EVALUATION OF AQUIFER PERFORMANCE AND WATER SUPPLY CAPABILITIES OF THE WASHITA RIVER ALLUVIUM IN OKLAHOMA.

FINAL REPORT

Submitted
To

THE OKLAHOMA WATER RESOURCES BOARD

By

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Project Title: Evaluation of Aquifer Performance and Water Supply Capabilities of the Washita River Alluvial Aquifer in Oklahoma.

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

Institution Funded: Oklahoma State University

Summary: The objective of this research was to determine the maximum annual yield of fresh water that can be produced from the Washita River alluvial aquifer in Roger Mills, Custer, Washita, Kiowa, Caddo, Grady, McClain, Garvin, Murray, Carter, and Johnston Counties, Oklahoma. The determination of maximum annual yield was based on criteria established by Oklahoma ground-water law (82 Oklahoma Statutes Supp. 1973, Paragraph 1020.1 et seq) using computer simulation of all prior appropriative and subsequent allocated pumping over the entire aquifer area for twenty years (July 1, 1973 to July 1, 1993).

The total alluvial aquifer area was subdivided into four subareas: Reach 1, Reach 2, Reach 3, and Reach 4. The combined maximum annual yield is 2,186,600 acre-feet.

The Oklahoma Water Resources Board has elected to use a separate allocation proportioned for each alluvial reach as follows:

Reach 1 (State Line to Clinton, OK, Roger Mills and Custer Co.)
2.0 Ac-ft/ac/yr.

Reach 2 (Clinton to eastern edge of Washita County; Note: The eastern portion of Reach 2 (Subreach B) is subject to the allocations specified for the Rush Springs sandstone aquifer.
1.5 Ac-ft/ac/yr.

Reach 3 (Anadarko, OK to Alex, OK; Caddo and Grady Counties)
1.5 Ac-ft/ac/yr.

Reach 4 Alex, OK to Lake Texoma; Grady, McClain, Garvin, Murray Carter and Johnston Counties)
1.0 Ac-ft/ac/yr.

The above allocations are based on the following parameters: (1) the total area overlying the Washita River alluvial aquifer is 296,000 acres. Areas for Reaches 1 through 4 are: 60,000 ac, 4,000 ac, 70,500 ac, and 161,500 ac respectively, (2) the amount of ground-water in storage in the Washita River drainage basin as of July 1, 1973 is 4,700,000 acre-feet. Storage volumes for Reaches 1 through 4 are: 1,928,000 Af, 57,000 Af, 1,000,000 Af and 1,717,000 Af, respectively, (3) the potential amount of water in storage plus return flow over the twenty-year life of the basin is 7,341,700 acre-feet. Storage volumes for Reaches 1 through 4 are: 2,600,000 Af, 80,700 Af, 1,423,700 Af, and 3,237,300 Af, (4) the estimated average rate of net recharge from the rainfall is 3.22 inches per year and for each reach the recharge is 3.17 in., 2.65 in., 2.65 in., and 4.41 in., respectively. The assumed irrigation return flow rate for all reaches is 15 percent, (5) the average initial transmissivity is 33,700 gallons per day per foot and for each reach, the transmissivities for each reach are 23,500 gpd/ft, 12,800 gpd/ft, 16,400 gpd/ft, and 43,100 gpd/ft, respectively, and (6) the average specific yield of the alluvium is 24.0% and for each reach, the specific yield is 26.3%, 20.4%, 20.4% and 29.2%, respectively.

Ground-water pollution induced by ground-water withdrawal is negligible due to a non-significant contribution through upward leakage by the underlying bedrock and because the Washita River should remain as a gaining stream after twenty years of pumping.

INTRODUCTION

This is a final report to the Oklahoma Water Resources Board in fulfillment of Contract No. OWRB 300080 through Oklahoma State University and the Department of Geology.

A hydrogeologic study of the Washita River aquifer was performed using a mathematical model to determine an annual allocation rate and maximum annual yield. The establishment of ground-water rights using a model is described in an ASCS symposium proceedings by J. W. Naney and D. C. Kent, (1980).

Similar studies have been prepared for the Tillman Terrace Deposits in Tillman County (D. C. Kent and J. W. Naney, 1978), the North Fork of the Red River alluvial and terrace deposits in Beckham, Greer, Kiowa, and Jackson Counties (D. C. Kent, 1982), the Enid isolated terrace deposits in Garfield County (D. C. Kent. Y. J. Beausoleil and F. E. Witz, 1982), and of the Elk City Aquifer in Washita, Beckham, Custer and Roger Mills Counties (D. C. Kent, T. Lyons and F. E. Witz, 1982).

The Washita River drainage basin contains 7,790 square miles of which 7,310 square miles are in Oklahoma and the remainder are in the Texas Panhandle (Figure 1). The basin area within the confines of Oklahoma was divided into four reaches as shown in Figure 2: Reach 1, from the western edge of Roger Mills county to Clinton (Schipper, 1983); Reach 2, from Clinton to Anadarko; Reach 3, from Anadarko to Alex (Neafus, 1984); and Reach 4, extending from Alex to Lake Texoma excluding the alluvium within the Arbuckle Mountains (Patterson, 1984).

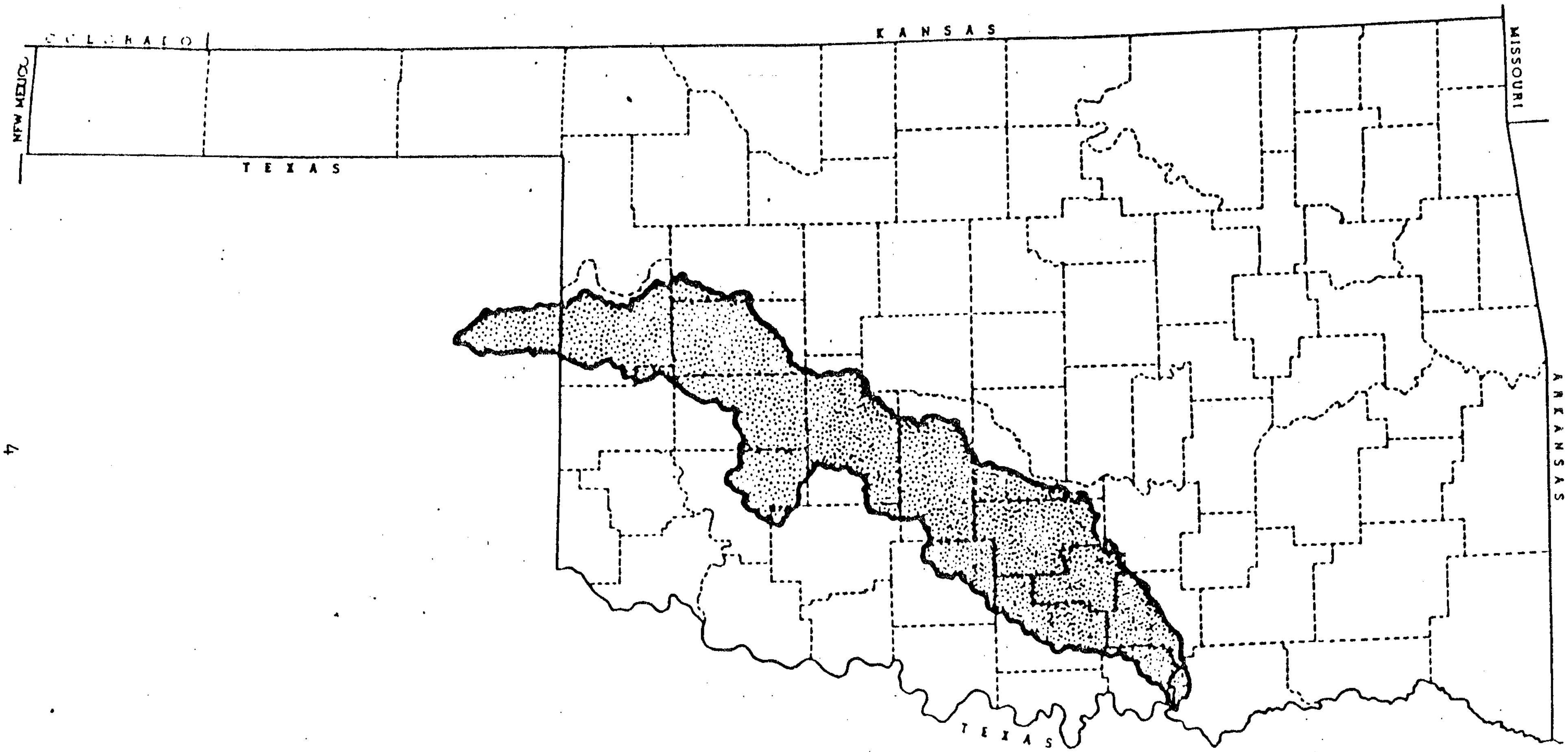


Figure 1. Map Showing The Washita River Drainage Basin Within Oklahoma.

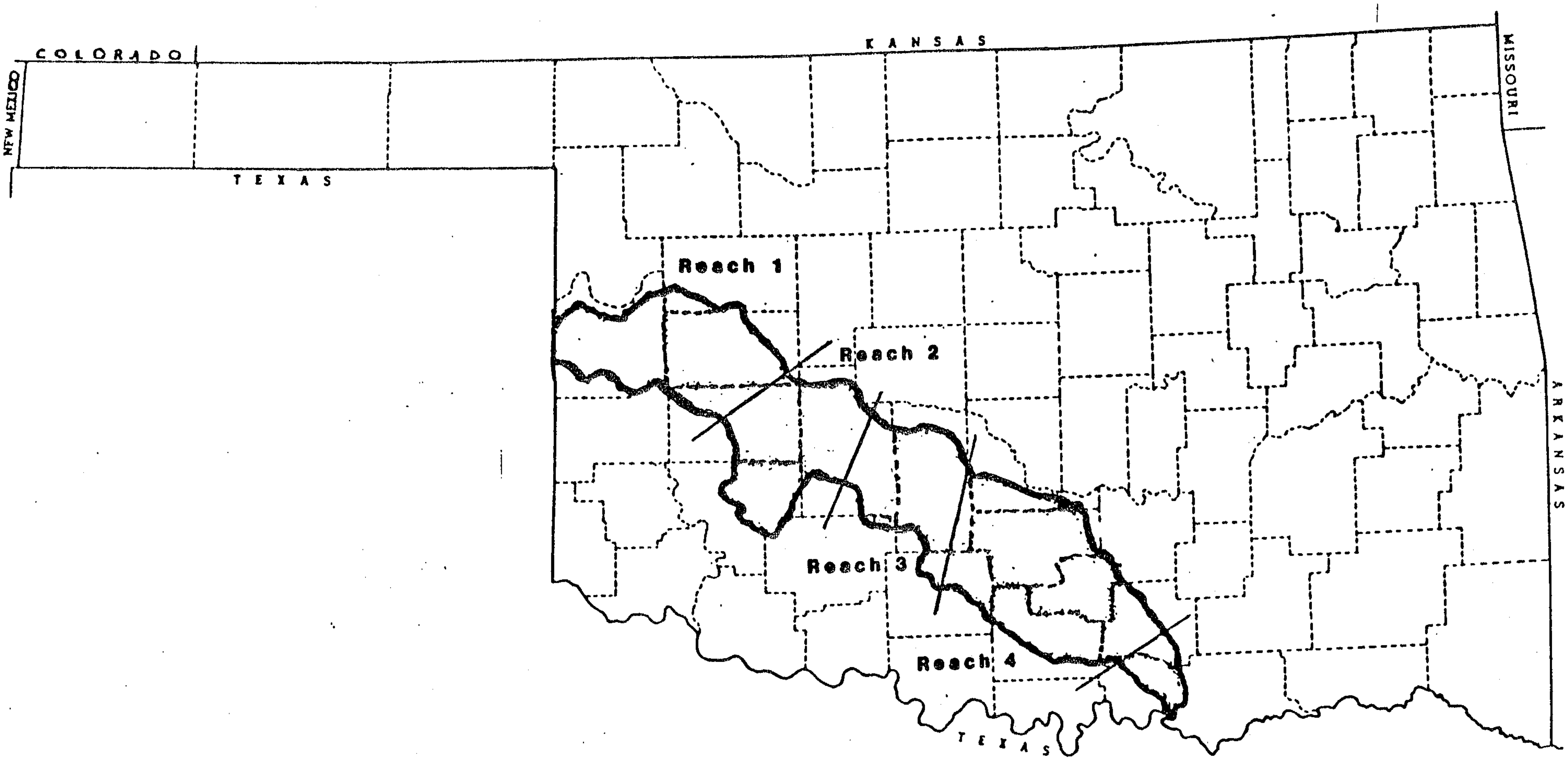


Figure 2. Reach Division Of The Washita River Drainage Basin.

The primary objective of the 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. Under Oklahoma Statute No. 82 S 1020.4 and 82 S 1020.5, 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 discharage 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.

The Washita River alluvial aquifer is an unconfined or water table aquifer. Permian aged bedrock underlies most of the aquifer except in the southern most portion of Reach 4 where the bedrock ranges from Precambrian to Cretaceous in age as shown in Figure 3. The bedrock underlying the alluvial aquifer serves as an aquitard and a lower boundary of the aquifer. The average depth to water is 22 feet and the average saturated thickness is 61 feet but can be as much as 189 feet. The sediments grade from coarse sands and the gravels at the base to finer sands and silts near the surface. The average permeability and transmissity are 770 gpd/ft**2 and 33,700 gpd/ft, respectively.

The Washita River is a gaining stream which is sustained by base flow from the aquifer during the drier months. The loss from the aquifer is replaced by a net recharge of approximately 3.72 in/yr, or approximately 11.5 percent of a mean precipitation of 32.2 in/yr. The average evapotranspiration is 28.6 in/yr. This information is summarized in Table 1.

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

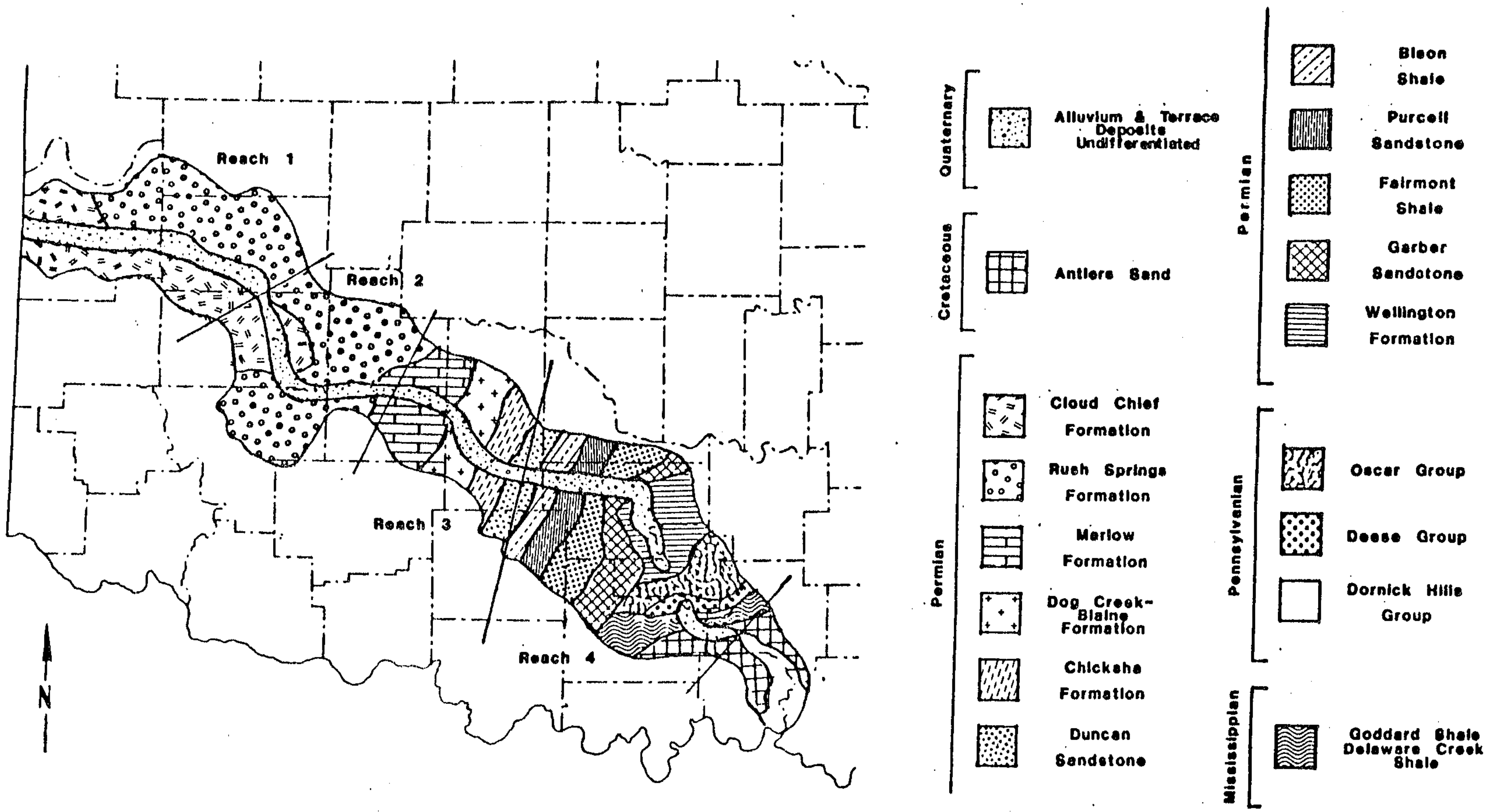


Figure 3. Geologic Map Showing The Formations That Underlie The Washita River Alluvial Aquifer.

TABLE 1

Summary Parameters Used To Determine Allocations By Reach

		Average Depth To Water (ft)		Average Saturated Thickness (ft)		Average Perme-ability (gpd/ft^2)	Average Transmissi-vity (gpd/ft)		Average Annual Precipi-tation (in/yr)	Net Recharge (in/yr)	Percent of Total Precipi-tation (%)	Average Annual E.T (in/yr)
		1973	1993	1973	1993		1973	1993				
Reach 1 Schipper		17	115	118	13	260	23,550	2,900	24.9	3.2	12.7	21.7
Reach 2	A	17*	-	52	-	250	12,850		28.9*	2.9 *	10.4*	26.1*
(not modeled)	B			53	-	280	14,900					
Reach 3 Neafus		17	69	67	6	260	16,400	1,400	33.0	2.7	8.0	30.4
Reach 4 Patterson		26	55	38	8	1,180	43,100	11,700	34.9	4.4	12.6	30.5
Total Combined Reaches (weighted average)		22.0	71	61	8.4	770	33,700	7,400	32.2	3.7	11.5	28.6

*averaged using Reaches 1 and 3.

GROUND-WATER

MODELING

Simulation Procedure

Initial ground-water levels, pumping rate, and transmissivity are primary variabales used in the model of the aquifer. Quantitative values must be assigned to the hydrogeologic parameters of the aquifer in order to model the aquifer within the accuracy of the data used. The quantitative values are either assigned directly by the hydrogeologist or generated by the computer model. A value for each hydrogeologic parameter is assigned to every eighth quarter mile section (node) in the aquifer. The model output consists of a mass balance and estimated volume of ground water in storage, as well as maps of predicted ground-water table elevations and saturated thicknesses at 5-year intervals throughout the 20-year minimum basin life as shown in the Appendix by river reach.

The modeling program used in this investigation was originally written by Pinder (1970) and revised by Trescott, Pinder, and Larson (1976). The finite difference model simulates ground-water flow in two dimensions for an artesian aquifer, a water table aquifer, or a combination of the two.

Some of the data management procedures in the model were modified for this OWRB project. The approach used to process the data for model simulation is shown by the flow diagram in Figure 4. The input data were divided into matrix and constant parameters (Figure 4). The matrix parameters include: water-table elevations; land, top, and bedrock elevations; river bed thickness and hydraulic conductivity; and well pumping rate and recharge rate. The matrix parameters were mapped, contoured, and digitized for the study area. A grid spacing of one-half mile was used to represent quarter sections to establish a matrix; however, a grid of

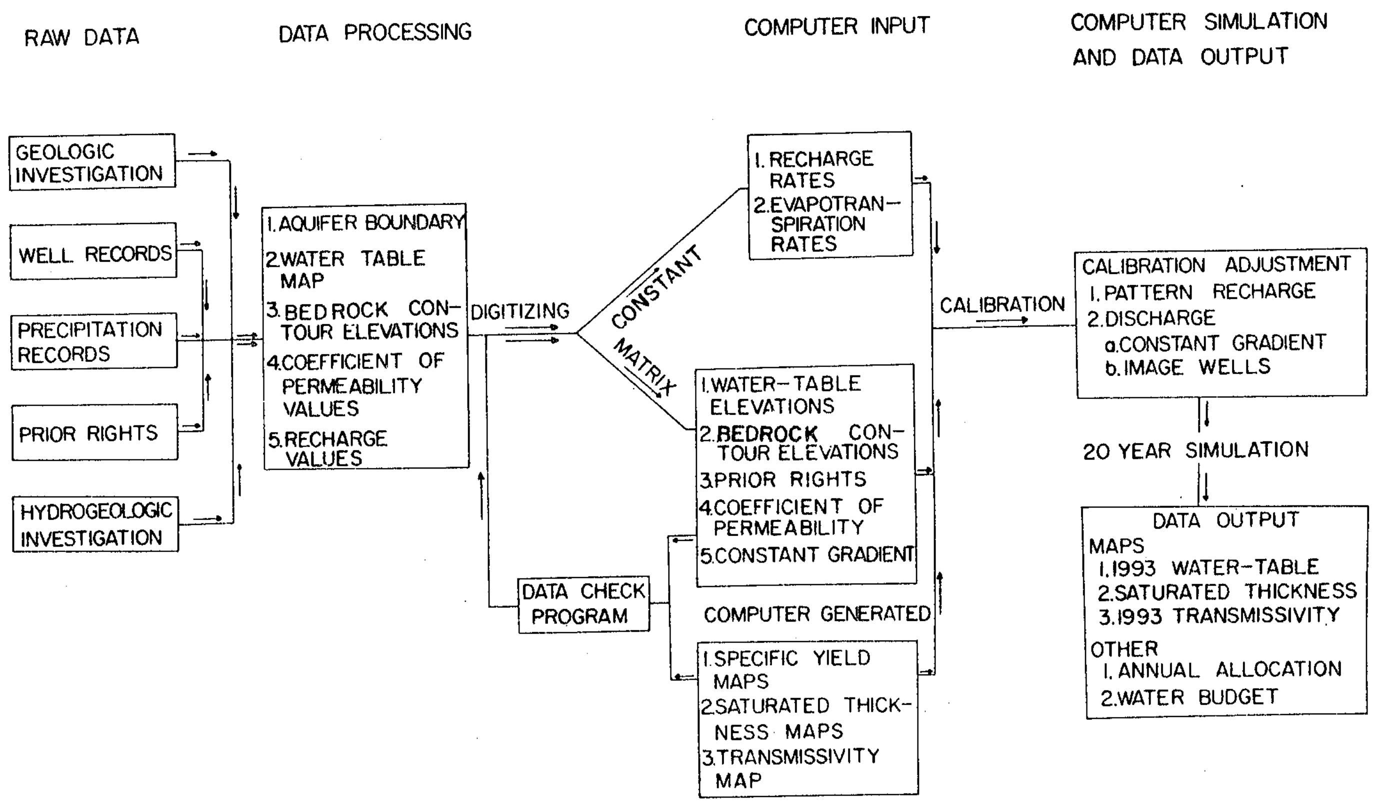


Figure 4. Flow Diagram of Data Processing for Model Simulation.

one-quarter mile spacing was used for Reach 1. The storage coefficient of the river bed is a constant parameter.

Basic contoured data which was to be entered as a matrix was gridded and digitized for input into the computer model. A grid, drawn at the same scale as the topographic maps for the area, was overlain onto each contour map. Values were assigned to each node of the grid by a perimeter-averaging technique developed by Griffen (1949). Griffen's method involves averaging the values at the corners and center of each node to obtain an average value for that node.

Calibration

The Washita River Alluvium Aquifer is considered to be a quasi-homogeneous aquifer occurring in a recharge-discharge equilibrium. The main objective in calibration of the model, was to maintain this recharge-discharge equilibrium. Equilibrium is established when the mass balance shows the inflow; and outflow as being equal and is indicated by negligible fluctuations in the water-table elevations.

To calibrate the model, a river program option was used to simulate ground-water discharge into the streams which are present in the area. This river option was used in conjunction with net recharge and constant gradient discharge node values.

Simulation Period

The model was used to simulate pumping and corresponding water-level changes over a one-year and a 20-year period. The one-year simulation run was used to calibrate the model. Twenty-year simulation runs were initiated for July 1, 1973 to July 1, 1993. The longer simulation period is based on Oklahoma Water Law Statute 82, Paragraphs 1020.4 and 1020.5 which requires that new annual pumping allocations be assigned based on a minimum aquifer life of 20 years. The 20-year simulation included two simulation runs: (1) prior appropriative rate only; and (2) prior appropriative rate with allocation pumping.

Allocation

The final 20-year computer simulation was conducted for the 1973 to 1993 period for each subbasin using pumping rates of prior appropriative right owners. This simulation was repeated with allocation pumping in conjunction with prior appropriative pumping.

Maximum annual yield was determined by adjusting the amount of allocated pumpage that would cause 50 percent of the nodes to go dry by the end of the simulation period (20 years). The maximum annual yield and allocated pumpage was optimized by repeating 20-year simulation in order to obtain the required 50 percent dry area. A saturated thickness of five feet was considered dry due to size limitations of screen length and size of a submersible pump which would be set at the bottom of a fully penetrating well capable of pumping the annual allocation rate.

Each node was pumped continuously for a four-month period during the summer of each year at three times the annual allocation rate. This schedule was continued throughout the 20-year period unless the node became dry prior to that time. It is assumed in the model that everyone pumps the same average maximum legal limit. This rate corresponds to an instantaneous pumping rate continuously pumped for the four-month period between June 1 and September 30 of each year. Under these conditions, various parts of the area go dry at different times; this is due to the nonhomogeneous nature of the alluvium (variable transmissivity and corresponding specific yield). The 50 percent dry criteria was used to accommodate this variability. The wells are turned off in the model when the five-foot saturated thickness is reached; and will turn on periodically to remove accumulation due to recharge. A series of 20-year simulation runs are made in order to select the pumping rate which will cause 50 percent of the total area to become less than or equal to 5.5 feet of saturated thickness ("dry") at the end of 20 years.The maximum annual yield is the resulting amount of water recovered over the 20-year period during which wells are being turned off and on as the aquifer is depleted and recharged. Because of these factors, the maximum annual yield does not simply equal the product of allocation rate times the area.

The computer simulation results are summarized in a ground-water budget for each model reach. Simulated changes in saturated thickness and of areas that become "dry" (≤ 5.5 feet) for 1973, 1983, and 1993 are shown as saturated thickness maps in the appendix.

A 20-year ground-water budget is computed for the final computer allocation run of each model reach and is shown in the Appendix. Other computer simulation results for the same period include transmissivity, water-table elevations and water depth (see Appendix).

REACH 1

Reach 1, located in Roger Mills and Custer counties, is described by Schipper (1983) who divided the reach into three subreaches; Subreach A, Subreach B, and Subreach C. The alluvial aquifer in Reach 1 is underlain by Permian aged material; especially the Rush Springs and Cloud Chief Formations (see Figure 3).

The Rush Springs Sandstone is the oldest rock outcropping in Reach 1. This Permian formation is primarily an orange-brown, fine-grained, calcite and gypsum cemented, quartzose sandstone; it outcrops on the northern side of the Washita River in Custer County. East of Reach 1, it is up to 430 feet thick, but averages approximately 200 feet thick in western Custer County. In many places the sandstone is crossbedded. The Rush Springs contains some gypsum beds that are laterally continuous. One of these, the Weatherford bed, is a gypsum or dolomite and occurs near the top of the formation. It is up to eight feet thick and caps escarpments over much of Custer County (Fay, 1978).

East of Reach 1, wells in the Rush Springs yield 200 to 700 gpm of water with suitable quality for municipal and irrigation use. However, within Reach 1, yields may be less than 50 gpm. Smaller yields are mainly due to a reduced saturated thickness. The decrease in yield is accompanied by a decrease in water quality. Water quality is poor due to the percolation of water through the soluble gypsum in the overlying Cloud Chief Formation and in the Rush Springs, which causes higher concentrations of calcium sulfate. Use of water from the Rush Springs in the southwestern corner of Custer County is limited because the water is highly mineralized (Hart, 1978).

The Cloud Chief Formation outcrops both north and south of the river in a wide band that parallels the river course within Reach 1. Through most of this length, the Washita River alluvium rests upon the Cloud Chief. Approximately 80 feet of the Cloud Chief is exposed in the Cheyenne area. The total thickness is about 190 feet (Bowers, 1967). Orange-brown shale and siltstone with some orange-brown sandstone make up most of the formation. Dolomite and gypsum are also found in the Cloud Chief. Two members, the Day Creek bed and the Moccasin Creek bed, have been named. They are in the lower half of the formation and are each about five feet thick (Hart, 1978).

The Washita River alluvium within Reach 1 consists of discontinuous layers of sand, silt, clay, and gravel derived from the Tertiary and Permian bedrock through which the river cuts. Drillers' logs show that its thickness is up to 223 feet northwest of Cheyenne in Roger Mills County. Well yields are more than 100 gpm in several areas. Numerous irrigation wells are completed in the alluvium.

The river basin area in Roger Mills and Custer counties is approximately 1,600 square miles. The average depth to water is 17 feet and the average saturated thickness is 118 feet. Water table maps for subreaches A, B, and C are shown in Appendix A. The average permeability is 257 gpd/ft**2 and the average transmissivity is 28,568 gpd/ft. Average depth to water, saturated thickness, permeability, and transmissivity for 1973 and 1993 for Reach 1 are summarized in Table 1. The water budget for Reach 1 is shown in Figure 5. Saturated thickness and transmissivity maps are shown in Appendix A for 1973 and 1993. Maps showing depth to water for 1973 and 1993 for Reach 1 are also shown in Appendix A. A relationship between saturated thickness and the percent of aquifer area which is dry for each subreach within Reach 1 is shown in Table 2.

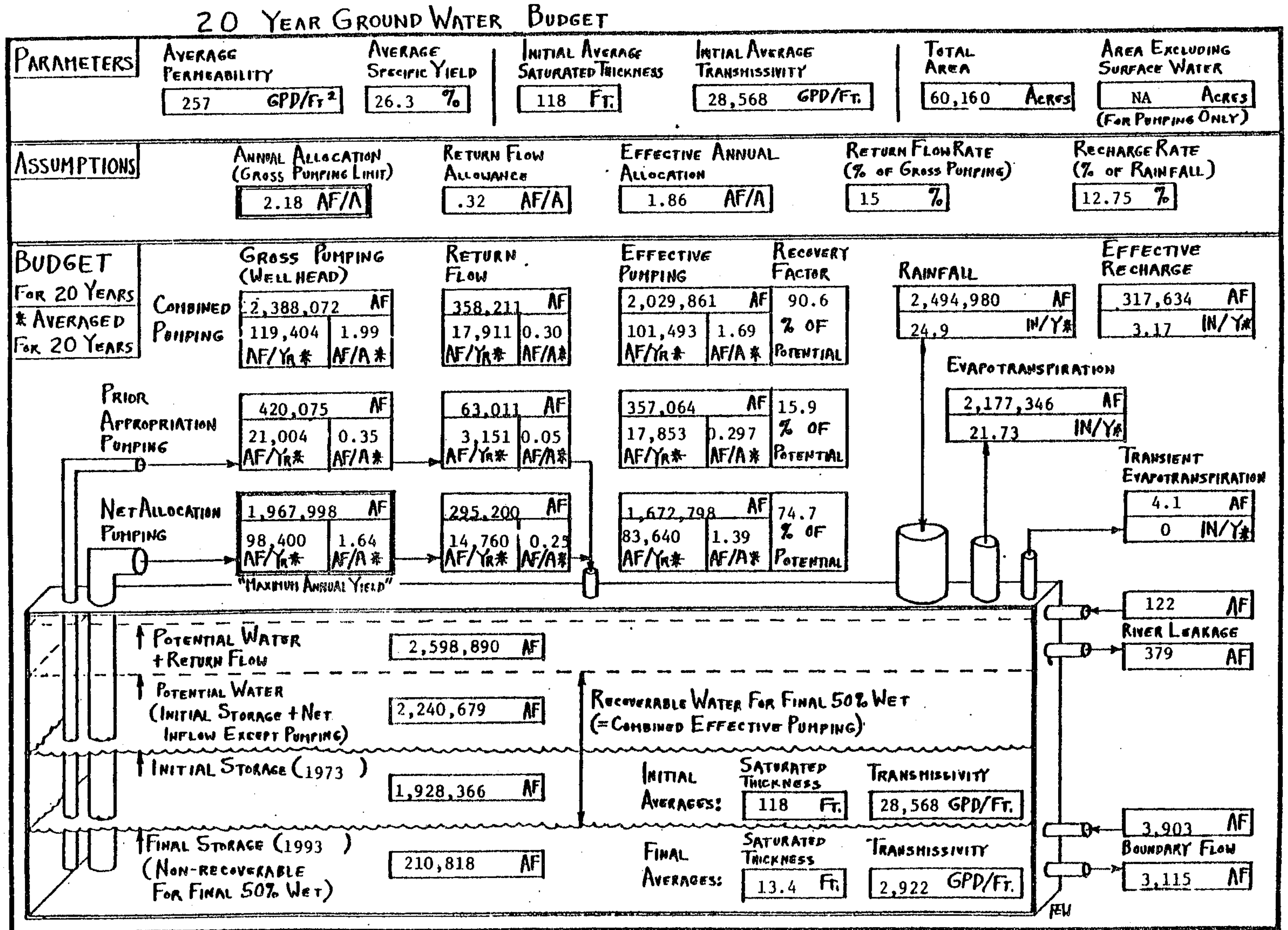


Figure 5. Ground-water Budget For Modeled Reach 1.

TABLE 2

Saturated Thickness and the Respective Percent Dry Aquifer Area For

Modeled Reach 1

	Saturated Thickness					Percent Dry Aquifer Area				
	1973	1978	1983	1988	1993	1973	1978	1983	1988	1993
Subreach A	150	113	75	39	13	0	0.4	1.4	8.0	49.9
Subreach B	91	68	45.	27	14	0	0	9.3	31.4	48.6
Subreach C	93	69	46	27	11	0	0	14.8	23.6	50.0

The average recharge is approximately 3.17 in/yr which is 12.7 percent of the total average precipitation of 24.9 in/yr. The average evapotranspiration for Reach 1 is 21.7 in/yr. This data along with the preceeding data is summarized in the ground-water budget for Reach 1 in Figure 5. Prior appropriative pumping rights and water distribution summaries are shown in Appendix A. An allocation rate of 2.18 acre-feet/acre/year was determined for Reach 1. Table 3 shows the method used to calculate this weighted allocation rate.

