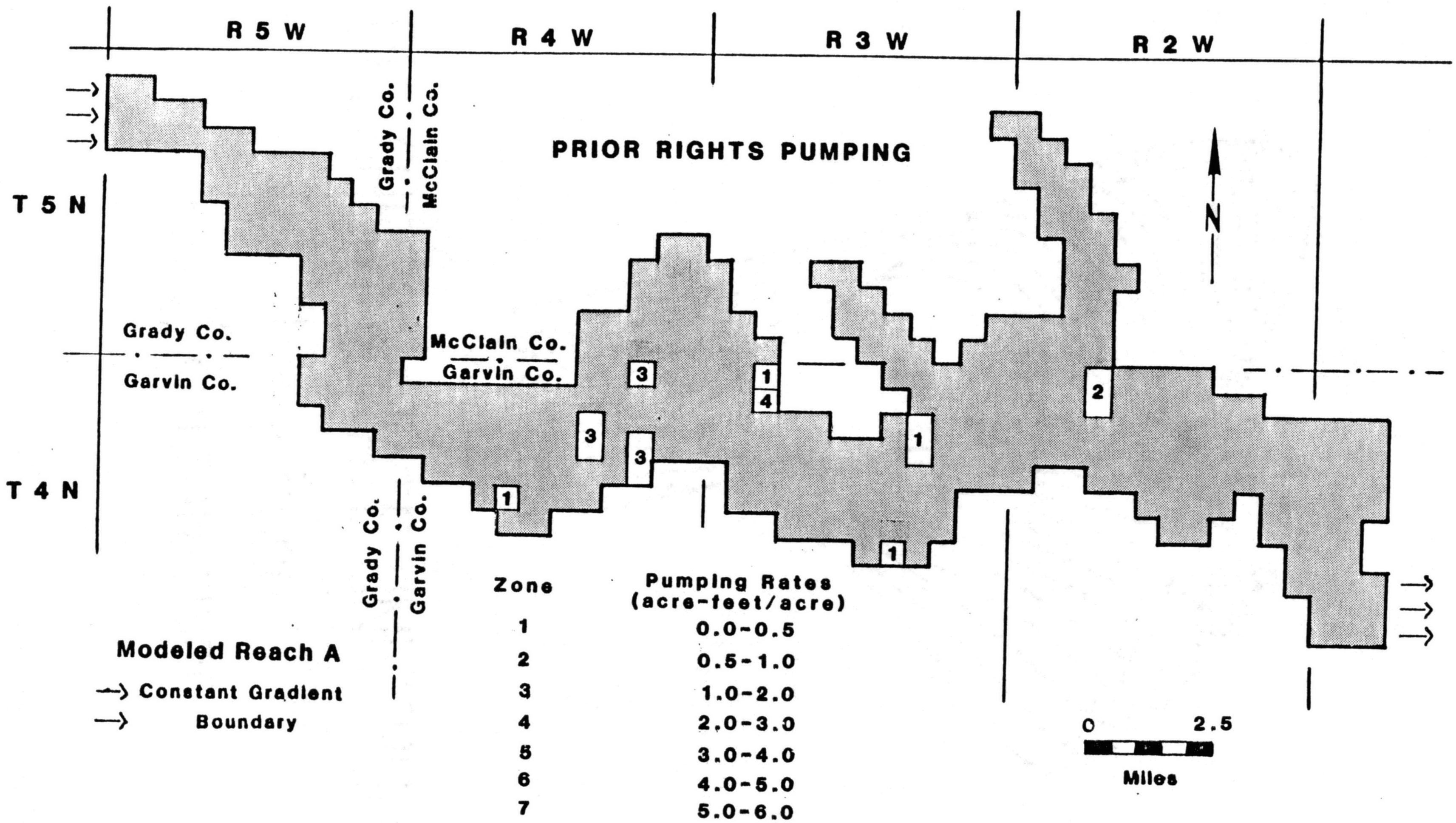


Figure 124. Distribution of Prior Appropriative Rights - Modeled Reach A

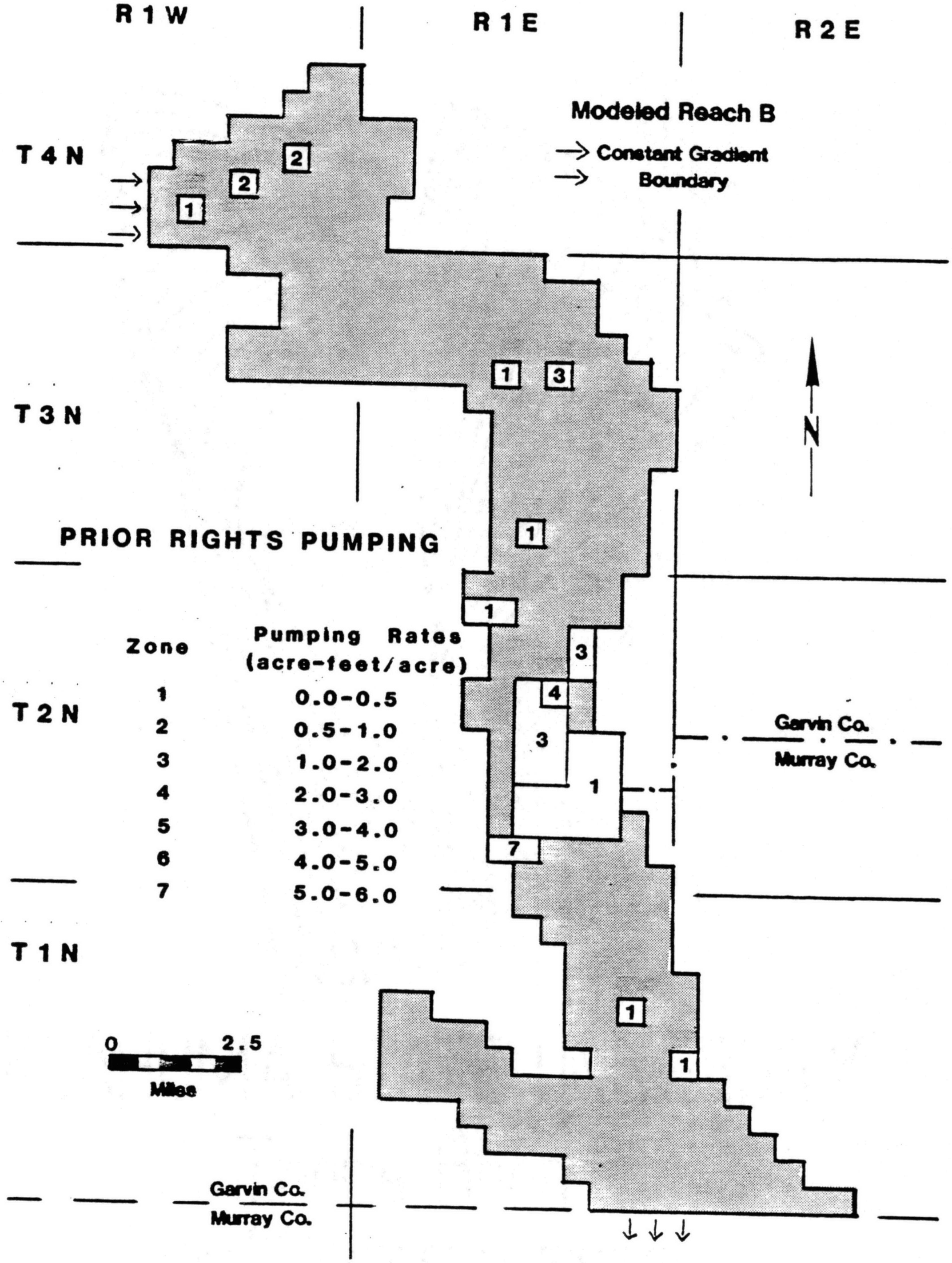


Figure 125. Distribution of Prior Appropriative Rights - Modeled Reach B

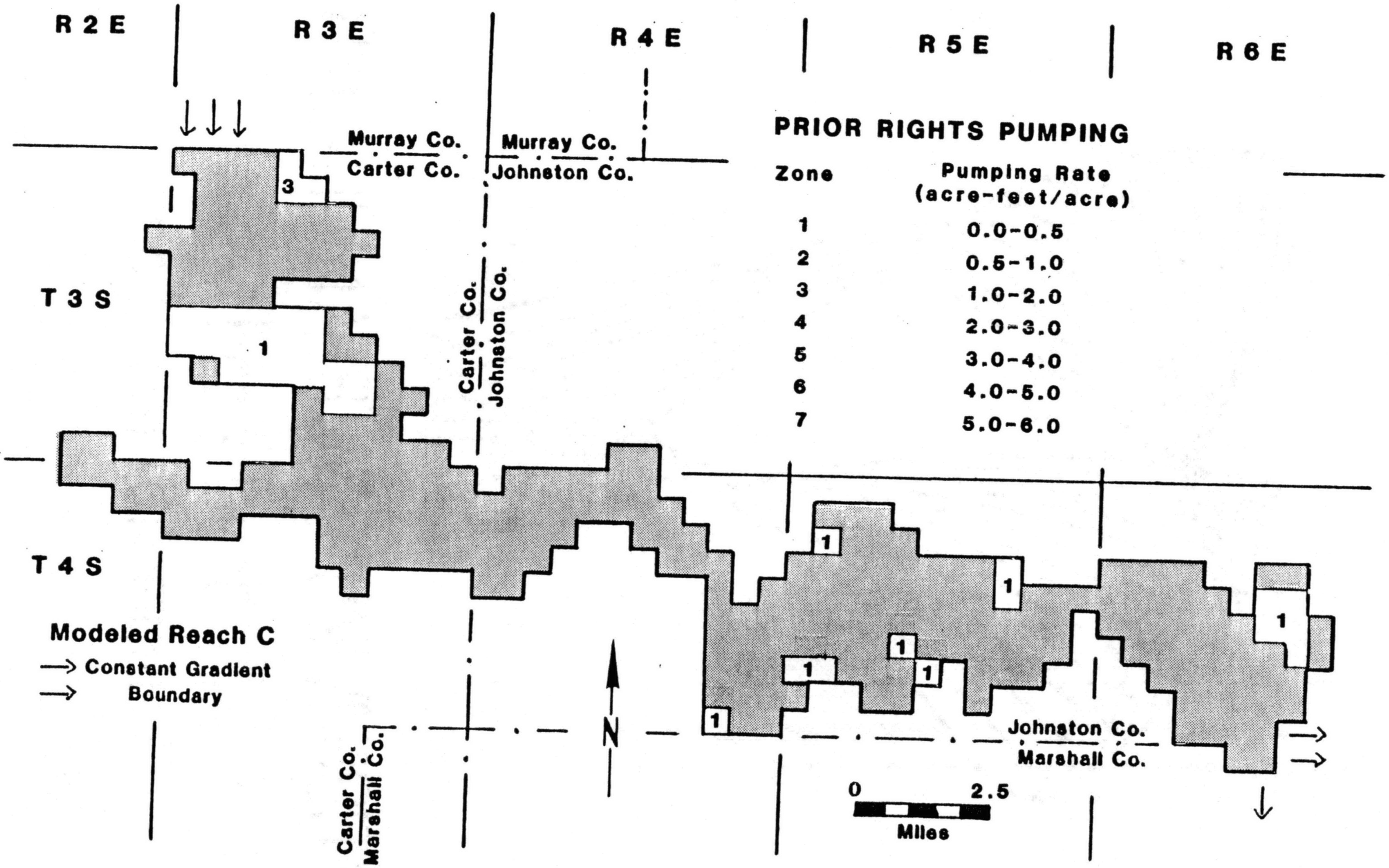


Figure 126. Distribution of Prior Appropriative Rights - Modeled Reach C

APPENDIX O

APPLICABLE PRIOR RIGHTS USED IN THE STUDY

APPLICABLE PRIOR RIGHTS BY COUNTY

OKLAHOMA WATER RESOURCES BOARD

TENTATIVE ORDER ESTABLISHING PRIOR GROUND WATER RIGHTS IN GARVIN COUNTY, OKLAHOMA COVERING ALL OR PARTS OF TOWNSHIPS 1N, 2N, 3N, AND 4N, AND RANGES 1WIM, 2WIM, 3WIM, 4WIM, 1EIM, 2EIM AND 3EIM

ORDER NO T-1

The Oklahoma Water Resources Board, under the authority of 82 O. S. 1981, Sections 1085.2, 1020.14 and pursuant to Oklahoma Water Resources Board Rules and Regulations, Chapter VIII, Section 875.1 - 875.17, reviewed all active ground water files and all known coaims by person not having previously filed an application in Garvin County, and finds that the following persons have establishing a prior right to the amounts shown:

ARTHUR, FRANCIS N. Application #70-264 - filed 10/3/70
PRIORITY DATE(S) AND AMOUNTS: 4/1/74 - 54 a.f.
PURPOSE: To irrigate 148 acres located in SE1/4 of the NE1/4, Sec. and E1/2 of the NE1/4 of the NE1/4, Sec. 32, Twp. 4N, Rge. 1WIM, from well(s) located in the NW1/4 of the SE1/4, Sec. 33, Twp. 4N, Rge. 1WIM
Total: 54 a.f.

BERRY, CHARLES L. Application #58-55 - filed 2/18/58
PRIORITY DATE(S) AND AMOUNTS: 4/1/57 - 120 a.f.
PURPOSE: To irrigate 40 acres located in SW1/4 of the NW1/4 and W1/4 of the SE1/4 of the NW1/4 and SE1/4 of the SE1/4 of the NW1/4 and N1/2 of the N1/2 of the SW1/4 and SW1/4 of the NW1/4 of the SW1/4, Sec. 11, Twp. 4N, Rge. 3WIM, from wells located in the same legal description.
Total: 120 a.f.

CARR, BILL Application #68-425 - filed 12/5/68
PRIORITY DATE(S) AND AMOUNTS: 12/5/68 - 167 a.f.
PURPOSE: To irrigate 200 acres located in S1/2 and NE1/4 of the SE1/4 and E1/2 of the NE1/4, Sec. 5, Twp. 4N, Rge 2WIM, from wells located in the SE1/4 of the NE1/4, Sec. 5, Twp. 4N, Rge. 2WIM.
Total: 167 a.f.

CARR, BILL Application #67-694B - filed 6/2/67
PRIORITY DATE(S) AND AMOUNTS: 6/2/67 61 - a.f.
PURPOSE: To irrigate 60 acres located in N1/2 of the NW1/4, Sec. 7, Twp. 4N, Rge. 1WIM, from wells located in the NW1/4 of the NW1/4, Sec. 7, Twp. 4N, Rge. 1WIM.
Total: 61 a.f.

GARRETT, W. W. Application #55-709 - filed 2/23/55
PRIORITY DATE(S) AND AMOUNTS: 2/23/55 - 20 a.f.
PURPOSE: To irrigate 30 acres located in the SW1/4 of the SE1/4, Sec. 15, Twp. 2N, Rge. 1EIM, from wells located in the same legal description.
Total: 25 a.f.

GOODNER, SUE MOODY Application #65-608 - filed 12/2/65
PRIORITY DATE(S) AND AMOUNTS: 12/2/65 - 115 a.f.
PURPOSE: To irrigate 80 acres located in the SE1/4 of the NE1/4, Sec. 26, Twnship 4N, Rge. 1WIM, from wells located in the same legal description.
Total: 115 a.f.

GREEN, CHARLES HUGO Application #67-115 - filed 2/14/67
PRIORITY DATE(S) AND AMOUNTS: 2/14/67 - 83 a.f.
PURPOSE: To irrigate 60 acres located in N1/2 of the SE1/4, Sec. 27, Twp. 4N, Rge. 1WIM, from wells located in the same legal description.
Total: 83 a.f.

GRIMES, RICHARD Application #67-539 - filed 6/5/67
PRIORITY DATE(S) AND AMOUNTS: 6/5/67 - 73 a.f.
PURPOSE: To irrigate 160 acres located in the SE1/4 and SE1/4 of the SE1/4 of the NE1/4, Sec. 22, Twp. 4N, Rge. 3WIM, from wells located in the NE1/4 of the SE1/4, Sec. 22, Twp. 4N, Rge. 3WIM.
Total: 73 a.f.

GRIMMETT, BILL Application #69-328 - filed 7/28/69
PRIORITY DATE(S) AND AMOUNTS: 7/28/69 - 320 a.f.
PURPOSE: To irrigate 160 acres located in NE1/4, Sec. 15, Twp. 3N, Rge. 1EIM, from well located in the SE1/4 of the NE1/4, Sec. 15, Twp. 3N, Rge. 1EIM.
Total: 320 a.f.

KERR MCGEE OIL CORP. Application #48-7 - filed 2/2/48
PRIORITY DATE(S) AND AMOUNTS: 2/2/48 - 1250 a.f.
PURPOSE: For oil refinery acres located in Sec.s 22, 23, 26, 27, Twp. 2N, Rge. 1EIM, from wells located in the same legal description.
Total: 1250 a.f.

KERR MCGEE OIL CORP. Application #55-1265 - filed 6/8/55
PRIORITY DATE(S) AND AMOUNTS: 6/8/55 - 1283 a.f.;
1/1/63 - 346 a.f.
PURPOSE: For asphalt Refinery on acres located in the NE1/4 of the NE1/4, Sec. 33, and NW1/4 of the NW1/4, Sec. 34, Twp. 2N, Rge. 1EIM, from wells located in the same legal description.
Total: 1629 a.f.

KERR MCGEE OIL CORP. Application #53-815B - filed 12/28/53
PRIORITY DATE(S) AND AMOUNTS: 12/28/53 - 1613 a.f.
PURPOSE: For processing crude oil on acres located in Secs. 15 and 22, Twp. 2N, Rge. 1EIM, from wells located in the same legal description.
Total: 1613 a.f.

LINDSAY, CITY OF Application #72-357A - filed 10/10/72
PRIORITY DATE(S) AND AMOUNTS: 10/10/72 - 738 a.f.
PURPOSE: For municipal use from wells located in the NE1/2 of the SW1/4 of the NE1/4, Sec. 2, and SE1/4 of the SE1/4 of the SE1/4; SW1/4 of the SE1/4 of the SE1/4; SE1/4 of the SE1/4 of the NE1/4; SW1/4 of the NE1/4 of the NE1/4, all in Sec. 10 and NW1/4 of the NW1/4 of the SE1/4, Sec. 11; and SE1/4 of the SE1/4 of the NE1/4, Sec. 14, all in Twp. 4N, Rge. 4WIM.
Total: 738 a.f.