The water quality in the Washita River alluvium is affected by the composition of the underlying bedrock and the alluvium itself. If water from the bedrock is characteristically high in dissolved solids, and if the bedrock contributes appreciable water to the alluvium through upward leakage, then this should be reflected in the water quality of the alluvium. The Cloud Chief Formation underlies the alluvium for most of Reach 1 except for relatively short distances near Hammon and Clinton, where the alluvium rests on the Rush Springs. The Cloud Chief contains interbedded gypsum with two gypsum and dolomite members up to eight feet thick identified in the lower portion of the formation. The Rush Springs Formation also contains interbedded gypsum. The Weatherford gypsum and dolomite is up to eight feet thick (Fay, 1978) and occurs near the top of the Rush Springs. Quality of runoff, which may at times be added to the ground-water storage, can also influence the water quality in the alluvium.

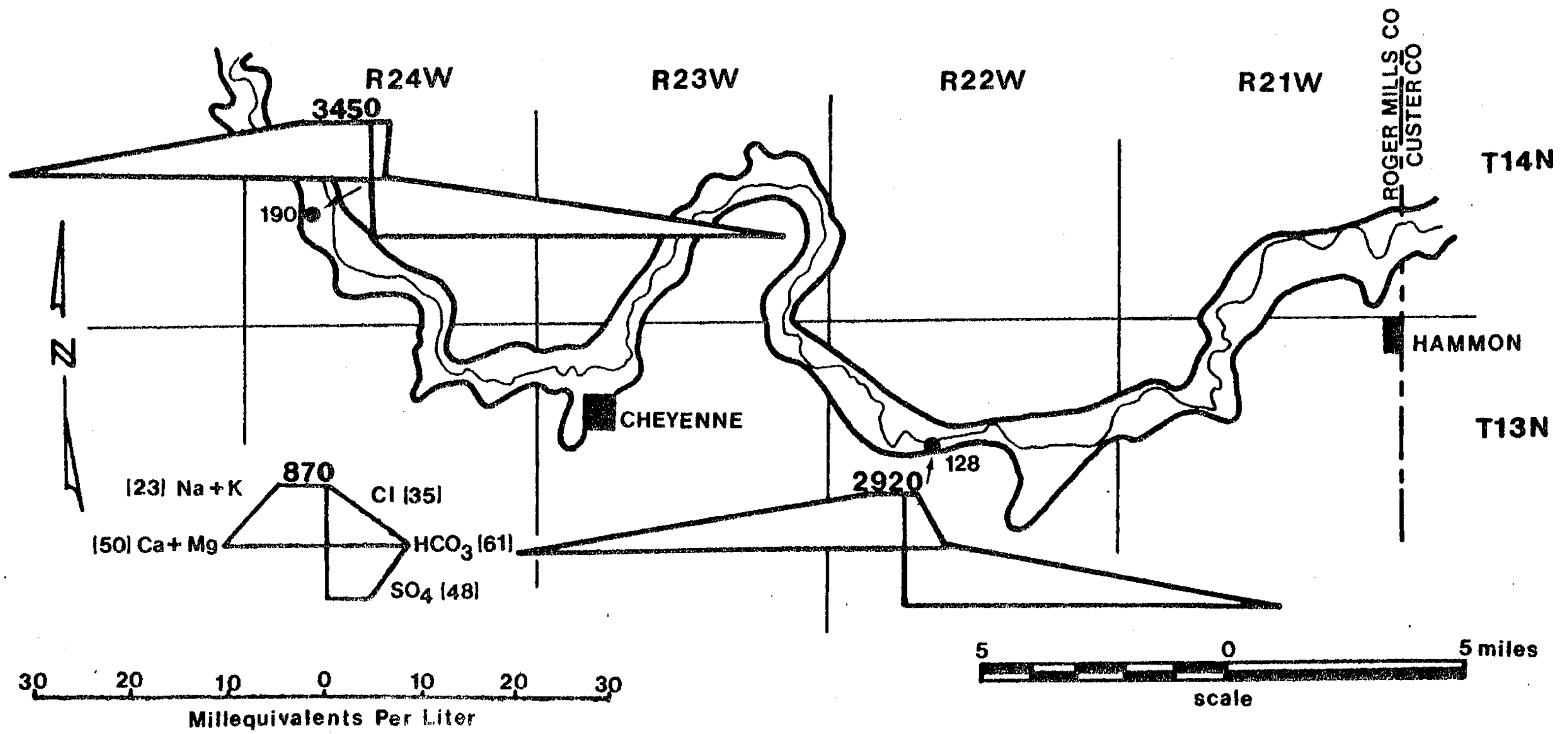
Two analyses of water from the Washita River alluvium were included in the Clinton Hydrologic Atlas (Carr, et al., 1976). They are presented in Figure 6. Both wells are located in the vicinity of Cheyenne; drillers' logs do not indicate penetration of the redbed in either case. The well northwest of Cheyenne is 190 feet deep and produced water with total dissolved solids of 3450 mg/1. The second well is east of Cheyenne and is 128 feet deep. Coarse

TABLE 3

WEIGHTED AVERAGE ALLOCATION FOR REACH 1 INCLUDING ALLOCATION BY MODELED SUBREACH

	Area, Modeled Reach (acres)	Area, Extended Modeled Reach (acres)	Fraction		% Total Area		Allocation by Modeled Reach (ac ft/ac/yr)	Weighted Allocation (ac ft/ac/yr)
Upper Modeled Reach (A)	19,960	27,240	$\frac{27,240}{60,160}$	=	45.3	x	2.70	1.22
Middle Modeled Reach (B)	11,600	13,720	$\frac{13,720}{60,160}$	=	22.8	x	1.75	0.40
Lower Modeled Reach (C)	8,640	19,160	$\frac{19,160}{60,160}$	=	31.9	x	1.75	0.56
	Total aquifer area (acres)	60,160			Net allocation for total aquifer area			2.18

	Allocation by Modeled Reach			Weighted Allocation
	Upper Reach (A)	Middle Reach (B)	Lower Reach (C)	Total area, A, B, and C including unmodeled areas
Allocation ac ft/ac/yr	2.70	1.75	1.75	2.18



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Sample Well Locations
Number indicates well depth.

WATER QUALITY DIAGRAMS

Number on top of diagram indicates total dissolved solids in milligrams per liter
Number in brackets is a multiplying factor.
Multiply it by millequivalents to get milligrams per liter.

CHEMICAL ANALYSIS, WATER FROM ALLUVIUM

	sw ne sec. 20 T14N R24W depth – 190 ft.	sw nw sec. 16 T13N R22W depth – 128 ft.
Na+K	207	115
Ca+Mg	1900	2000
Cl	70	42
HCO_3	61	244
SO_4	2112	1872
dissolved solids ROE at 180°C	3450	2920

Figure 6. Ground-Water Quality Analyses For Modeled Reach 1.

sand and gravel were penetrated in the lower 52 feet. It reportedly yielded 1000 gpm upon completion; total dissolved solids were 2920 mg/l. Hardness (Ca + Mg) and sulfate (SO**4) are the main cause of the relatively high values of dissolved solids. The hardness and sulfate are probably related to the gypsum (CaSO**4 2H**2O) in the underlying Cloud Chief and Rush Springs.

Analyses of 15 water samples from the Cloud Chief (Carr, et al., 1976) showed an average dissolved solids of 2850 mg/l. Total hardness averaged 1700 mg/l and the average sulfate concentration was 1700 mg/l. Four water samples taken from the Rush Springs Formation in the Washita River basin above Clinton had an average total dissolved solids of 2428 mg/l with an average total hardness of 1488 mg/l and sulfate concentration of 1416 mg/l. Further east in Caddo County, water quality in the Rush Springs is better and dissolved solids average 280 mg/l. The higher dissolved solids in Reach 1 are probably due to solution of gypsum in the overlying Cloud Chief. Downward percolation carries the dissolved minerals into the Rush Springs Formation. Gypsum contained in the Rush Springs may also contribute to the poor ground-water quality.

REACH 2

Reach 2 extends from Clinton to Anadarko (Figure 2). The western one-third of the reach is primarily in Washita County and is underlain by the Cloud Chief Formation; whereas, the eastern two-thirds is primarily in Caddo County and is underlain by the Rush Springs Formation as shown in Figures 7 and 8, respectively. The average saturated thickness of the alluvium in Reach 2 is 53 feet and the average transmissivity is 13,900 gpd/ft (see Table 1). Maps showing water table elevations, saturated thickness, and transmissivity are illustrated in Figures 9-14, respectively. The transmissivity values are based on assigned permeability ranges of 10, 60, 350 and 700 gpd/ft2, respectively, using sample logs (see discussion of permeability ranges in Kent, et al, 1973).

That portion of Reach 2 (subreach A, Washita County) underlain by the Cloud Chief Formation (Figure 7) was not modeled because of lack of data and because it is hydrogeologically similar to Reach 3; thus, the allocation determined for Reach 3 (1.6 acre-feet/acre/year) was also used in Reach 2, subreach A. The remaining portion of Reach 2 (subreach B, Caddo County), is similar to subreach A but is underlain by the Rush Springs formation (see Figure 8). Subreach B (Caddo County) was excluded from both modeling and allocation because of the large number of wells which are either totally completed in the underlying Rush Springs sandstone aquifer or are commingled with the alluvial aquifer. Therefore, Subreach B is only subject to the allocation specified for the Rush Springs sandstone aquifer.

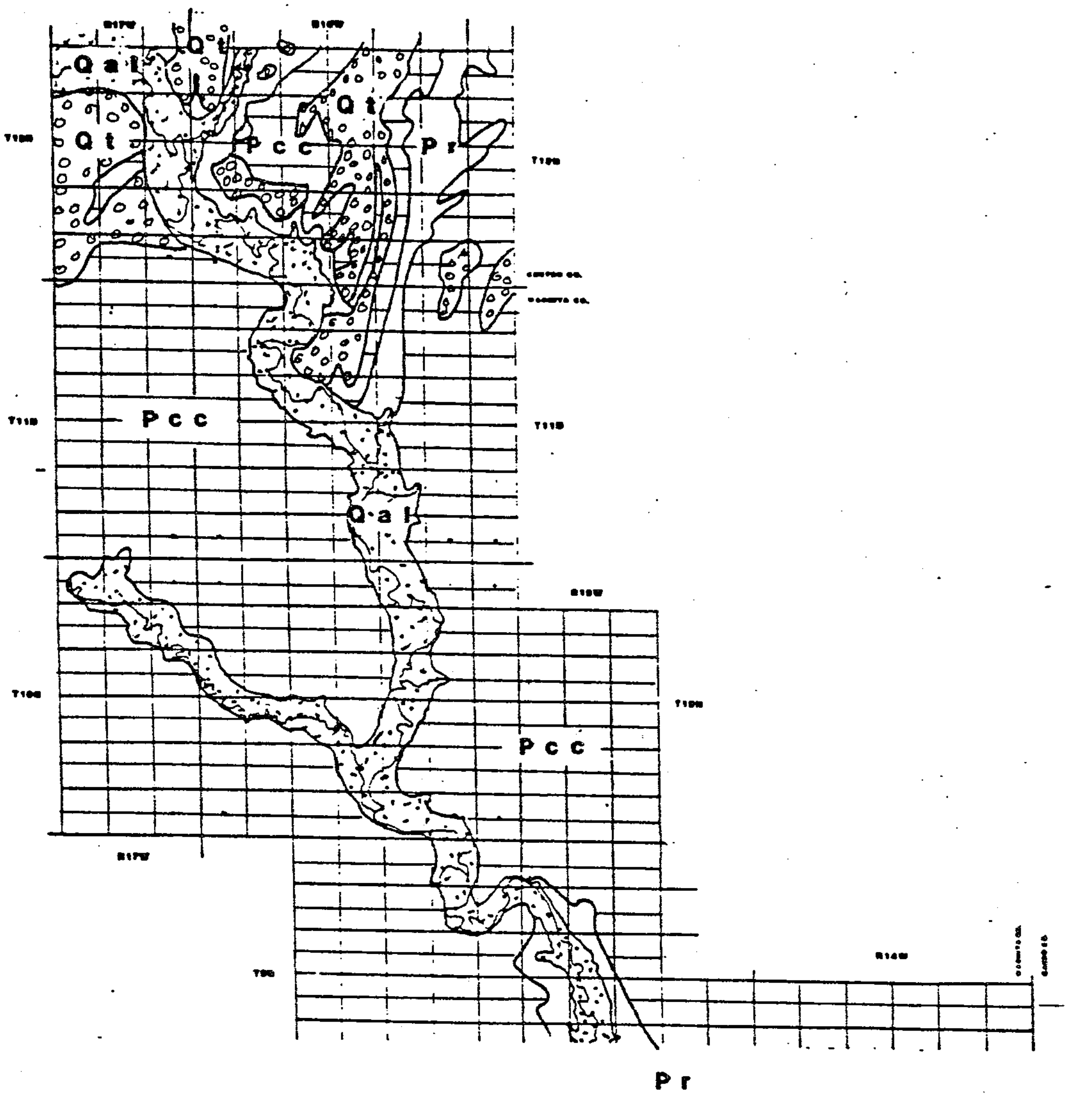

Figure 7.

Geologic Map

Reach 2 Subreach A

0 2 4

miles

N

Qal	Alluvium
Qt	Terrace Deposits
Pcc	Cloud Chief Fm.
Pr	Rush Springs Fm
Pm	Marlow Fm.
Per	El Reno Group
Phy	Hennessey Group

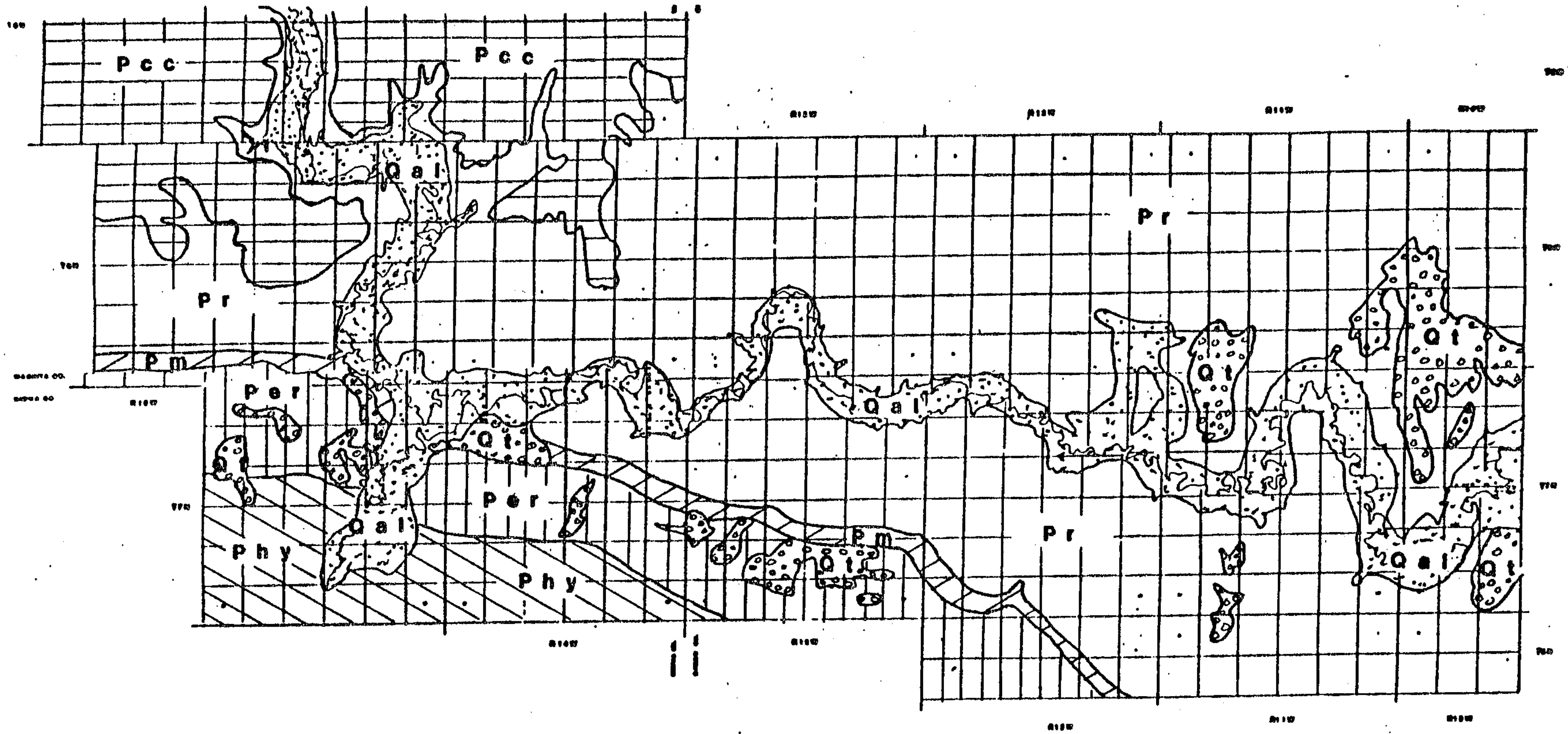

Figure 8.

Geologic Map

Reach 2 Subreach B

0 2 4

miles

N

Qal	**Alluvium**
Qt	**Terrace Deposits**
Pcc	**Cloud Chief Fm.**
Pr	**Rush Springs Fm.**
Pm	**Marlow Fm.**
Per	**El Reno Group**
Phy	**Hennessey Group**

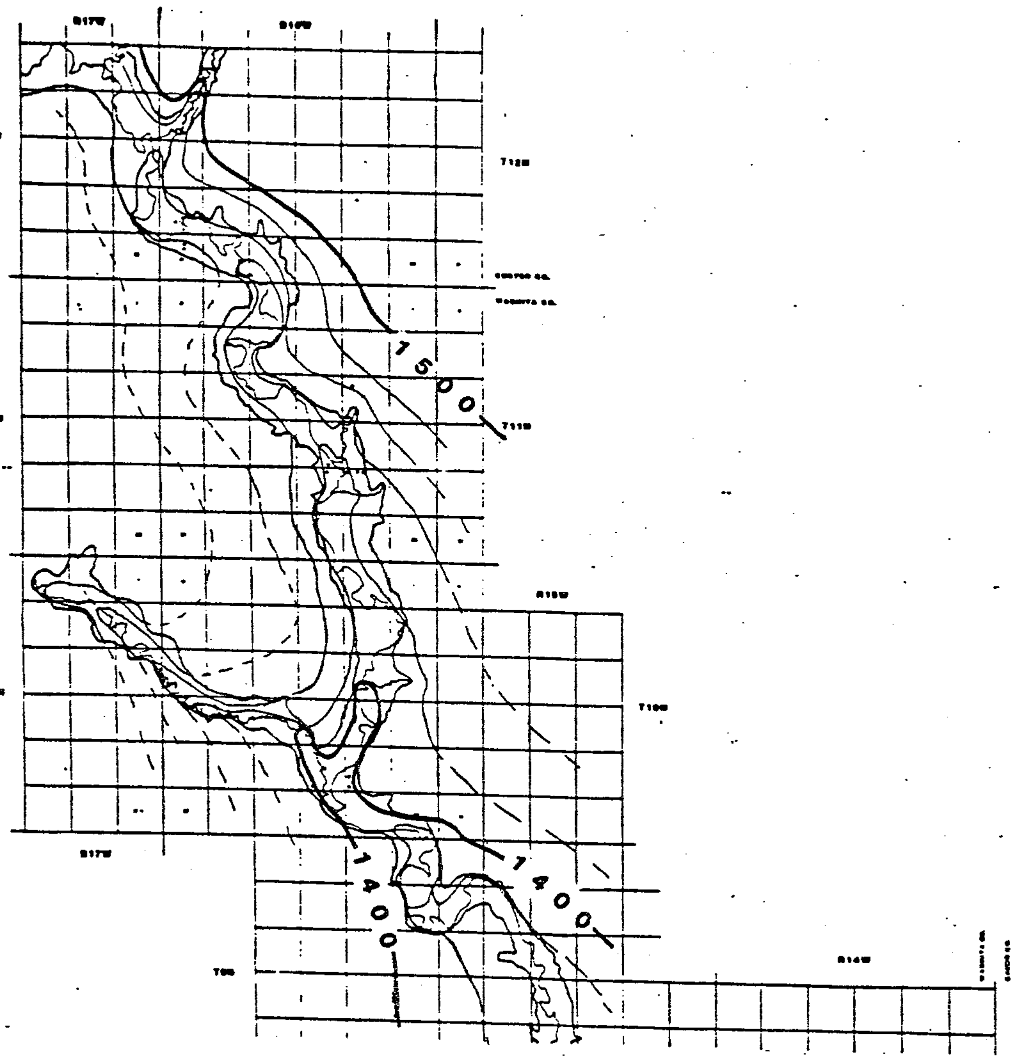

Figure 9. Water Table Map,

Subreach A, Reach 2.

0 2 4

miles

N

CI.= 20ft.

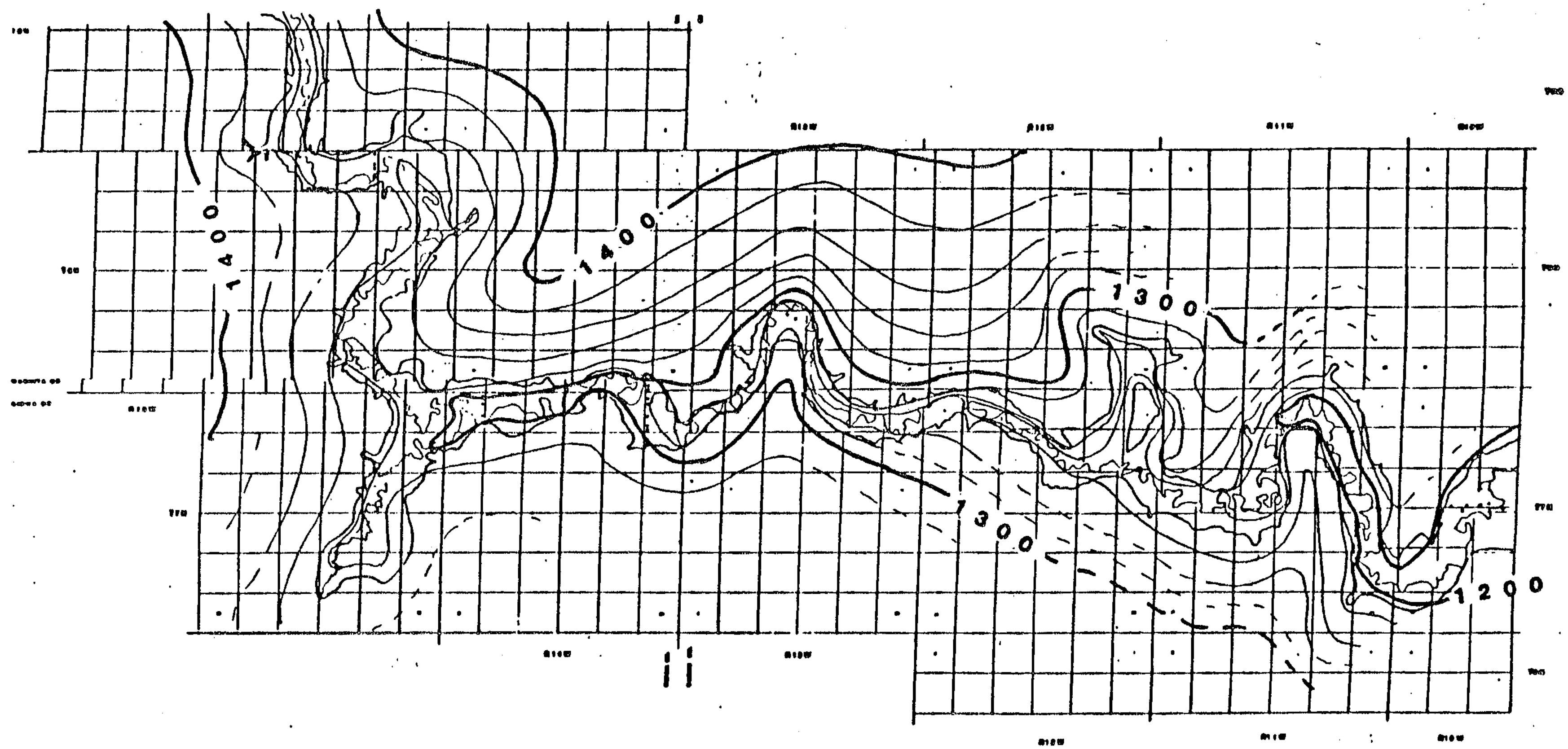

Figure 10. Water Table Map,

Subreach B, Reach 2.

0 2 4

miles

CI.= 20ft.

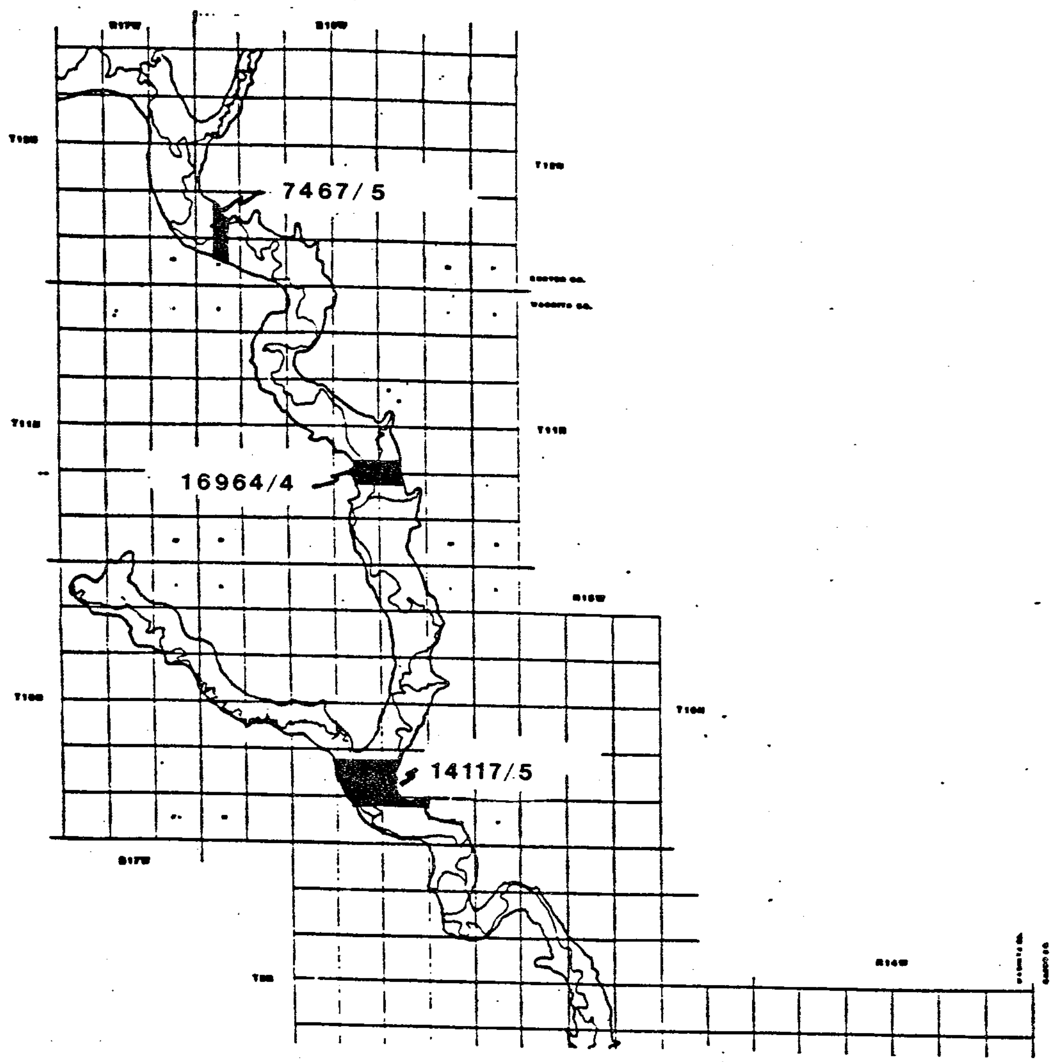

Figure 11. Saturated Thickness Map,

Subreach A, Reach 2.

2 4

miles

N

avg. value in feet/no. of wells for avg.

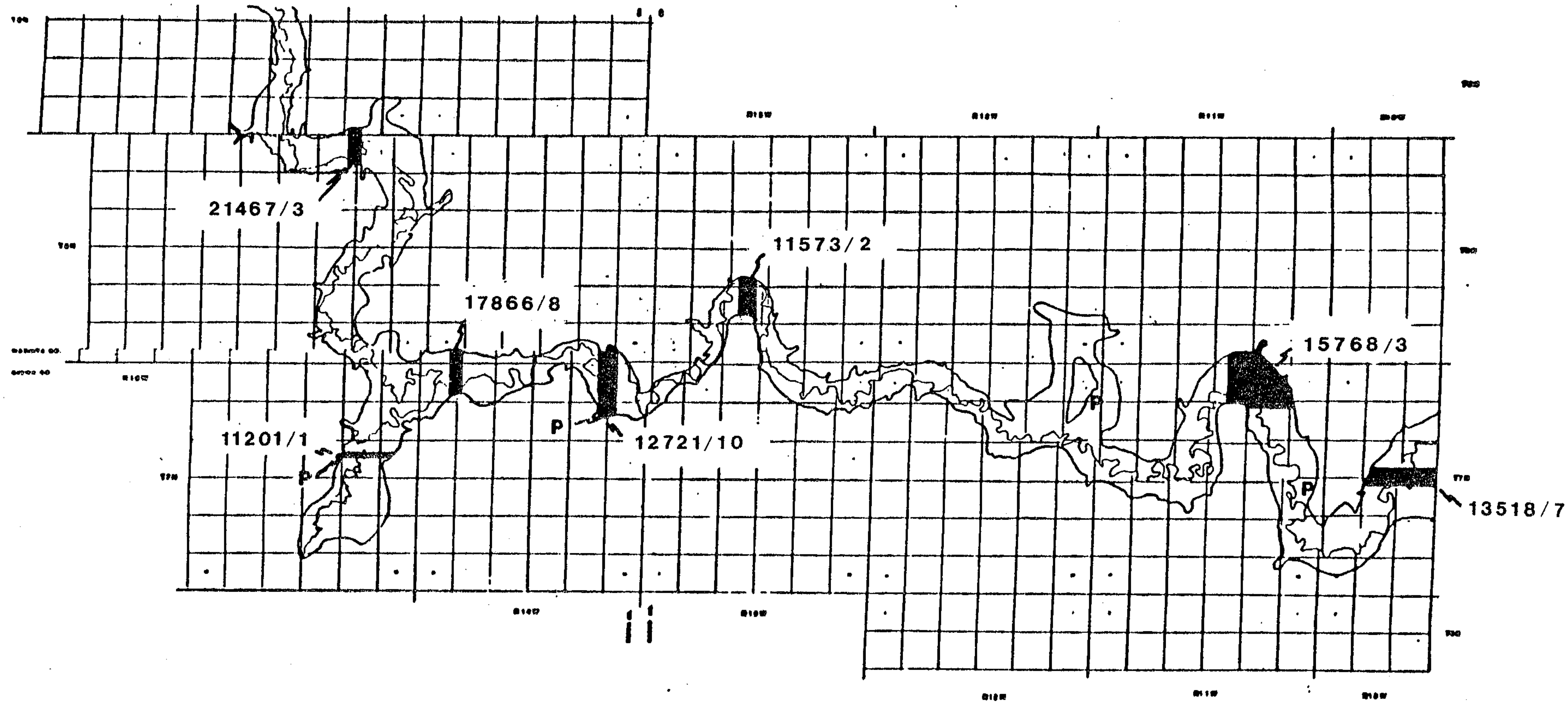

Figure 12. Saturated Thickness Map,

Subreach B, Reach 2.

avg. value in feet/no. of wells for avg.

P — Prior Rights: Alluvium only

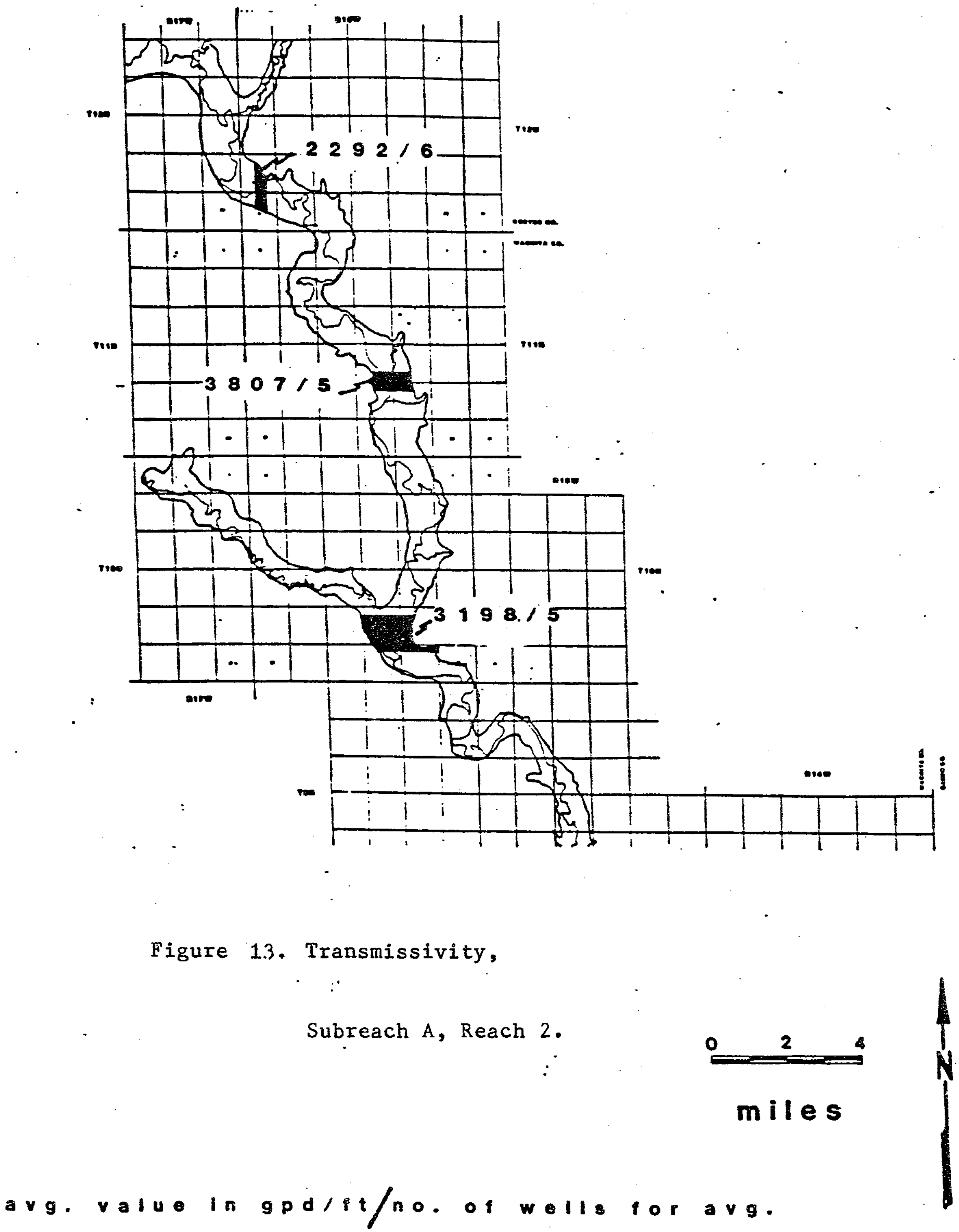

Figure 13. Transmissivity,

Subreach A, Reach 2.