MORRIS, EMMITT E. Application #54-429 - filed 8/5/54
PRIORITY DATE(S) AND AMOUNTS: 8/5/54 - 100 a.f.
PURPOSE: To irrigate 100 acres located in the SW1/4, Sec. 18, Twp. 3N, Rge. 1EIM, from wells located in the same legal description.
Total: 100 a.f.

POSEY, CLAYTON E. Application #67-694A - filed 6/2/67
PRIORITY DATE(S) AND AMOUNTS: 6/2/67 - 160 a.f.
PURPOSE: To irrigate 98 acres located in N1/4 of the NE1/4, Sec. 7, Twp. 4N, Rge. 1WIM, from wells located in the NW1/4 of the NW1/4, Sec. 7, Twp. 4N, Rge. 1WIM.
Total: 67 a.f.

SIMMS, JACK Application #58-55 - filed 2/18/58
PRIORITY DATE(S) AND AMOUNTS: 12/31/57 - 120 a.f.
PURPOSE: To irrigate 40 acres located in the SW1/4 of the NW1/4 and W1/2 of the SE1/4 of the NW1/4, and SE1/4 of the SE1/4 of the NW1/4 and N1/2 of the N1/2 of SW1/4 of the NW1/4 of the SW1/4 , Sec. 11, Twp. 4N, Rge. 3WIM, from wells located in the SW1/4 of the SE1/4 of the NW1/4, Sec. 11, Twp. 4N, Rge. 3WIM.
Total: 120 a.f.

TWAM NURSERY INC. Application #51-78 - filed 8/17/51
PRIORITY DATE(S) AND AMOUNTS: 8/17/51
PURPOSE: To irrigate 94 acres located in the S1/2, Sec. 4, Twp. 2N, Rge. 1EIM, from wells located in the SE1/4 of the SW1/4, Sec. 4, Twp. 2N, Rge. 1EIM.
Total: 147 a.f.

WARREN PETROLEUM CORP. Application #57-145 - filed 2/13/57
PRIORITY DATE(S) AND AMOUNTS: 2/13/57 - 80 a.f.
PURPOSE: Industrial use of acres located in NE1/4 of the NW1/4, Sec. 5, Twp. 4N, Rge. 3WIM.
Total: 80 a.f.

WARREN PETROLEUM CORP. Application #63-348 - filed 10/24/63
PRIORITY DATE(S) AND AMOUNTS: 10/24/63 - 161 a.f.
PURPOSE: Industrial use on land located in the SW1/4 of the SW1/4, Sec. 5, Twp. 4N, Rge. 3WIM, from wells located in the same legal description.
Total: 161 a.f.

WARREN PETROLEUM CORP. Application #64-33 - filed 1/22/64
PRIORITY DATE(S) AND AMOUNTS: 1/22/64 - 177 a.f.
PURPOSE: For industrial use on lands located in the SW1/4 of the SW1/4, Sec. 5, Twp. 4N, Rge. 3WIM, from wells located in the same legal description.
Total: 177 a.f.

WOODS, D. C. Application #53-516 - filed 6/18/53
PRIORITY DATE(S) AND AMOUNTS: 6/18/53 - 21 a.f.
PURPOSE: To irrigate 160 acres located in the SW1/4, Sec. 16, Twp. 4N, Rge. 4WIM, from well located in the same legal description.
Total: 21 a.f.

WYNNEWOOD, CITY OF Application #52-12 - filed 1/15/52
PRIORITY DATE(S) AND AMOUNTS: 1/15/52 - 600 a.f.
PURPOSE: For municipal use from wells located in the N1/2 of NE1/4, Sec. 15 and E1/2 of the NW1/4 and S1/2 of the NE1/4 and W1/2 of the W1/2, Sec. 11, all in Twp. 2N, R1EIM.
Total: 600 a.f.

TENTATIVE ORDER ESTABLISHING PRIOR GROUND WATER RIGHTS IN MURRAY COUNTY, OKLAHOMA, COVERING ALL OR PARTS OF TOWNSHIPS 1S, 2S, 1N, AND 2N, AND RANGES 1WIM, 1EIM, 2EIM, 3EIM, AND 4EIM

BAKER, JAMES W. Application #55-72 - filed 1/7/55
PRIORITY DATE(S) AND AMOUNTS: 7/5/61 - 13 a.f.
PURPOSE: To irrigate 80 acres located in SW1/4 of Sec. 18 and NW1/4 of Sec. 19, Twp. 1N Rge. 2EIM, from well(s) located in same legal description.
Total: 13 a.f.

CONTINENTAL OIL CO. Application #63-306 - filed 9/12/63
PRIORITY DATE(S) AND AMOUNTS: 9/12/63 - 46 a.f.
PURPOSE: For industrial use from well(s) located in NE1/4 NW1/4, Sec. 13, Twp. 1N, Rge. 1EIM.
Total: 46 a.f.

GILBERT, NORMAN Application #56-652 - filed 9/6/56
PRIORITY DATE(S) AND AMOUNTS: 7/5/61 - 42 a.f.
PURPOSE: To irrigate 105 acres located in Sec. 2, Twp. 1N, Rge. 1EIM from well(s) located in same legal description.
Total: 42 a.f.

TENTATIVE ORDER ESTABLISHING PRIOR GROUND WATER RIGHTS IN CARTER COUNTY, OKLAHOMA, COVERING ALL OR PARTS OF TOWNSHIPS 1S, 2S, 3S, 4S, AND 5S, AND RANGES 1WIM, 2WIM, 3WIM, 1EIM, 2EIM, AND 3EIM

MERRICK FARMS Application #56-578 - filed 8/9/56
PRIORITY DATE(S) AND AMOUNTS: 7/4/61 - 80 a.f.
PURPOSE: To irrigate 1,380 acres located in Secs. 19, 20, 21, 27, 28, 29, Twp. 3S, Rge. 3EIM from well(s) located in same legal description.
Total: 80 a.f.

MERRICK FARMS Application #69-391 - filed 9/5/69
PRIORITY DATE(S) AND AMOUNTS: 7/4/61 - 650 a.f.
PURPOSE: To irrigate 325 acres located in S1/2 and S1/2 of NW1/4 and SW1/4 of NE1/4 of Sec. 4, Twp. 4S, Rge. 3EIM from well(s) located in same legal description.
Total: 650 a.f.

TENTATIVE ORDER ESTABLISHING PRIOR GROUND WATER RIGHTS IN JOHNSTON COUNTY, OKLAHOMA, COVERING ALL OR PARTS OF JOHNSTON COUNTY, TOWNSHIPS 1S, 2S, 3S, 4S, AND 5S AND RANGES 4EIM, 5EIM, 6EIM, 7EIM, AND 8EIM

BAKER, ROGER G. Application #52-159 - filed 7/11/52
PRIORITY DATE(S) AND AMOUNTS: 7/11/52 - 18 a.f.
PURPOSE: To irrigate 90 acres located in NW1/4 of Sec. 15, Twp. 4S, Rge. 6EIM, from well(s) located in same legal description.

Total: 18 a.f.

BAKER, ROGER G. Application #64-154 - filed 3/9/64
PRIORITY DATE(S) AND AMOUNTS: 3/9/64 - 22 a.f.
PURPOSE: To irrigate 210 acres located in W1/2 of Sec. 15, Twp. 4S, Rge. 6EIM, from well(s) located in same legal description.

Total: 22 a.f.

CHAPMAN, FRED A. Application #58-299 - filed 9/4/58
PRIORITY DATE(S) AND AMOUNTS: 7/4/61 - 217 a.f.
PURPOSE: To irrigate 1,025 acres located in, 80 acs. in E1/2 of NW1/4 and 40 acs. in SW1/4 of NW1/2, and 20 acs. in S1/2 of NW1/2 of NW1/4 and 15 acs. in S1/2 of NW1/4 of NE1/4 of Sec. 5, and 160 acs. in NW1/4 and 80 acs. in W1/2 of NE1/4 and 40 acs. in NE1/4 of NE1/4 and 80 acs. in W1/2 of SW1/4 and 40 acs. in SE1/4 of SW1/4 of Sec. 6, and 160 acs. in NW1/4 and 40 acs. in NW1/4 of NE1/4 and 10 acs. in NW1/4 of SW1/4 of NE1/4 of Sec. 7, and 80 acs. in E1/2 of SE1/4 and 20 acs. in E1/2 of SW1/4 of SE1/4 and 10 acs. in SE1/4 of SW1/4 of SW1/4, of Sec. 19, and 40 acs. in W1/2 of W1/2 of NE1/4, and 40 acs. in S1/2 of S1/2 of NW1/4 and 40 acs. in NW1/4 of SE1/4 of Sec. 21, and 10 acs. in NW1/4 of NW1/4 of NW1/4 of Sec. 29, and 20 acs. in N1/2 of NE1/4 of NE1/4 of Sec. 30, all in Twp. 4S, Rge. 5EIM, from wells located in same legal description.

DAVIS, A. T. Application #67-698 - filed 8/30/67
PRIORITY DATE(S) AND AMOUNTS: 8/30/67 - 37 a.f.
PURPOSE: To irrigate 110 acres located in, 80 acs. in E1/2 of SE1/4 and 10 acs. in SE1/4 of SE1/4 of NE1/4 of Sec. 15, and 20 acs. W1/2 of NE1/4 of NE1/4 of Sec. 22, all in Twp. 4S, Rge., 6EIM, from well(s) located in NW1/4 of SW1/4 of Sec. 15, and SW1/4 of NW1/4 of Sec. 22, both in Twp. 4S, Rge. 6EIM.

Total: 37 a.f.

JOHNSTON COUNTY RURAL WATER DISTRICT NO. 2
Application #67-432 - filed 4/11/67
PRIORITY DATE(S) AND AMOUNTS: 4/11/67 - 34 a.f.
PURPOSE: For municipal use from well(s) located in NW1/4 of SE1/4 of Sec. 26, and E1/2 of SW1/4 of SE1/4 of Sec. 16, both in Twp. 4S, Rge. 4EIM.
Total: 34 a.f.

RAVIA, TOWN OF Application #63-15 - filed 1/21/63
PRIORITY DATE(S) AND AMOUNTS: 1/21/63 - 64 a.f.
PURPOSE: For municipal use from well(s) located in NE1/4 of NE1/4 of Sec. 10, and SW1/4 of SW1/4 of SW1/4 of Sec. 11, and NW1/4 of NW1/4 of NW1/4 of Sec. 14, all in Twp. 4S, Rge. 5EIM.
Total: 64 a.f.

APPENDIX P

MASS BALANCES OF PRIOR APPROPRIATIVE PUMPING FROM JULY 1, 1973 TO JULY 1, 1993 FOR MODELED REACHES A, B, AND C

TABLE XVI

MASS BALANCE OF PRIOR APPROPRIATIVE PUMPING
FROM JULY 1, 1973 TO JULY 1, 1993
(Modeled Reach A)

	Average Annual (acre feet)		Twenty Year Total (acre feet)	
	Inflow	Outflow	Inflow	Outflow
Recharge	20,581	0	407,369	0
Pumpage	0	-4,980	0	-32,129
River Leakage	0	-14,625	178	-326,698
Subsurface Flow	55	-40	1,287	-878
Evapotranspiration		-1,721		-11,542
TOTALS	20,636	-21,366	408,834	-371,248
Net Storage		-730	37,586	

Total Prior Rights for Modeled Reach A (1973) = 1925 ac-ft
or 0.035 ac-ft/acre

TABLE XVII

MASS BALANCE OF PRIOR APPROPRIATIVE PUMPING
FROM JULY 1, 1973 TO JULY 1, 1993
(Modeled Reach B)

	Average Annual (acre feet)		Twenty Year Total (acre feet)	
	Inflow	Outflow	Inflow	Outflow
Recharge	20,818	0	412,062	0
Pumpage	0	-15,572	0	-97,490
River Leakage	0	-14,868	3	-320,423
Subsurface Flow	248	-1,484	5,059	-29,963
Evapotranspiration		-733		-5,781
TOTALS	21,064	-32,658	417,124	-453,657
Net Storage		-11,593		-36,515

Total Prior Rights for Modeled Reach B (1973) = 6221 ac-ft or 0.12 ac-ft/acre

TABLE XVIII

MASS BALANCE OF PRIOR APPROPRIATIVE PUMPING
FROM JULY 1, 1973 TO JULY 1, 1993
(Modeled Reach C)

	Average Annual (acre feet)		Twenty Year Total (acre feet)	
	Inflow	Outflow	Inflow	Outflow
Recharge	18,803	0	372,160	0
Pumpage	0	-2,504	0	-16,661
River Leakage	0	-15,266	3	-300,972
Subsurface Flow	806	-179	15,941	-3,663
Evapotranspiration		-3,281		-68,586
TOTALS	19,608	-21,231	388,104	-389,882
Net Storage		-1,623		-1,778

Total Prior Rights for Modeled Reach C (1973) = 934 ac-ft or 0.021 ac-ft/acre

APPENDIX Q

PRIOR APPROPRIATIVE WATER TABLE MAPS

FOR JULY 1, 1973 AND JULY 1, 1993

FOR MODELED REACHES A, B, AND C

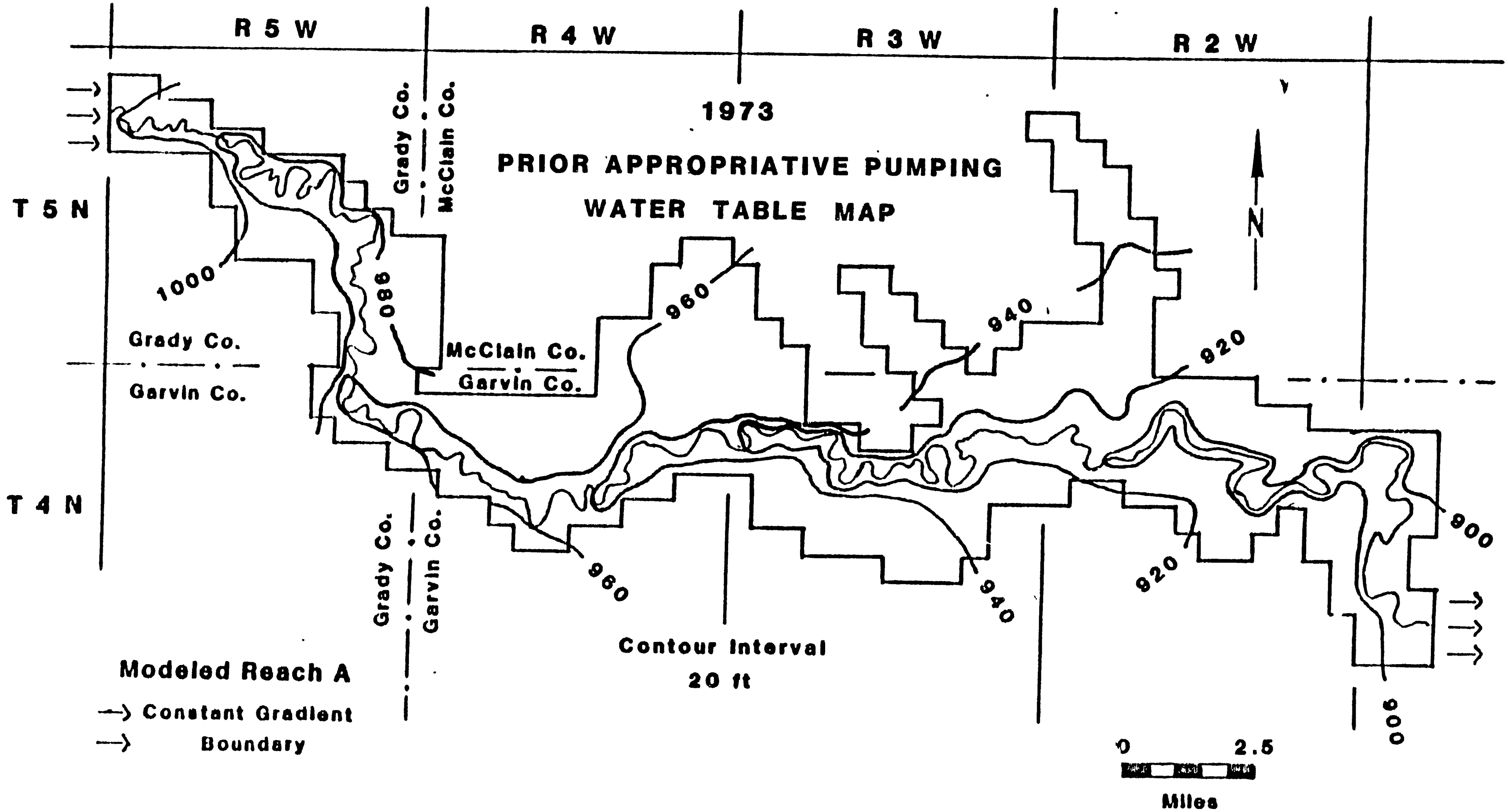


Figure 127. Prior Appropriative Water Table Map, 1973 - Modeled Reach A

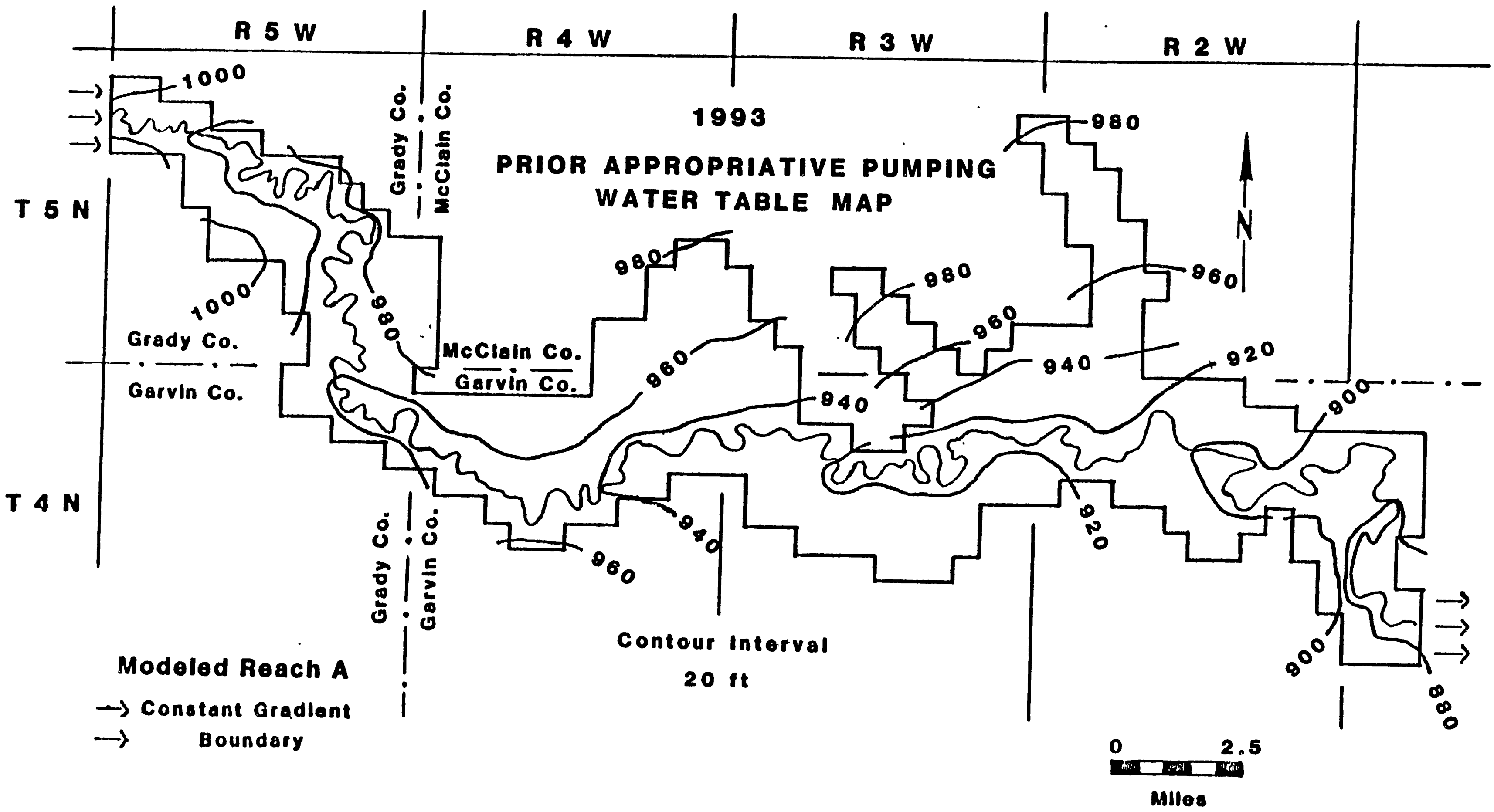


Figure 128. Prior Appropriative Water Table Map, 1993 - Modeled Reach A

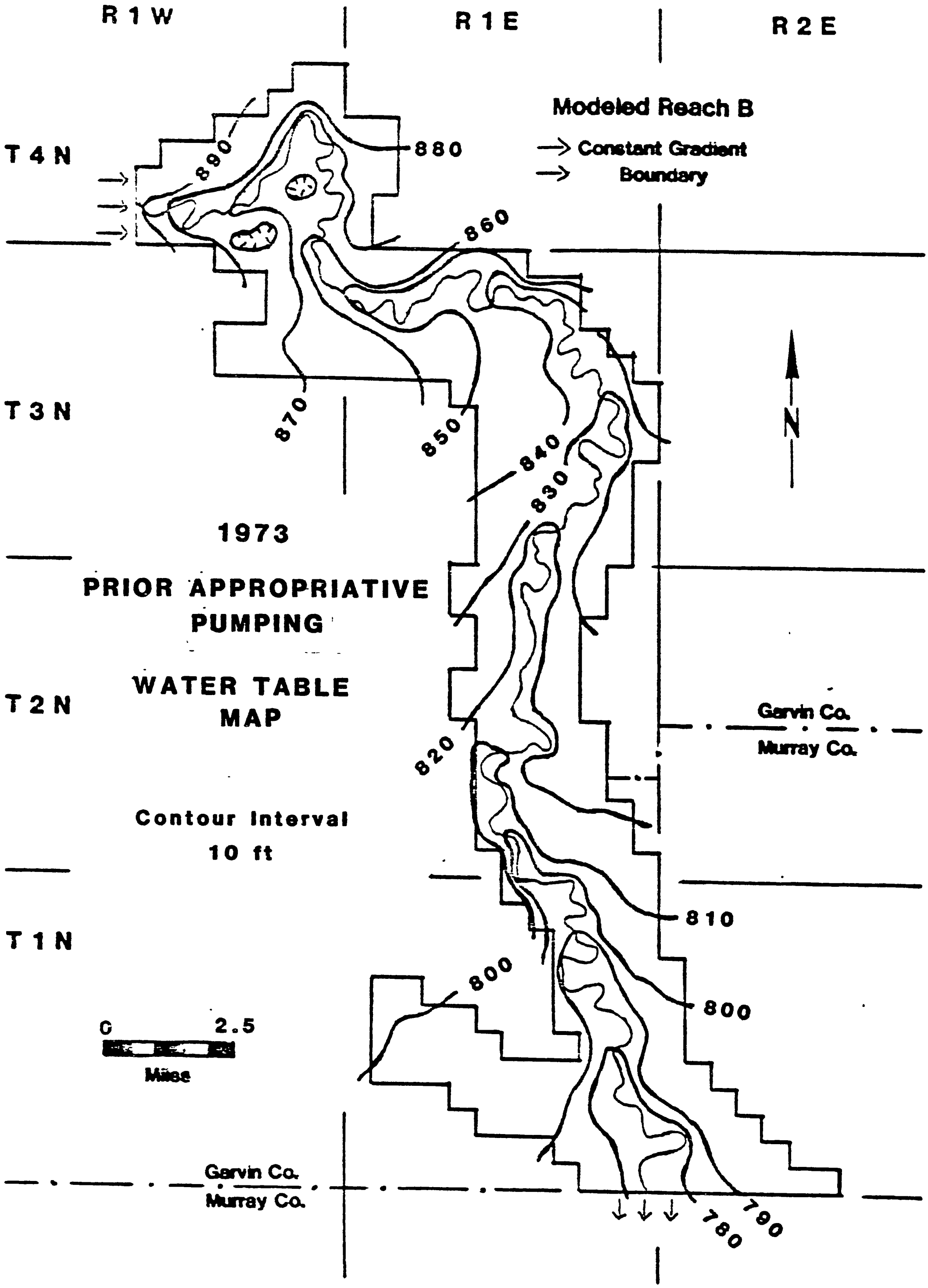


Figure 129. Prior Appropriative Water Table Map, 1973 - Modeled Reach B

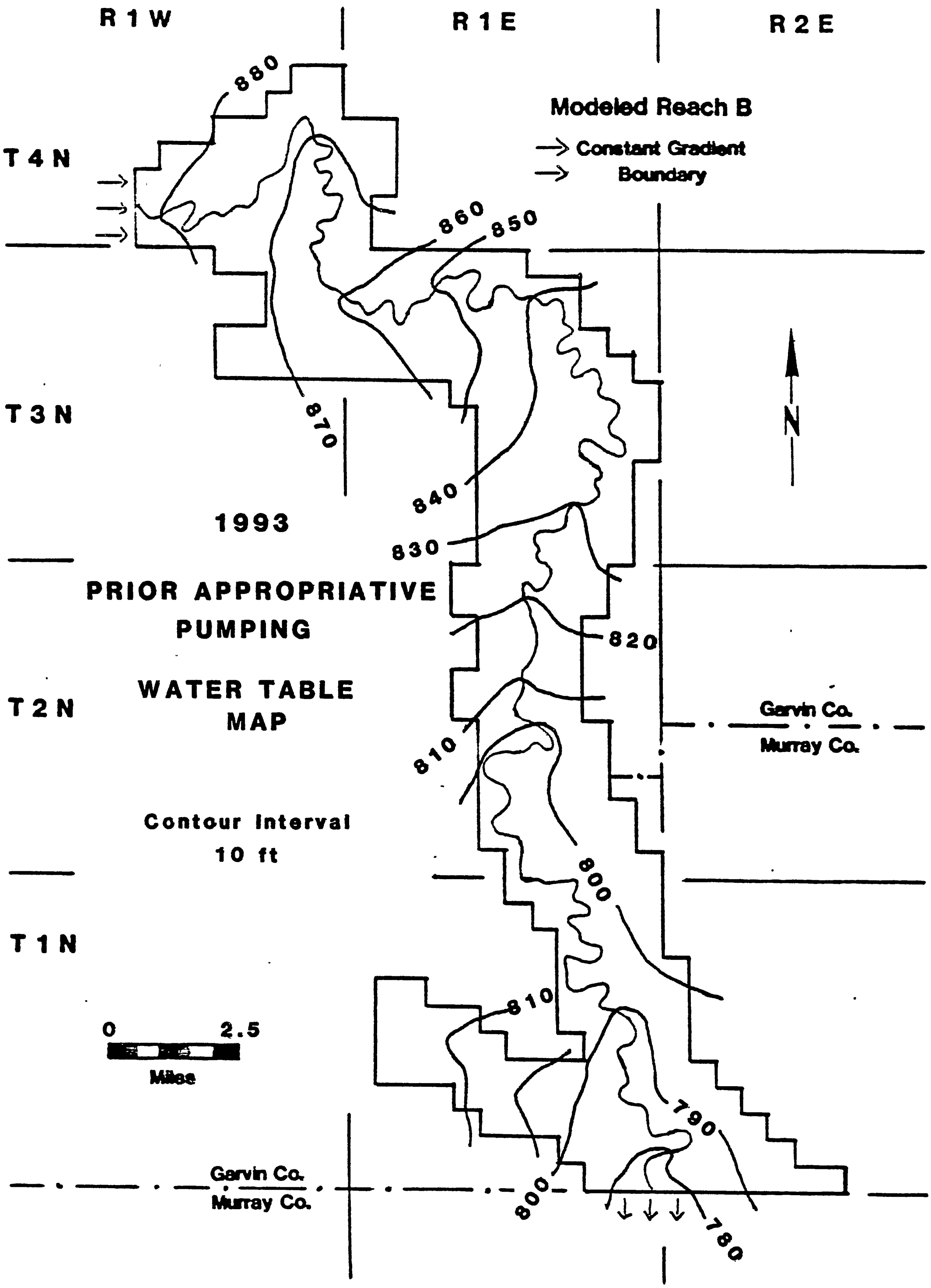


Figure 130. Prior Appropriative Water Table Map, 1993 - Modeled Reach B

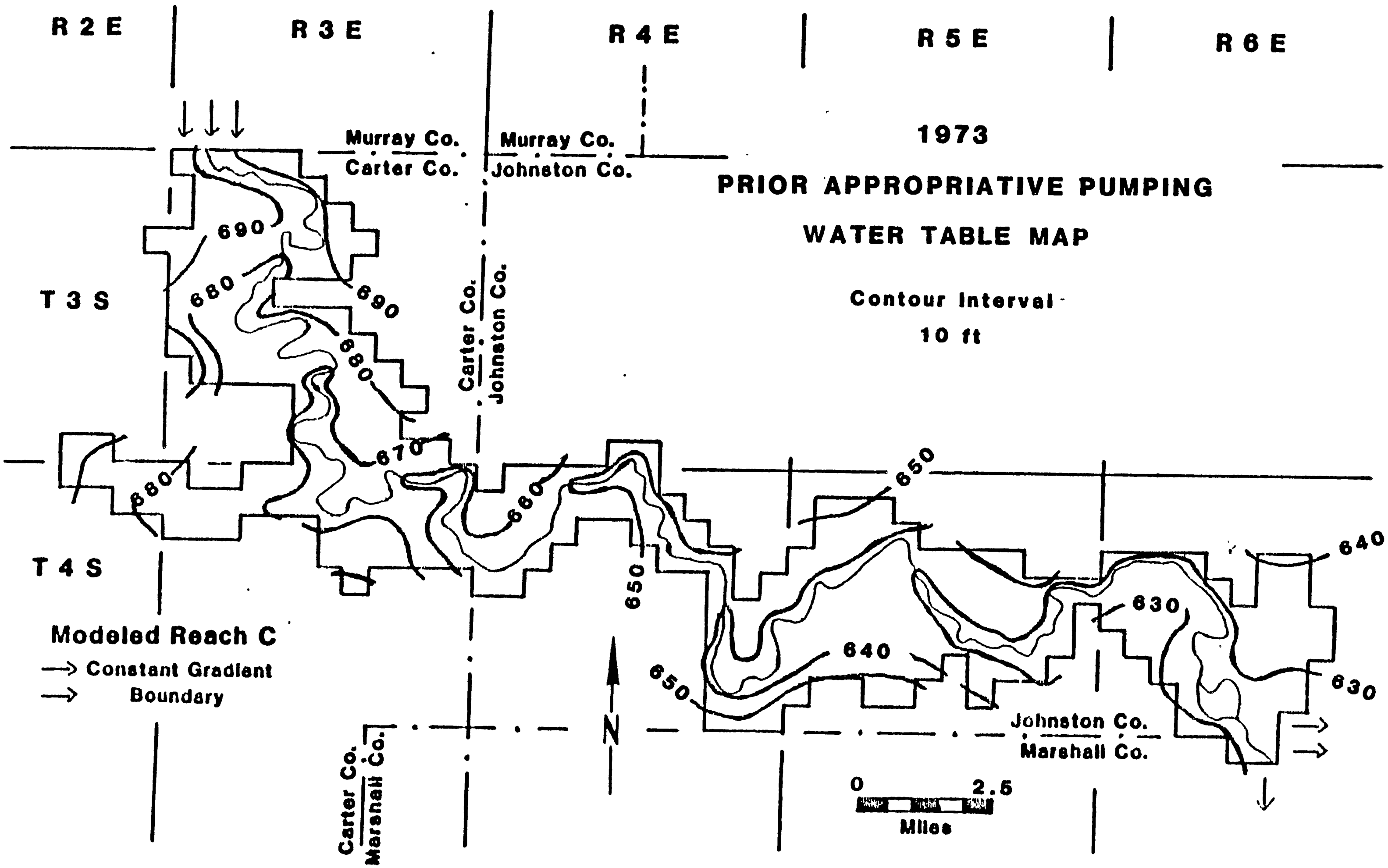


Figure 131. Prior Appropriative Water Table Map, 1973 - Modeled Reach C

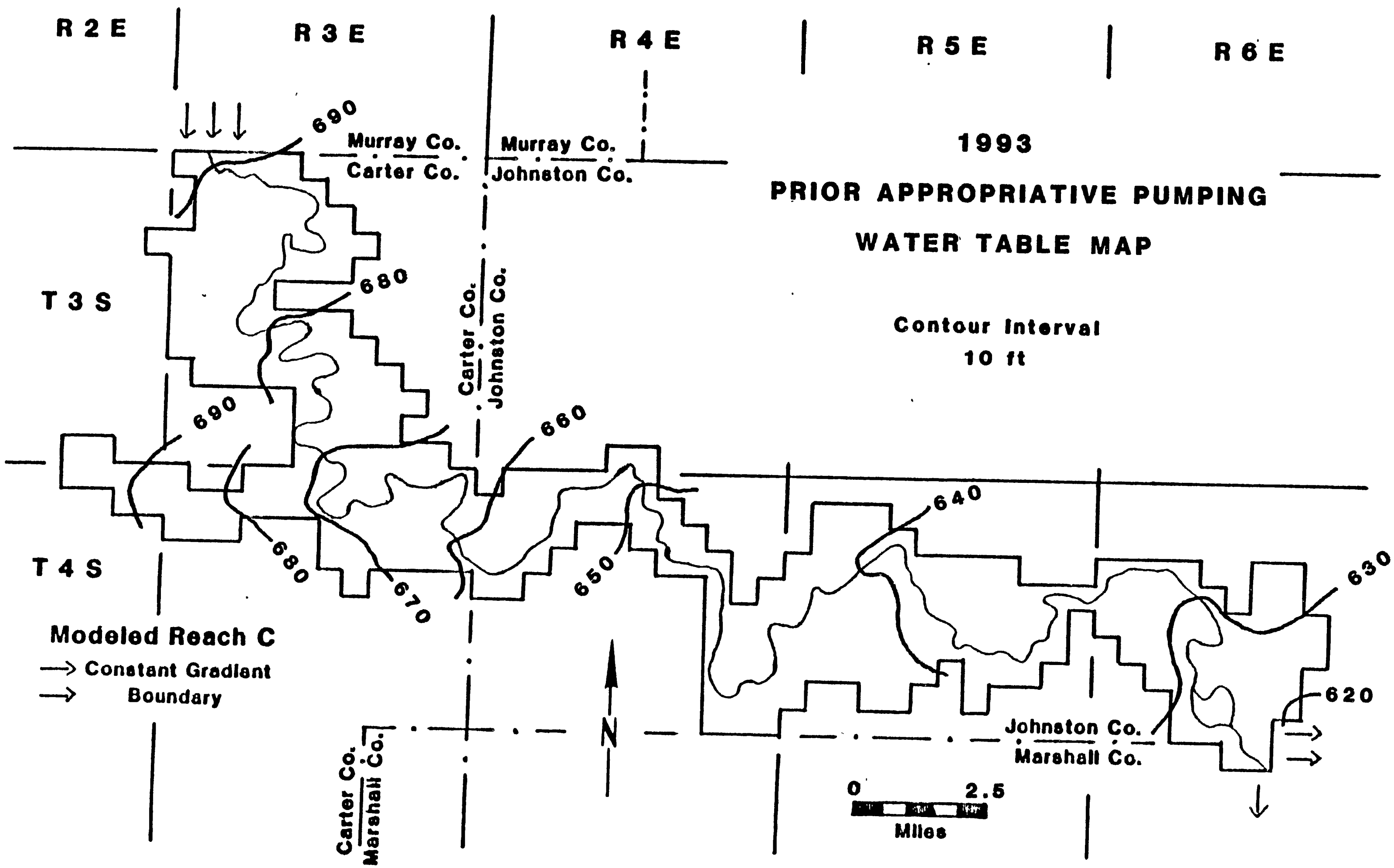


Figure 132. Prior Appropriative Water Table Map, 1993 - Modeled Reach C

APPENDIX R

PRIOR APPROPRIATIVE SATURATED THICKNESS MAPS FOR JULY 1, 1973 AND JULY 1, 1993 FOR MODELED REACHES A, B, AND C