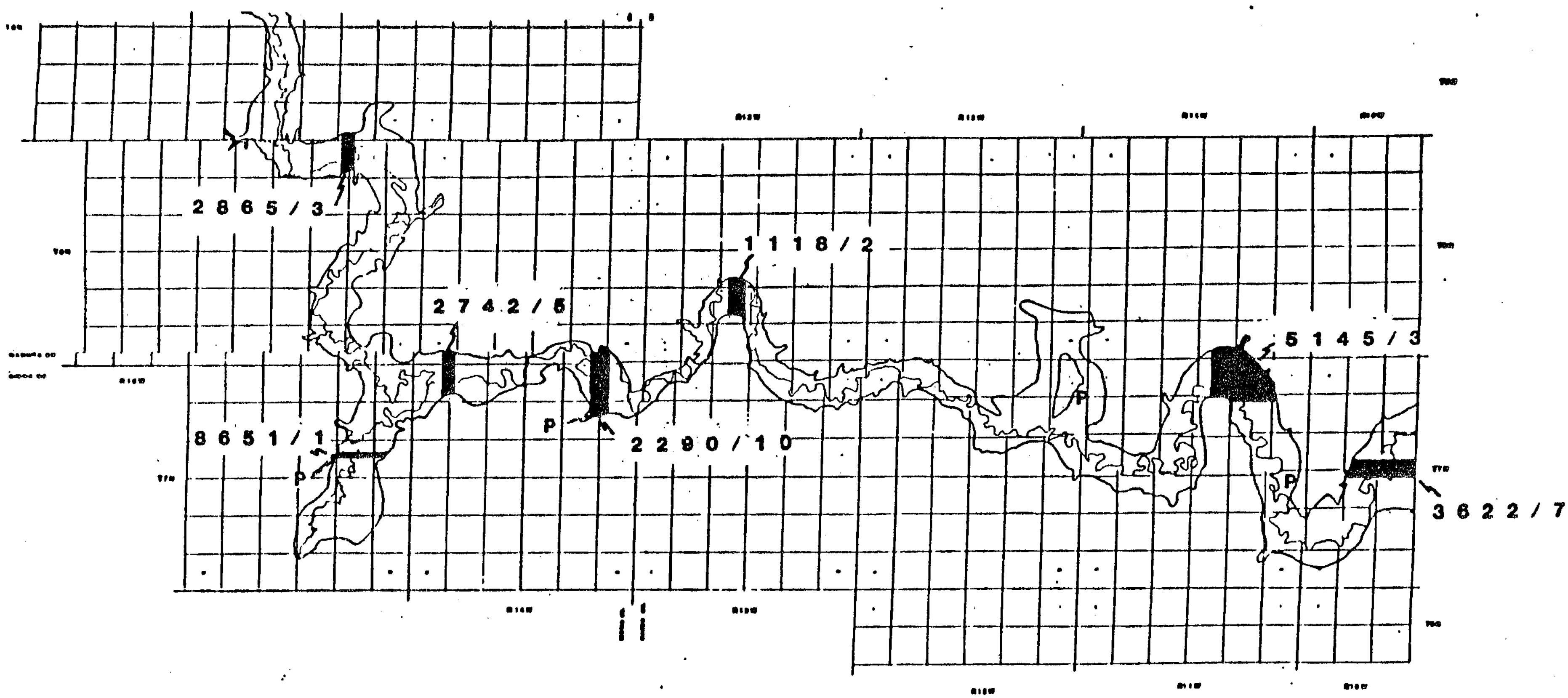

Figure 14. Transmissivity,

Subreach B, Reach 2.

avg. value in gpd/ft/no. of wells for avg.

P= Prior Rights:Alluvium only

REACH 3

Reach 3 includes the area between Anadarko and Alex in Caddo and western Grady counties. This reach has been extensively studied by personnel from the Agricultural Research Service in Chickasha and Durant, Oklahoma and from the Department of Geology at the Oklahoma State University in Stillwater, Oklahoma. An approach to hydrogeologic investigations within this reach is described in a journal article by D. C. Kent, J. W. Naney and B. B. Barnes (1973). The article includes maps, cross sections, a description of a hydrogeologic data storage and retrieval system and procedures for determining the hydraulic parameters (permeability storage coefficient). A M.S. thesis, which has been completed but not published, includes information and results used for this report (see R. Neafus, 1984).

A detailed model study has been in progress for several years by D. C. Kent and J. W. Naney. Some of the published results of computer simulation are shown in Figure 15 (see D. C. Kent, J. W. Naney and F. E. Witz, 1982).

The alluvium in this area is underlain by the Marlow Formation, the Dog Creek-Blaine Formation, and the Chickasha Formation (see Figure 3). The bedrock formations in Reach 3 represent only the Permian System. The oldest formations are in the eastern part of Reach 3 with the formations dipping 5 to 10 degrees to the west. The Chickasha Formation, which crops out in the eastern part of Reach 3, is the oldest strata and is made up of a layered sequence of medium-dark red sandstone, shale, siltstone, and siltstone conglomerate with iron and calcite cement. The outcrops are predominately channeled siltstones with cherty, pebble conglomerate occurring in the bottom of the channels. Overlying and outcropping to the west of the

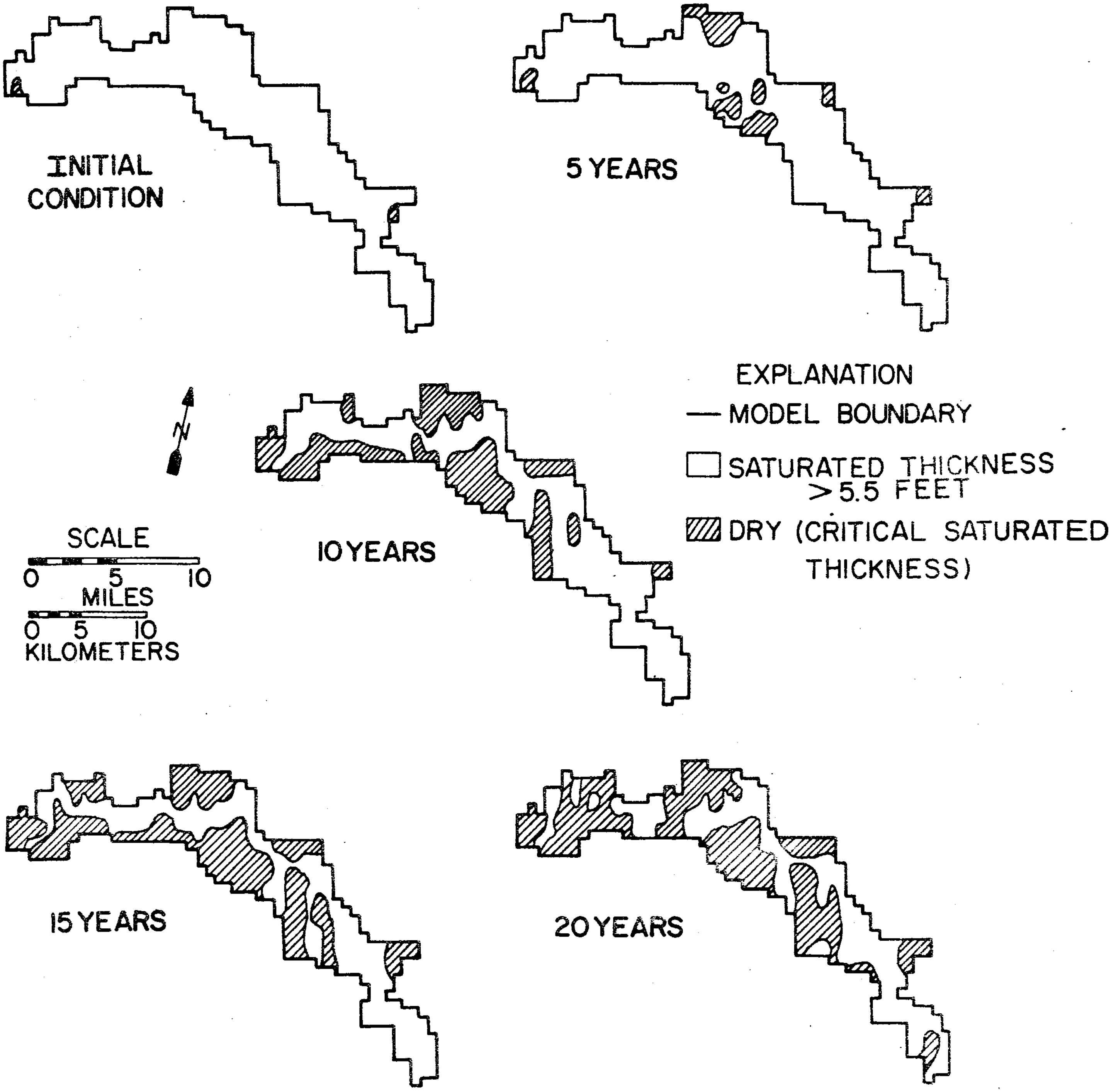

Figure 15. THE CRITICAL SATURATED THICKNESS FOR THE WASHITA RIVER ALLUVIUM BETWEEN ANADARKO AND ALEX, OKLAHOMA.
(D. C. Kent, J. W. Naney, and F. E. Witz, 1982)

Chickasha Formation is the Dog Creek-Blaine Formation. This formation is mostly dark red, even bedded, dolomitic shale interbedded with thin gypsiferous sandstone. To the west and overlying the Dog Creek-Blaine Formation is the Marlow Formation. The Marlow Formation consists mainly of evenly bedded, red, sandy, dolomitic, gypsiferous shale. The Marlow crops out over most of the western half of Reach 3 with outcrops along the western half of the Washita River valley and along most of the length of the Sugar Creek tributary to the north.

The Washita River basin between Anadarko and Alex contains approximately 109 square miles of alluvial deposits. The average depth to water is 17 feet, the average saturated thickness is 67 feet, the average permeability is 258 gpd/ft**2, and the average transmissivity is 16,440 gpd/ft (see Table 1).

A generalized water table map for Reach 3 is shown in Figure 16. Average depth to water, saturated thickness, permeability, and transmissivity for 1973 and 1993 are also presented in Table 1. Maps for saturated thickness, transmissivity and depth to water for 1973 and 1993 water are shown i Appendix B. Saturated thickness is compared to percent of aquifer area in Reach 3 which is predicted to be dry in Table 4. Average recharge is approximately 2.65 in/yr which represents 8 percent of the total average precipitation of 33 in/yr. These data, along with the preceeding, is summarized in the ground-water budget for Reach 3 as shown in Figure 17. Prior appropriative pumping rights and water distribution summaries are also shown in Appendix B. An allocation of 1.60 acre-feet/acre/year was calculated for Reach 2.

Ground-water chemistry is summarized in Figure 18. The major constitutents map in Figure 18 represent patterns of occurrence which can be generalized for large portions of the study area.

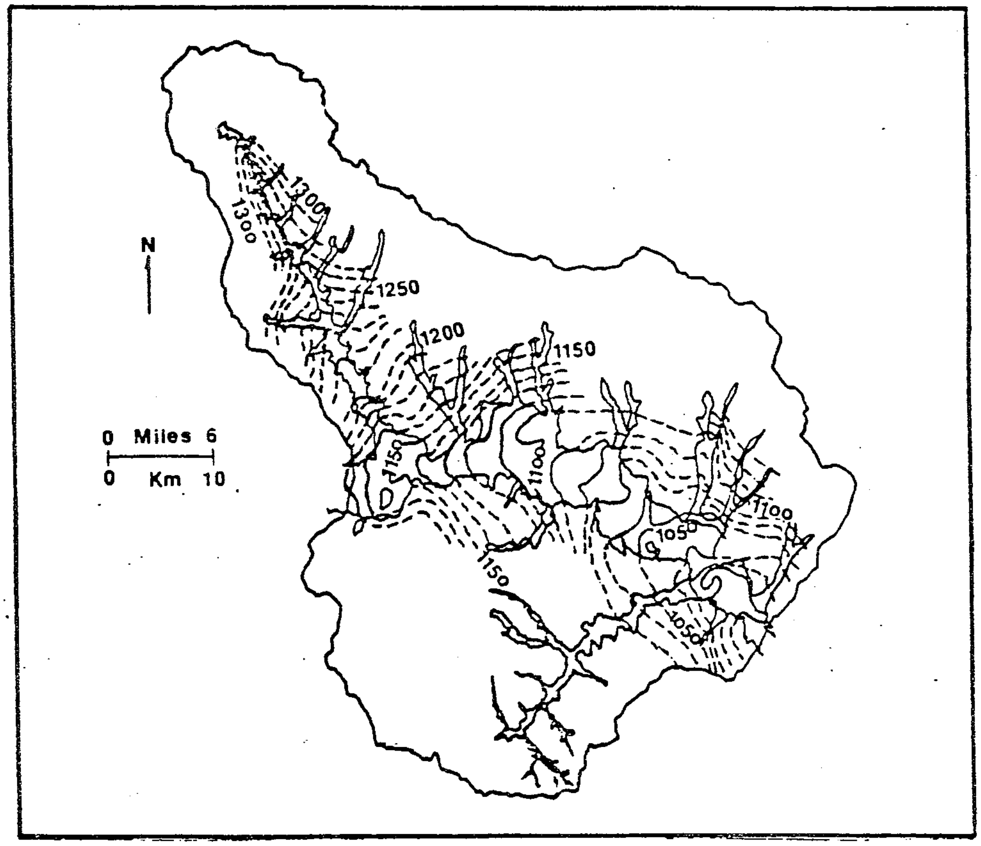

Figure 16. Water Table Map,

Modeled Reach 3.

(after Silka, 1975)

TABLE 4

Saturated Thickness and the Respective Percent Dry Aquifer

Area For

Modeled Reach 3

Average Saturated Thickness (ft)					Percent Dry Aquifer Area (ft)				
1973	1978	1983	1988	1993	1973	1978	1983	1988	1993
67	38	16	7	6	0	2.3	19.5	47.0	52.0

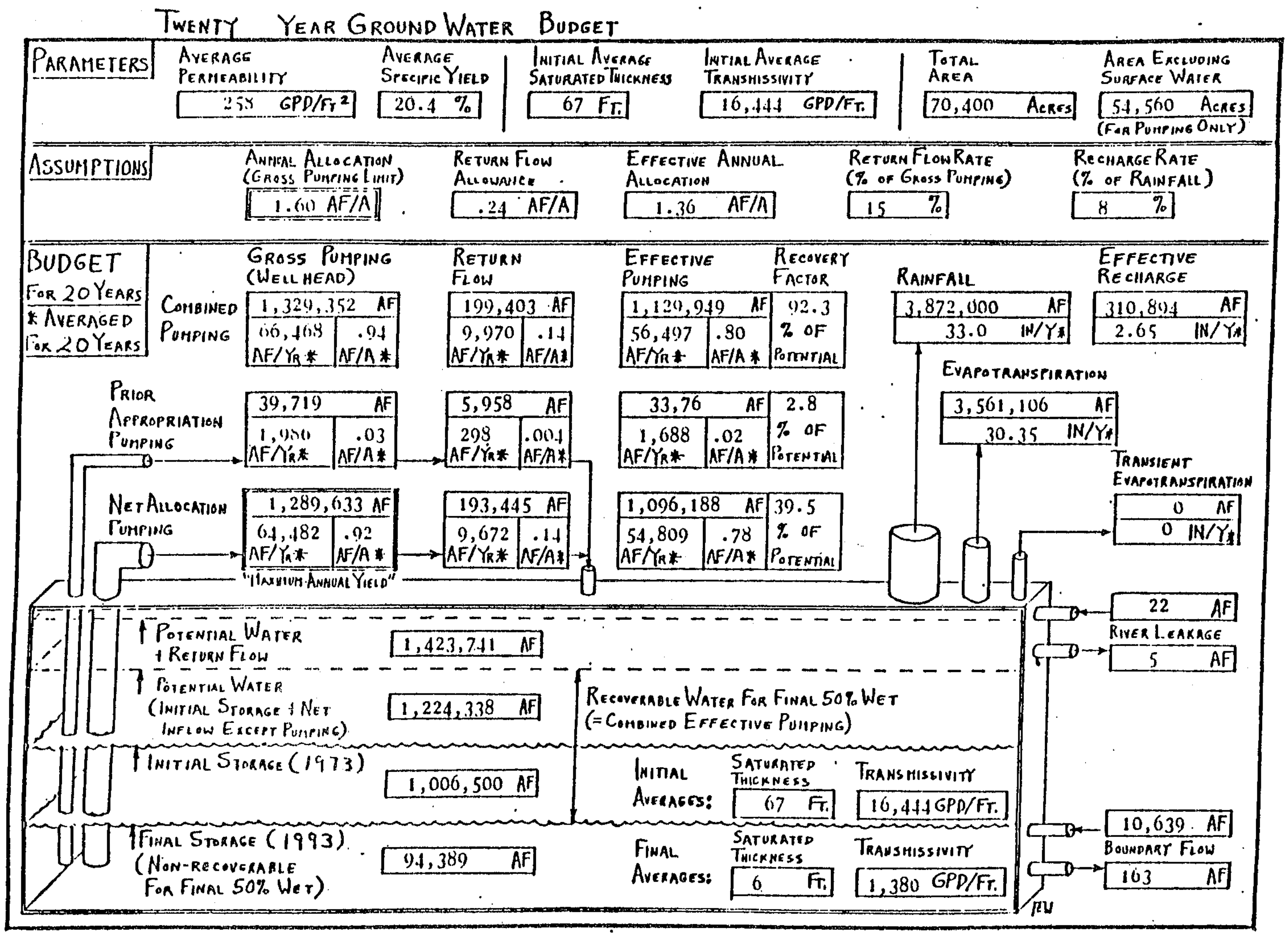

Figure 17. Ground-water Budget For Modeled Reach 3.

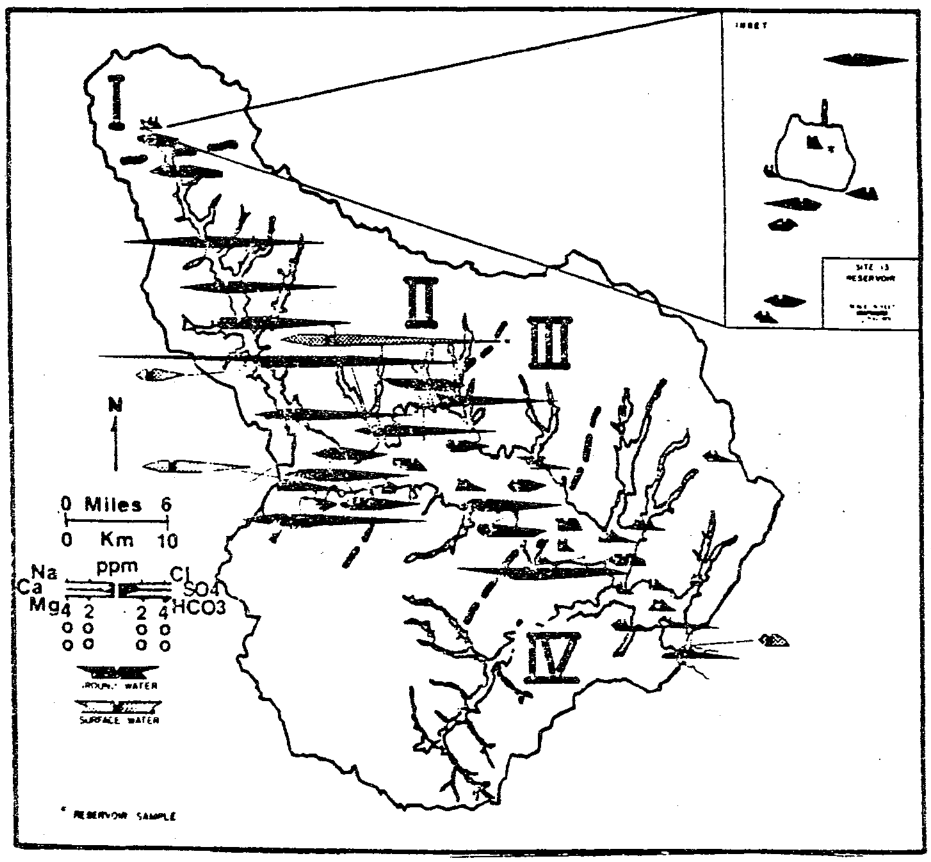

Figure 18. Ground-Water Quality Analyses For Modeled Reach 3. (after Silka, 1975)

REACH 4

Reach 4, located between Alex and Lake Texoma in south-central Oklahoma in Grady, McClain, Garvin, Murray, Carter, and Johnston counties, is described by Patterson (1984). Reach 4 was subdivided into three subreaches; subreach A, subreach B, and subreach C. The area within the Arbuckle Mountains was not included because the alluvium was either too thin or absent.

The formations that underlie the Washita River allulvium in Reach 4 include the Goddard and Delaware Creek Shales of Mississippian age, the Dornick Hills, Deese, and Oscar Groups of Pennsylvanian age, the Wellington Formation, the Garber Sandstone, the Fairmont Shale, the Purcell Sandstone, the Bison Shale, and the Duncan Sandstone all of Permian age, and the Antlers Sandstone of Cretaceous age. Of these formations, two are potential aquifer units; the Garber-Wellington and the Antlers Sandstone, (see Figure 3).

The basin area in Reach 4 covers approximately 2,800 square miles of alluvial deposits. The average depth to water is 26 feet and the average saturated thickness is 38 feet. The average permeability and transmissivity are 1,180 gpd/ft**2 and 43,120 gpd/ft, respectively. Average depth to water, saturated thickness, permeability, and transmissivity for 1973 and 1993 for Reach 4 are shown in Table 1. Water table elevations, depth to water, saturated thickness and transmissivity maps for 1973 and 1993 are also shown for each subreach in Appendix C. A comparison of saturated thickness and percent of aquifer area which is predicted to be dry for each subreach within Reach 4 is presented in Table 5.

The average recharge is approximately 4.41 in/yr which is 12.6 percent of the total average precipitation of 34.9 in/yr. The average evapotranspiration for Reach 4 is 30.5 in/yr. This data along with the preceeding data is summarized in the ground-water budget for Reach 4 shown in Figure 19. Prior appropriative pumping rights and water distribution summaries for Reach 4 are shown in Appendix C. An average allocation of 0.99 acre-feet/acre/year was determined for Reach 4. The method which is used to calculate allocation for Reach 4 is shown in Table 6.

Various formations underlie the Washita River alluvium in Reach 4 (Figure 3). These formations affect the quality of the 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 510 to 1,020 mg/l, average 319 mg/l. Averages for each major constituents are 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 documented and summarized graphically in Figure 20.

TABLE 5

Saturated Thickness and the Respective Percent Dry Aquifer

Area For

Modeled Reach 4

	Saturated Thickness					Percent Dry Aquifer Area				
	1973	1978	1983	1988	1993	1973	1978	1983	1988	1993
Subreach A	38	28	20	13	9	0	0	2.3	18.3	50.7
Subreach B	41	29	20	12	8	0	0.3	8.3	27.8	50.9
Subreach C	36	26	19	14	8	0	5.4	33.8	44.6	50.4

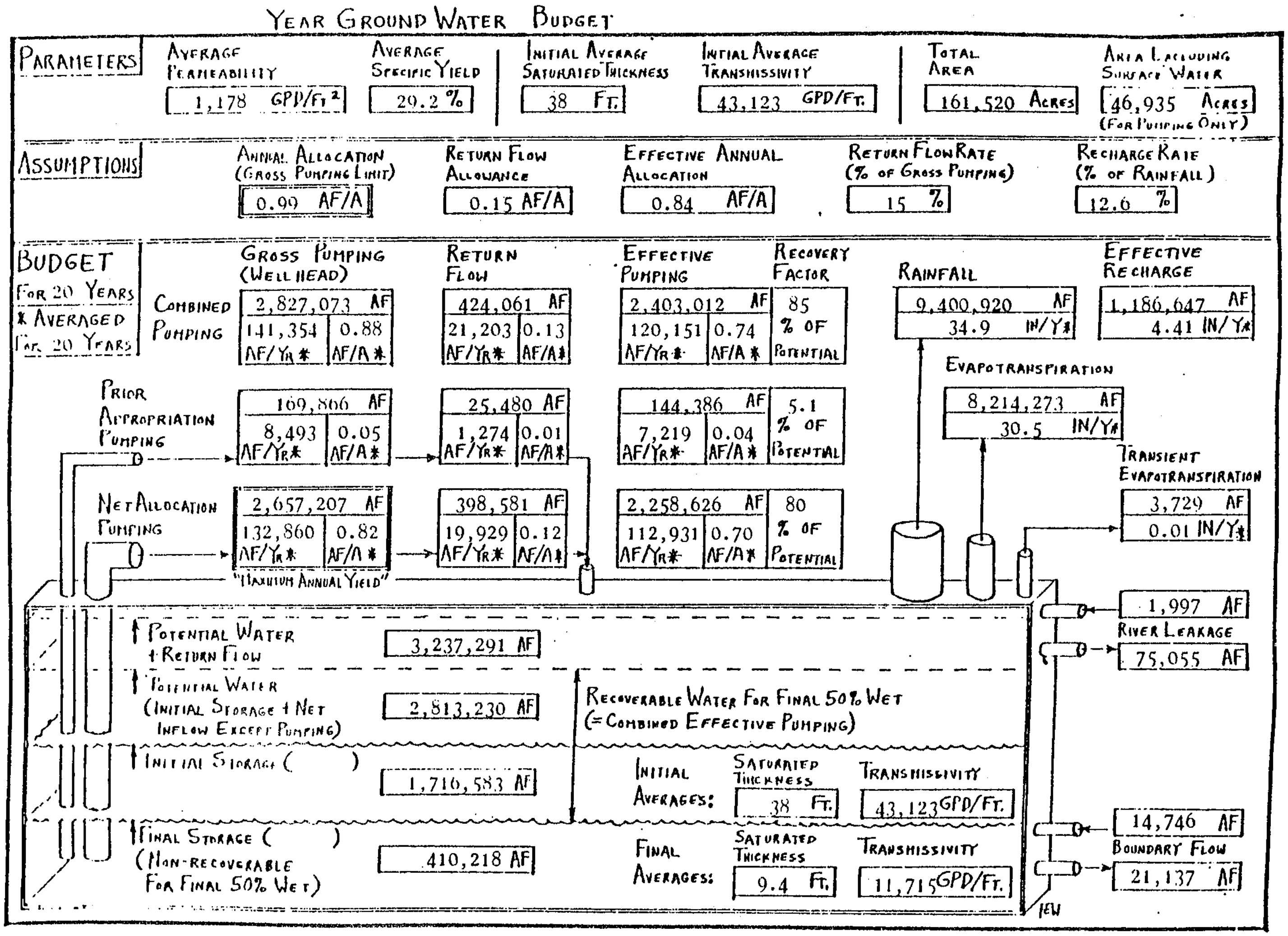

Figure 19. Ground-water Budget For Modeled Reach 4.

TABLE 6

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	$\frac{55,200}{161,520}$	= 34.2	*	0.882	0.30
Middle Modeled Reach (B)	51,840	161,520	$\frac{51,840}{161,520}$	= 32.1	*	1.14	0.36
Lower Modeled Reach (c)	44,480	161,520	$\frac{44,480}{161,520}$	= 27.5	*	1.20	0.33
				Net allocation for total aquifer area			0.99

	Allocation by Modeled Reach: Upper Reach	Middle Reach	Lower Reach	Weighted Allocation: Total area, A, B, and C
Allocation ac-ft/ac/yr	0.882	1.14	1.20	0.99 $\approx$ 1.0

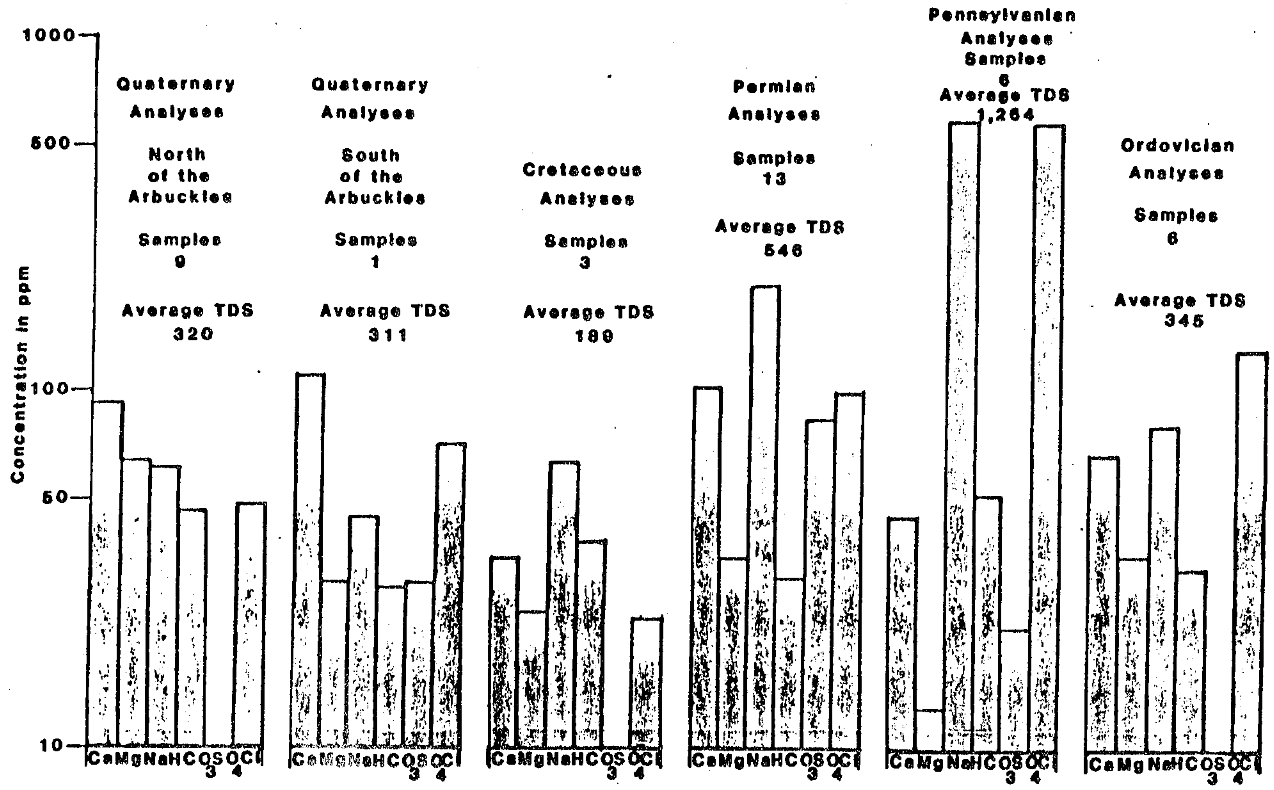

Figure 20. Ground-Water Quality Analyses For Modeled Reach 4.

RESULTS

Computer simulations were made for each reach and their subreaches (except Reach 2) for a 20-year period extending from 1973 to 1993 for both prior appropriative and allocation pumping. Prior appropriative pumping rates were determined using prior appropriative rights established for each county prior to 1973. Prior rights pumping for each reach are shown in the appropriate appendix (except Reach 2). Prior appropriative pumping simulations showed little to no change in saturated thickness from 1973 to 1993.

The maximum allowable allocation rate was found by adjusting the amount of allocated pumping so that 50 percent of each modeled reach would go dry by the end of the simulation period (20 years). 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. The pumping allocation rates were distributed over a four month pumping period (June-September) with the remaining eight months considered to be non-pumping.

The model results are shown by Reach as water budgets in Figures 5, 17, and 19 and by maps and graphs in the respective Appendices in the following order:

(1) Prior Rights Pumping Maps

(2) Water Distribution Summaries

(3) Water Table Maps

(4) Depth to Water Maps

(5) Saturated Thickness Maps

(6) Transmissivity Maps

CONCLUSIONS

The allocation pumping rate for the Washita River alluvial aquifer can be analyzed two ways; either by individual reach (Reach 1, 2, 3, and 4) or by a weighted allocation combining Reaches 1, 2, 3, and 4.

The weighted allocation determined by combining Reaches 1, 2, 3, and 4 is 1.38 or approximately 1.4 ac-ft/ac/yr. The method used to determine this weighted average allocation is shown in Table 7.

The Oklahoma Water Resources Board has elected to use a separate allocation proportioned for each alluvial reach as follows:

Reach 1 (State line to Clinton, OK, Roger Mills and Custer Co.)
2.0 Ac-ft/ac/yr.

Reach 2 (Clinton to eastern edge of Washita County; Note: The eastern portion of Reach 2 (Subreach B) is subject to the allocations specified for the Rush Springs sandstone aquifer.
1.5 Ac-ft/ac/yr.

Reach 3 (Anadarko, OK to Alex, OKG;, Caddo and Grady Counties)
1.5 Ac-ft/ac/yr.

Reach 4 Alex, OK to Lake Texoma; Grady, McClain, Garvin, Murray Carter and Johnston Counties)
1.0 Ac-ft/ac/yr.

Ground-water pollution was considered to be negligible after twenty years of simulated pumping on the Washita River alluvial aquifer. Local ground-water pollution may be found along some areas of the Washita River because of localized losing stream conditions. However, it is predicted that the Washita River will generally remain as a gaining stream after twenty years of pumping; and therefore, induced ground-water pollution by ground-water withdrawal is considered to be negligible in the future.

TABLE 7

Method Used To Determine The Weighted Allocation
For The Entire Washita River Alluvial Aquifer

	Area Modeled Reach (acres)	Total Area All Modeled Reaches (acres)	Fraction	% Total Area	Allocation By Reach (ac-ft/ac)		Weighted Allocation (ac-ft/ac)
Reach 1 (Schipper)	60,160	296,240	$\frac{60,160}{296,240}$	20.3 *	$\approx$ 2.0	=	0.442
Reach 2 Subreach A	4,160	296,240	$\frac{4,160}{296,240}$	1.4 *	$\approx$ 1.50	=	0.022
Reach 3 (Neafus)	70,400	296,240	$\frac{70,400}{296,240}$	23.7 *	$\approx$ 1.50	=	0.380
Reach 4 (Patterson)	161,520	296,240	$\frac{161,520}{296,240}$	54.5 *	$\approx$ 1.00	=	0.539

Total weighted allocation = 1.38

$\approx$ 1.4 ac-ft/ac

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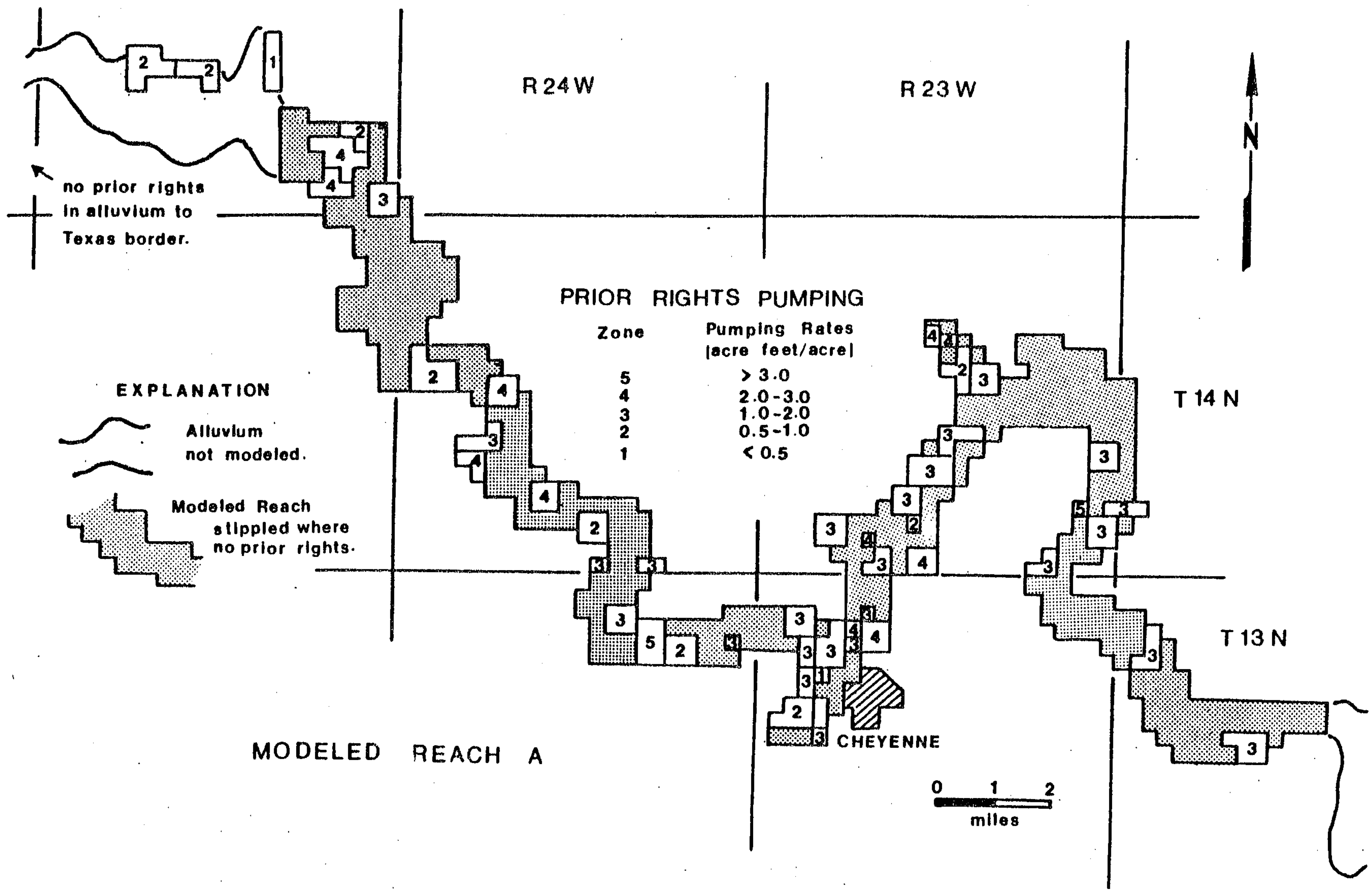
APPENDIX

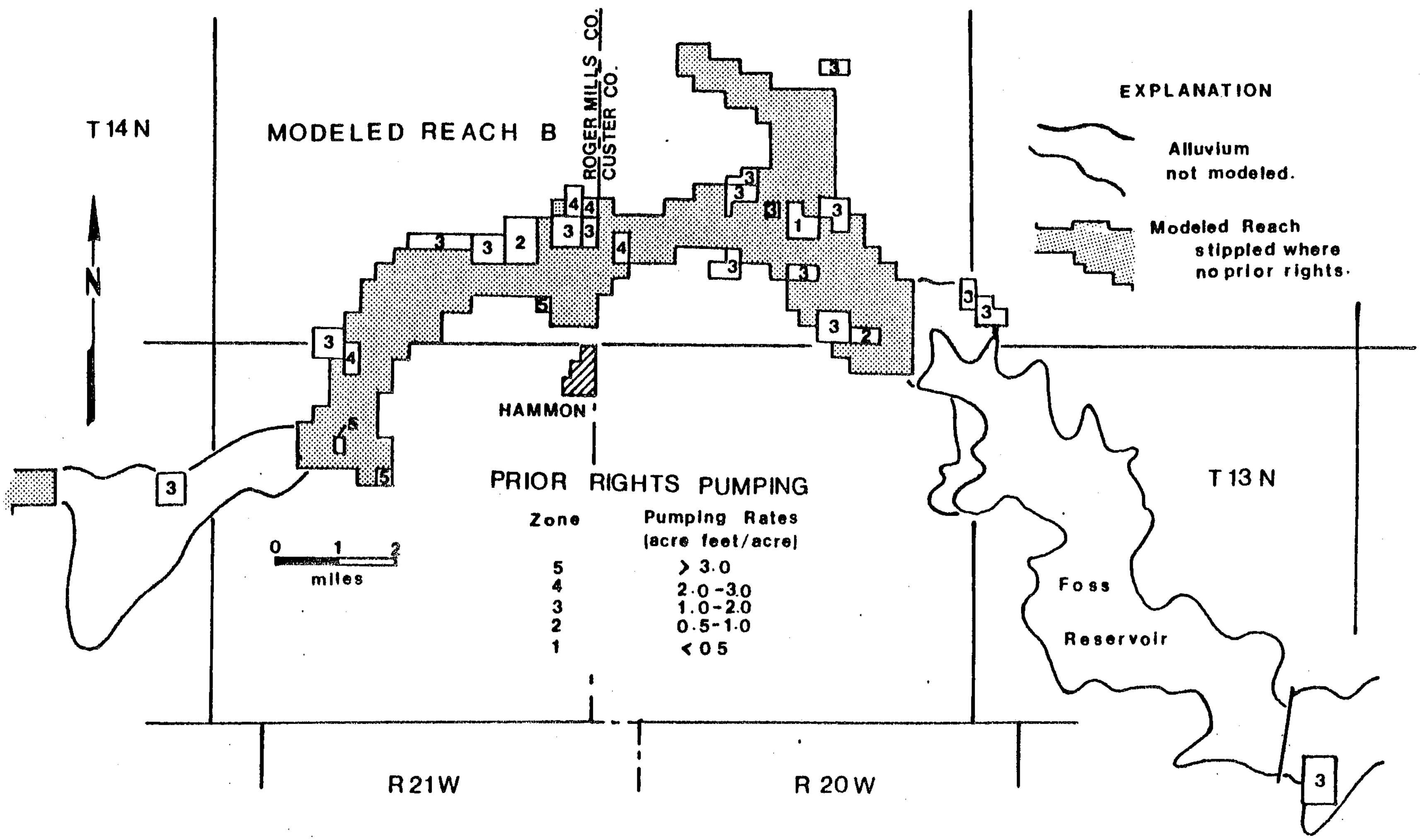
COMPUTER SIMULATION RESULTS

APPENDIX A

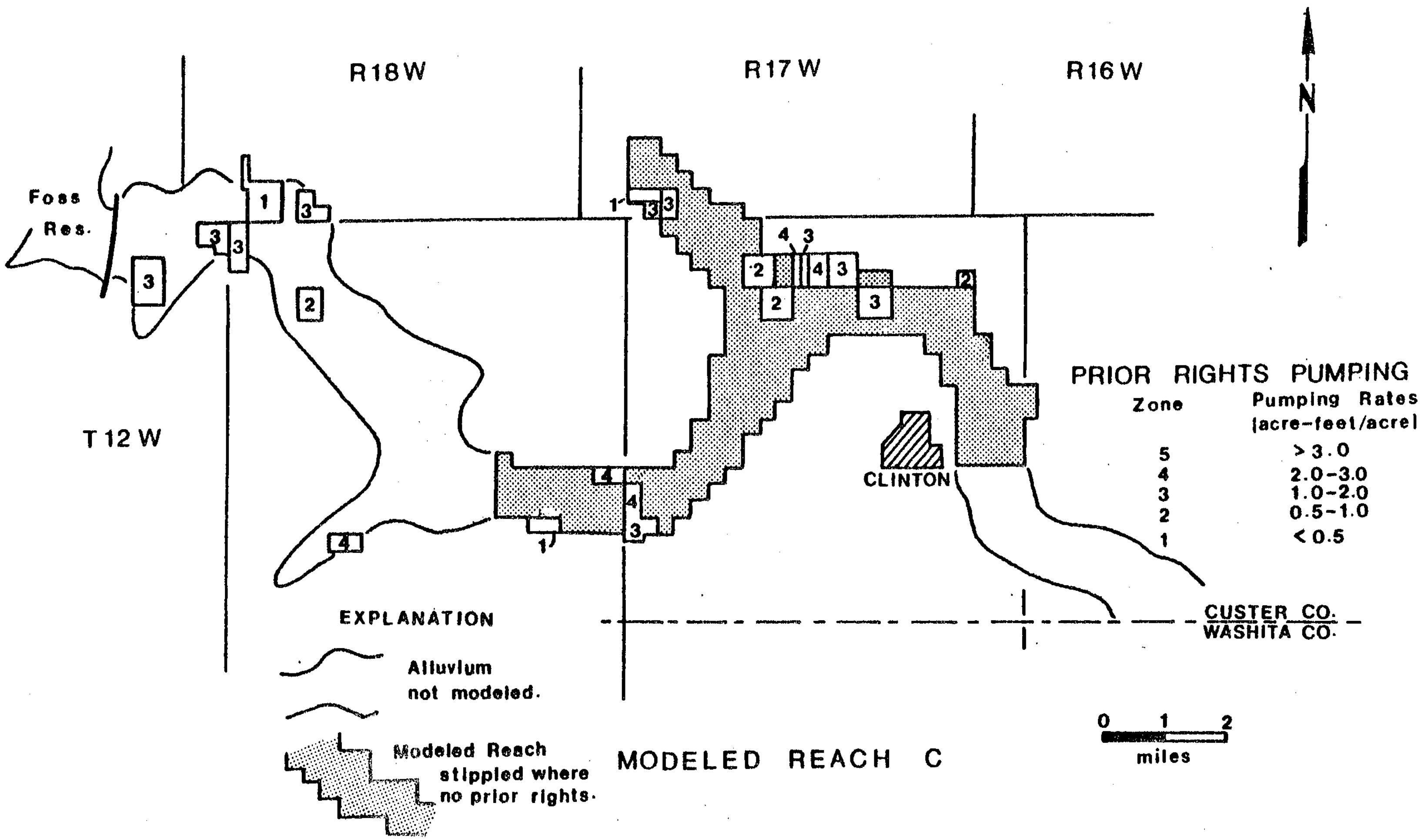
RESULTS FOR MODELLED REACH 1



Prior Rights Pumping, Subreach A, Modeled Reach 1.



Prior Rights Pumping, Subreaches B and C, Modeled Reach 1.



Prior Rights Pumping, Subreach C, Modeled Reach 1.

AREA: WASA
RUN: A820827.2259
NODE AREA: 40 ACRES
PUMPING PERIOD: 0.33 (FRACTION OF YEAR)
RETURN FLOW RATE: 15 PERCENT
NET PUMPING RATE: 85 PERCENT

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
50.0-- 60.0	0.6	120	52.6	26.6	1,679
60.0-- 70.0	0.6	120	67.6	26.6	2,157
70.0-- 80.0	0.2	40	71.0	26.6	755
80.0-- 90.0	0.8	160	85.3	26.6	3,631
90.0--100.0	0.4	80	93.2	26.6	1,984
100.0--110.0	1.0	200	108.3	26.6	5,764
110.0--120.0	5.8	1,160	116.9	26.6	36,086
120.0--130.0	9.2	1,840	124.1	26.6	60,761
130.0--140.0	16.8	3,360	136.0	26.6	121,560
140.0--150.0	12.2	2,440	144.4	26.6	93,742
150.0--160.0	7.8	1,560	155.8	26.6	64,647
160.0--170.0	18.6	3,720	165.8	26.6	164,055
170.0--180.0	21.8	4,360	174.6	26.6	202,507
180.0--190.0	4.0	800	183.1	26.6	38,954
ALL RANGES	100.0 (TOTAL)	19,960 (TOTAL)	150.4 (AVERAGE)	26.6 (AVERAGE)	798,282 (TOTAL)

DATA FROM:
A820827.2259 ALLOC=2.70AF/A; RATE=250GPD*.075; M=330; RIVER+1; RECH 3

AREA: WASA
RUN: A820827.2259
NODE AREA: 40 ACRES
PUMPING PERIOD: 0.33 (FRACTION OF YEAR)
RETURN FLOW RATE: 15 PERCENT
NET PUMPING RATE: 85 PERCENT

WATER DISTRIBUTION SUMMARY
JULY 1, 1993

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
0.0-- 5.5	49.9	9,960	4.4	26.6	11,769
5.5-- 10.0	3.8	760	7.6	26.6	1,533
10.0-- 20.0	19.4	3,880	15.7	26.6	16,219
20.0-- 30.0	18.4	3,680	24.3	26.6	23,835
30.0-- 40.0	6.8	1,360	34.5	26.6	12,490
40.0-- 50.0	1.6	320	42.8	26.6	3,643
ALL RANGES	100.0 (TOTAL)	19,960 (TOTAL)	13.1 (AVERAGE)	26.6 (AVERAGE)	69,489 (TOTAL)

DATA FROM:
A820827.2259 ALLOC=2.70AF/A; RATE=250GPD*.075; M=330; RIVER+1; RECH 3

Water Distribution Summaries,

Subreach A, Modeled Reach 1.

AREA: WASB
RUN: A820902.0230
NODE AREA: 40 ACRES
PUMPING PERIOD: 0.33 (FRACTION OF YEAR)
RETURN FLOW RATE: 15 PERCENT
NET PUMPING RATE: 85 PERCENT

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
30.0-- 40.0	1.4	160	39.0	27.5	1,716
40.0-- 50.0	6.9	800	45.8	27.5	10,075
50.0-- 60.0	6.6	760	55.1	27.5	11,522
60.0-- 70.0	7.9	920	66.2	27.5	16,744
70.0-- 80.0	14.1	1,640	74.5	27.5	33,619
80.0-- 90.0	9.0	1,040	84.8	27.5	24,254
90.0--100.0	14.8	1,720	95.0	27.5	44,929
100.0--110.0	13.4	1,560	105.4	27.5	45,202
110.0--120.0	11.7	1,360	114.5	27.5	42,816
120.0--130.0	9.0	1,040	125.7	27.5	35,937
130.0--140.0	5.2	600	133.6	27.5	22,043
ALL RANGES	100.0 (TOTAL)	11,600 (TOTAL)	90.6 (AVERAGE)	27.5 (AVERAGE)	288,858 (TOTAL)

DATA FROM:
A820902.0230 ALLOC=1.75AF/A;RATE=313GPD*.075;M=330;RIVER+1;RECH 3.2

AREA: WASB
RUN: A820902.0230
NODE AREA: 40 ACRES
PUMPING PERIOD: 0.33 (FRACTION OF YEAR)
RETURN FLOW RATE: 15 PERCENT
NET PUMPING RATE: 85 PERCENT

WATER DISTRIBUTION SUMMARY
JULY 1, 1993

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
0.0-- 5.5	48.6	5,640	4.3	27.5	6,630
5.5-- 10.0	9.0	1,040	7.4	27.5	2,123
10.0-- 20.0	19.0	2,200	14.0	27.5	8,459
20.0-- 30.0	8.6	1,000	23.8	27.5	6,541
30.0-- 40.0	5.2	600	35.2	27.5	5,800
40.0-- 50.0	8.6	1,000	43.8	27.5	12,055
50.0-- 60.0	1.0	120	51.3	27.5	1,693
ALL RANGES	100.0 (TOTAL)	11,600 (TOTAL)	13.6 (AVERAGE)	27.5 (AVERAGE)	43,302 (TOTAL)

DATA FROM:
A820902.0230 ALLOC=1.75AF/A;RATE=313GPD*.075;M=330;RIVER+1;RECH 3.2

Water Distribution Summaries,

Subreach B, Modeled Reach 1.

AREA: WASC
RUN: A820902.0311
NODE AREA: 40 ACRES
PUMPING PERIOD: 0.33 (FRACTION OF YEAR)
RETURN FLOW RATE: 15 PERCENT
NET PUMPING RATE: 85 PERCENT

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
30.0-- 40.0	1.9	160	38.2	25.0	1,526
40.0-- 50.0	11.1	960	45.3	25.0	10,861
50.0-- 60.0	4.6	400	53.6	25.0	5,359
60.0-- 70.0	4.2	360	65.4	25.0	5,888
70.0-- 80.0	4.2	360	74.9	25.0	6,742
80.0-- 90.0	5.1	440	84.6	25.0	9,309
90.0--100.0	12.0	1,040	96.1	25.0	24,988
100.0--110.0	30.1	2,600	105.4	25.0	68,513
110.0--120.0	21.3	1,840	113.4	25.0	52,174
120.0--130.0	5.6	480	124.2	25.0	14,905
ALL RANGES	100.0 (TOTAL)	8,640 (TOTAL)	92.7 (AVERAGE)	25.0 (AVERAGE)	200,265 (TOTAL)

DATA FROM:
A820902.0311 ALLOC=1.75AF/A;RATE=170GPD*.075;M=330;RIVER+1;RECH 3.4

AREA: WASC
RUN: A820902.0311
NODE AREA: 40 ACRES
PUMPING PERIOD: 0.33 (FRACTION OF YEAR)
RETURN FLOW RATE: 15 PERCENT
NET PUMPING RATE: 85 PERCENT

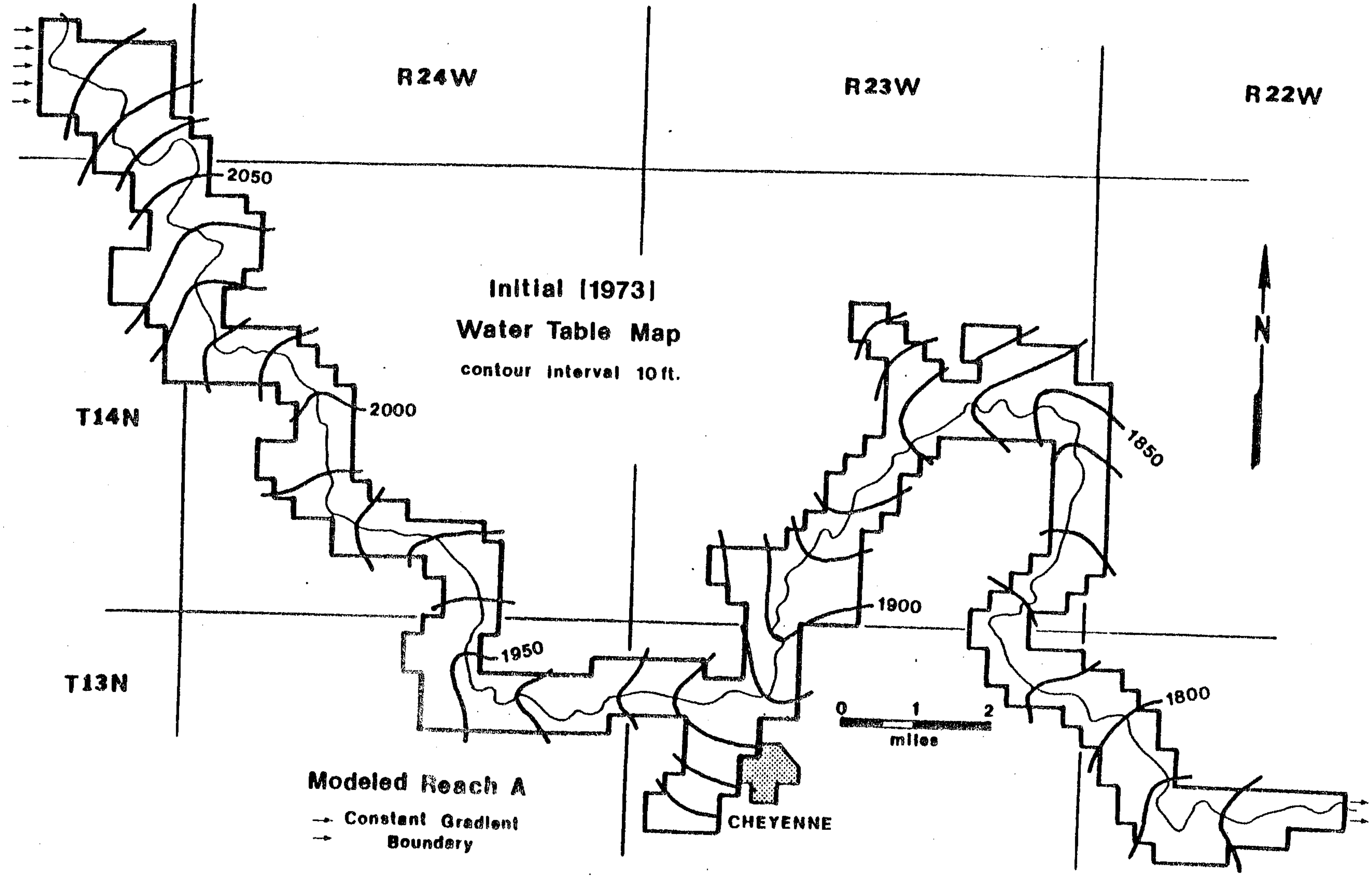
WATER DISTRIBUTION SUMMARY
JULY 1, 1993

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
0.0-- 5.5	50.0	4,320	4.7	25.0	5,034
5.5-- 10.0	8.3	720	8.0	25.0	1,441
10.0-- 20.0	28.7	2,480	14.6	25.0	9,031
20.0-- 30.0	6.5	560	25.3	25.0	3,539
30.0-- 40.0	5.6	480	33.8	25.0	4,053
40.0-- 50.0	0.9	80	41.1	25.0	822
ALL RANGES	100.0 (TOTAL)	8,640 (TOTAL)	11.1 (AVERAGE)	25.0 (AVERAGE)	23,919 (TOTAL)

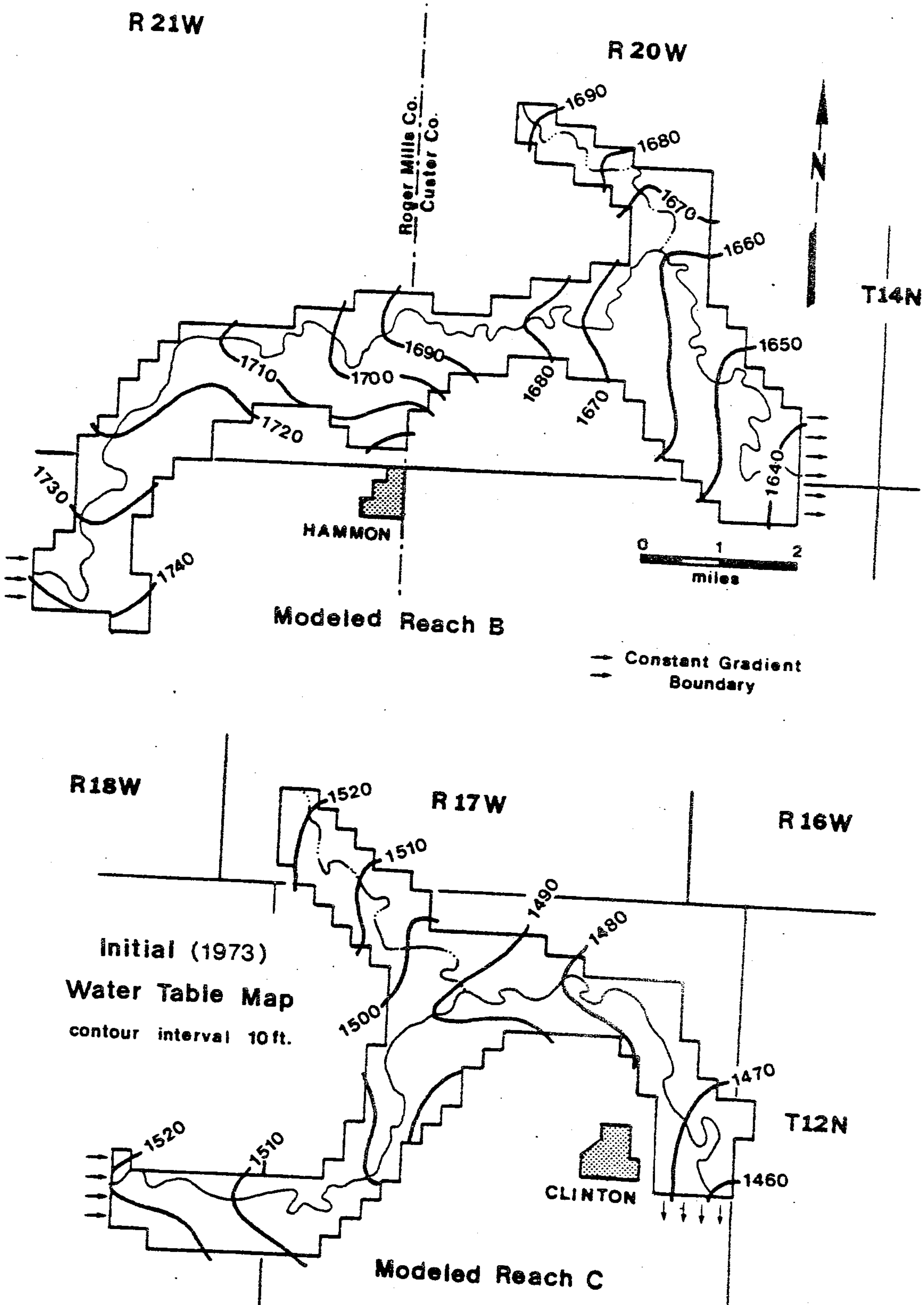
DATA FROM:
A820902.0311 ALLOC=1.75AF/A;RATE=170GPD*.075;M=330;RIVER+1;RECH 3.4

Water Distribution Summaries,

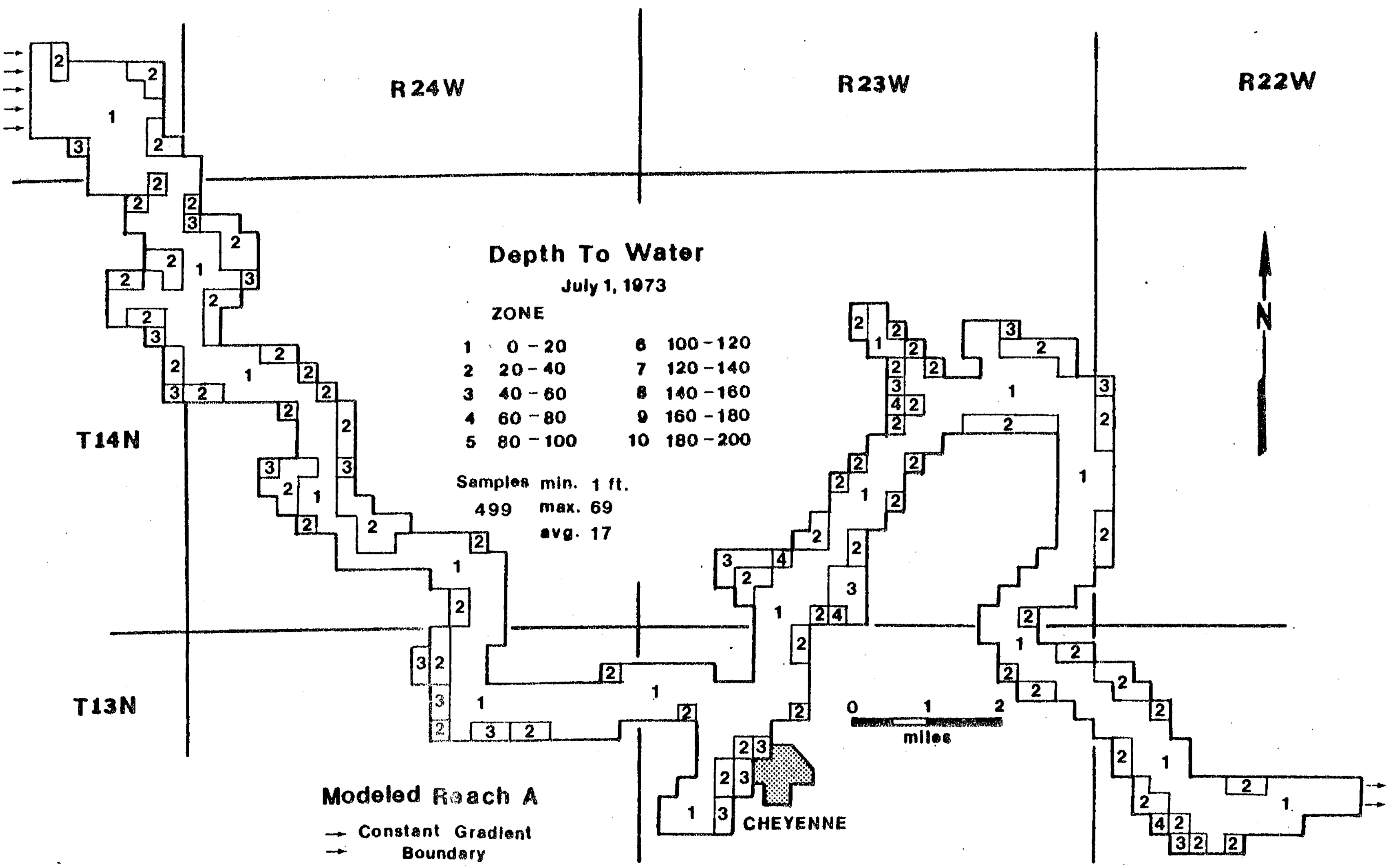
Subreach C, Modeled Reach 1.



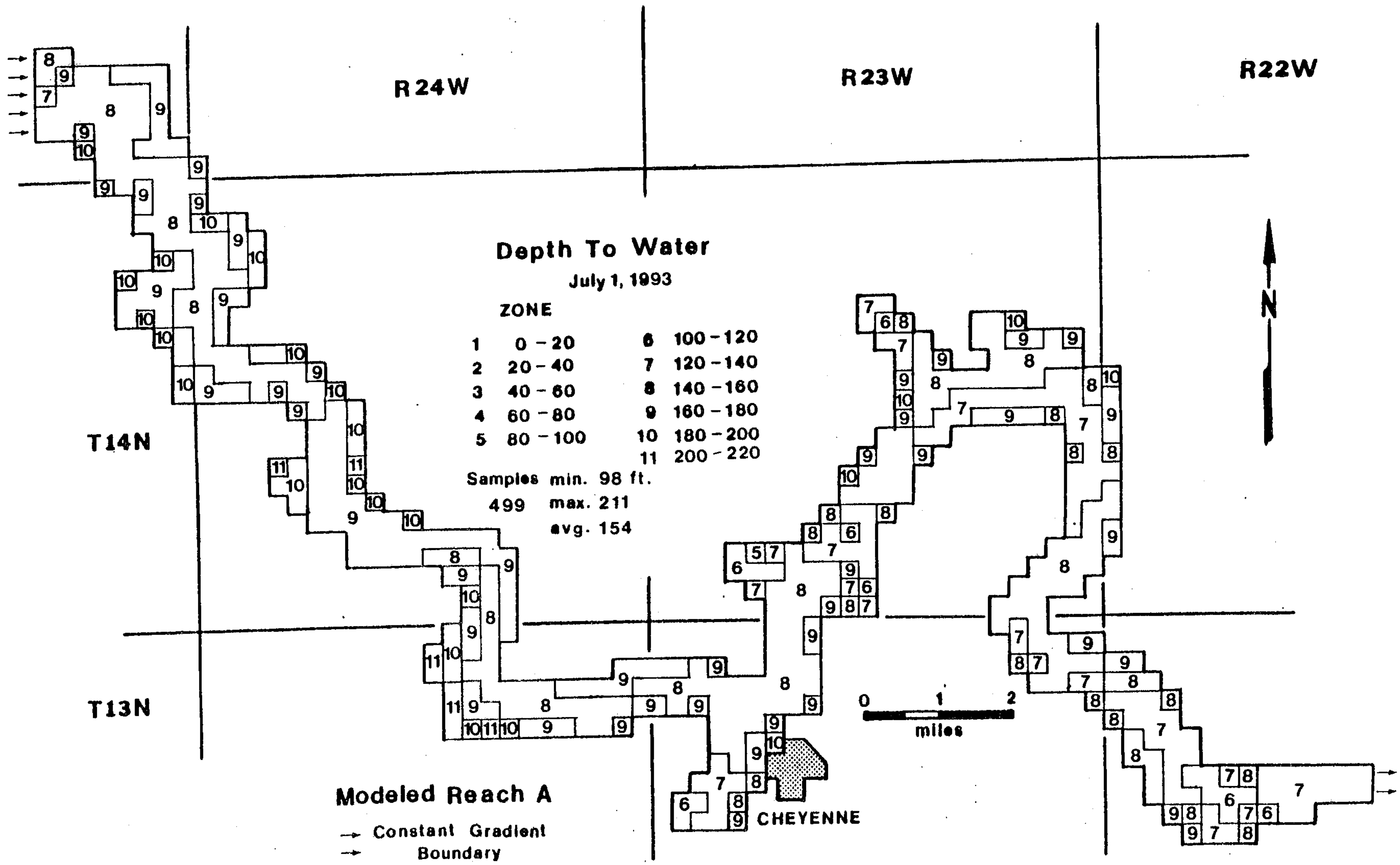
Water Table Map, July 1, 1973, Subreach A, Modeled Reach 1.



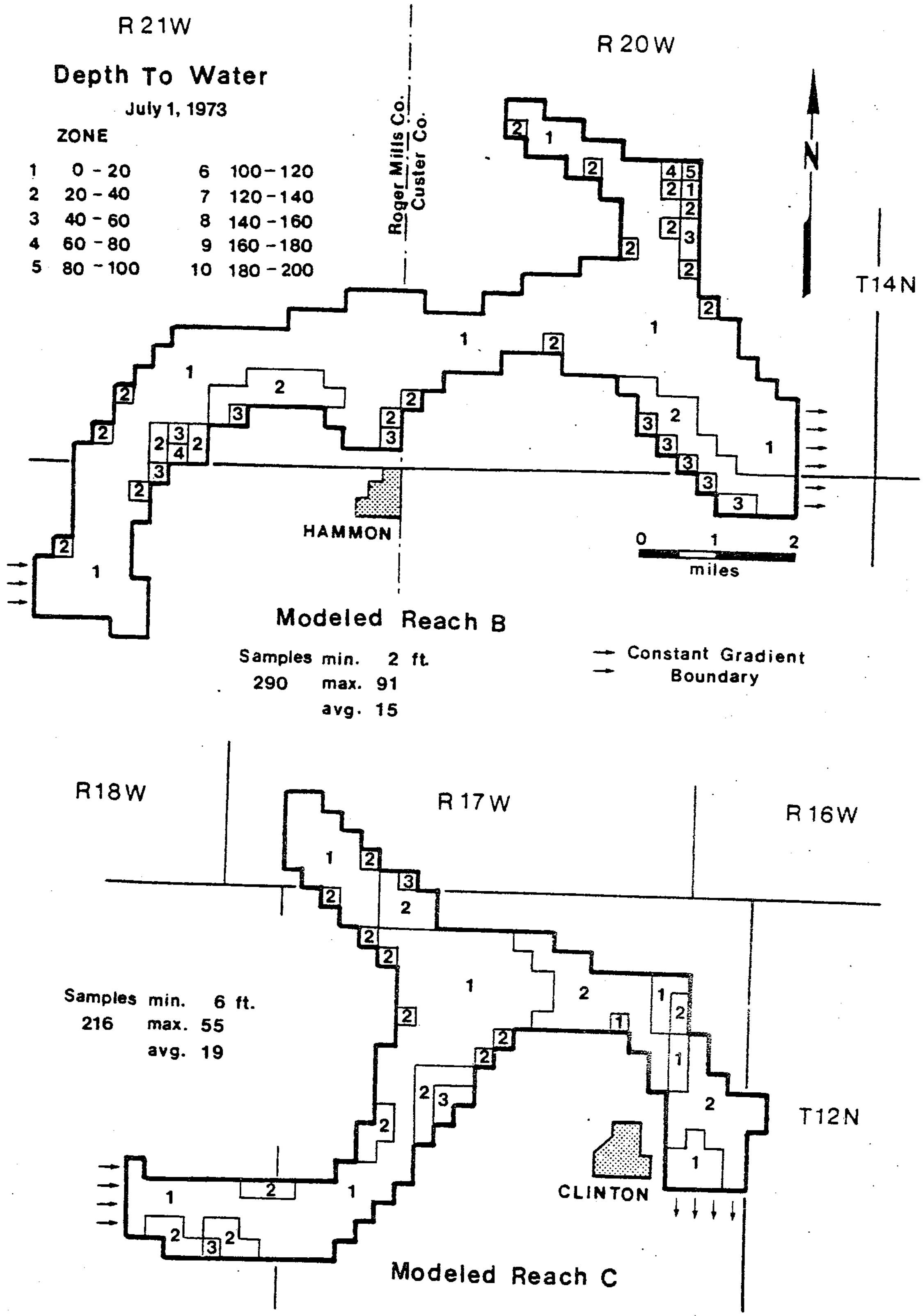
Water Table Map, July 1, 1973, Subreaches B and C, Modeled Reach 1.