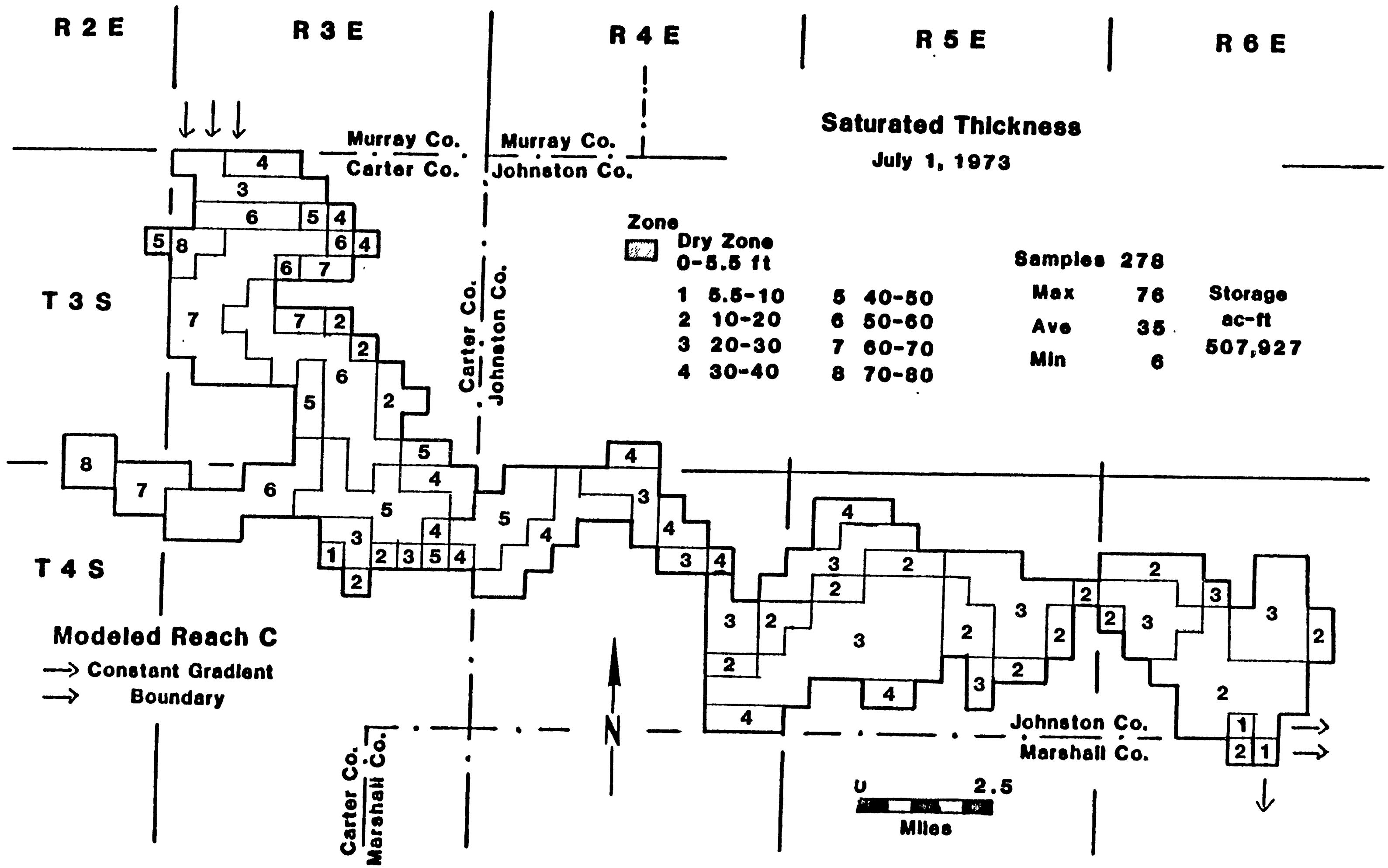


Figure 133. Prior Appropriative Saturated Thickness Map, 1973 - Modeled Reach A

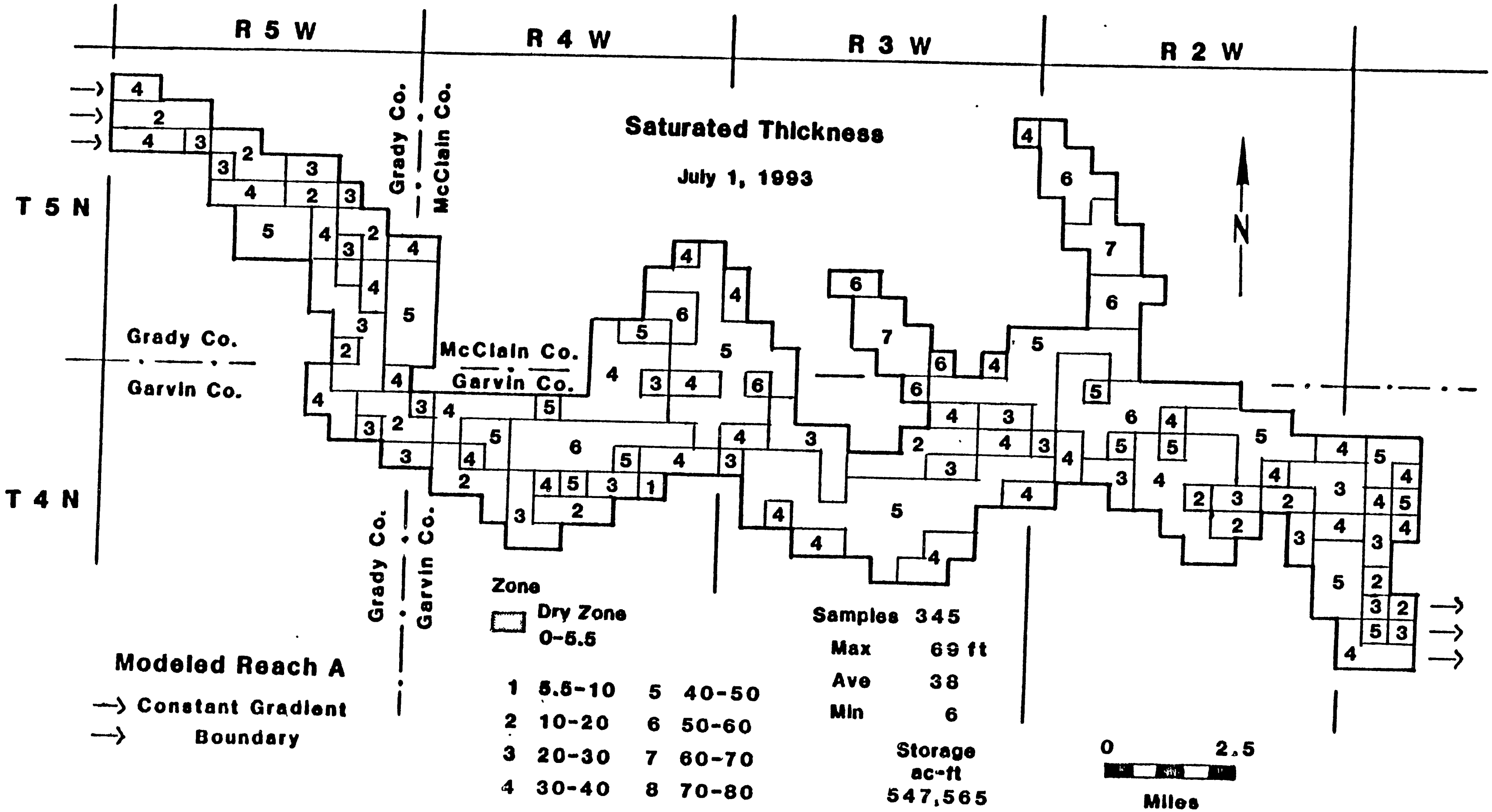


Figure 134. Prior Appropriative Saturated Thickness Map, 1993 - Modeled Reach A

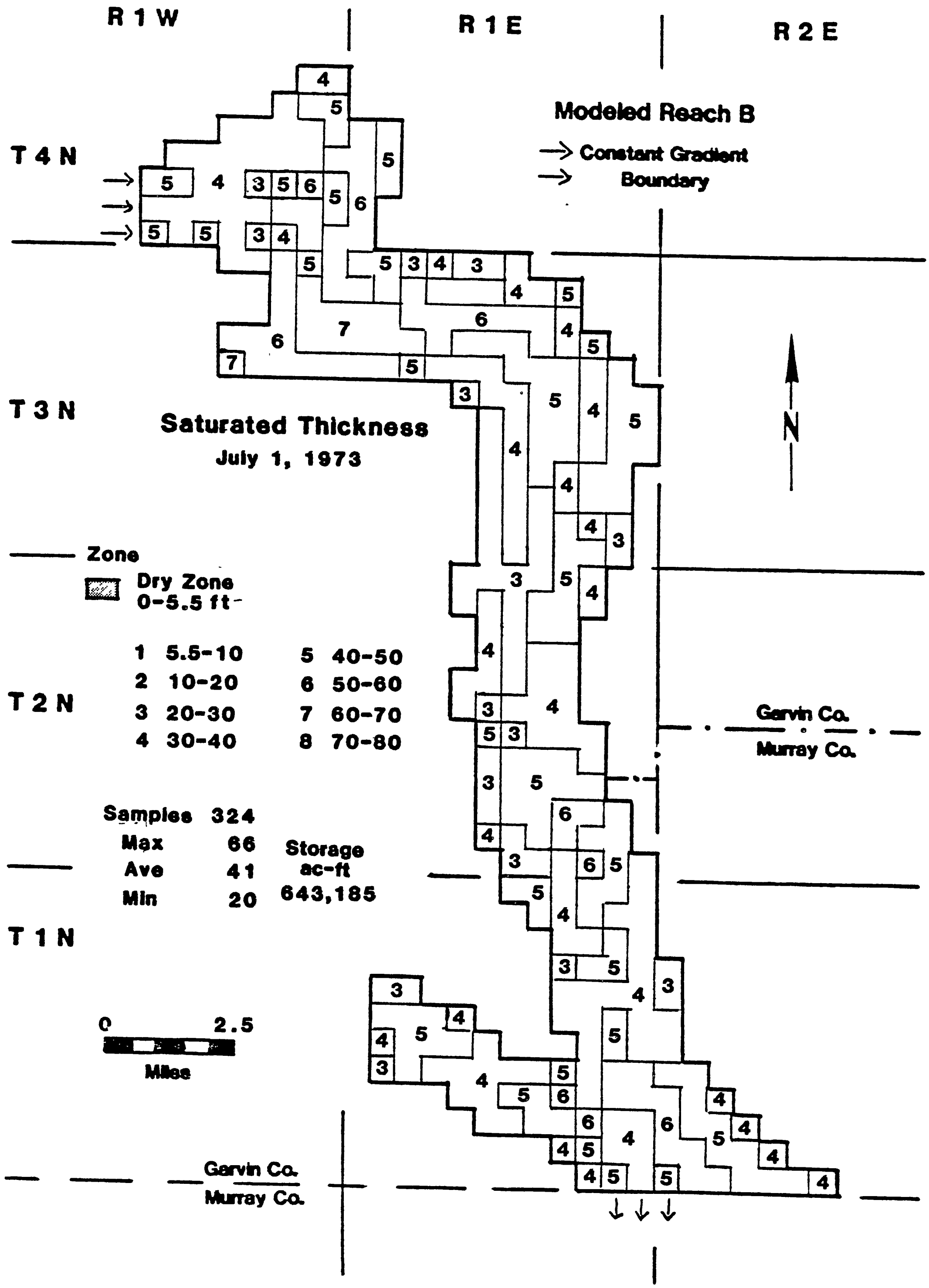


Figure 135. Prior Appropriative Saturated Thickness Map, 1973 - Modeled Reach B

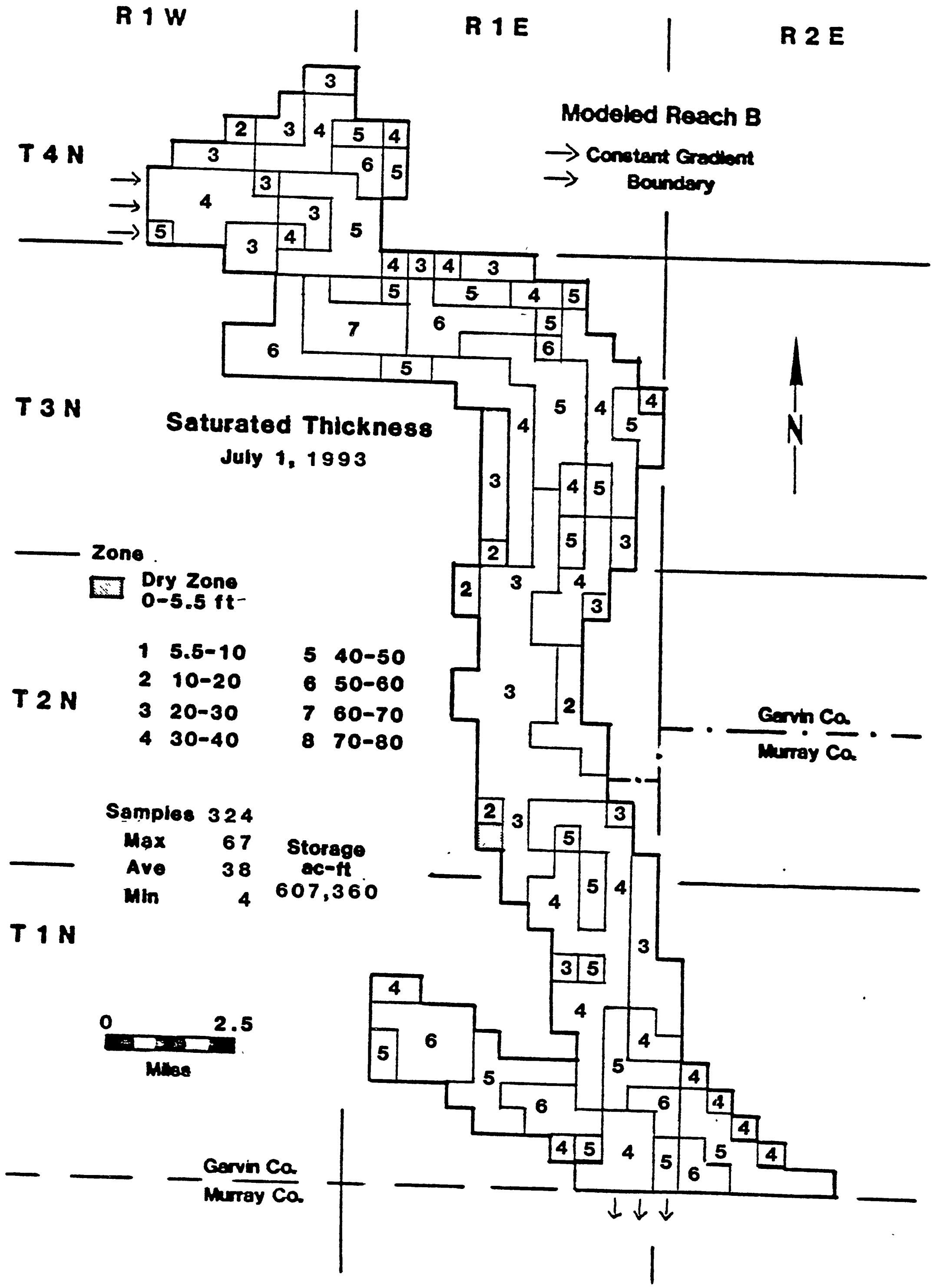


Figure 136. Prior Appropriative Saturated Thickness Map, 1993 - Modeled Reach B

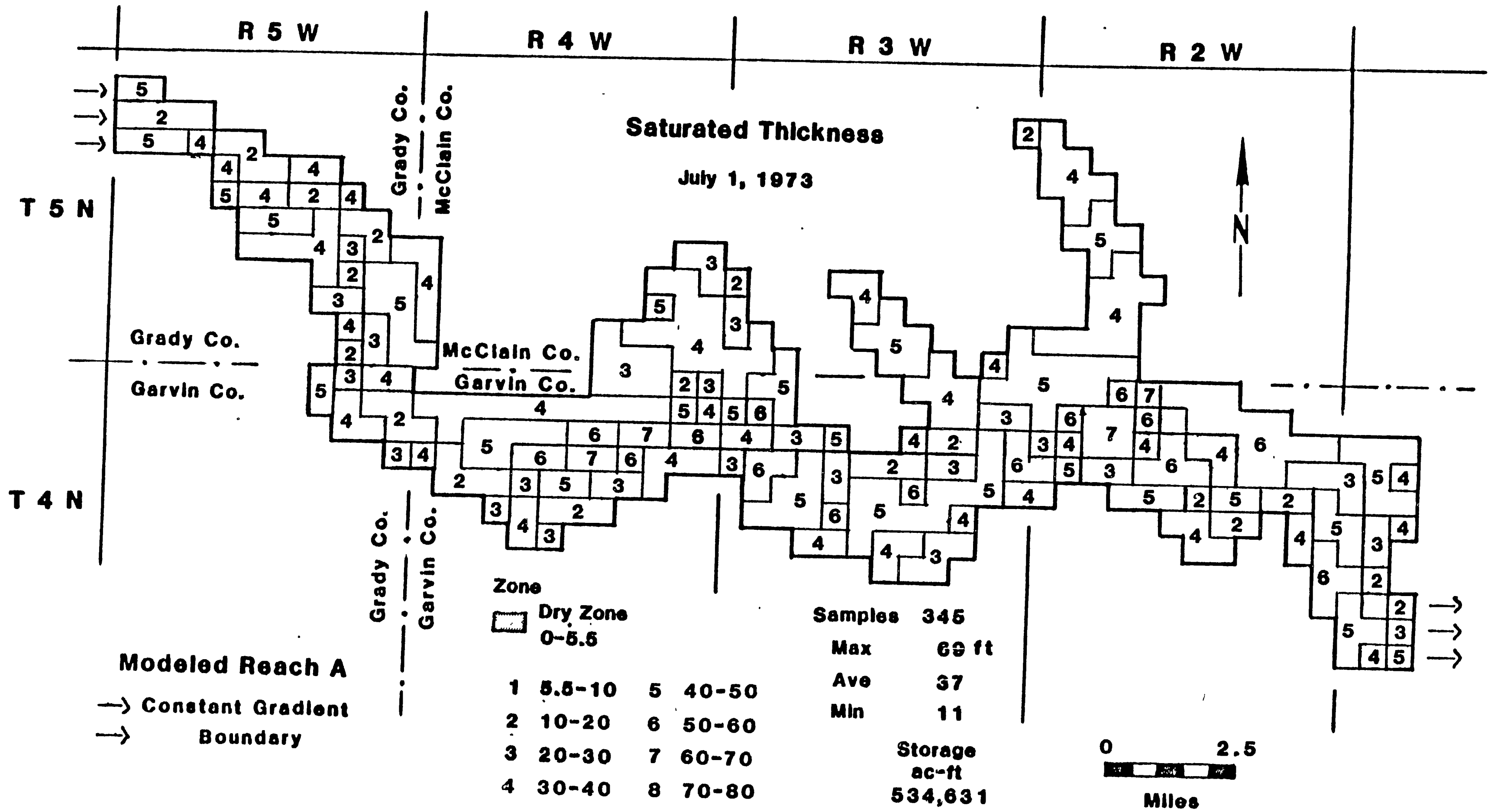


Figure 137. Prior Appropriative Saturated Thickness Map, 1973 - Modeled Reach C

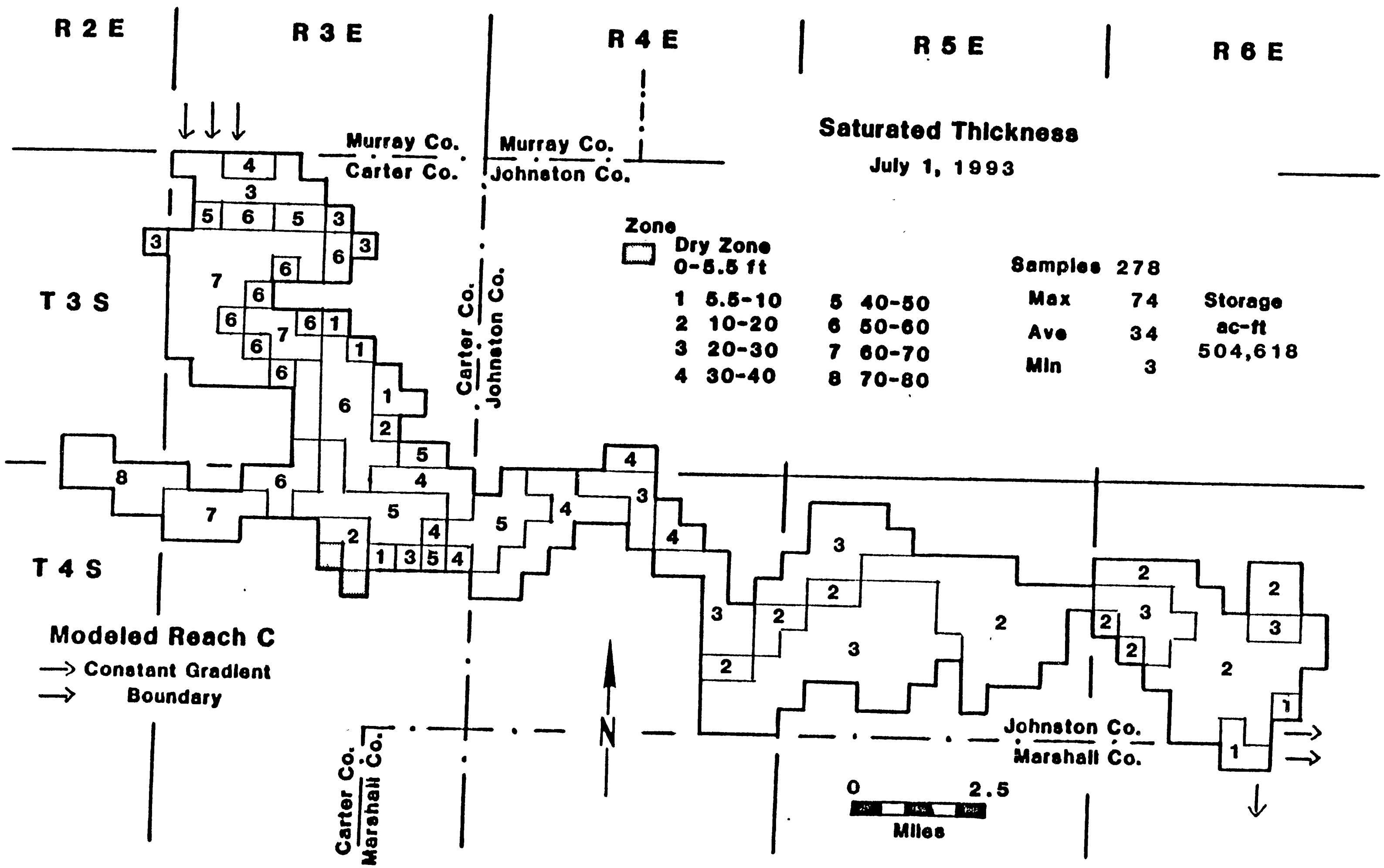


Figure 138. Prior Appropriative Saturated Thickness Map - Modeled Reach C

APPENDIX S

APPARENT RESISTIVITY GRAPHS

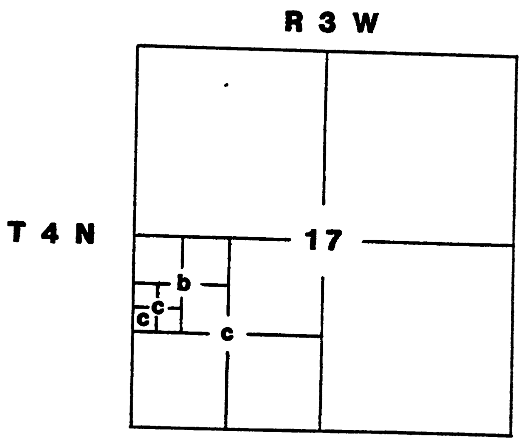
KEY FOR APPARENT RESISTIVITY GRAPHS

Marks approximate depth of water table ∇

T4N R3W Sec. 17 cbcc

This identifies where the survey was made

T4N = Township 4 North
R3W = Range 3 West
Sec. 17 = Section 17
cbcc = where in Section 17