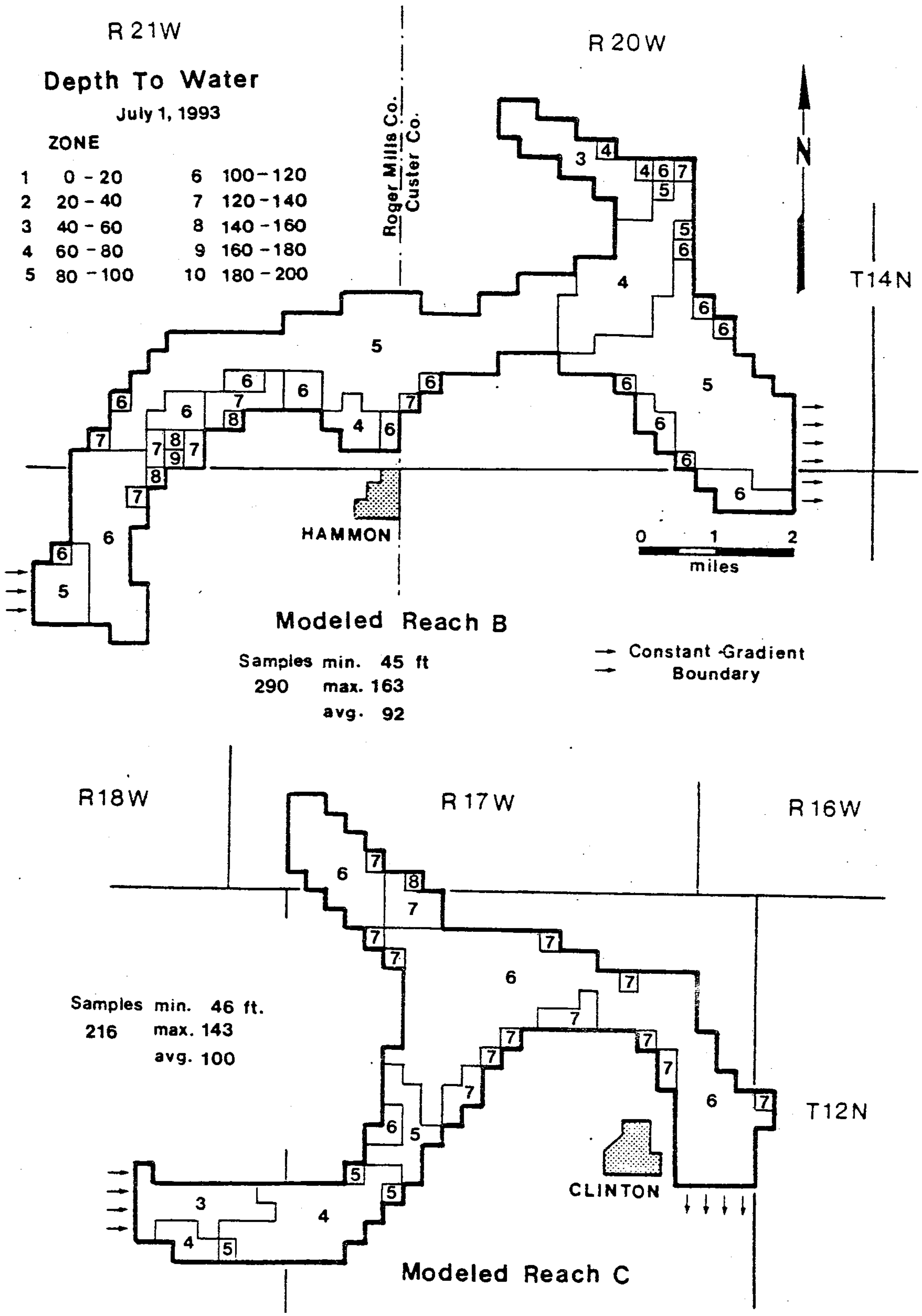
Depth to water, July 1, 1973, Subreach A. Modeled Reach 1.



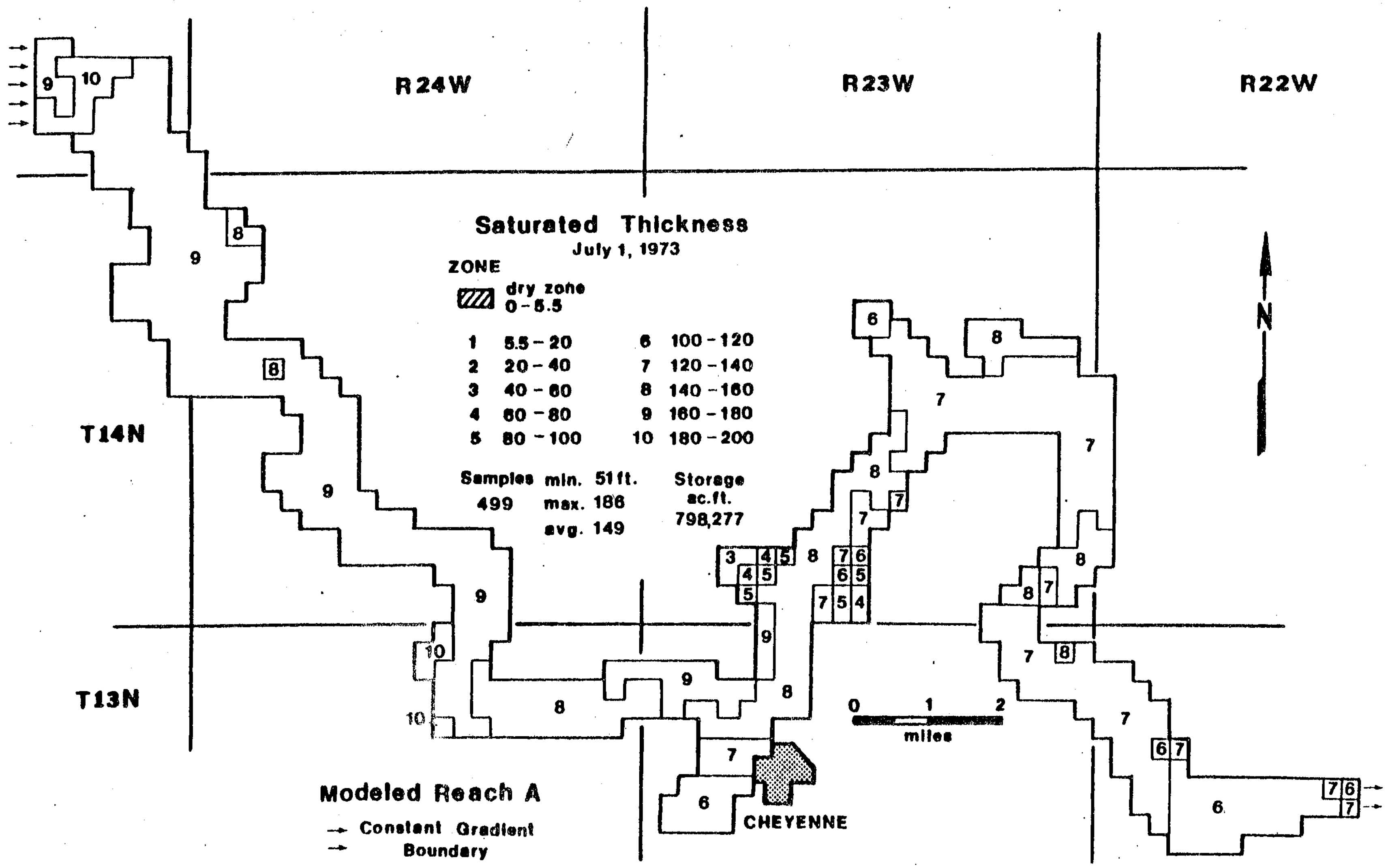
Depth to water, July 1, 1993, Subreach A, Modeled Reach 1.



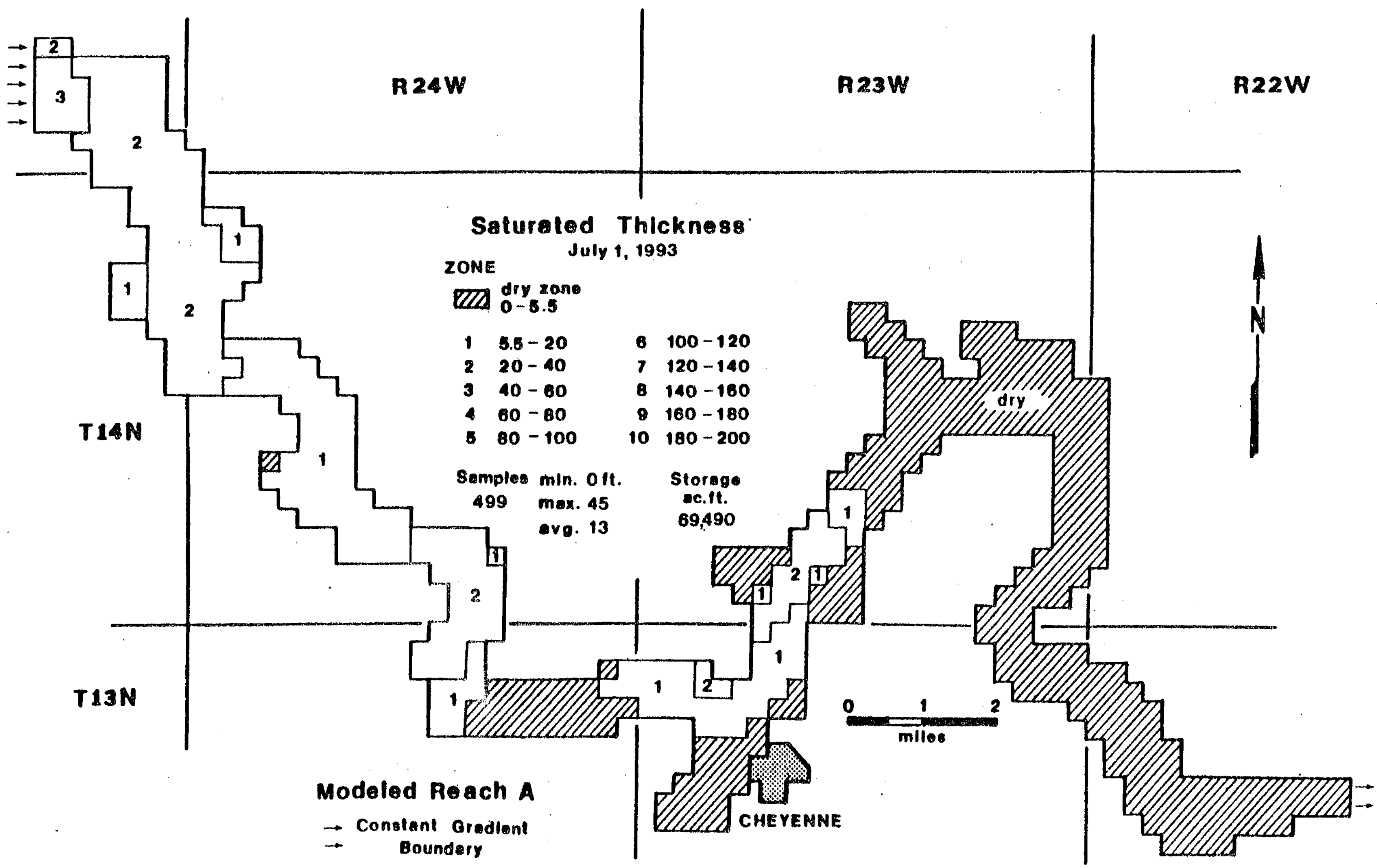
Depth to water, July 1, 1973, Subreaches B and C, Modeled Reach 1.



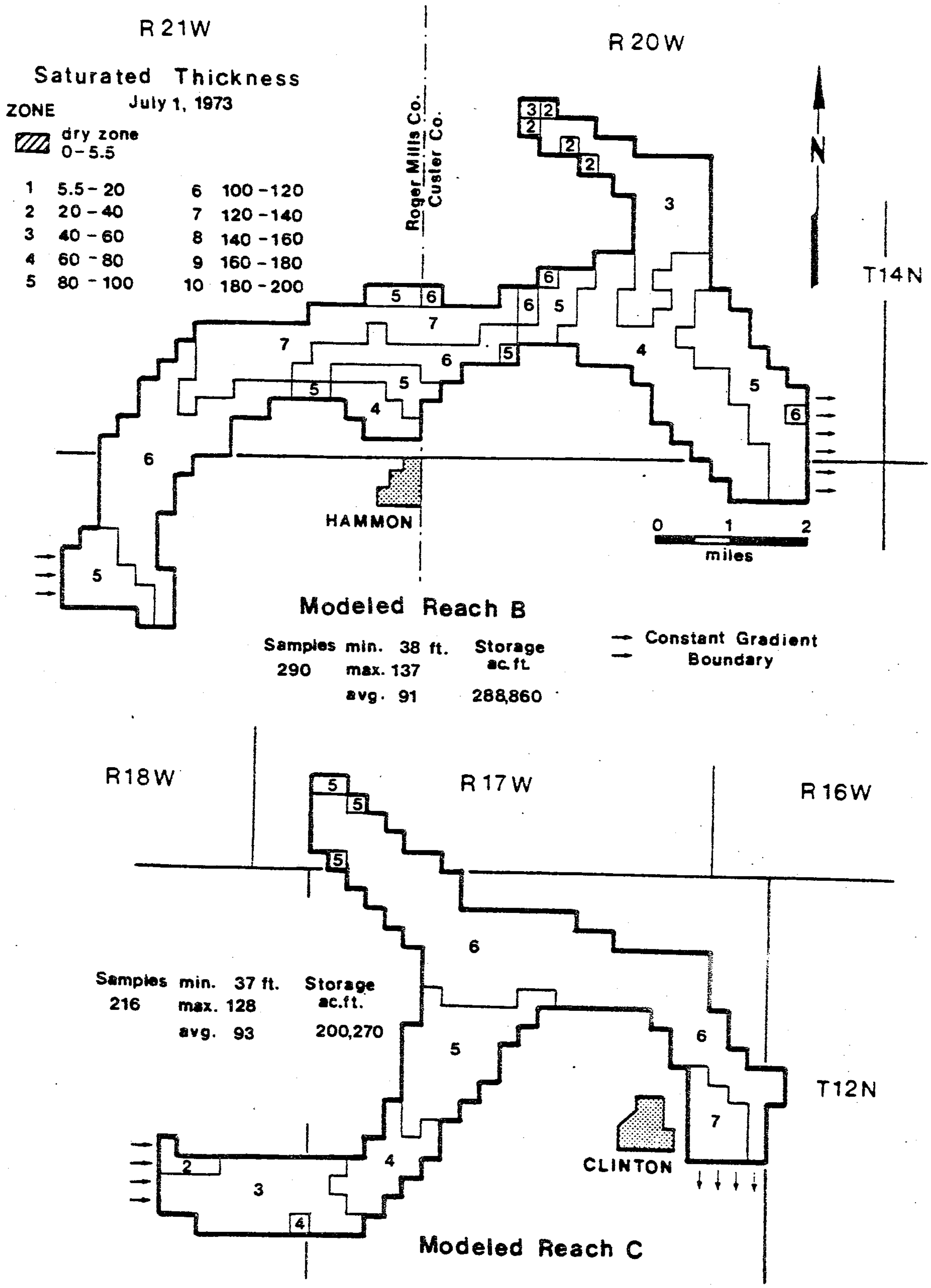
Depth to water, July 1, 1993,
Subreaches B and C, Modeled Reach 1.



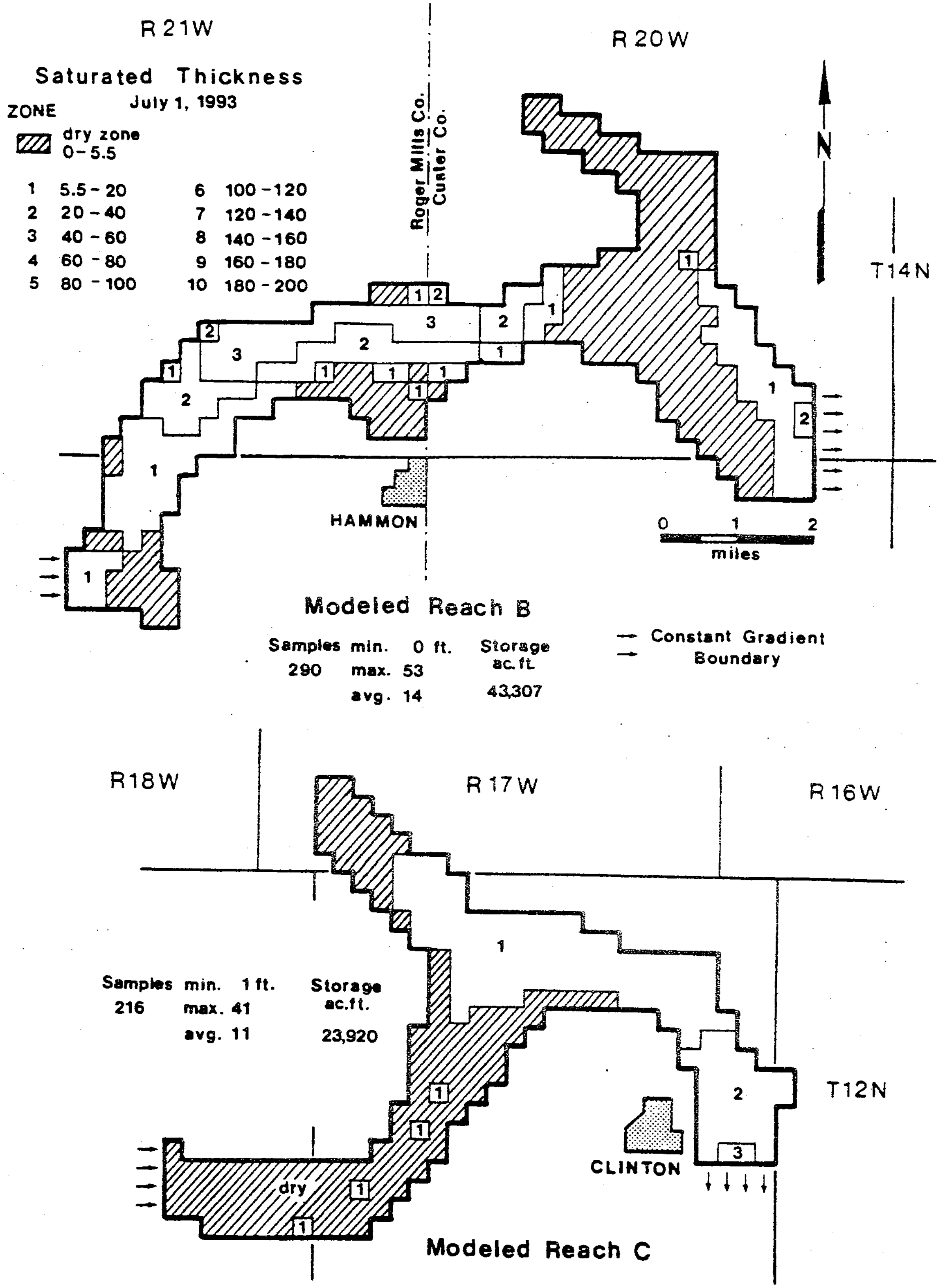
Saturated Thickness Map, July 1, 1973, Subreach A, Modeled Reach 1.



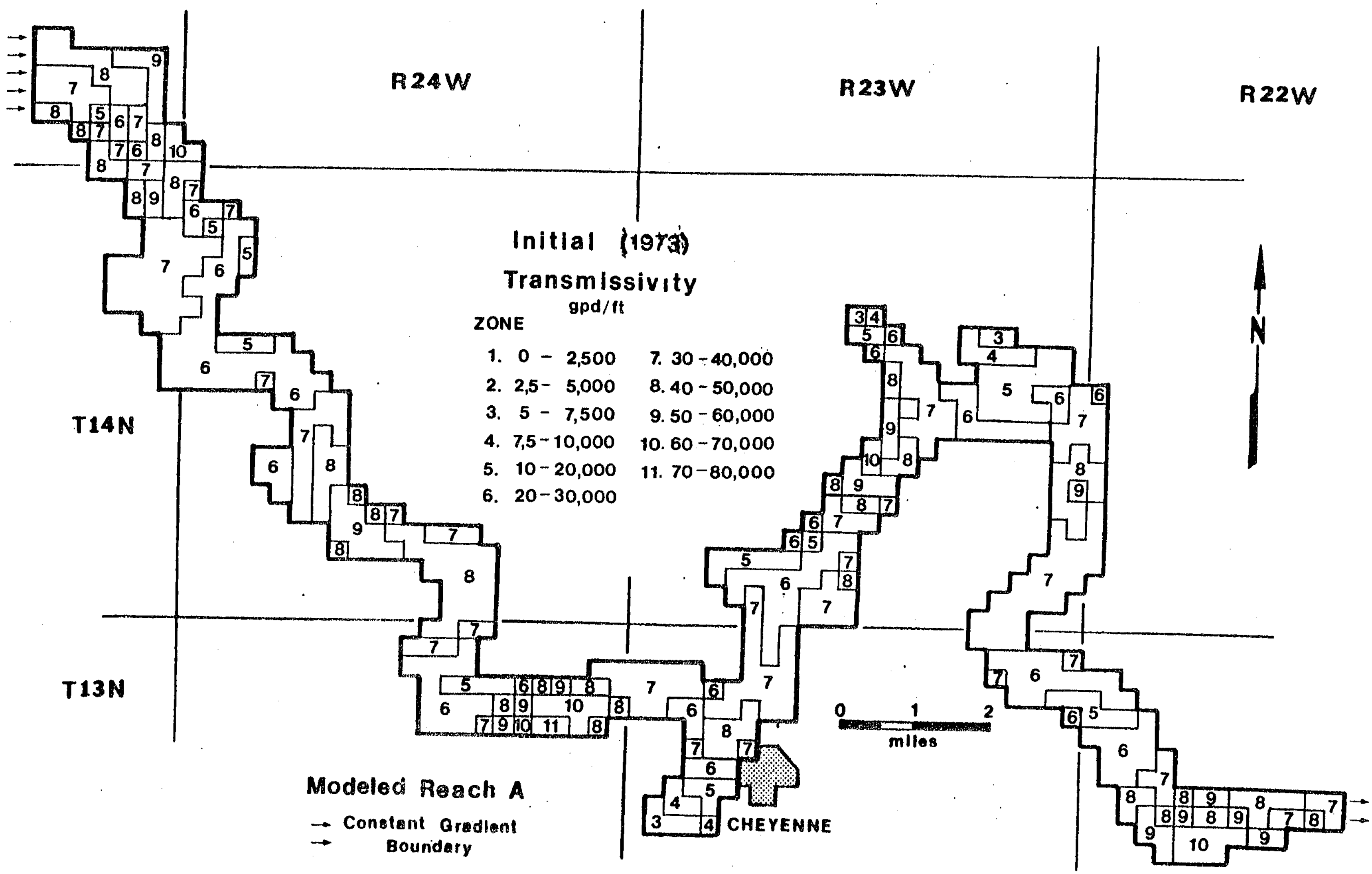
Saturated thickness Map, July 1, 1993, Subreach A, Modeled Reach 1.



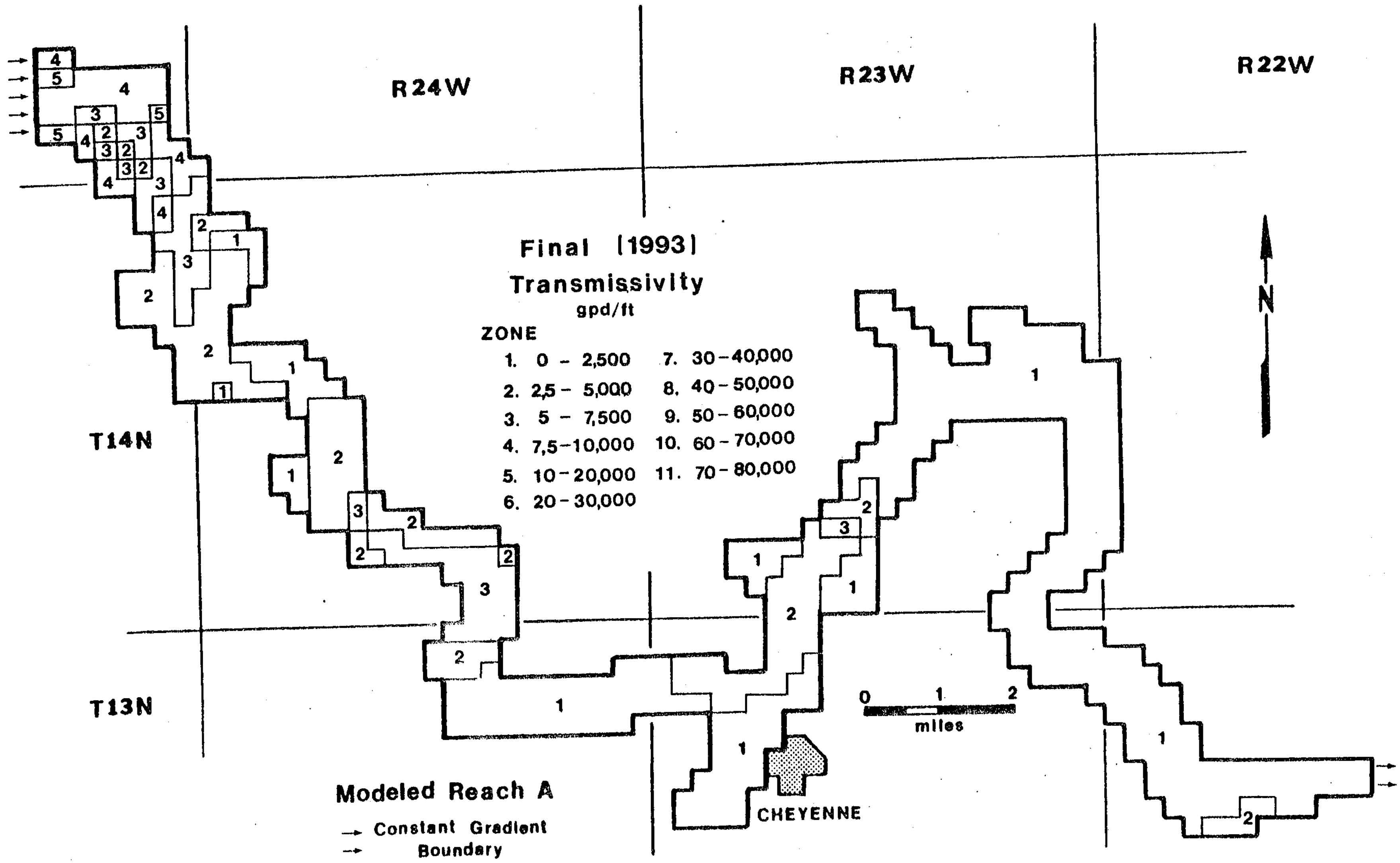
Saturated Thickness Map, July 1, 1973, Subreaches B and C, Modeled Reach 1.



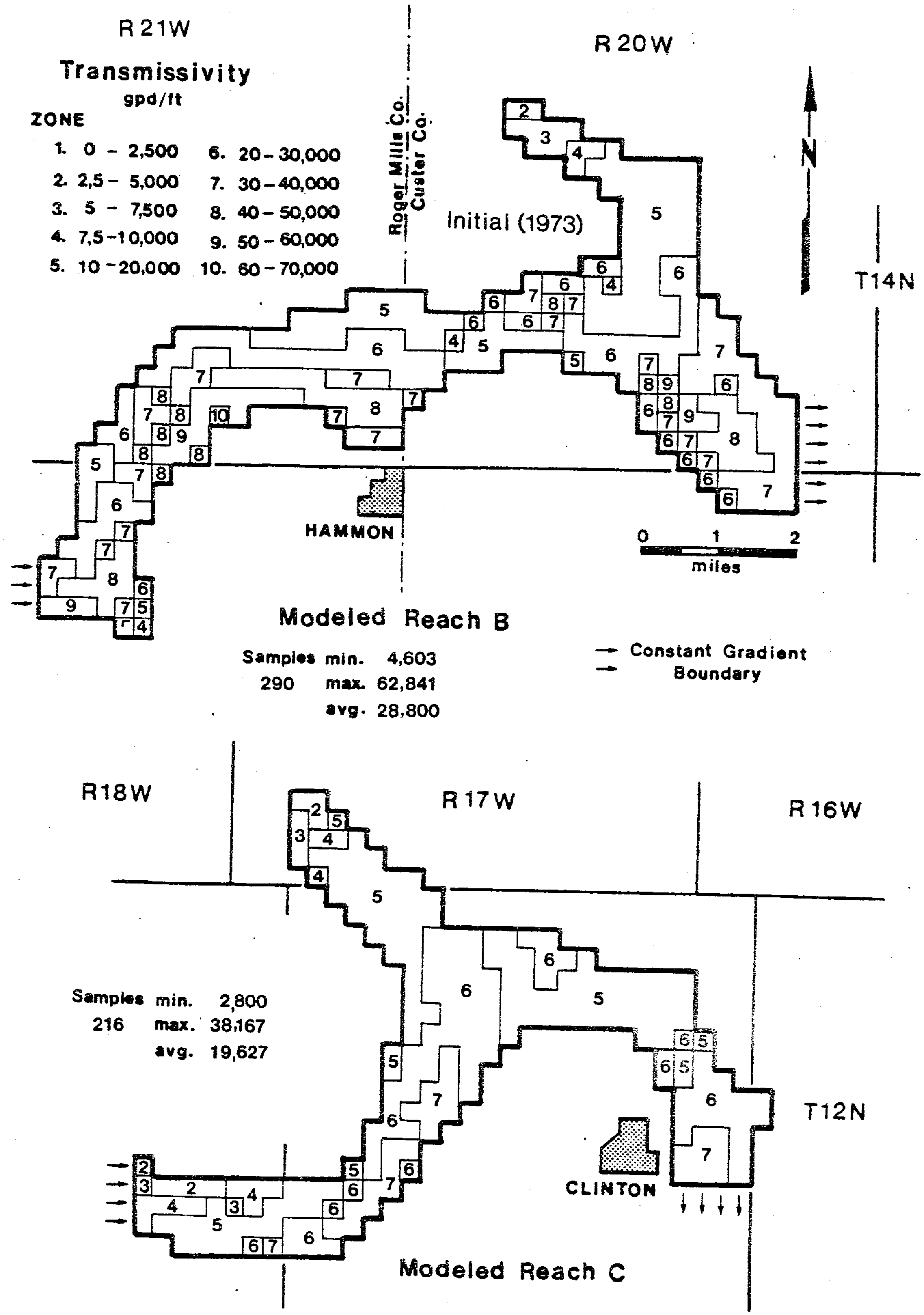
Saturated Thickness Map, July 1, 1993, Subreaches B and C, Modeled Reach 1.



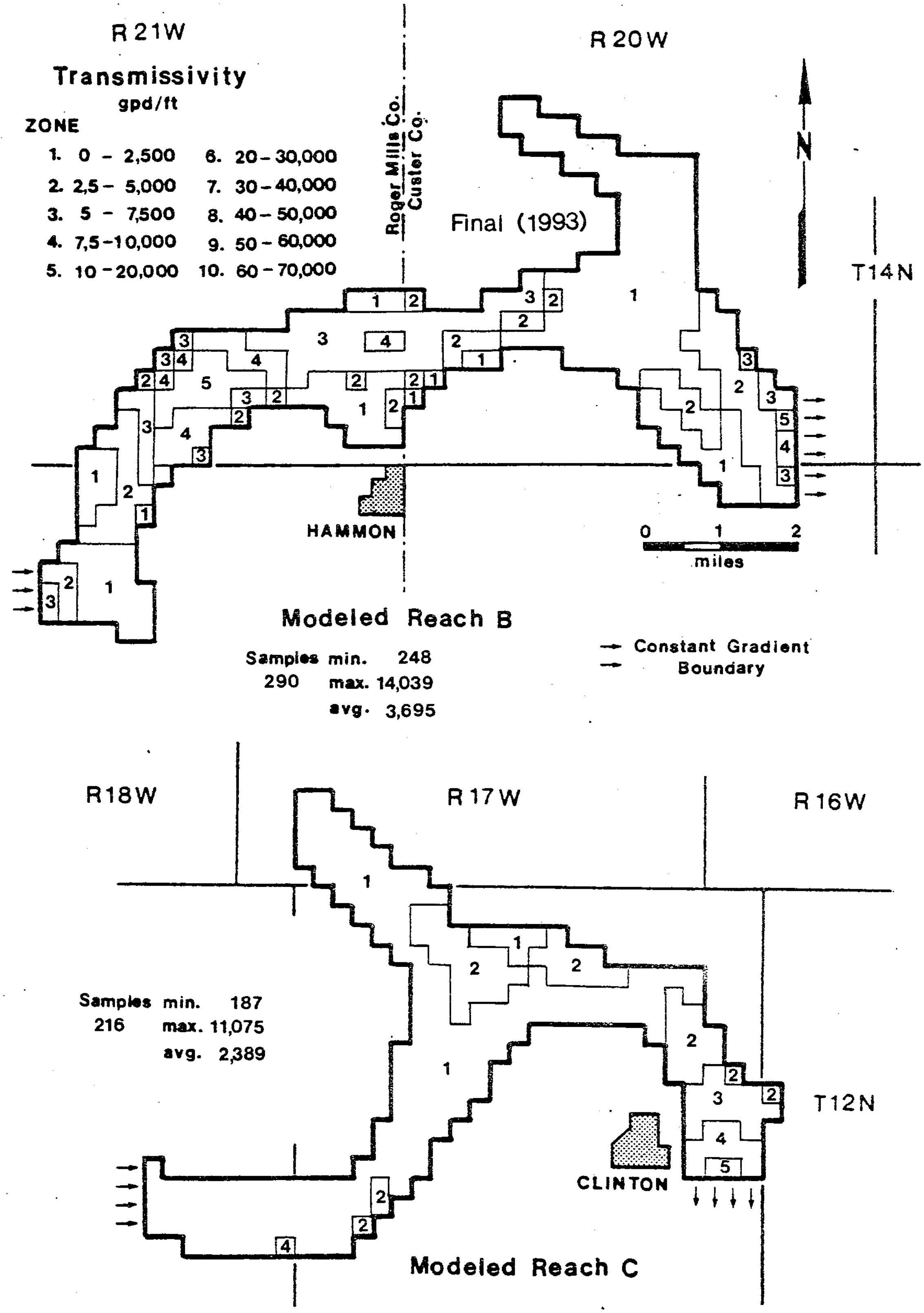
Transmissivity, July 1, 1973, Subreach A, Modeled Reach 1.



Transmissivity, July 1, 1993, Subreach 4, Modeled Reach 1.



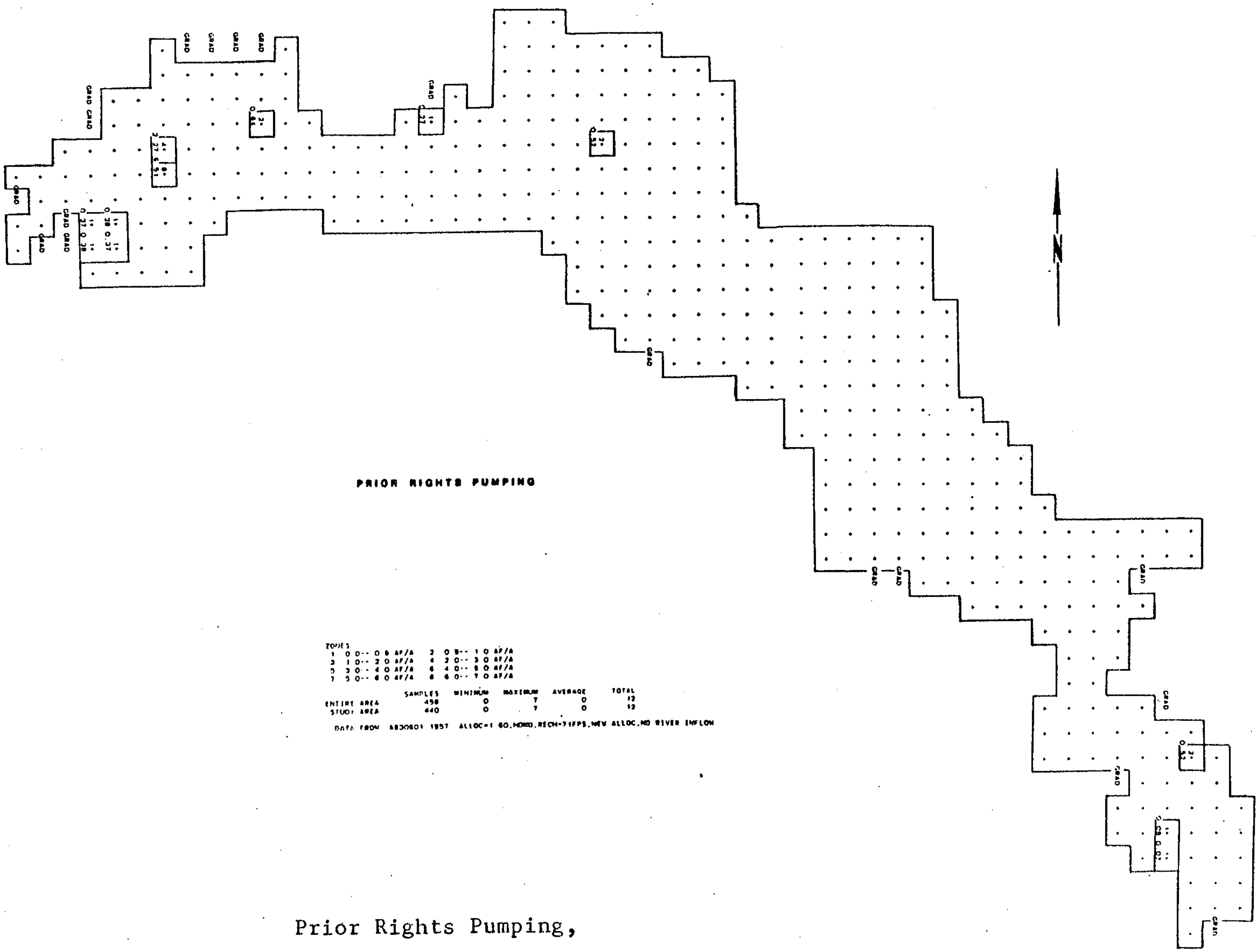
Transmissivity, July 1, 1993, Subreaches B and C, Modeled Reach 1.



Transmissivity, July 1, 1993, Subreaches B and C, Modeled Reach 1.

APPENDIX B

RESULTS FOR MODELLED REACH 3



PRIOR RIGHTS PUMPING

ZONES
1 0.0-- 0.8 AF/A 2 0.8-- 1.0 AF/A
3 1.0-- 2.0 AF/A 4 2.0-- 3.0 AF/A
5 3.0-- 4.0 AF/A 6 4.0-- 5.0 AF/A
7 5.0-- 6.0 AF/A 8 6.0-- 7.0 AF/A

	SAMPLES	MINIMUM	MAXIMUM	AVERAGE	TOTAL
ENTIRE AREA	458	0	7	0	12
STUDY AREA	440	0	7	0	12

DATA FROM AB30801 1957 ALLOC=1 60,HOMO,RECH=71FPS,NEW ALLOC,NO RIVER INFLOW

Prior Rights Pumping,

Modeled Reach 3.

AREA: WASH
RUN: A830601.1957
NODE AREA: 160 ACRES
PUMPING PERIOD: 0.33 (FRACTION OF YEAR)
RETURN FLOW RATE: 15 PERCENT
NET PUMPING RATE: 85 PERCENT

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
20.0-- 30.0	1.8	1,280	24.4	21.2	6,398
30.0-- 40.0	6.4	4,480	36.5	20.1	33,017
40.0-- 50.0	9.1	6,400	46.0	20.3	59,499
50.0-- 60.0	14.3	10,080	54.9	20.9	115,780
60.0-- 70.0	21.4	15,040	65.2	19.8	194,467
70.0-- 80.0	22.3	15,680	74.1	21.0	244,297
80.0-- 90.0	16.6	11,680	84.4	20.9	205,504
90.0--100.0	5.9	4,160	93.8	18.5	72,415
100.0--110.0	2.3	1,600	104.3	18.8	31,379
ALL RANGES	100.0 (TOTAL)	70,400 (TOTAL)	67.1 (AVERAGE)	20.4 (AVERAGE)	962,758 (TOTAL)

DATA FROM:
A830601.1957 ALLOC=1.60,HOMO,RECH=71FPS,NEW ALLOC,NO RIVER INFLOW

AREA: WASH
RUN: A830601.1957
NODE AREA: 160 ACRES
PUMPING PERIOD: 0.33 (FRACTION OF YEAR)
RETURN FLOW RATE: 15 PERCENT
NET PUMPING RATE: 85 PERCENT

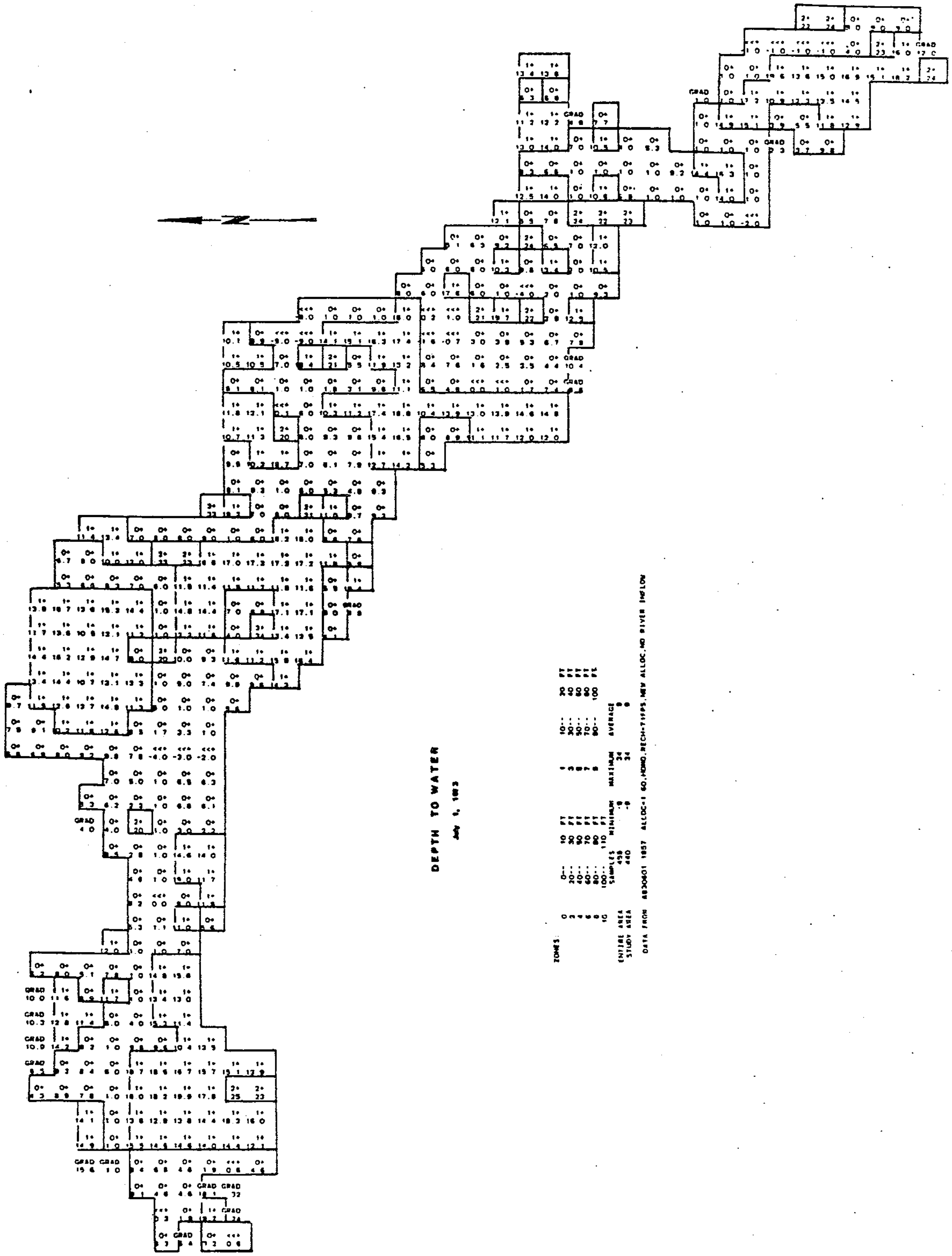
WATER DISTRIBUTION SUMMARY
JULY 1, 1993

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
0.0-- 5.5	52.0	36,640	4.8	21.3	36,723
5.5-- 10.0	45.9	32,320	6.0	19.4	37,336
10.0-- 20.0	0.7	480	14.2	22.1	1,482
20.0-- 30.0	1.4	960	25.0	20.9	5,017
30.0-- 40.0	0.0	0			0
40.0-- 50.0	0.0	0			0
ALL RANGES	100.0 (TOTAL)	70,400 (TOTAL)	5.7 (AVERAGE)	20.4 (AVERAGE)	80,558 (TOTAL)

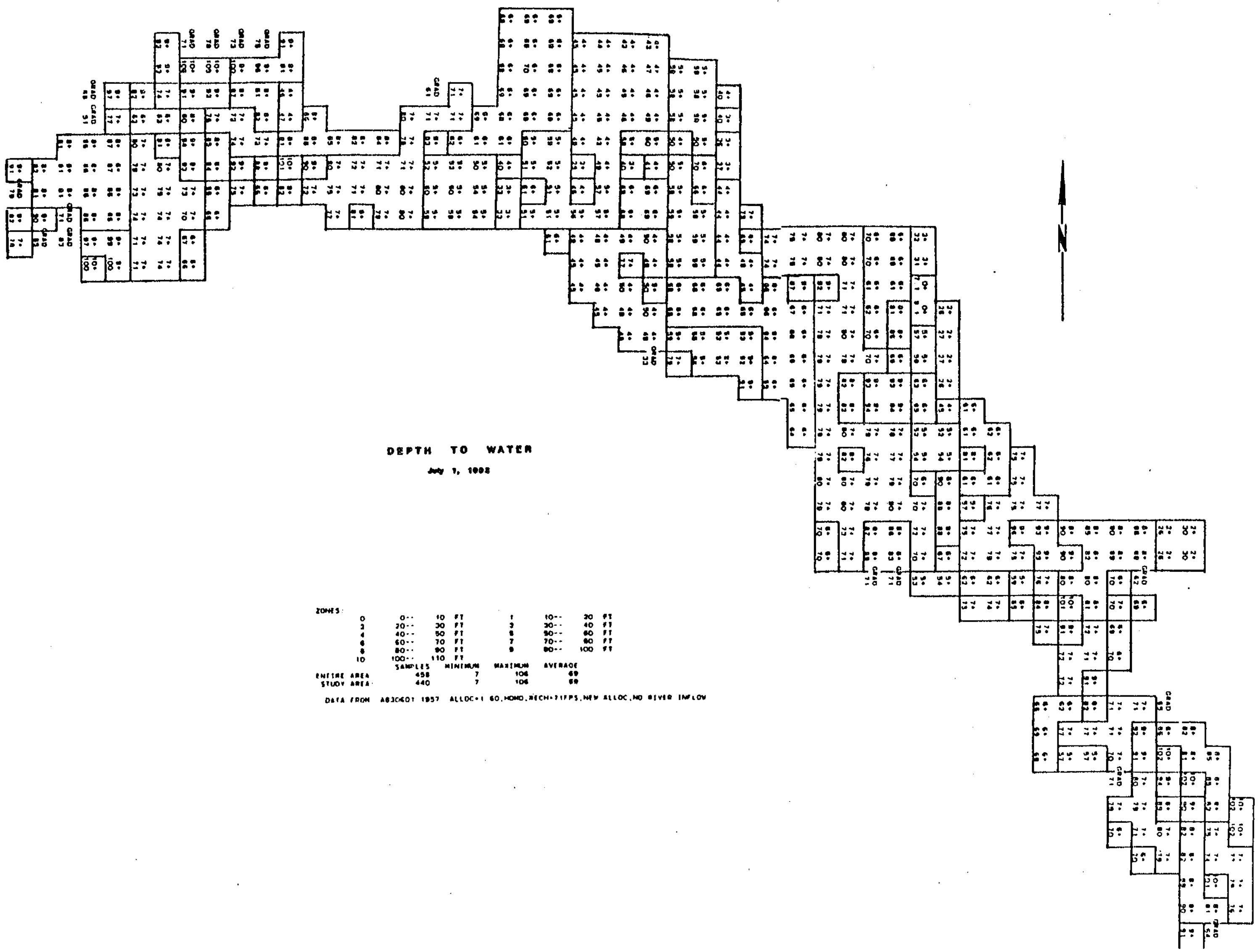
DATA FROM:
A830601.1957 ALLOC=1.60,HOMO,RECH=71FPS,NEW ALLOC,NO RIVER INFLOW

Water Distribution Summaries,

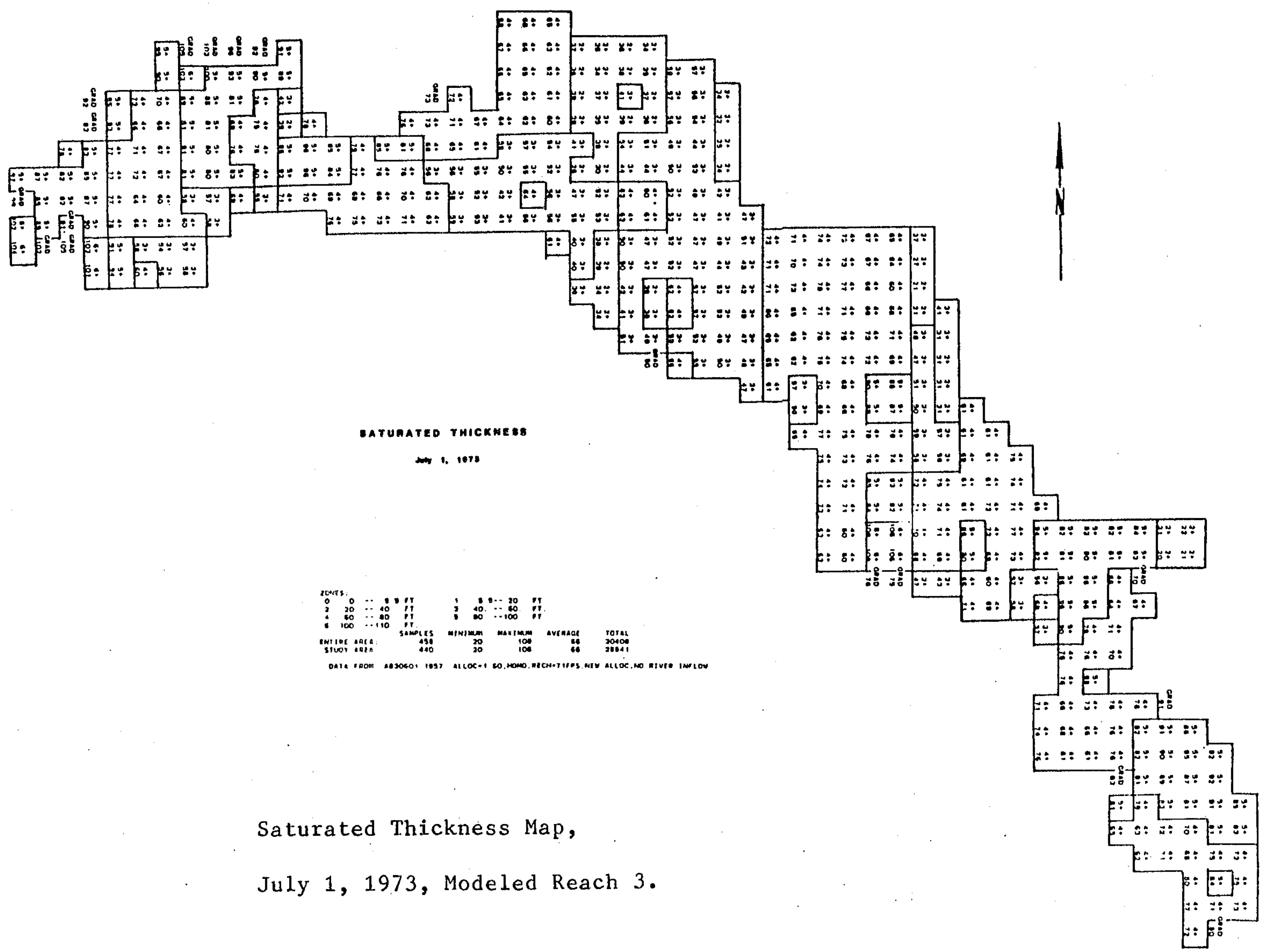
Modeled Reach 3.



Depth to water, July 1, 1973, Modeled Reach 3.

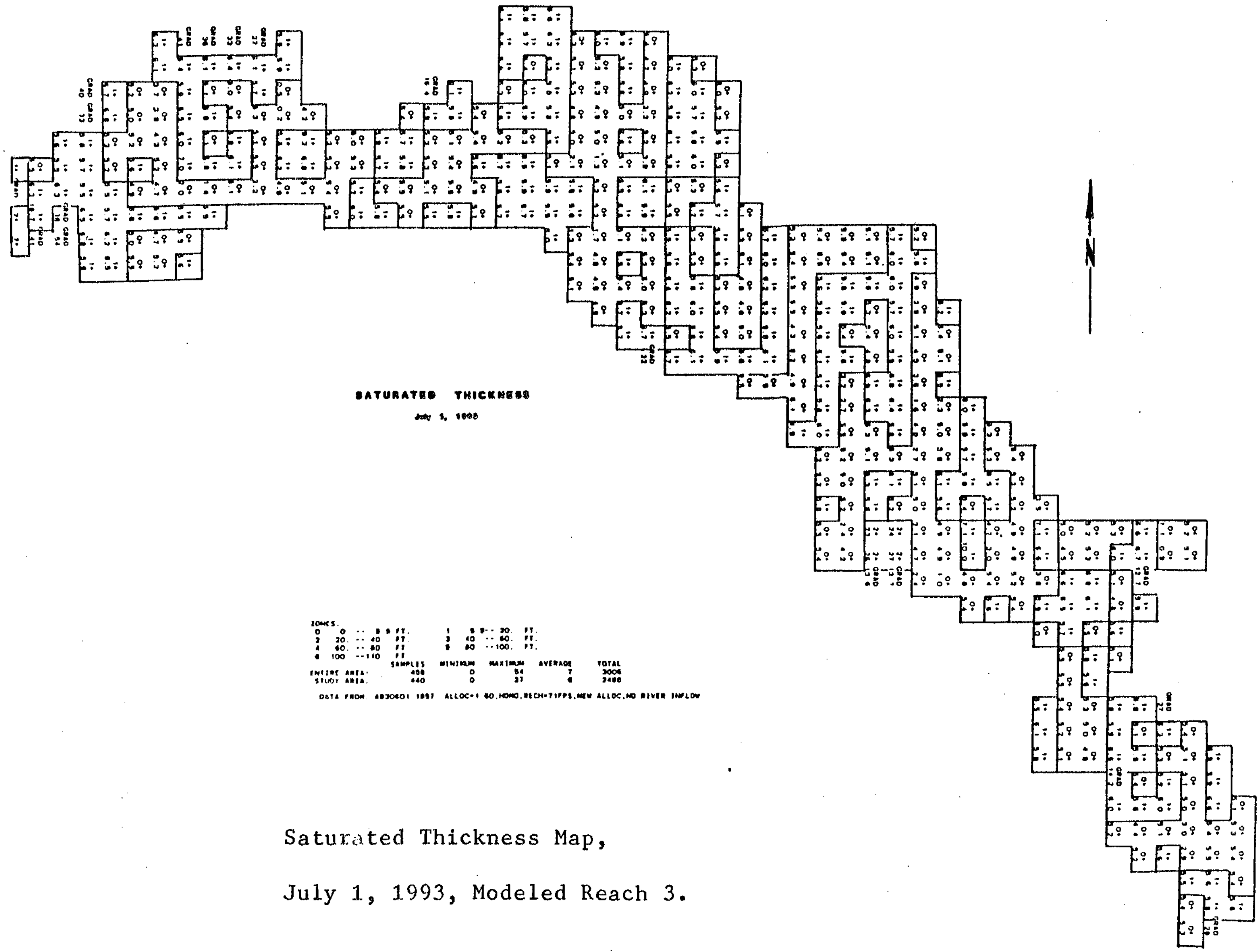


Depth to water, July 1, 1993, Modeled Reach 3.



Saturated Thickness Map,

July 1, 1973, Modeled Reach 3.



SATURATED THICKNESS

July 1, 1993

ZONES.

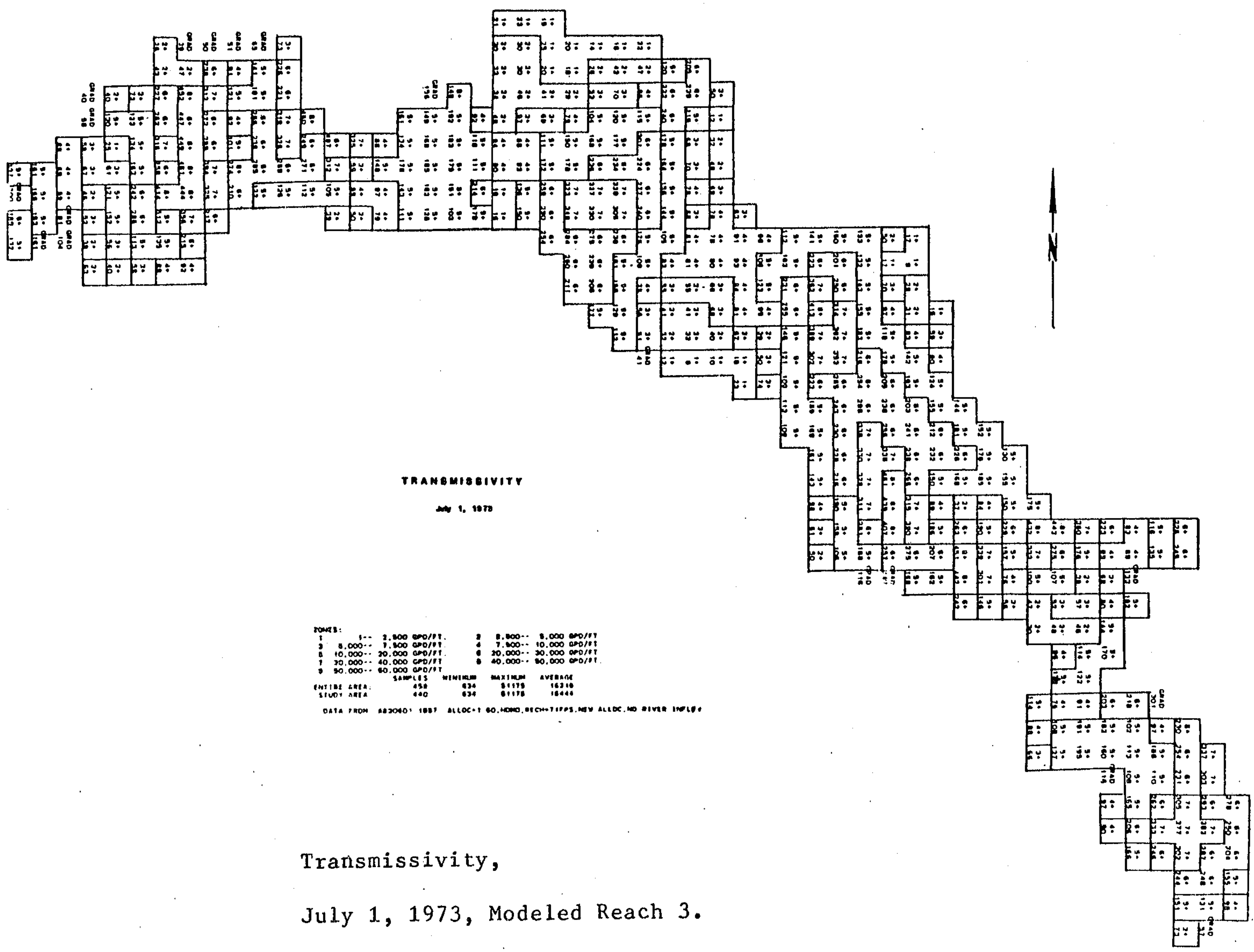
0	0 -- 9.9 FT.		1	9.9 -- 20. FT.	
2	20. -- 40 FT.		3	40 -- 60. FT.	
4	60. -- 80 FT.		5	80 --100. FT.	
6	100 --110 FT.				

	SAMPLES	MINIMUM	MAXIMUM	AVERAGE	TOTAL
ENTIRE AREA:	488	0	54	7	3006
STUDY AREA:	440	0	27	6	2488

DATA FROM: AB30601 1997 ALLOC=1 80,HOMO,RECH=71FPS,NEW ALLOC,NO RIVER INFLOW

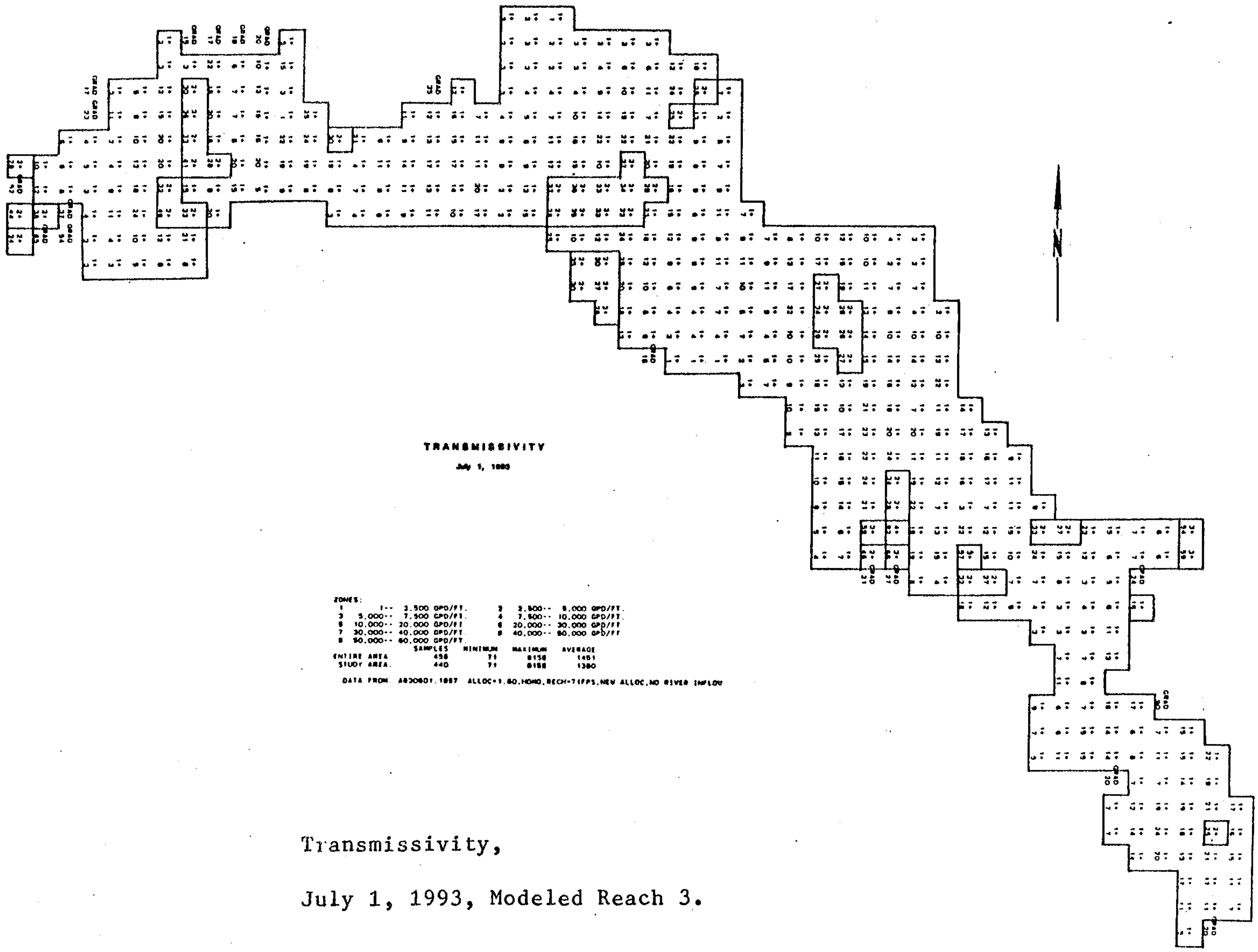
Saturated Thickness Map,

July 1, 1993, Modeled Reach 3.



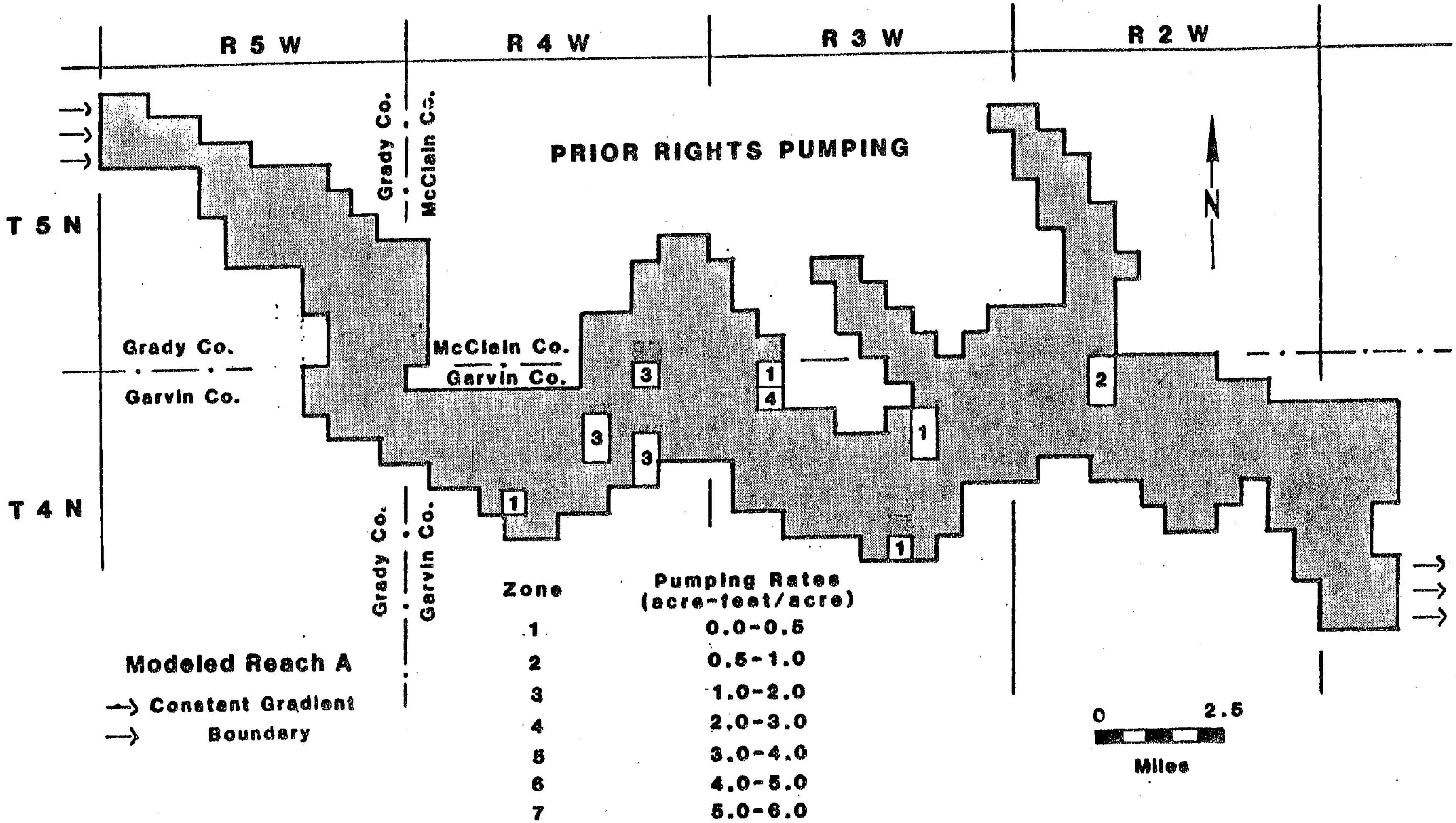
Transmissivity,

July 1, 1973, Modeled Reach 3.



Transmissivity,

July 1, 1993, Modeled Reach 3.