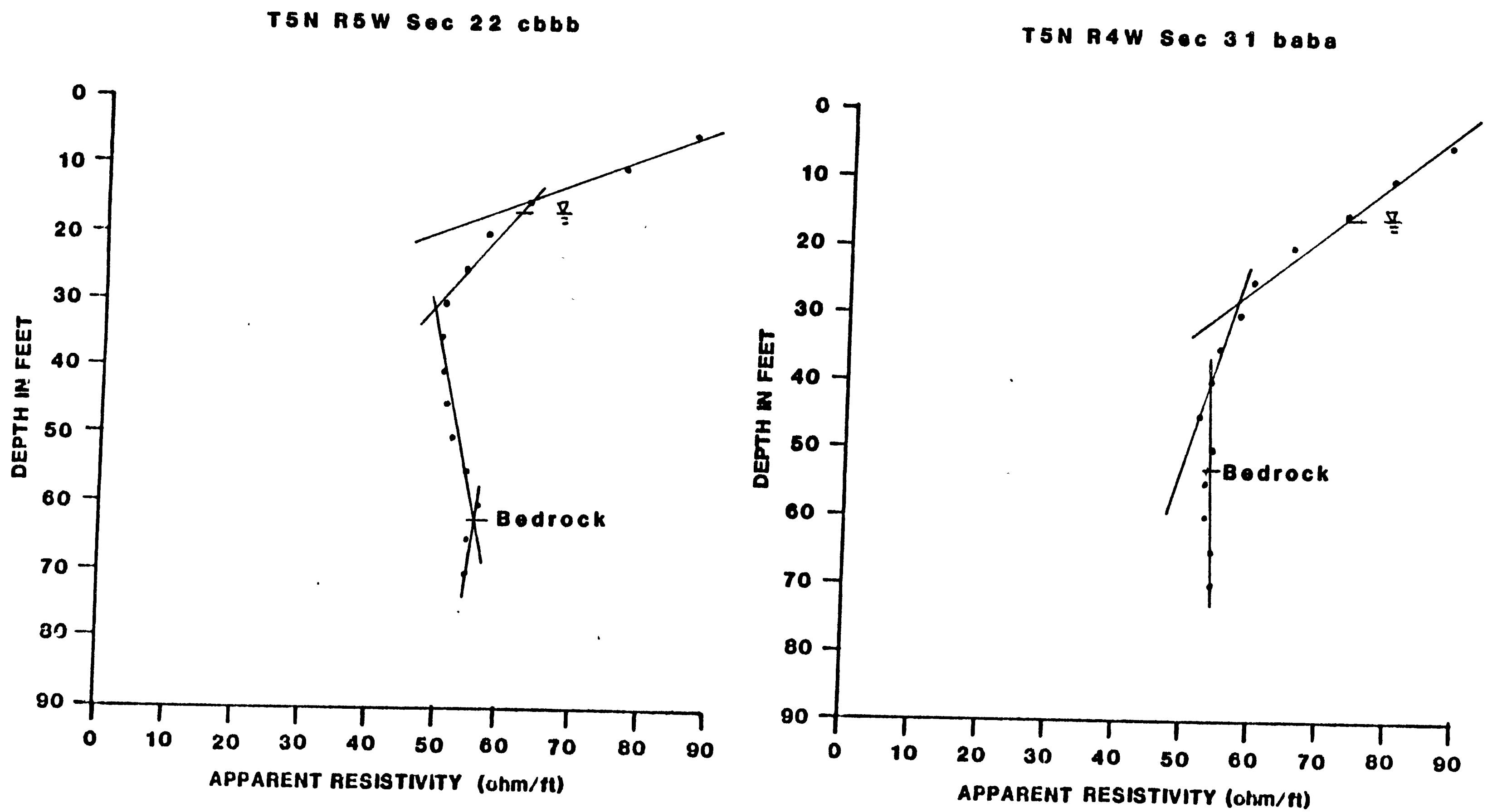


Figure 139. Apparent Resistivity Graphs

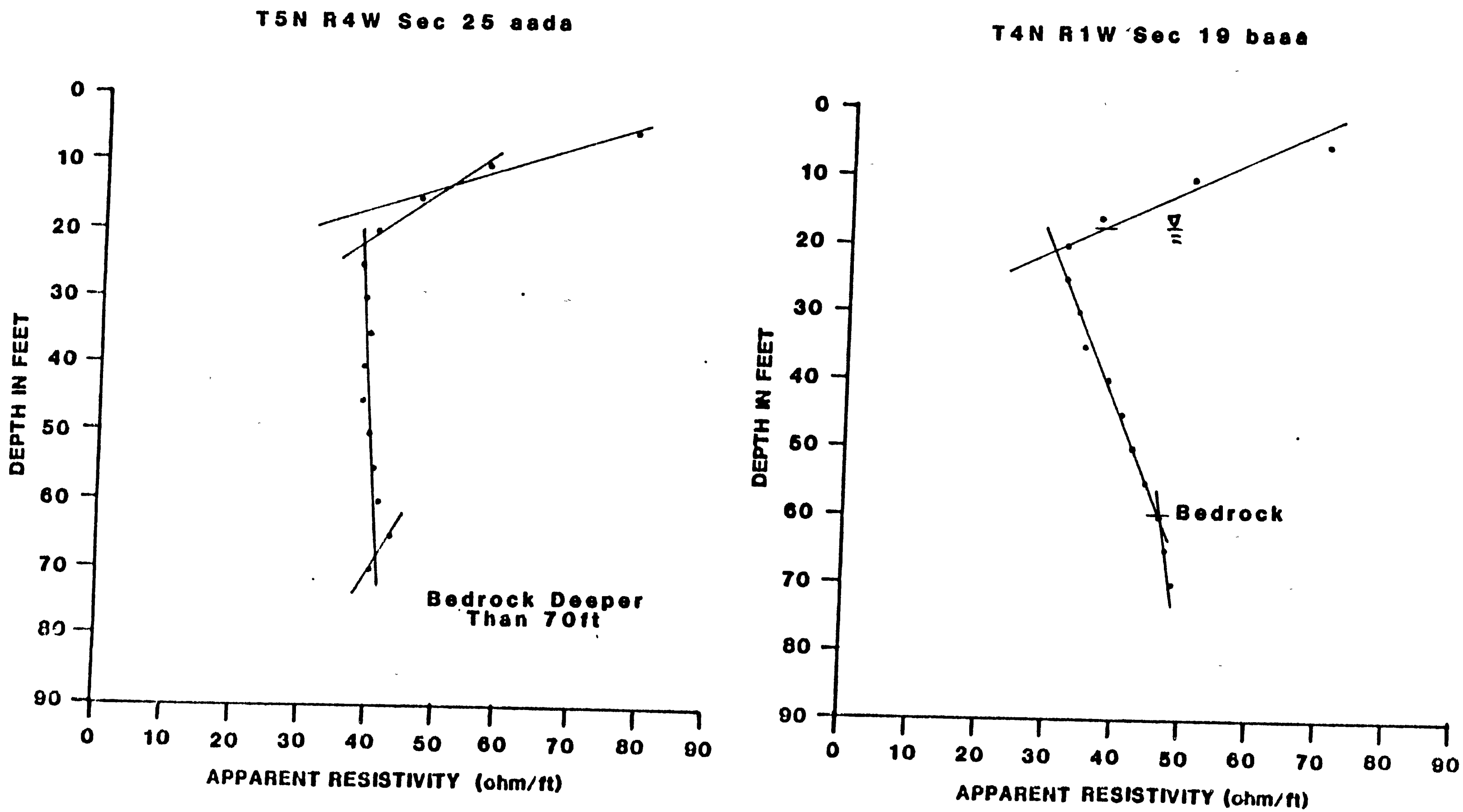


Figure 140. Apparent Resistivity Graphs

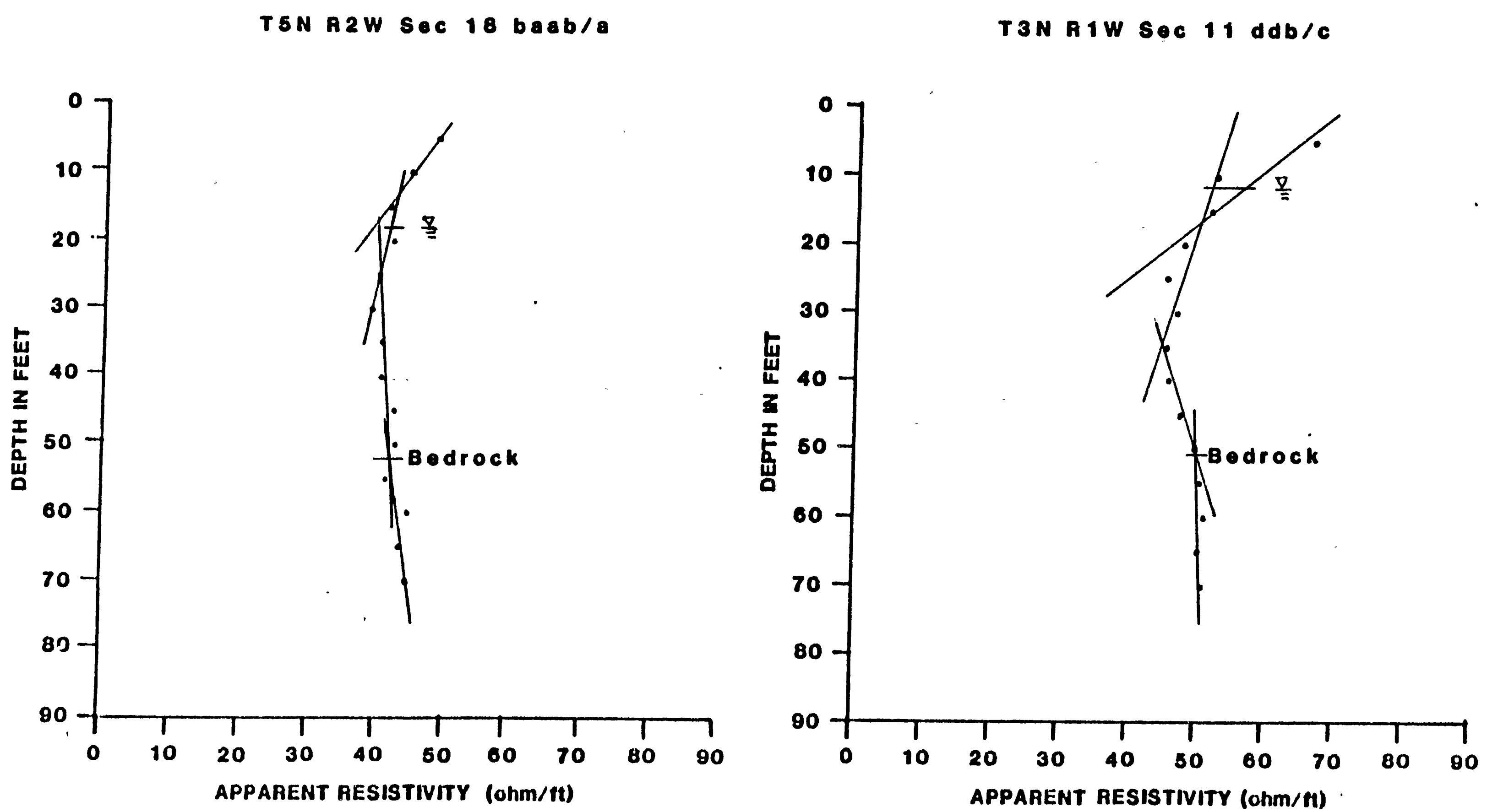


Figure 141. Apparent Resistivity Graphs

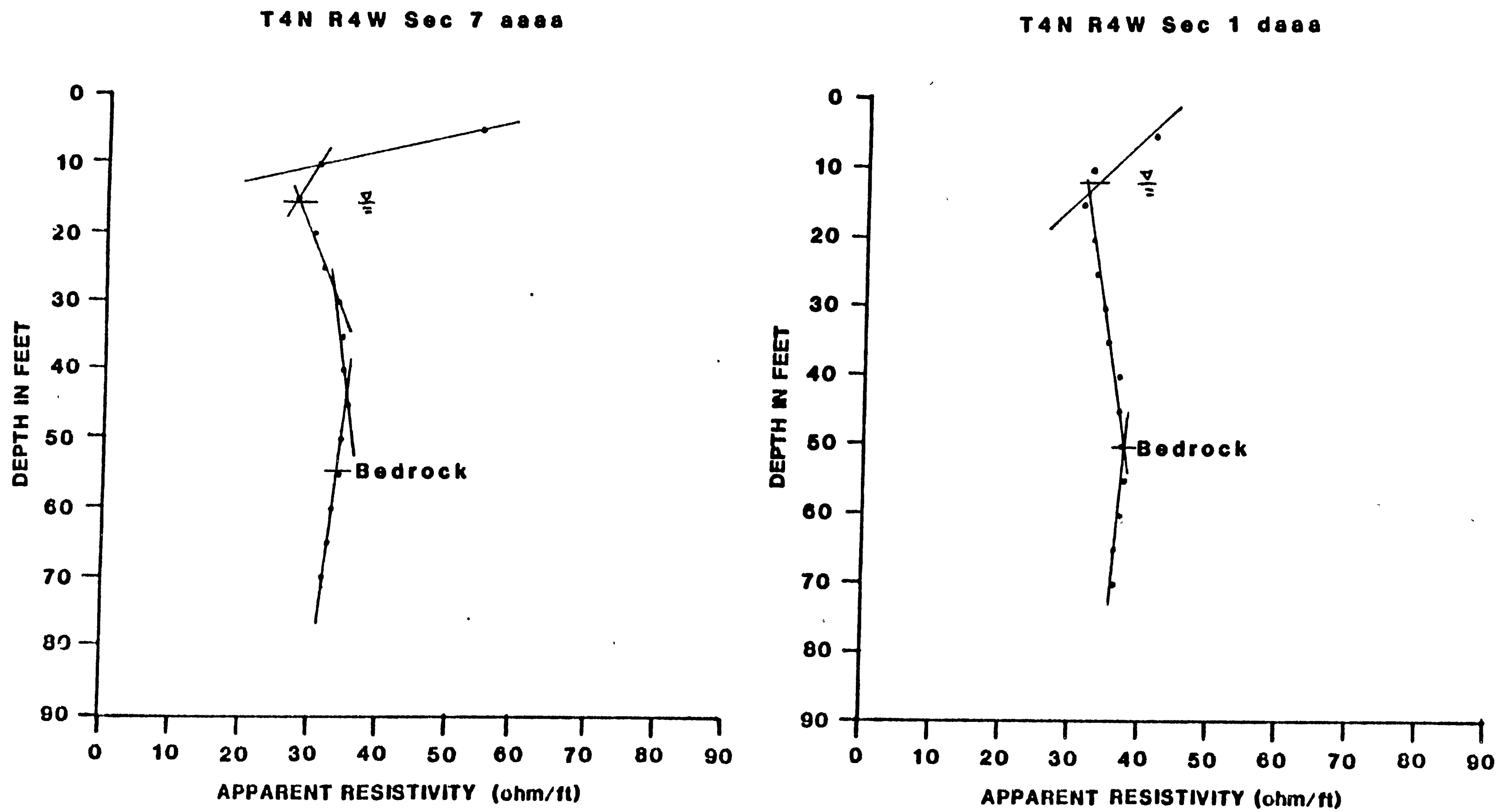


Figure 142. Apparent Resistivity Graphs

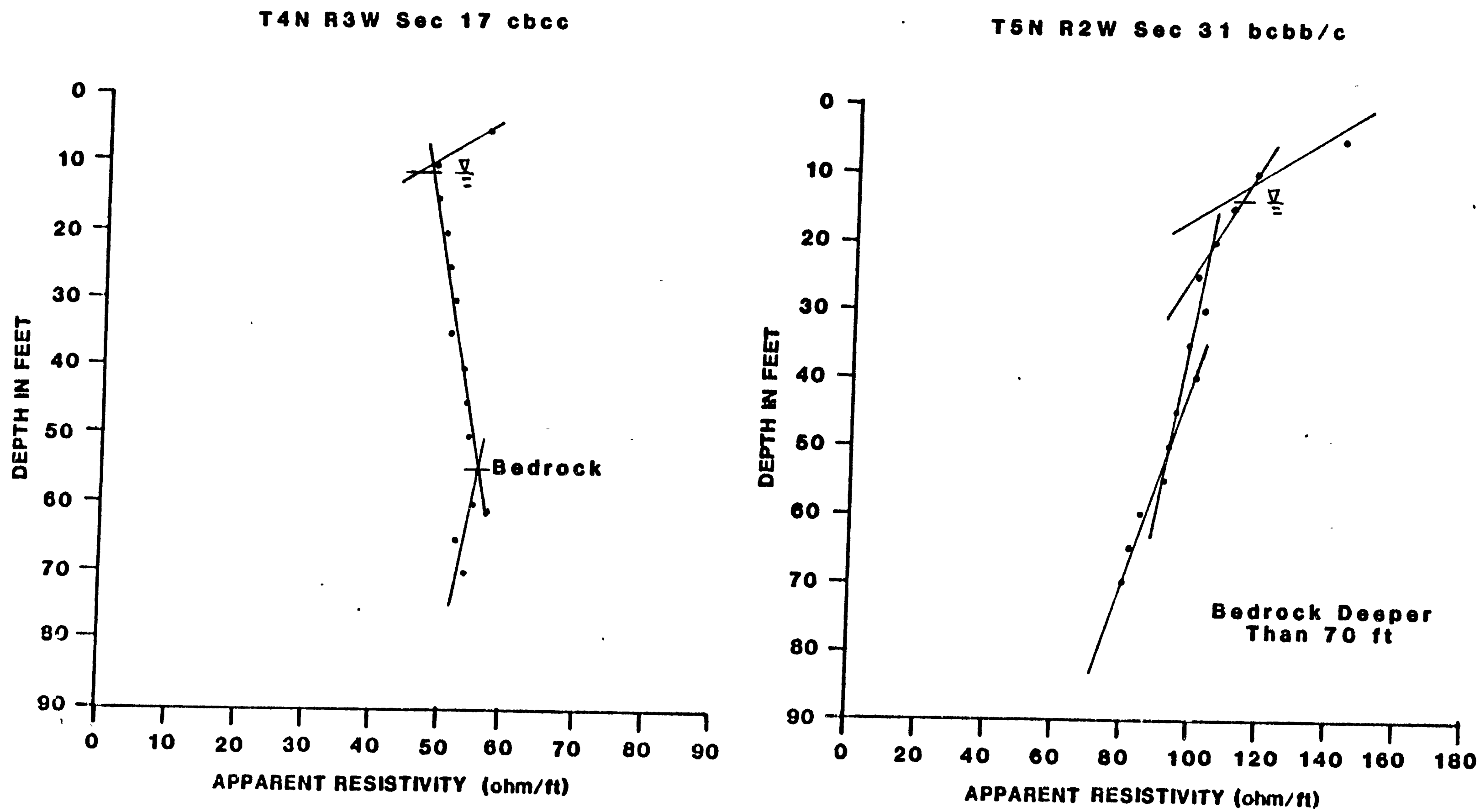


Figure 143. Apparent Resistivity Graphs

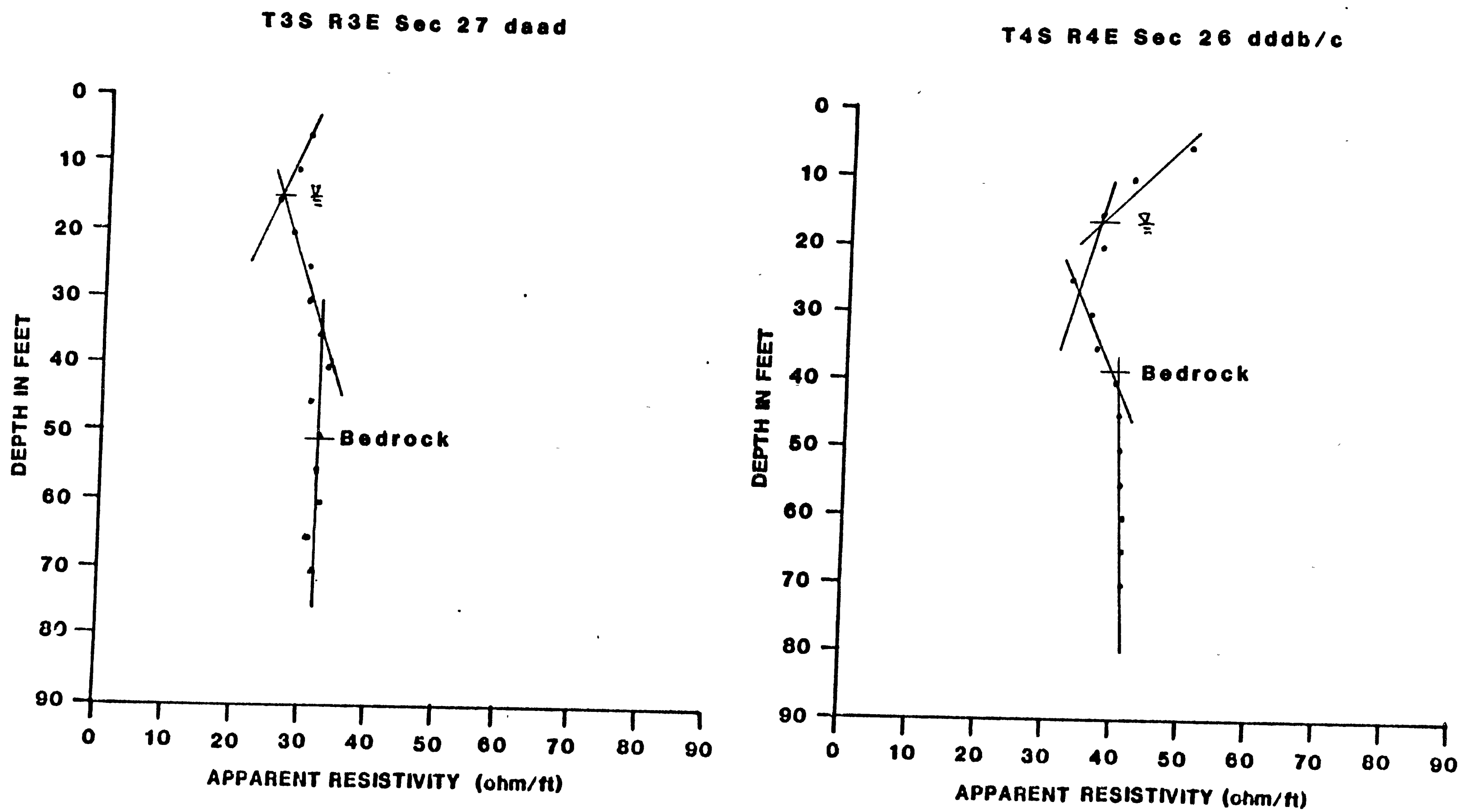


Figure 144. Apparent Resistivity Graphs

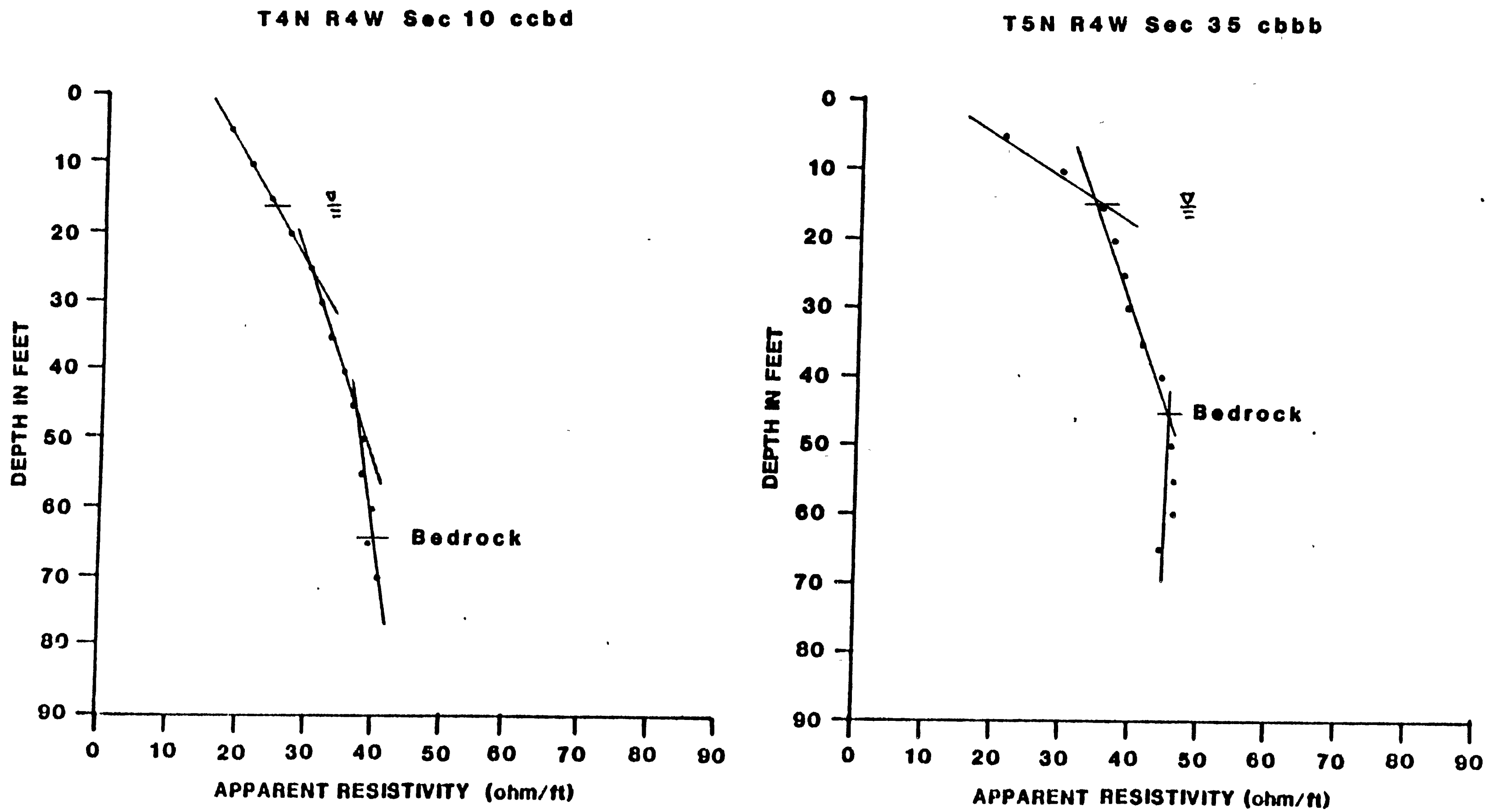


Figure 145. Apparent Resistivity Graphs

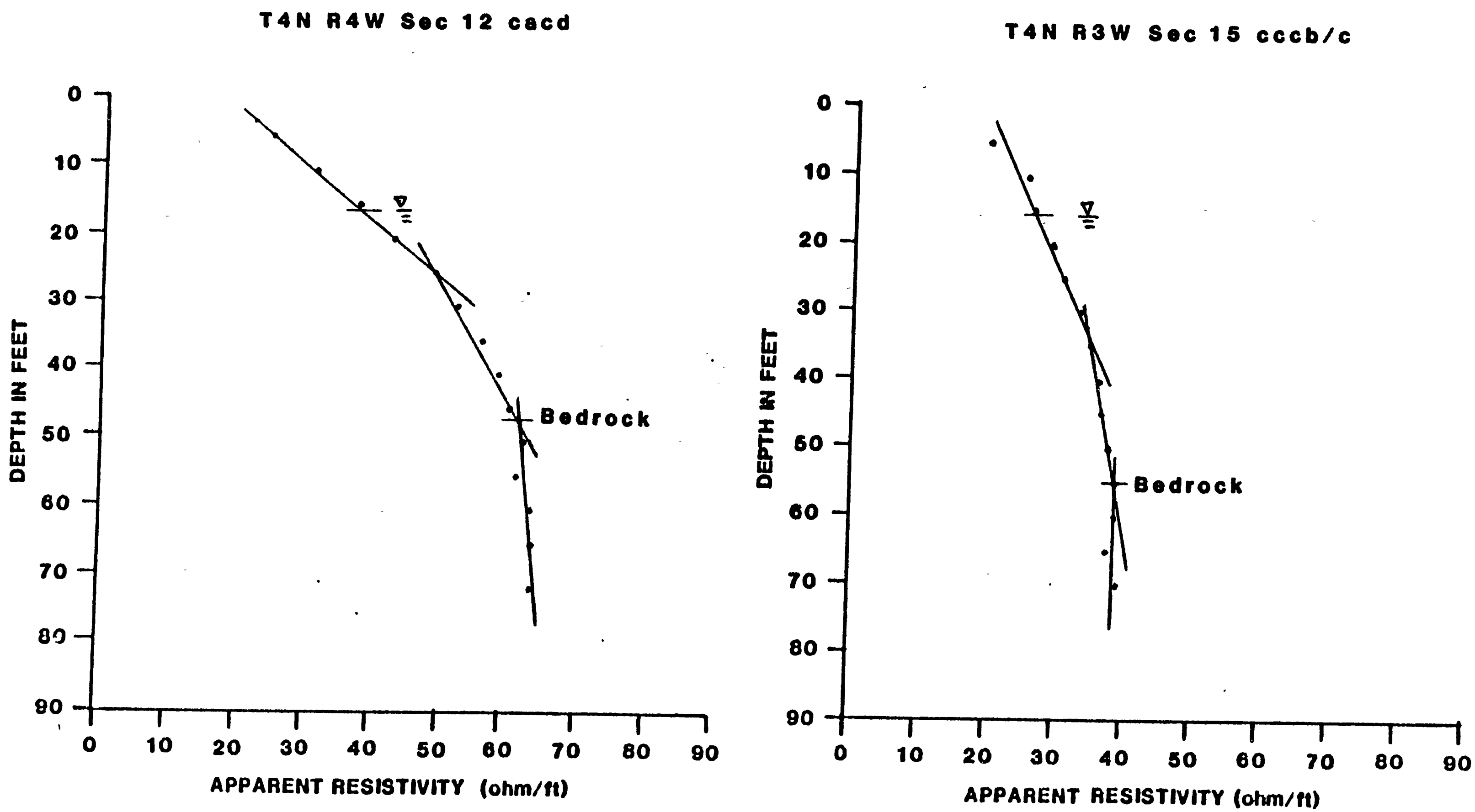


Figure 146. Apparent Resistivity Graphs

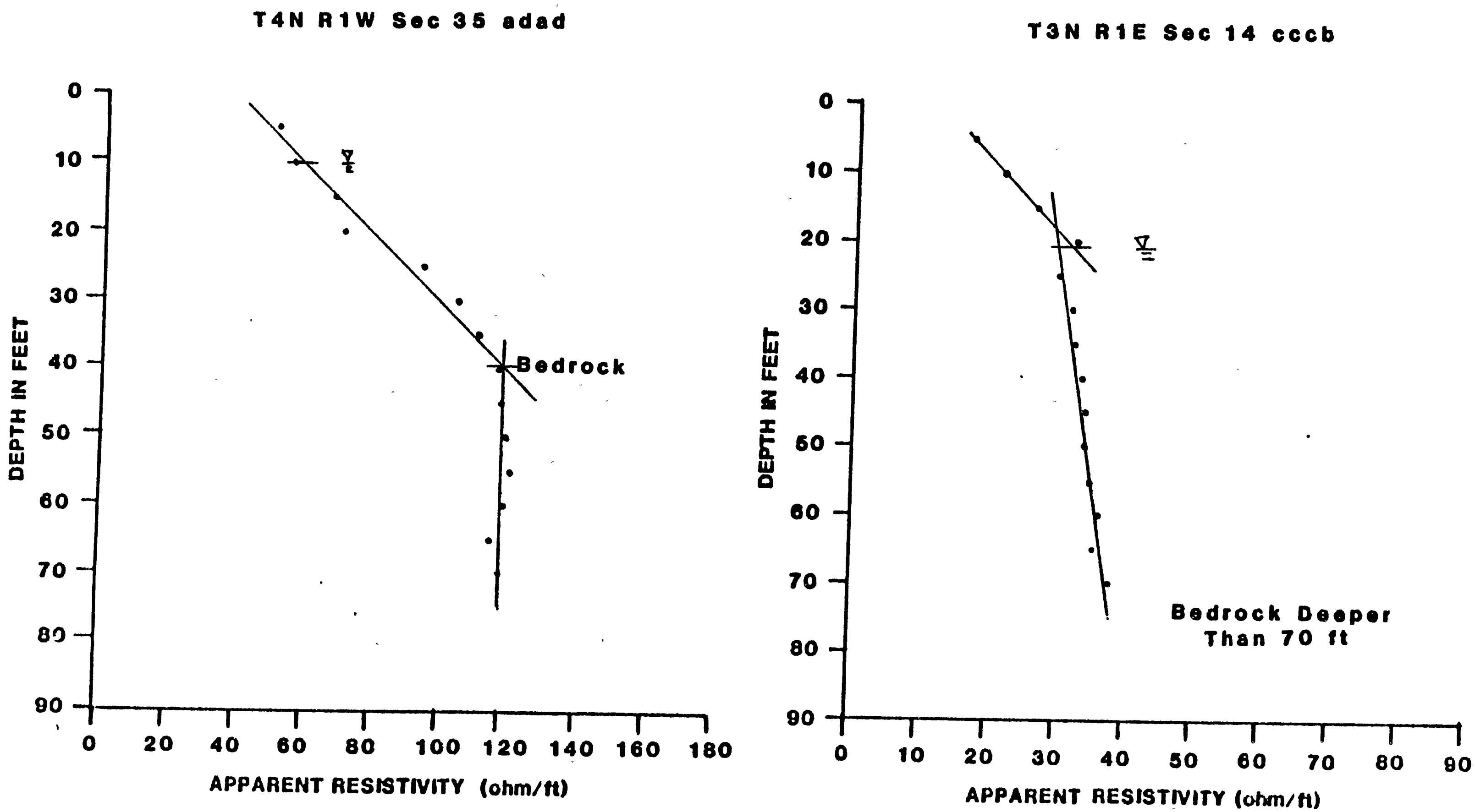


Figure 147. Apparent Resistivity Graphs

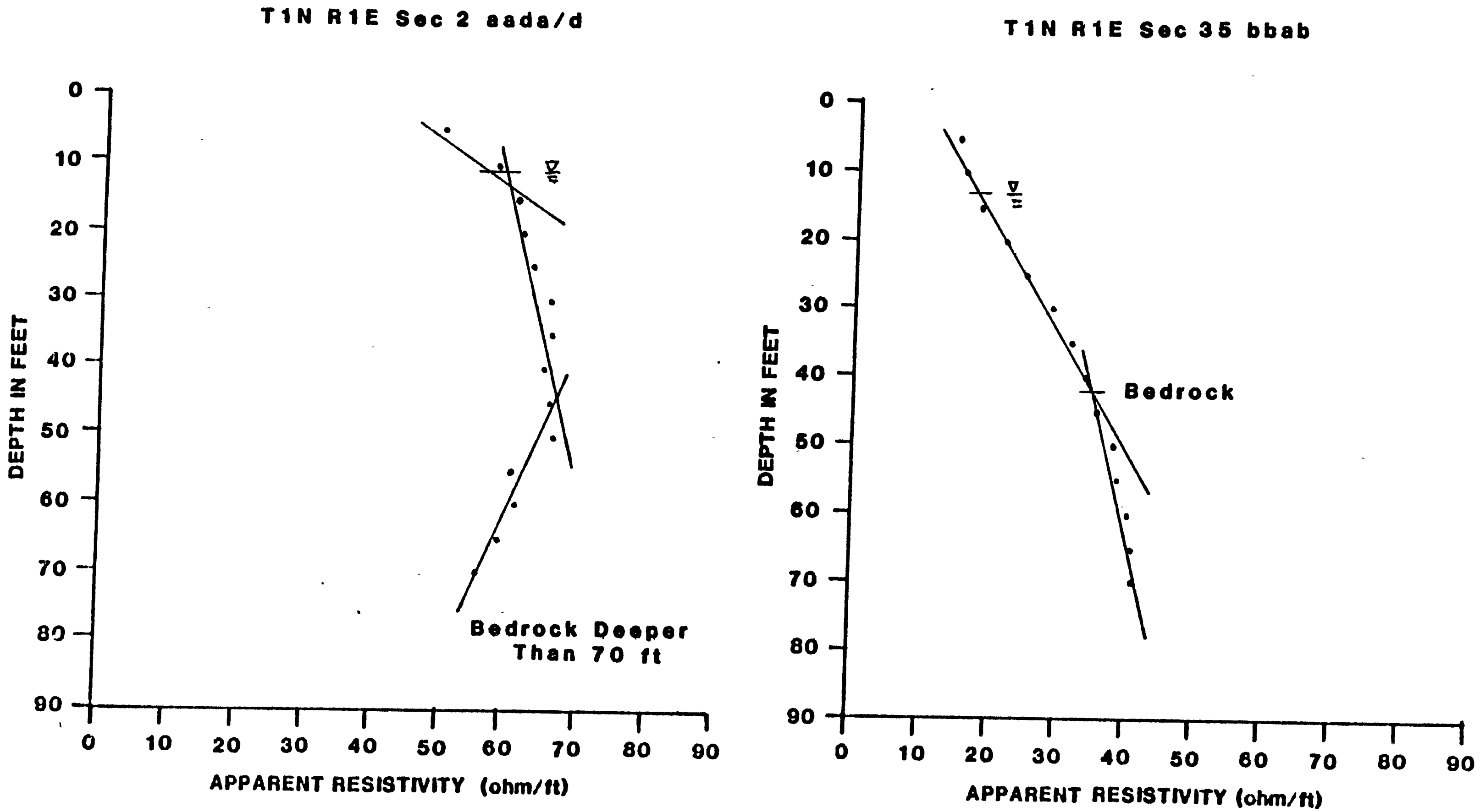


Figure 148. Apparent Resistivity Graphs

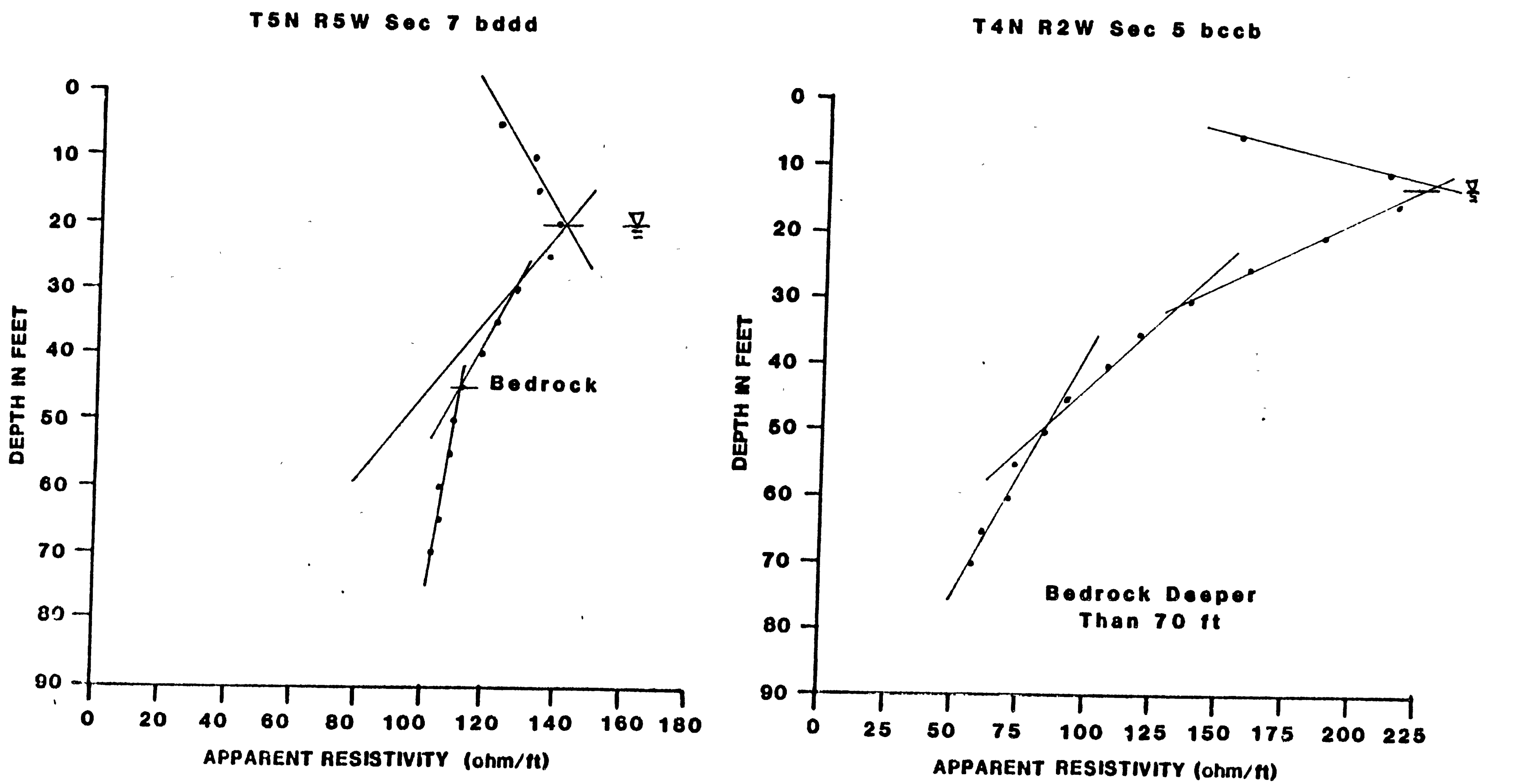


Figure 149. Apparent Resistivity Graphs

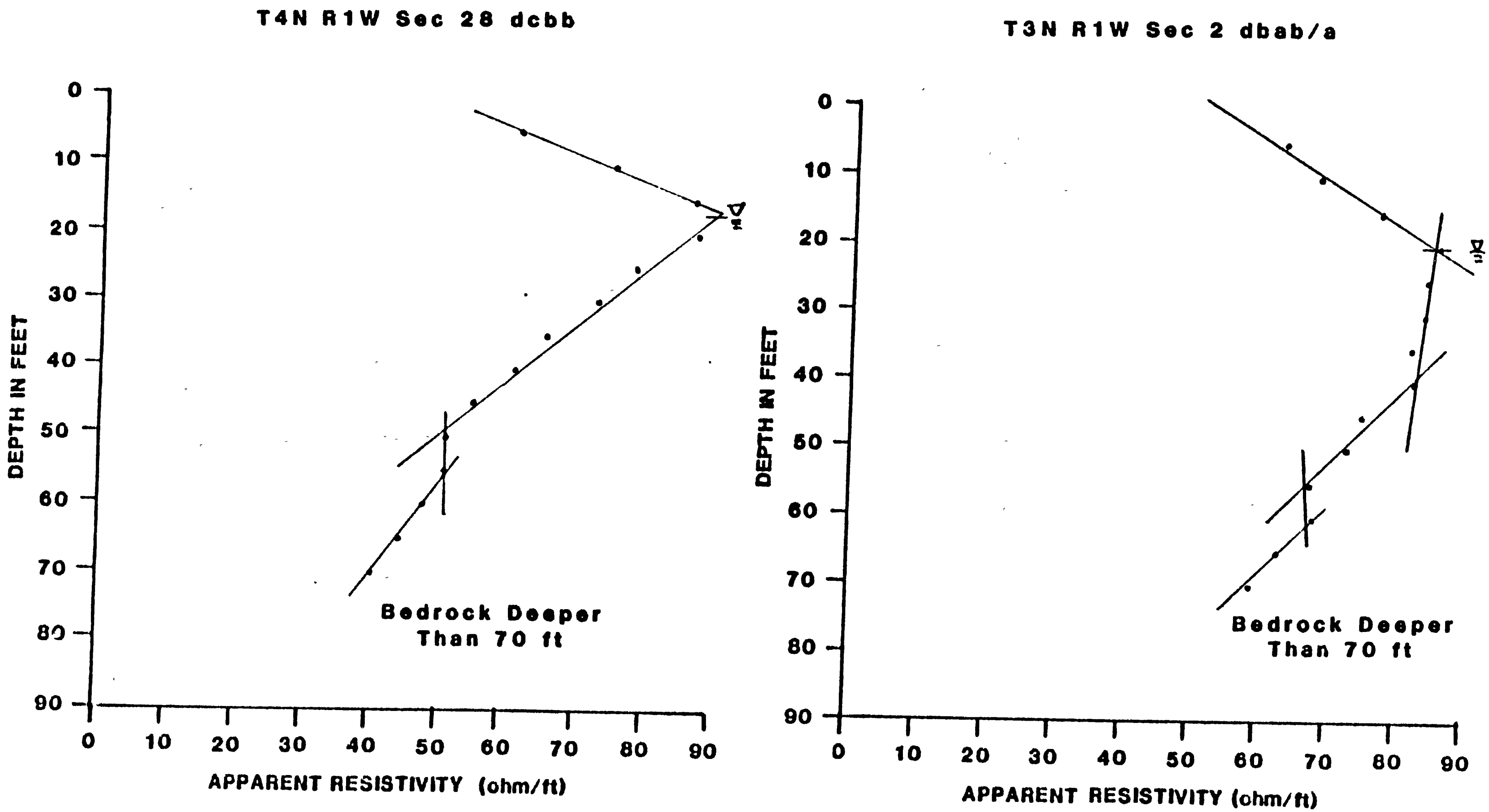


Figure 150. Apparent Resistivity Graphs

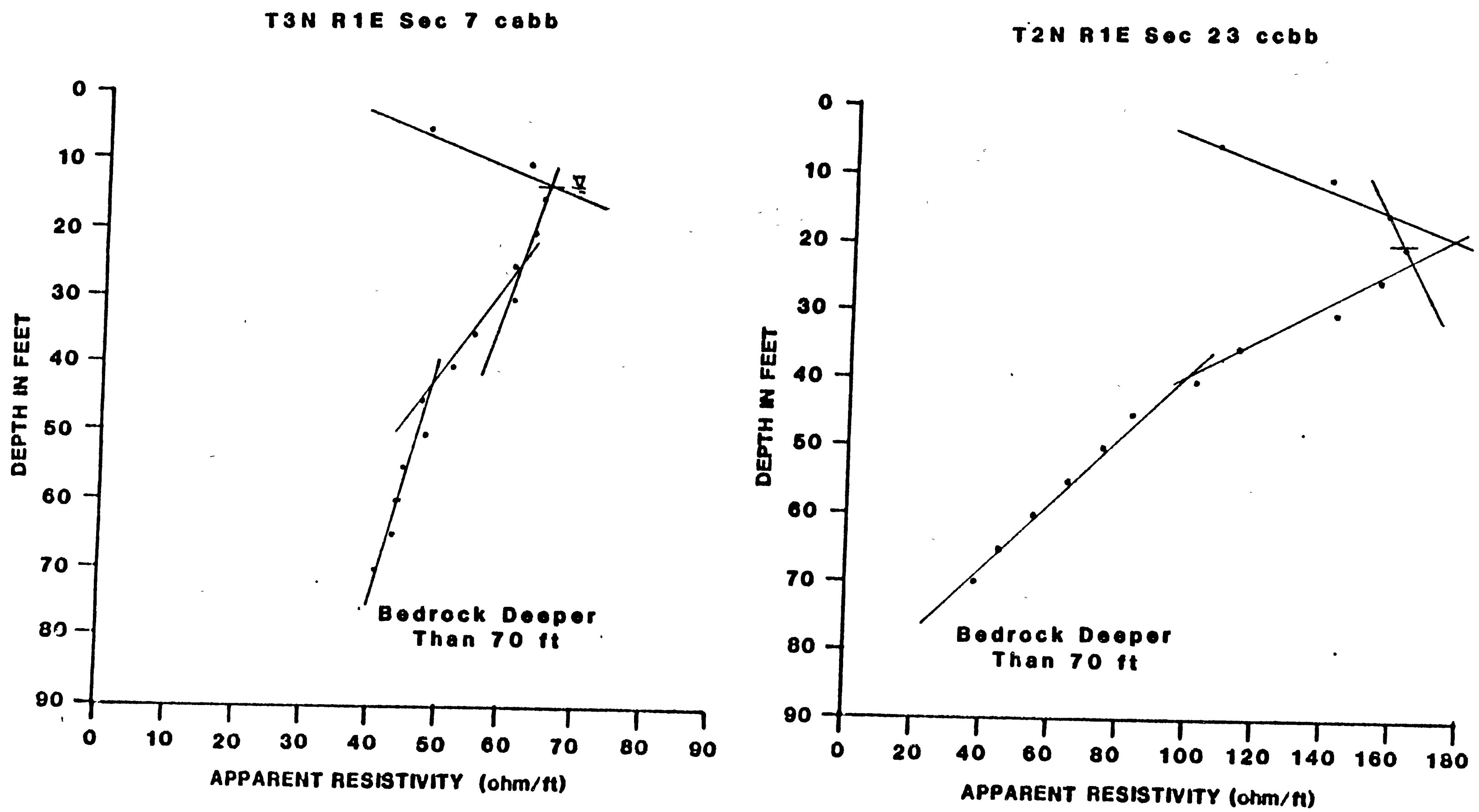


Figure 151. Apparent Resistivity Graphs

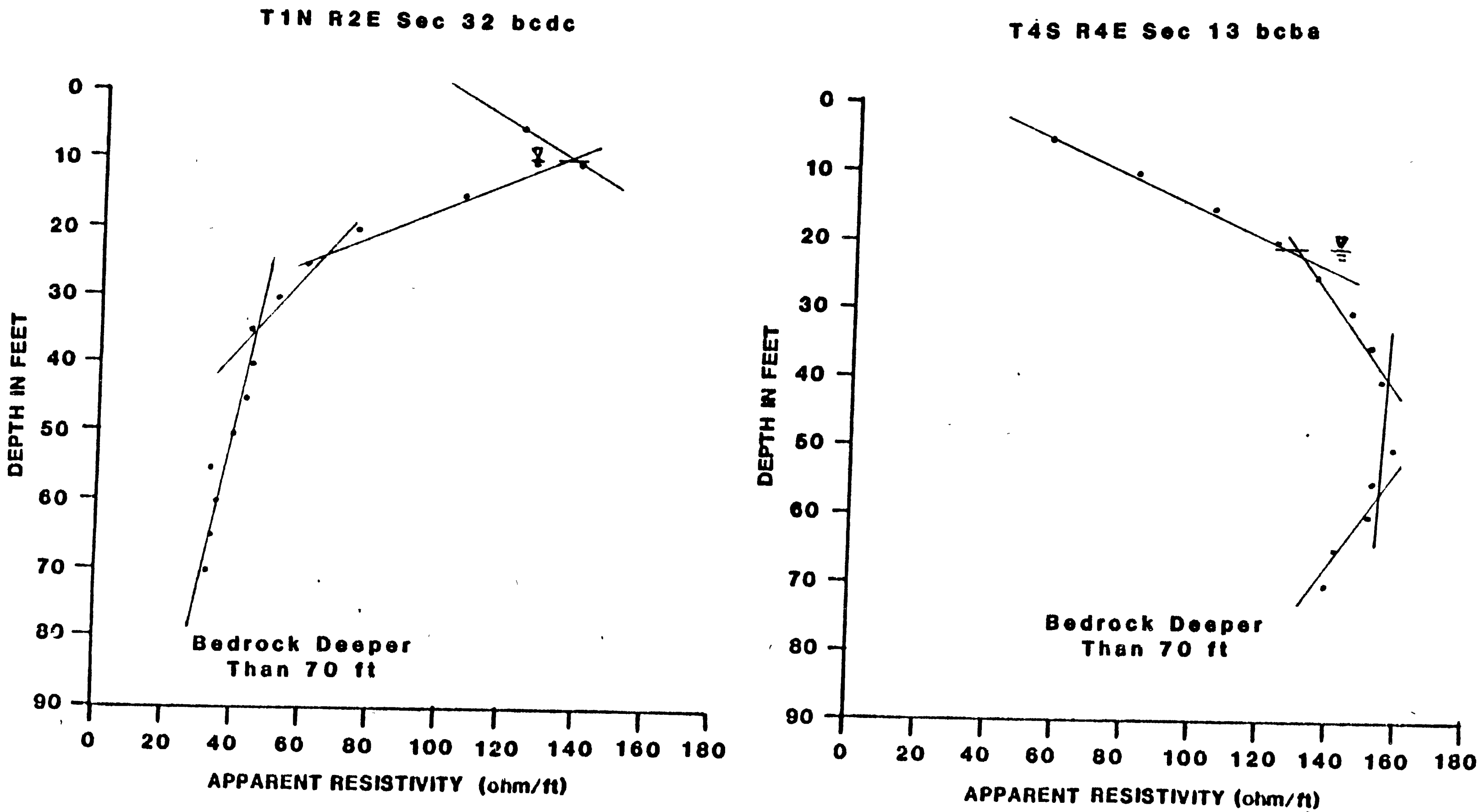