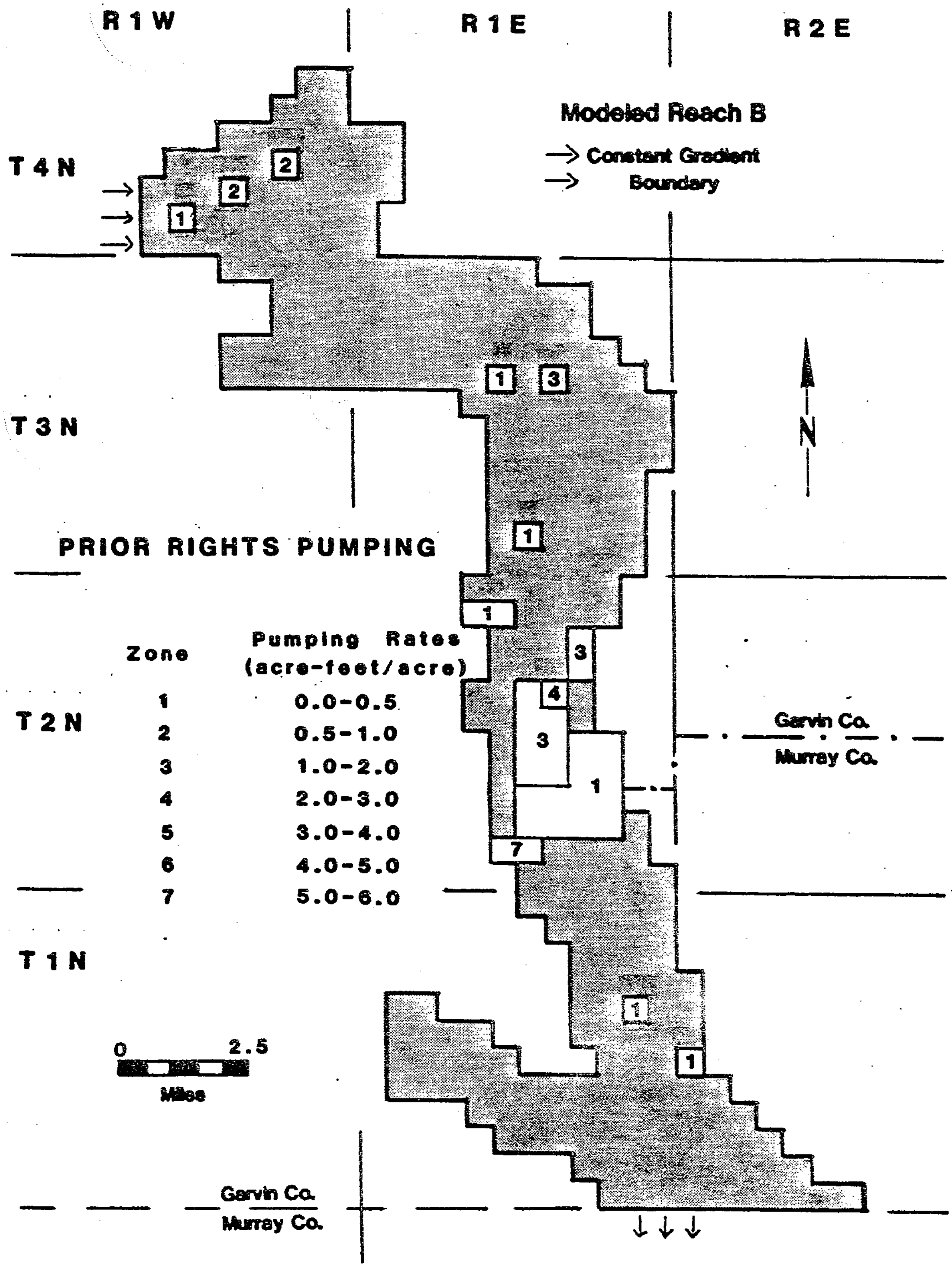


Prior Rights Pumping,

Subreach A, Modeled Reach 4.

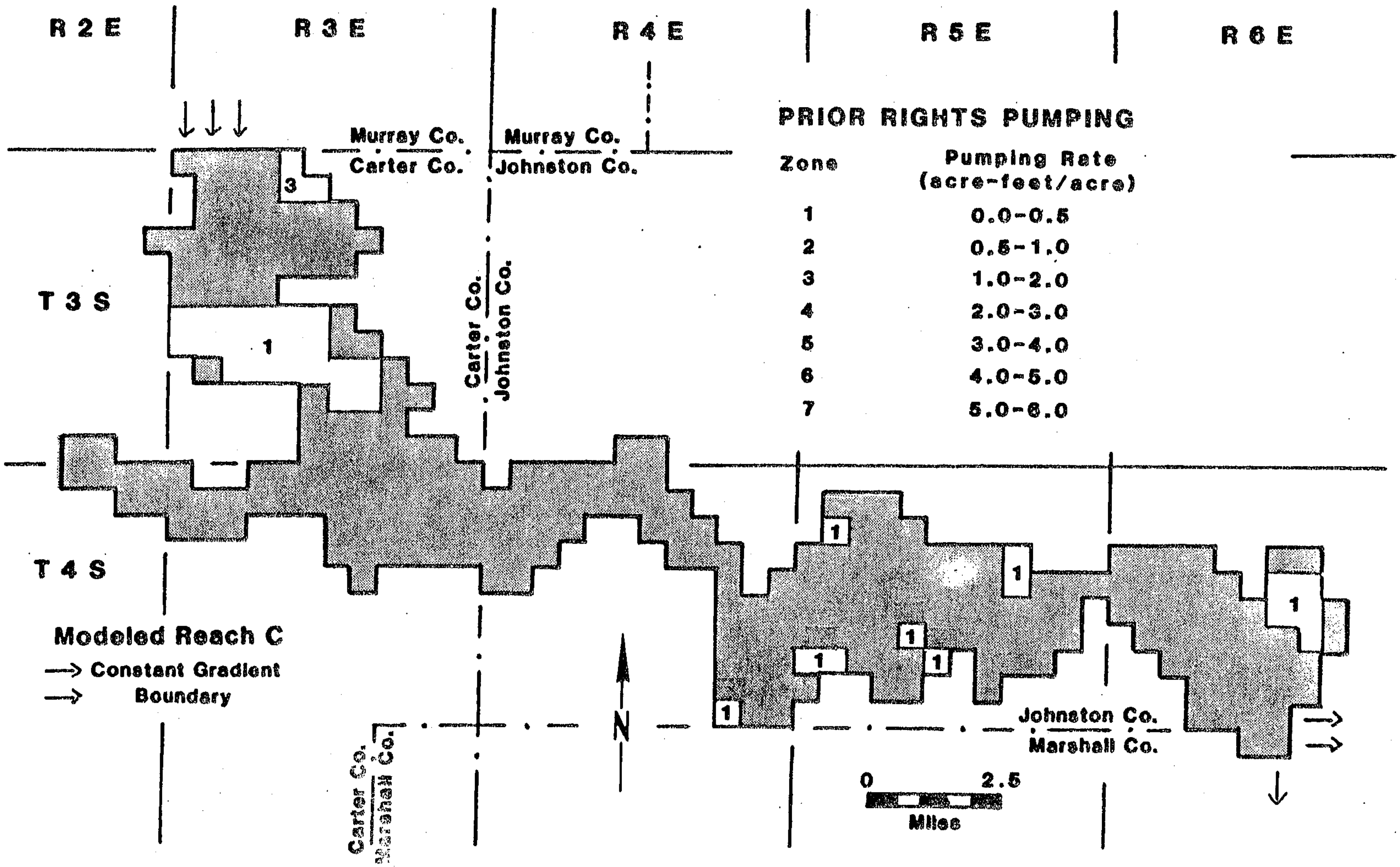
APPENDIX C

RESULTS FOR MODELLED REACH 4



Prior Rights Pumping,

Subreach B, Modeled Reach 4.



Prior Rights Pumping,

Subreach C, Modeled Reach 4.

```
                AREA: SCWA
                 RUN: A830730.0942
           NODE AREA:          160 ACRES
      PUMPING PERIOD:         0.33 (FRACTION OF YEAR)
    RETURN FLOW RATE:           15 PERCENT
    NET PUMPING RATE:           85 PERCENT
```

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
10.0-- 20.0	9.3	5,120	17.3	25.7	22,752
20.0-- 30.0	15.7	8,640	24.9	25.7	55,353
30.0-- 40.0	33.0	18,240	35.3	25.8	166,335
40.0-- 50.0	27.8	15,360	44.5	25.8	176,418
50.0-- 60.0	11.6	6,400	54.4	25.9	90,312
60.0-- 70.0	2.6	1,440	63.1	25.8	23,460
ALL RANGES	100.0 (TOTAL)	55,200 (TOTAL)	37.5 (AVERAGE)	25.8 (AVERAGE)	534,631 (TOTAL)

DATA FROM:
A830730.0942 RUN 20YR,ALLOC.882,RIVER-20.FT,RATE=7.1E-6,QRE=4.41IN/YR

```
                AREA: SCWA
                 RUN: A830730.0942
           NODE AREA:          160 ACRES
      PUMPING PERIOD:         0.33 (FRACTION OF YEAR)
    RETURN FLOW RATE:           15 PERCENT
    NET PUMPING RATE:           85 PERCENT
```

WATER DISTRIBUTION SUMMARY
JULY 1, 1993

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
0.0-- 5.5	50.7	28,000	5.2	25.8	37,296
5.5-- 10.0	19.1	10,560	7.4	25.8	20,272
10.0-- 20.0	25.5	14,080	13.7	25.9	49,867
20.0-- 30.0	4.6	2,560	23.2	25.9	15,383
ALL RANGES	100.0 (TOTAL)	55,200 (TOTAL)	8.6 (AVERAGE)	25.8 (AVERAGE)	122,818 (TOTAL)

DATA FROM:
A830730.0942 RUN 20YR,ALLOC.882,RIVER-20.FT,RATE=7.1E-6,QRE=4.41IN/YR

Water Distribution Summaries,

Subreach A, Modeled Reach 4.

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

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
10.0-- 20.0	0.3	160	19.7	30.0	946
20.0-- 30.0	9.0	4,960	27.2	30.0	40,511
30.0-- 40.0	33.3	18,400	35.6	30.0	196,241
40.0-- 50.0	33.9	18,720	43.9	30.0	246,357
50.0-- 60.0	14.2	7,840	53.5	30.0	125,874
60.0-- 70.0	3.2	1,760	63.0	30.0	33,256
ALL RANGES	93.9 (TOTAL)	51,840 (TOTAL)	41.4 (AVERAGE)	30.0 (AVERAGE)	643,185 (TOTAL)

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

WATER DISTRIBUTION SUMMARY
JULY 1, 1993

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
0.0-- 5.5	47.8	26,400	4.7	30.0	37,003
5.5-- 10.0	25.2	13,920	7.1	30.0	29,555
10.0-- 20.0	16.2	8,960	13.1	30.0	35,087
20.0-- 30.0	4.6	2,560	22.5	30.0	17,267
ALL RANGES	93.9 (TOTAL)	51,840 (TOTAL)	7.6 (AVERAGE)	30.0 (AVERAGE)	118,913 (TOTAL)

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

Water Distribution Summaries,

Subreach B, Modeled Reach 4.

AREA: SCWC
RUN: A830726.2210
NODE AREA: 160 ACRES
PUMPING PERIOD: 0.33 (FRACTION OF YEAR)
RETURN FLOW RATE: 15 PERCENT
NET PUMPING RATE: 85 PERCENT

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
5.5-- 10.0	0.6	320	8.6	32.0	881
10.0-- 20.0	14.2	7,840	16.3	32.0	40,785
20.0-- 30.0	24.6	13,600	23.6	32.0	102,765
30.0-- 40.0	11.6	6,400	34.1	32.0	69,895
40.0-- 50.0	9.3	5,120	45.9	32.0	75,142
50.0-- 60.0	10.1	5,600	55.4	32.0	99,310
60.0-- 70.0	8.1	4,480	64.8	32.0	92,851
70.0-- 80.0	2.0	1,120	73.4	32.0	26,299
ALL RANGES	80.6 (TOTAL)	44,480 (TOTAL)	35.7 (AVERAGE)	32.0 (AVERAGE)	507,927 (TOTAL)

DATA FROM:
A830726.2210 RUN 20YR,ALLOC1.2,RIVER-3,RATE=9.8E-9,QRE=5.00IN/YR

AREA: SCWC
RUN: A830726.2210
NODE AREA: 160 ACRES
PUMPING PERIOD: 0.33 (FRACTION OF YEAR)
RETURN FLOW RATE: 15 PERCENT
NET PUMPING RATE: 85 PERCENT

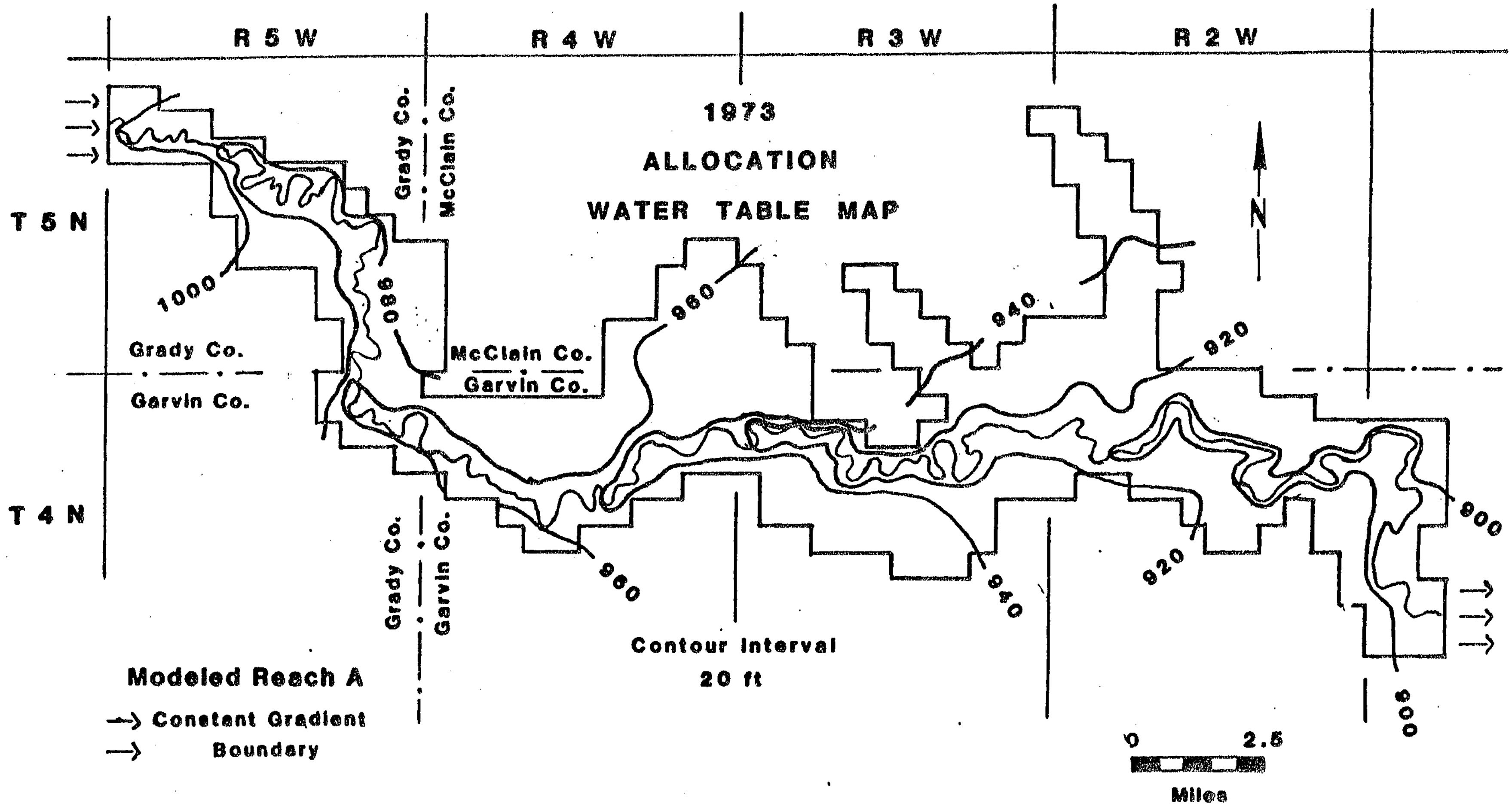
WATER DISTRIBUTION SUMMARY
JULY 1, 1993

SATURATED THICKNESS RANGE (FEET)	AREA (PERCENT OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)
0.0-- 5.5	40.6	22,400	4.5	32.0	32,412
5.5-- 10.0	12.2	6,720	6.3	32.0	13,643
10.0-- 20.0	8.1	4,480	15.3	32.0	21,997
20.0-- 30.0	16.2	8,960	24.2	32.0	69,343
30.0-- 40.0	3.5	1,920	32.3	32.0	19,872
ALL RANGES	80.6 (TOTAL)	44,480 (TOTAL)	11.0 (AVERAGE)	32.0 (AVERAGE)	157,267 (TOTAL)

DATA FROM:
A830726.2210 RUN 20YR,ALLOC1.2,RIVER-3,RATE=9.8E-9,QRE=5.00IN/YR

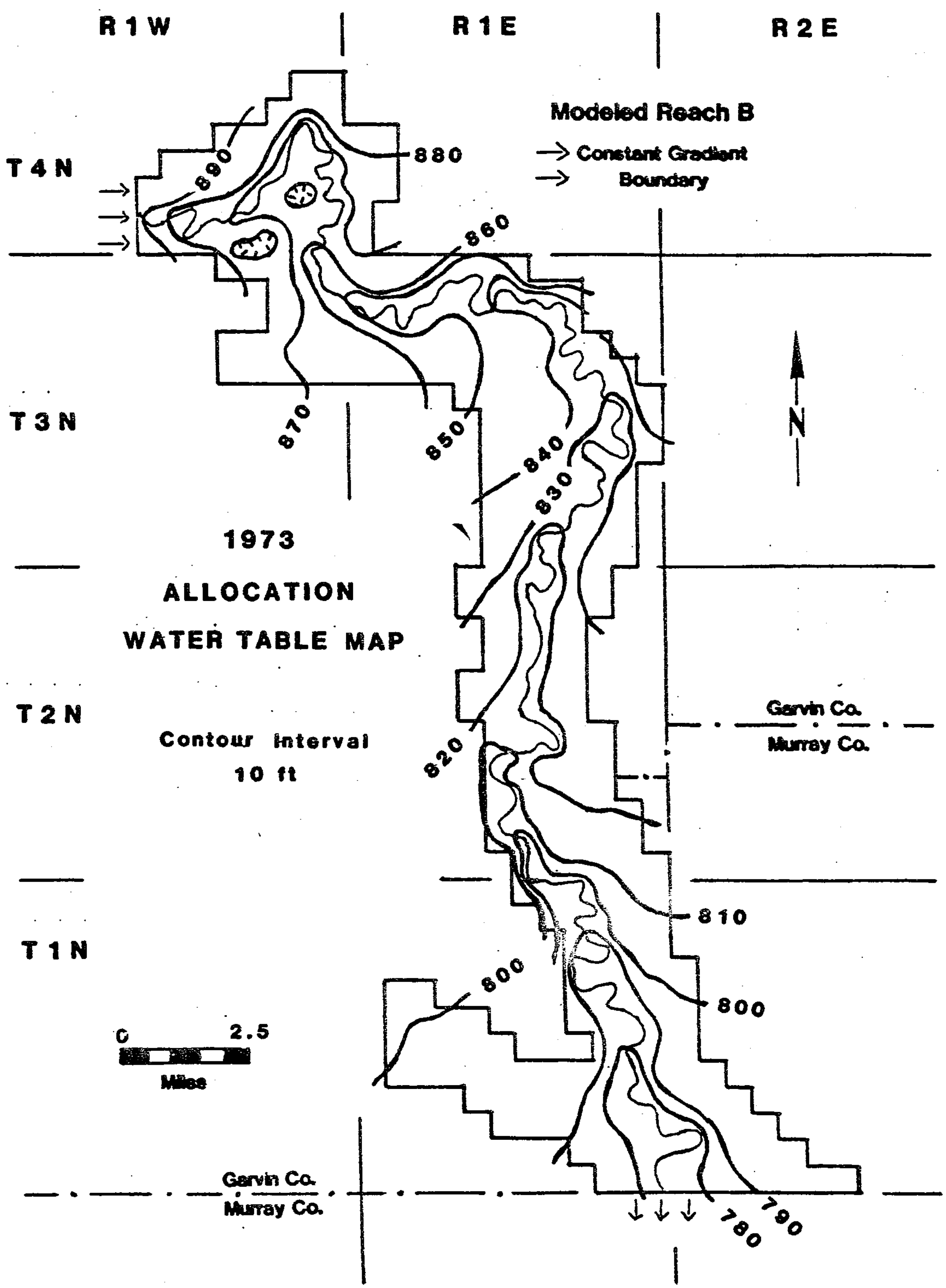
Water Distribution Summaries,

Subreach C, Modeled Reach 4.



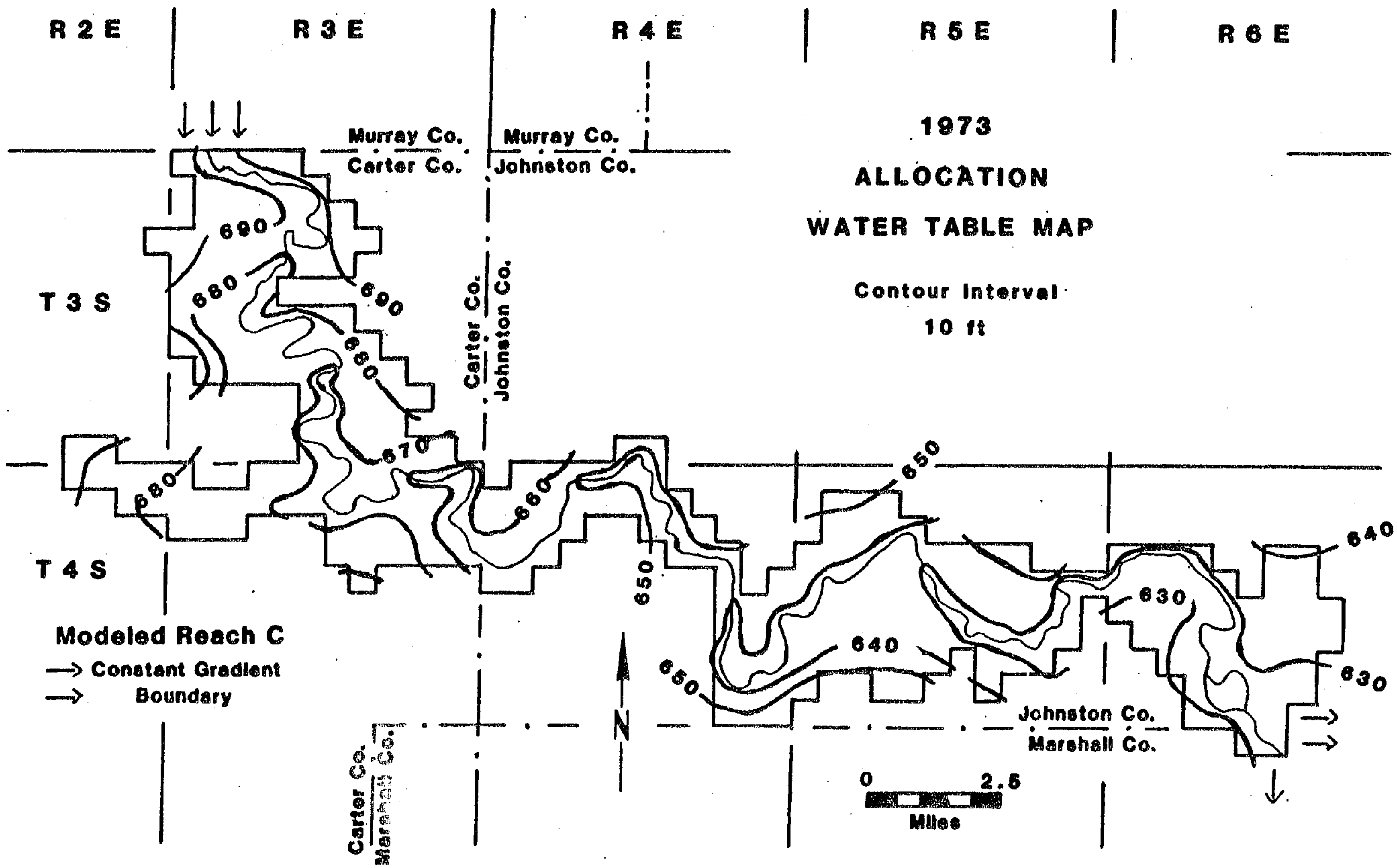
Water Table Map,

Subreach A, Modeled Reach 4.

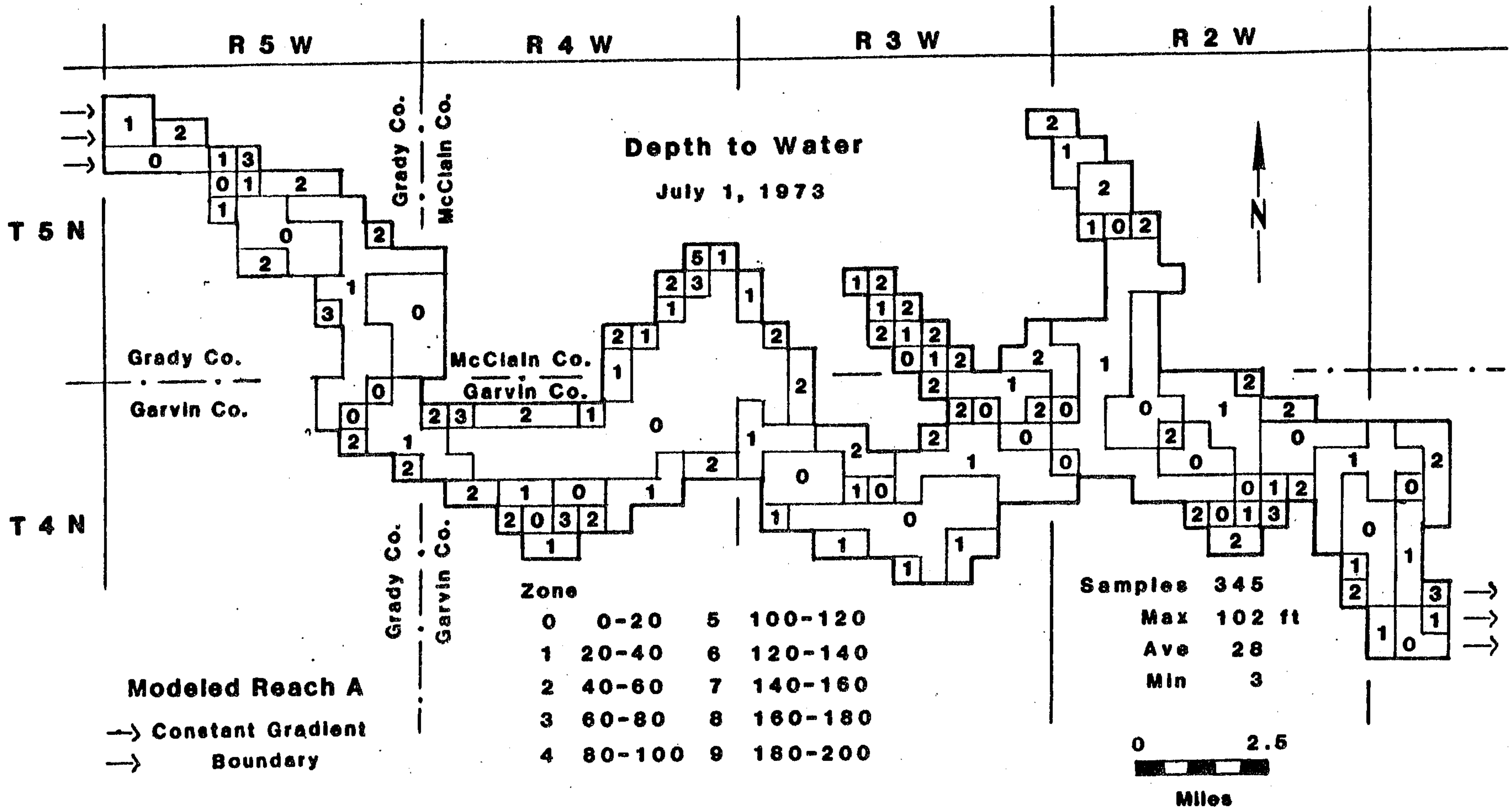


Water Table Map,

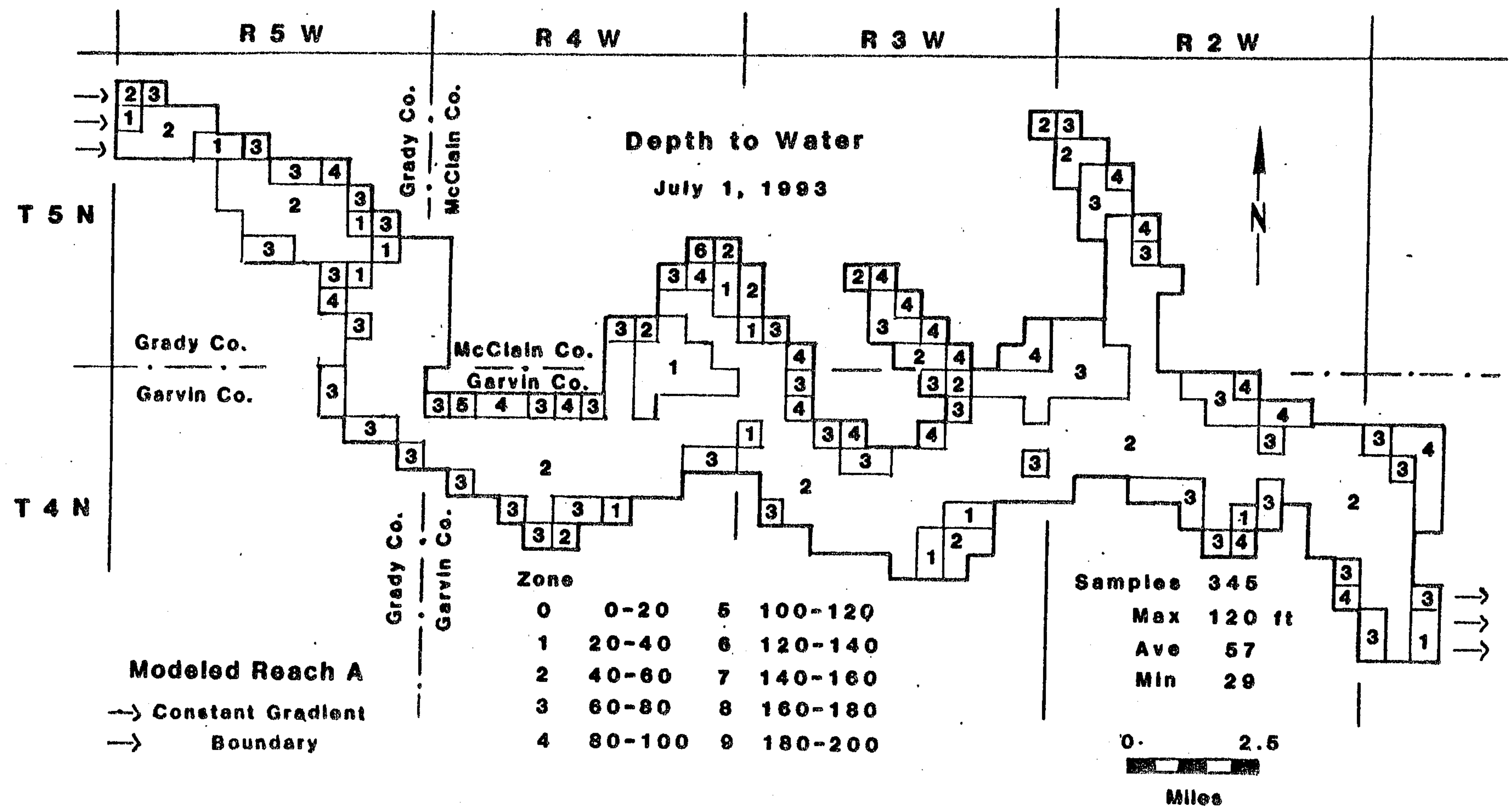
Subreach B, Modeled Reach 4.



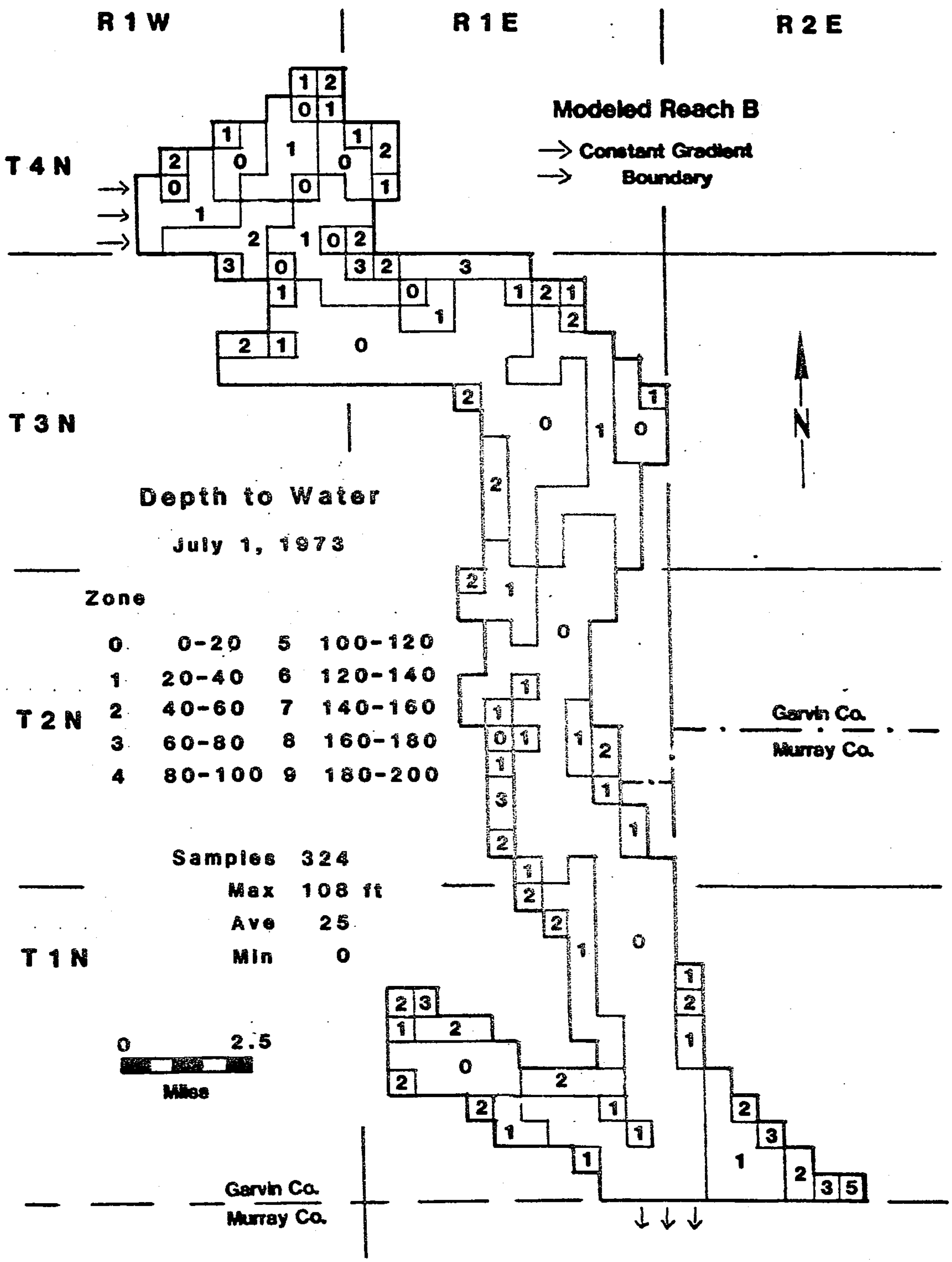
Water Table Map,
Subreach C, Modeled Reach 4.