Figure 152. Apparent Resistivity Graphs

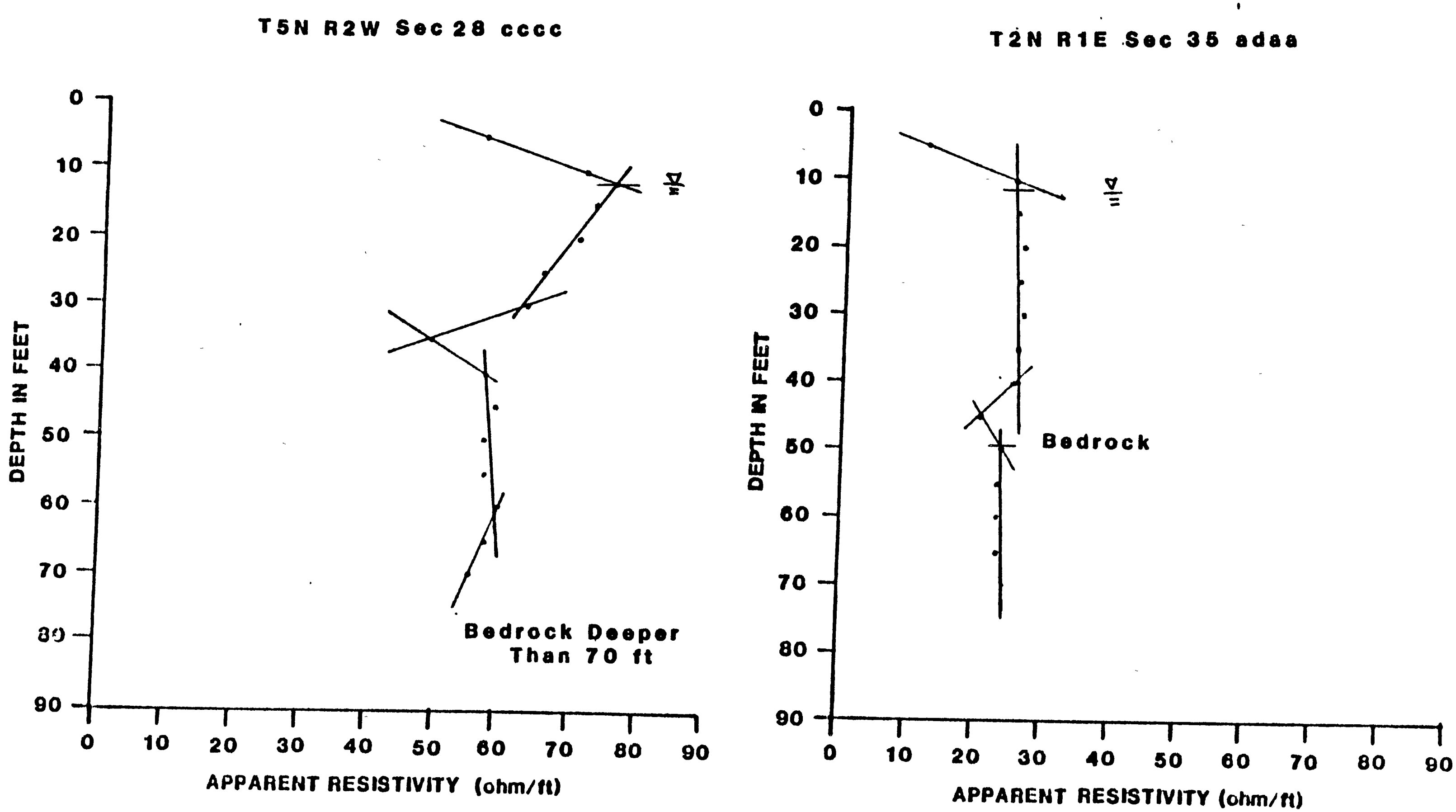


Figure 153. Apparent Resistivity Graphs

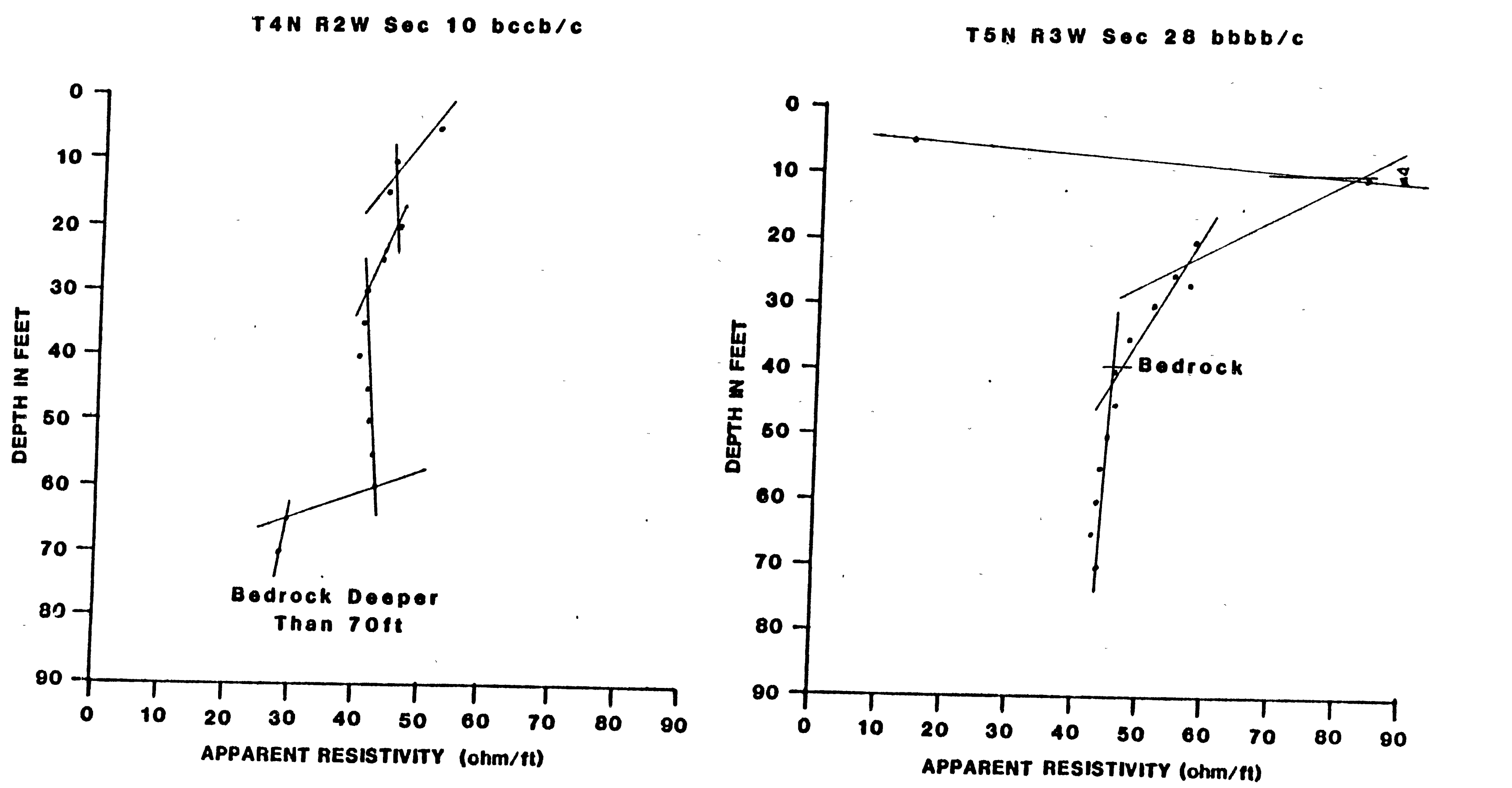


Figure 154. Apparent Resistivity Graphs

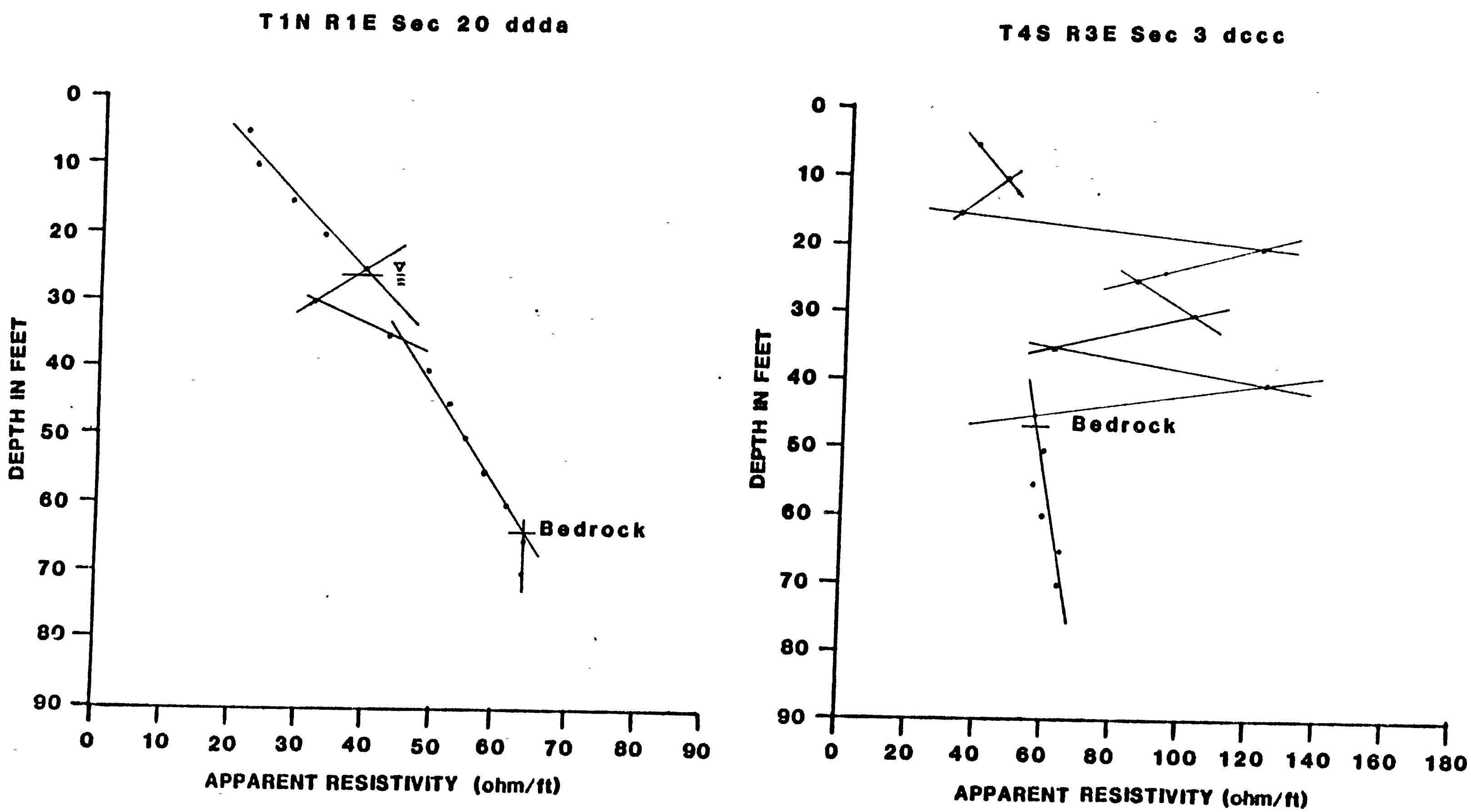


Figure 155. Apparent Resistivity Graphs

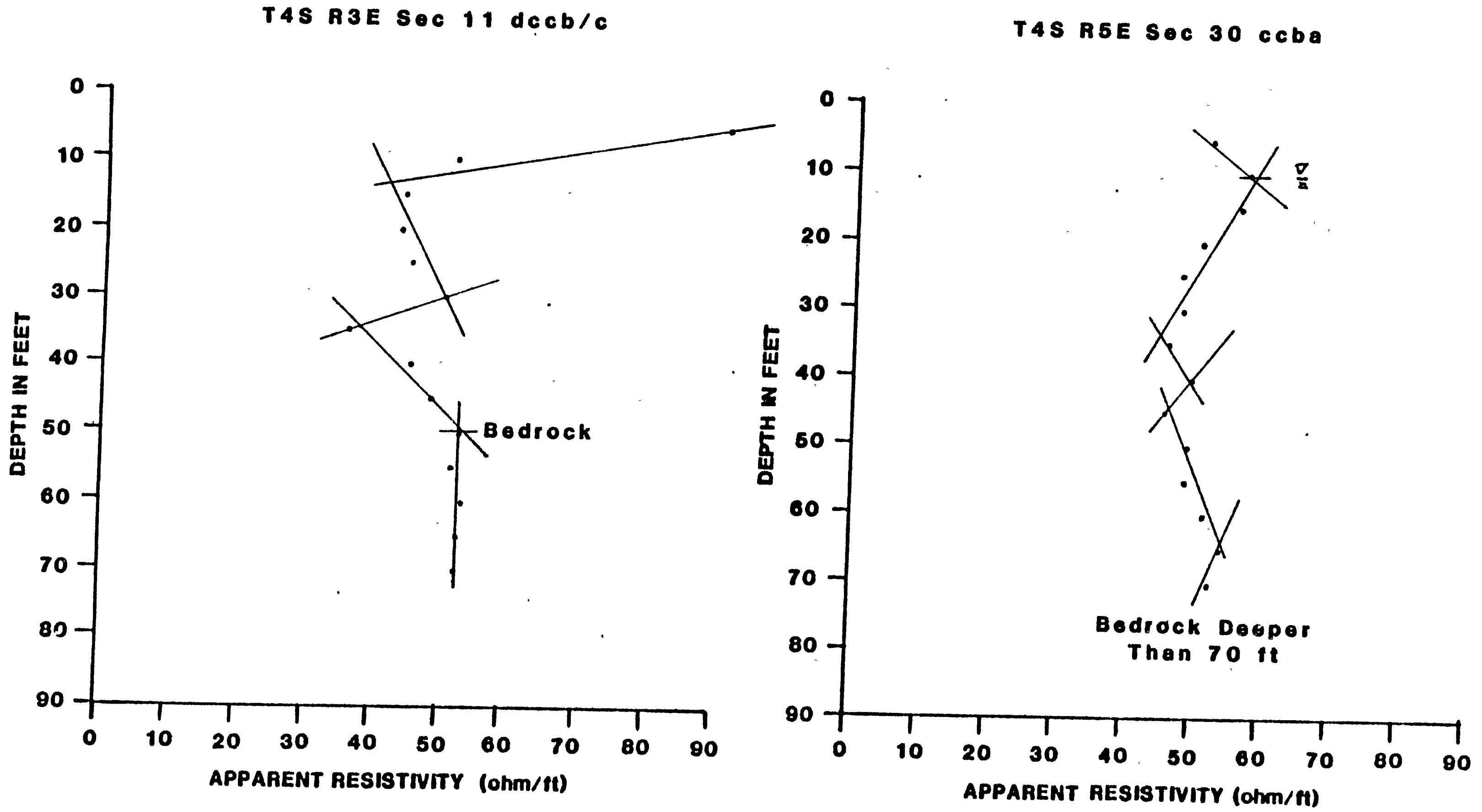


Figure 156. Apparent Resistivity Graphs

VITA 2

James William Patterson, Jr.

Candidate for the Degree of

Master of Science

Thesis: A GROUND-WATER MANAGEMENT MODEL OF THE WASHITA RIVER ALLUVIAL AQUIFER IN GRADY, MCCLAIN, GARVIN, MURRAY, CARTER, AND JOHNSTON COUNTIES IN SOUTH-CENTRAL OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Richmond, Virginia, July 24, 1957, the son of Mr. and Mrs. James W. Patterson.

Education: Graduated from Lafayette High School, Williamsburg, Virginia, in June, 1975; received Bachelor of Science degree from James Madison University, Harrisonburg, Virginia, May, 1980, with a major in Geology; completed requirements for the Master of Science degree at Oklahoma State University in May, 1984.

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