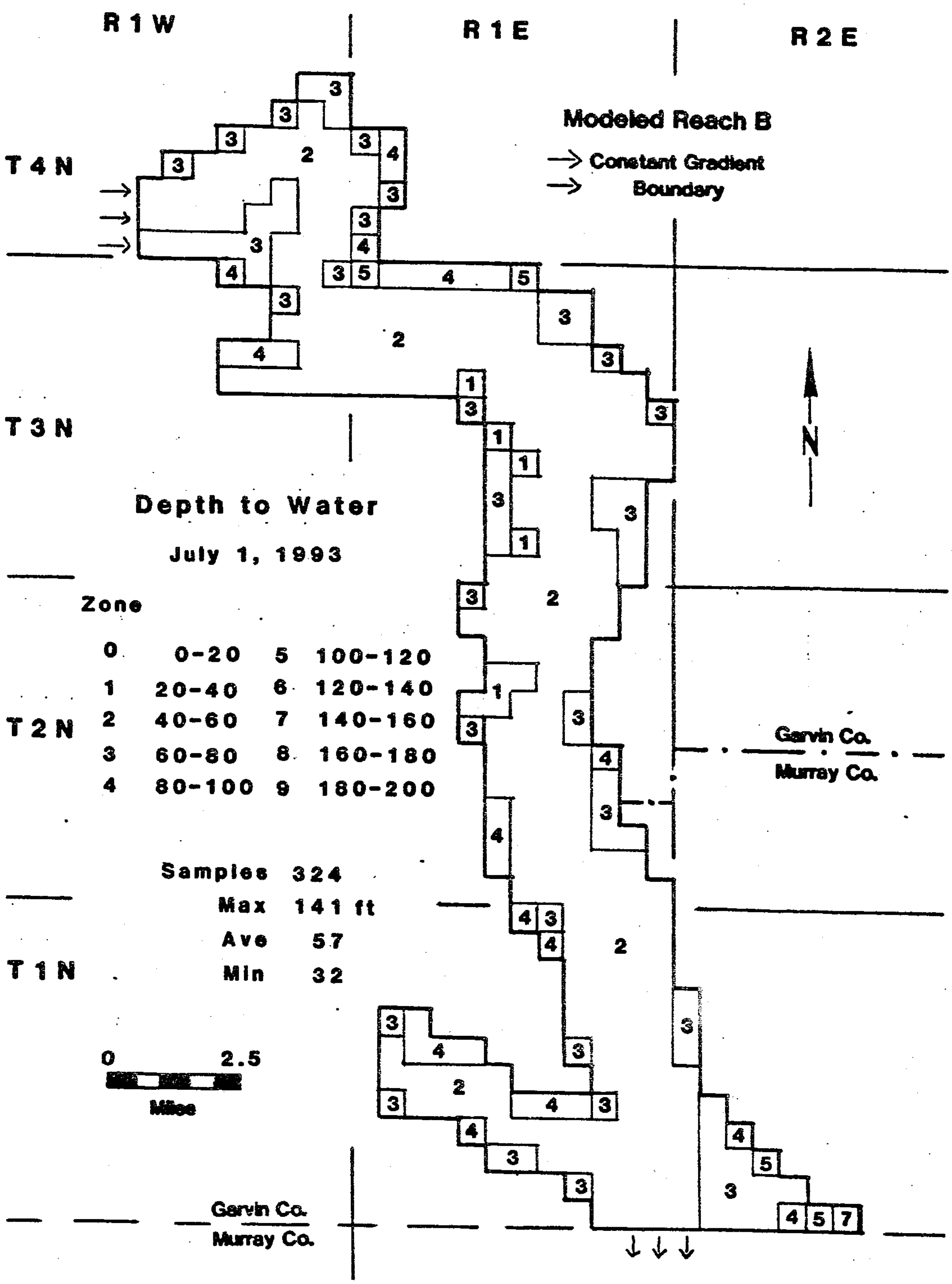
Depth to water, July 1, 1973, Subreach A, Modeled Reach 4.



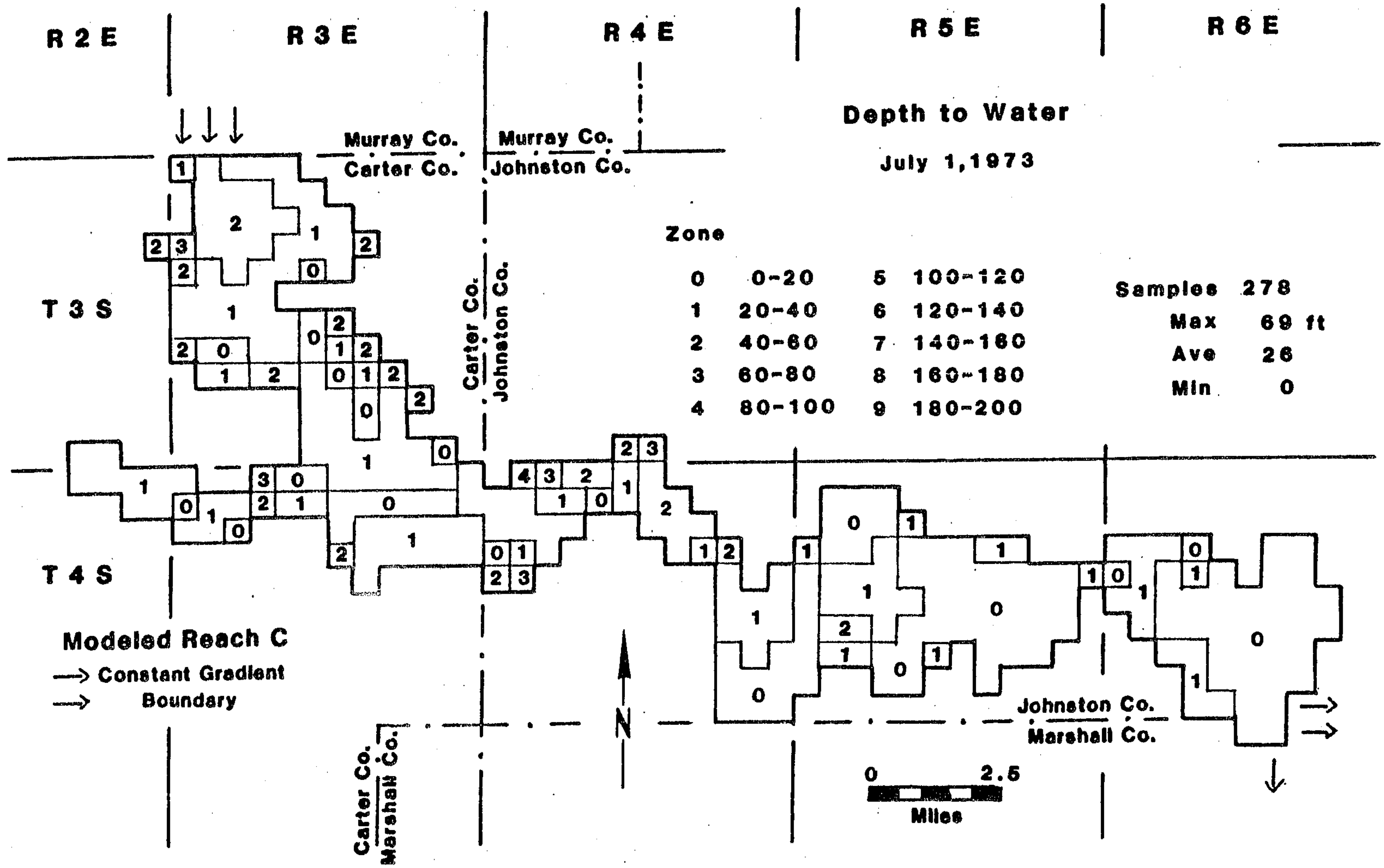
Depth to water, July 1, 1993, Subreach A, Modeled Reach 4.



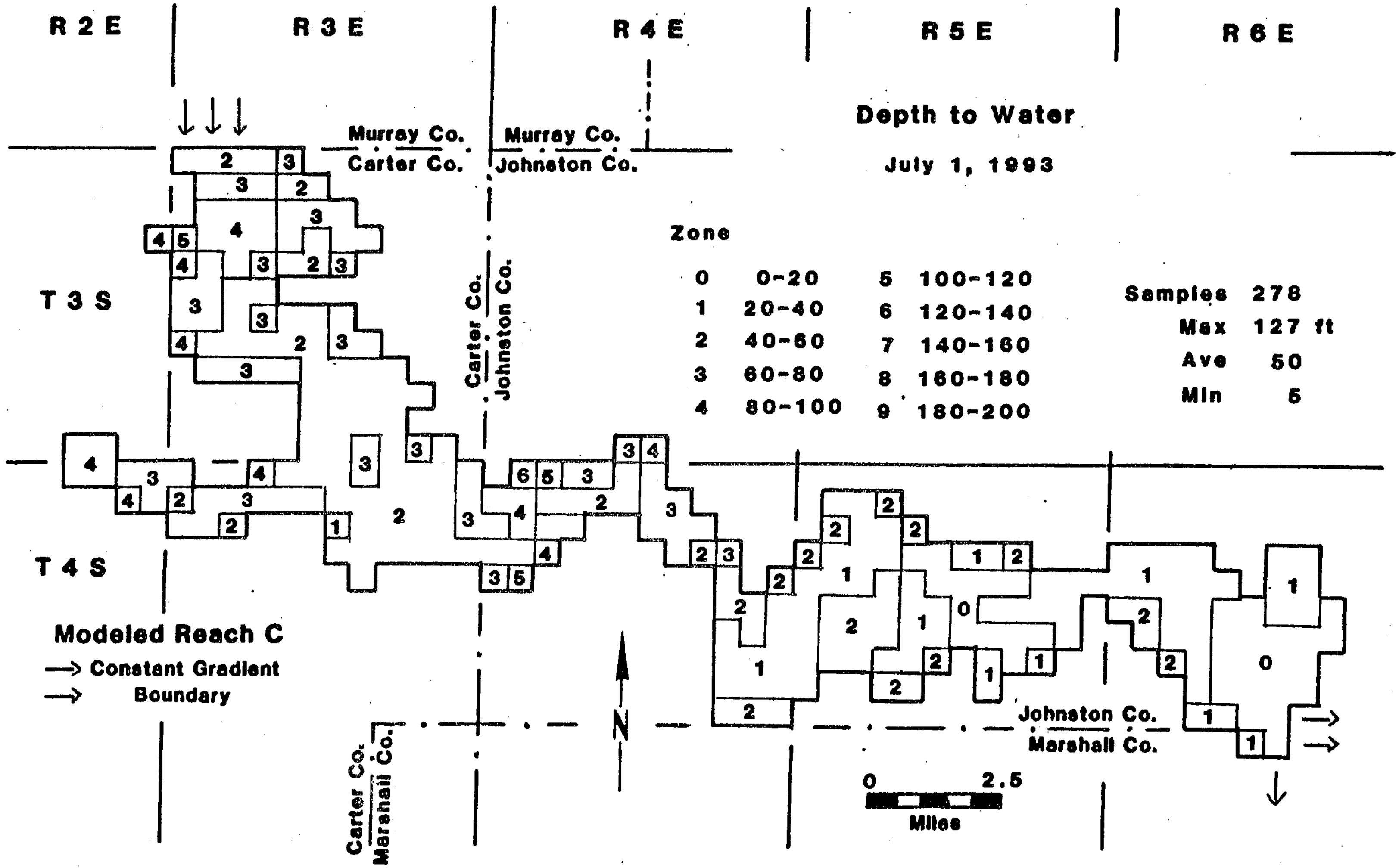
Depth to water, July 1, 1973, Subreach B, Modeled Reach 4.



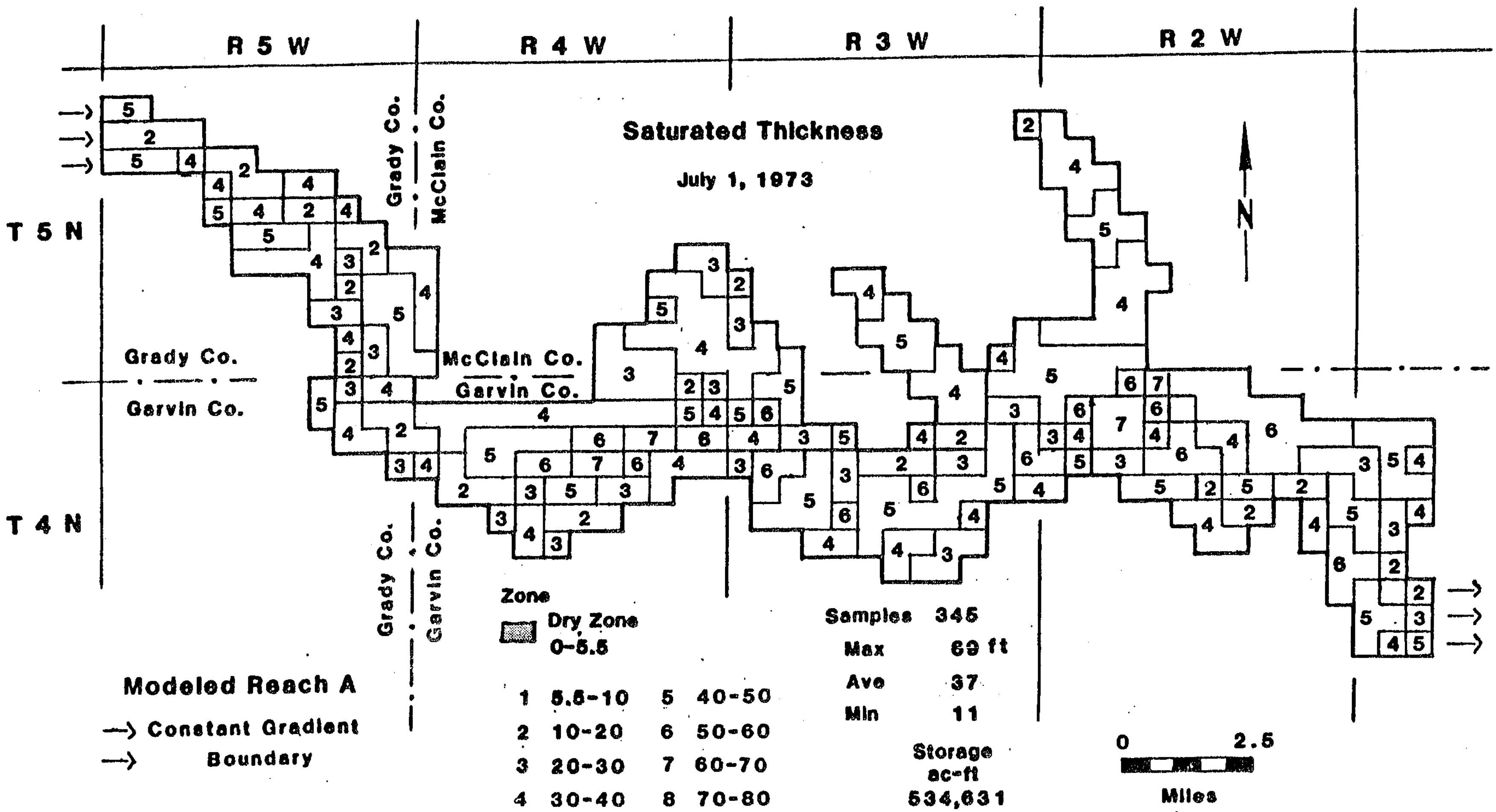
Depth to water, July 1, 1993, Subreach B, Modeled Reach 4.



Depth to water, July 1, 1973, Subreach C, Modeled Reach 4.

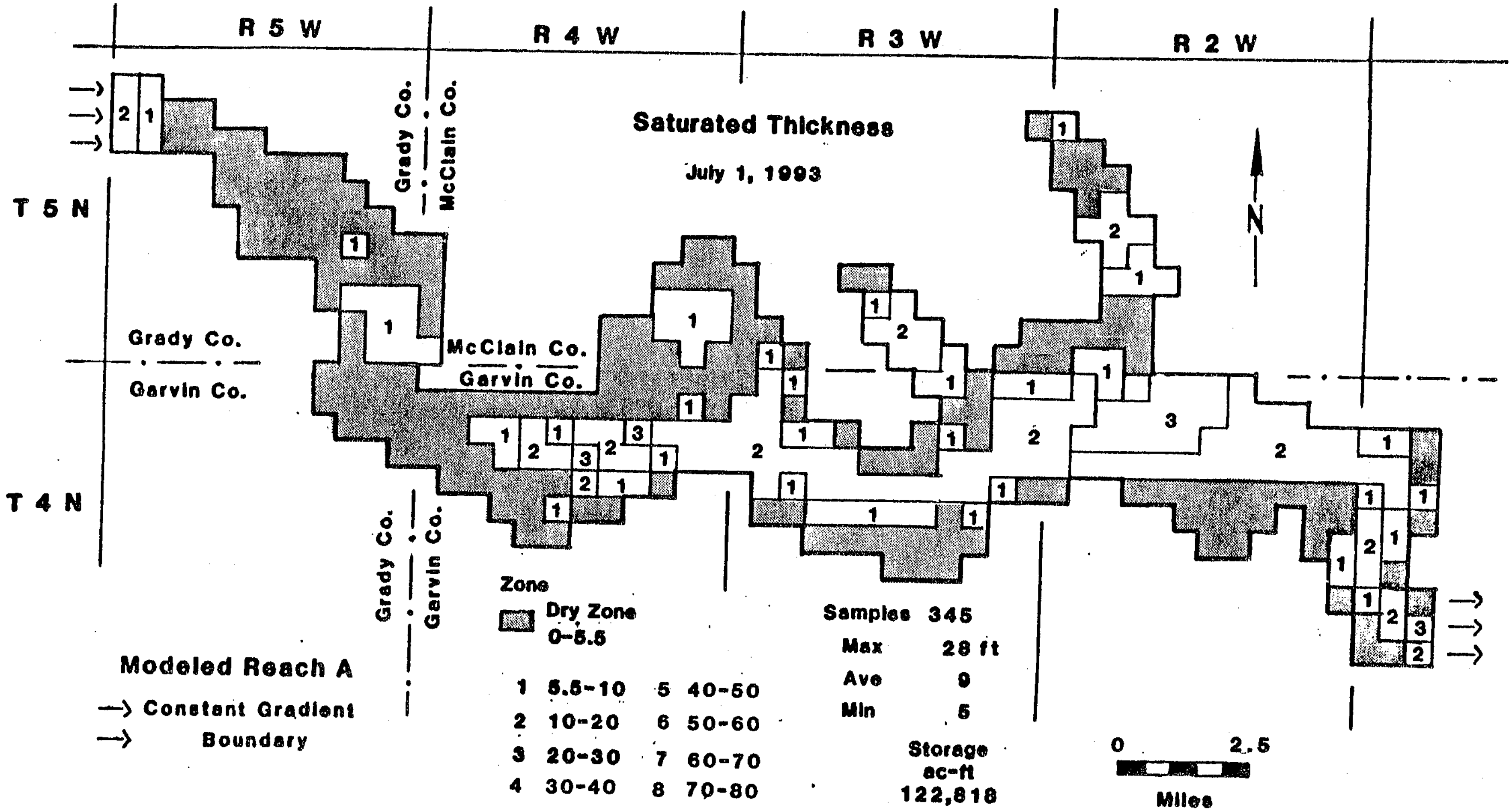


Depth to water, July 1, 1993, Subreach C, Modeled Reach 4.



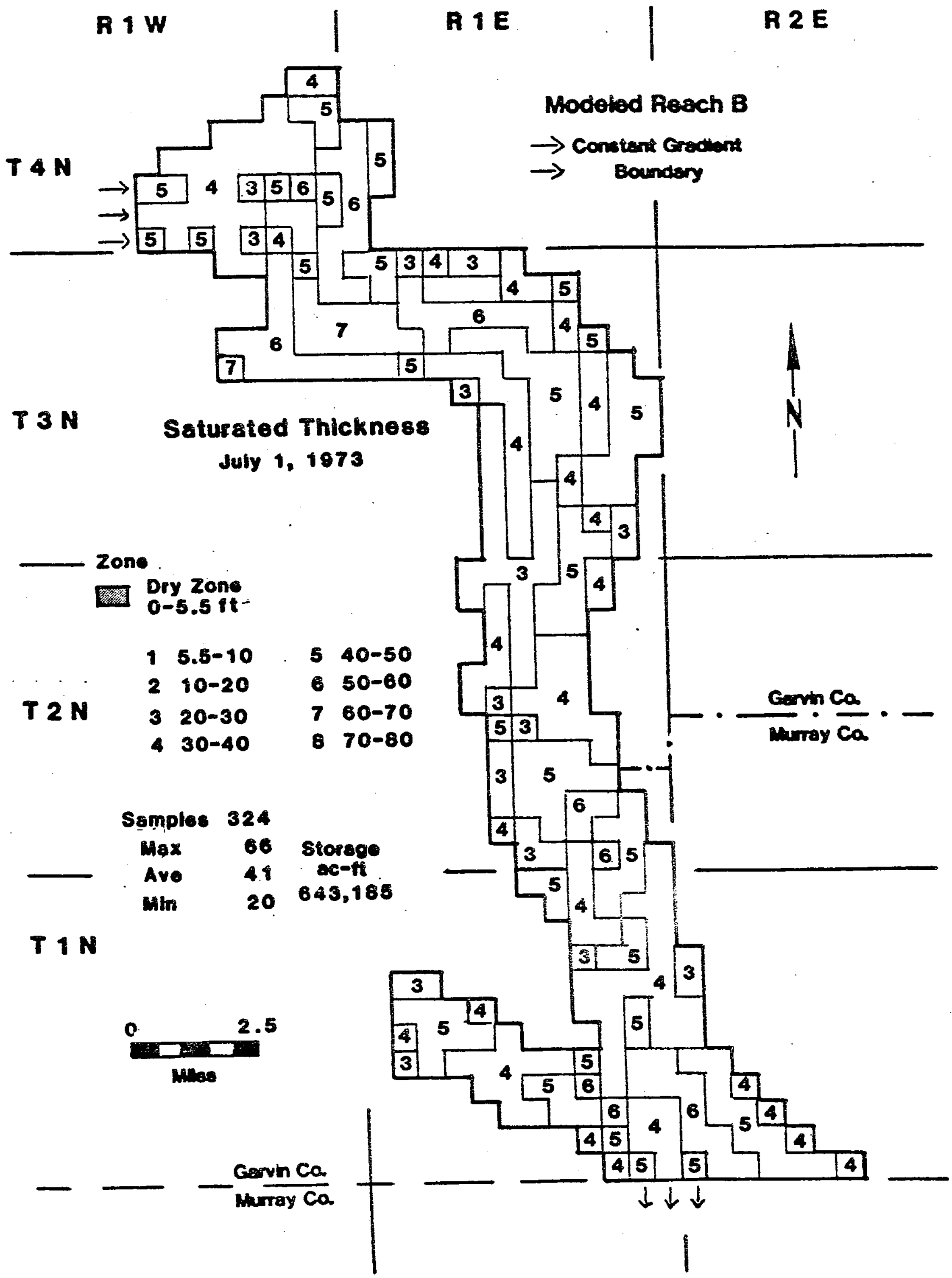
Saturated Thickness Map,

July 1, 1973, Subreach A, Modeled Reach 4.



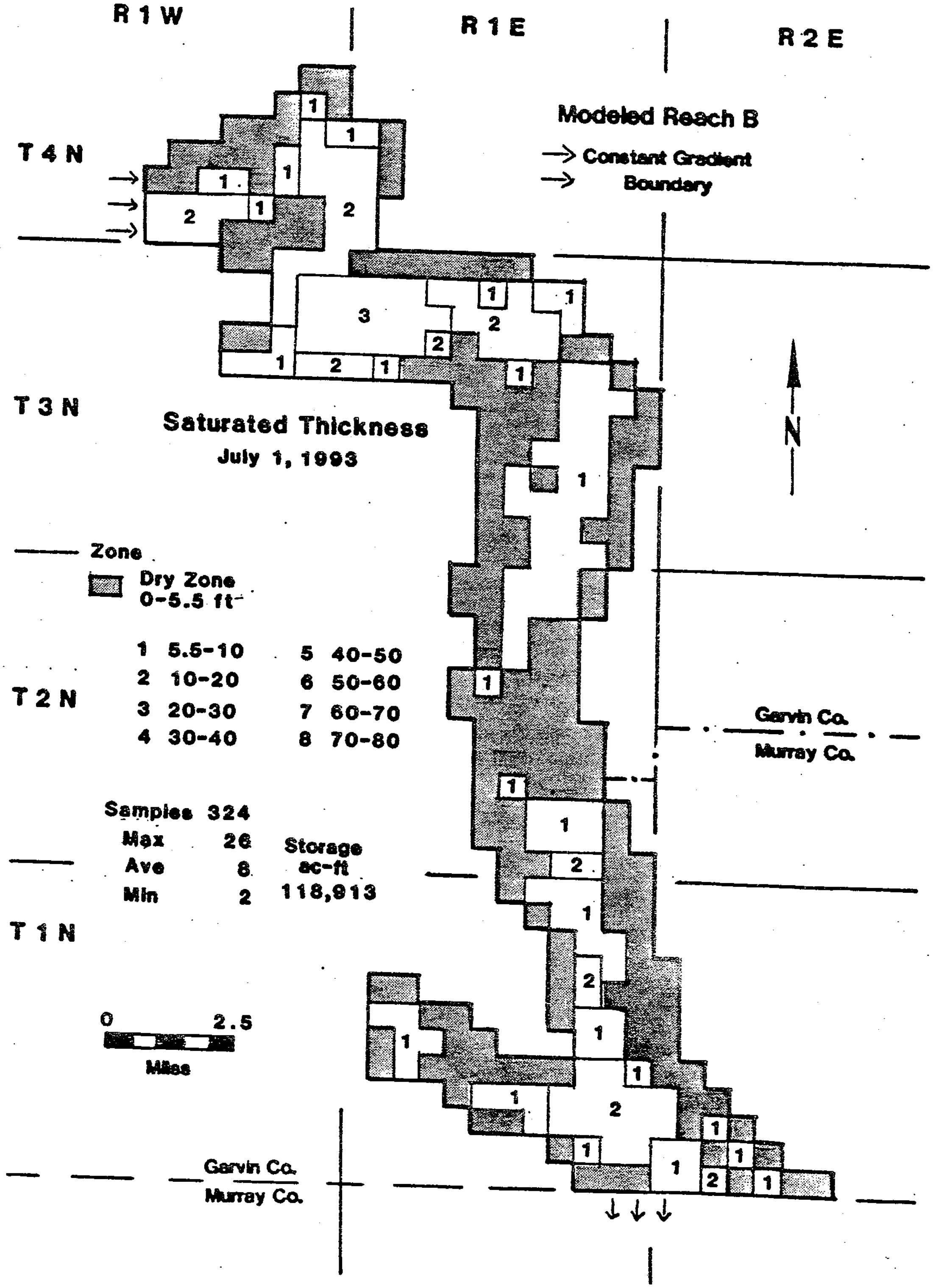
Saturated Thickness Map,

July 1, 1993, Subreach A, Modeled Reach 4.



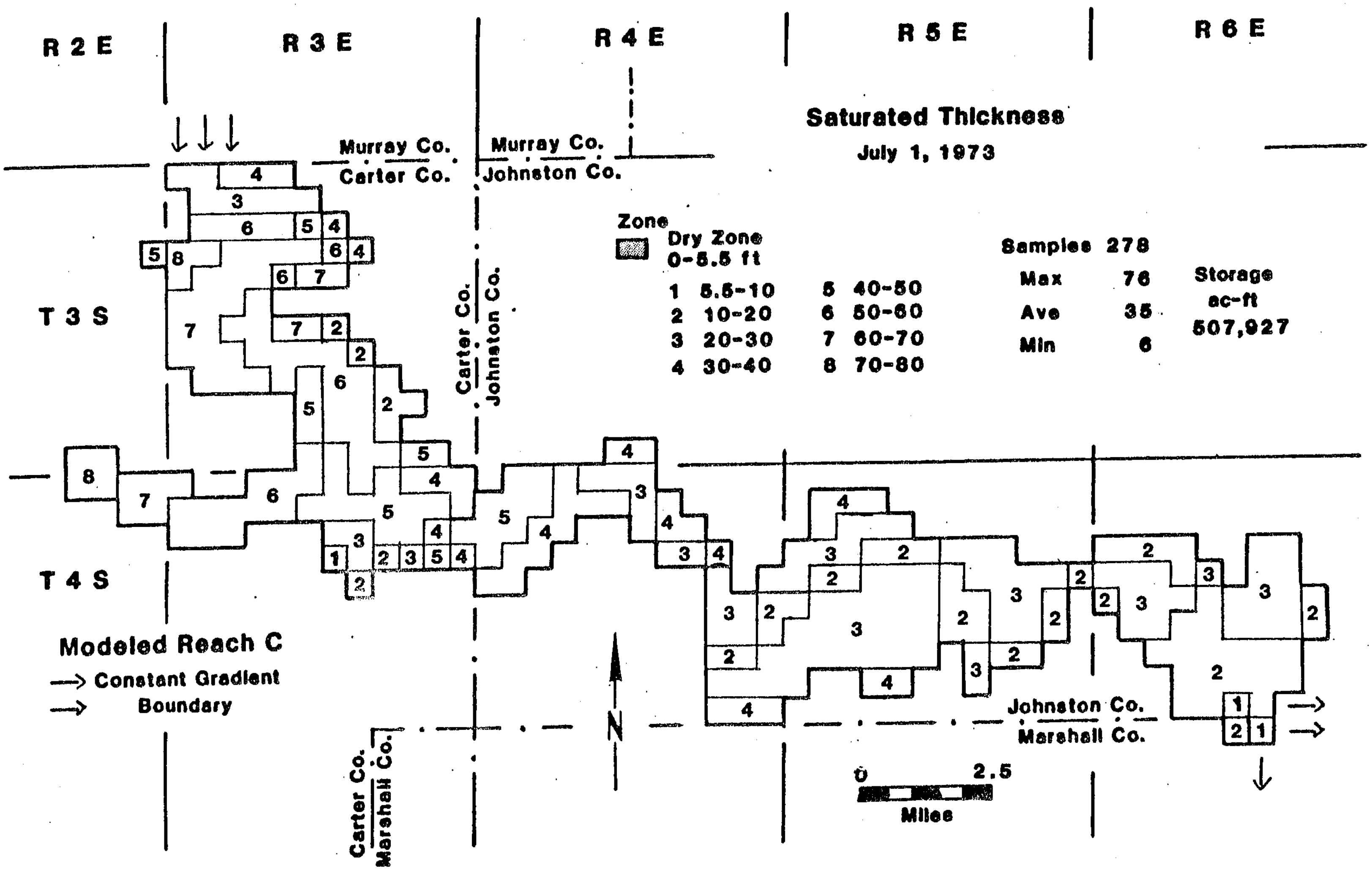
Saturated Thickness Map,

July 1, 1973, Subreach B, Modeled Reach 4.



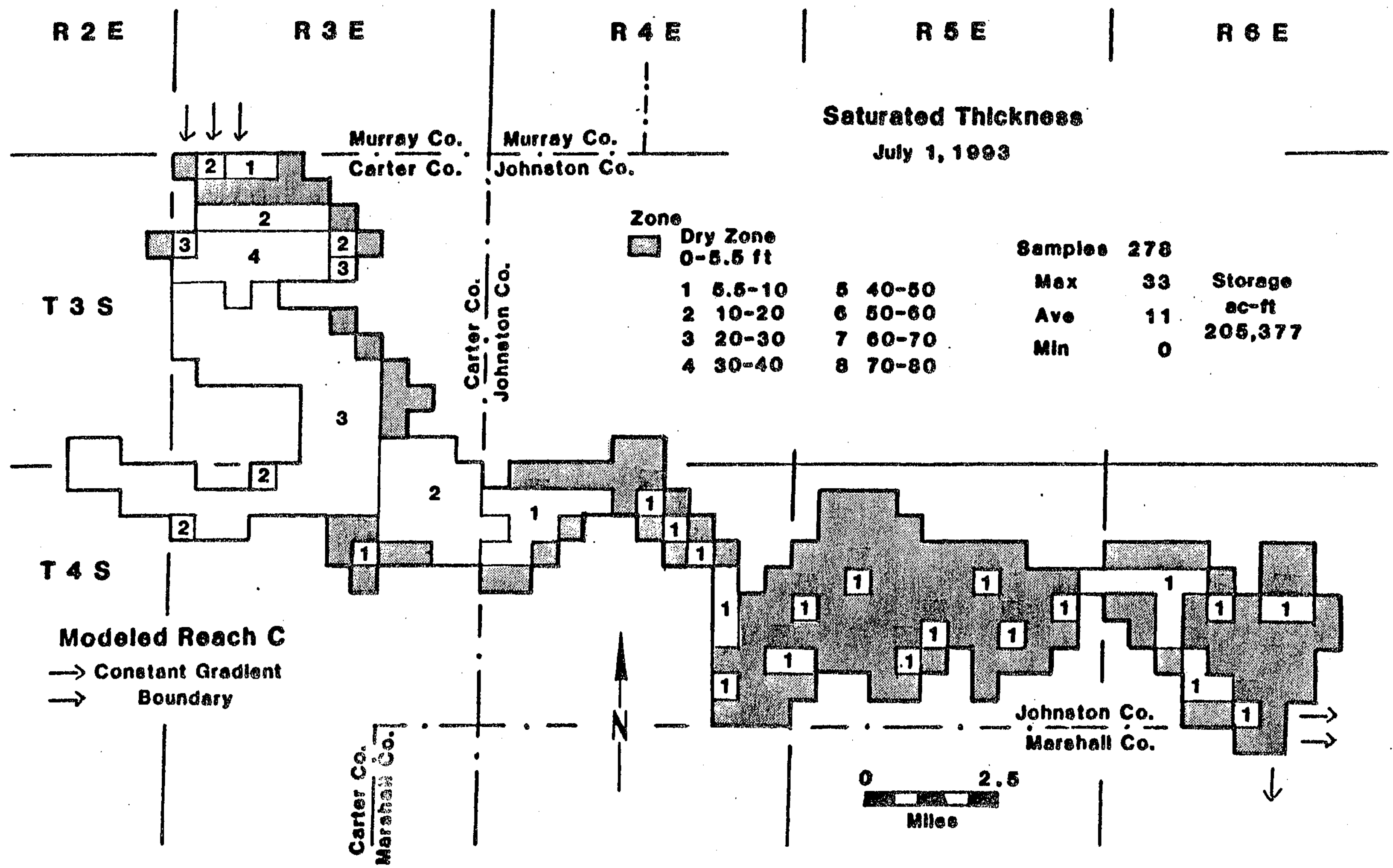
Saturated Thickness Map,

July 1, 1993, Subreach B, Modeled Reach 4.



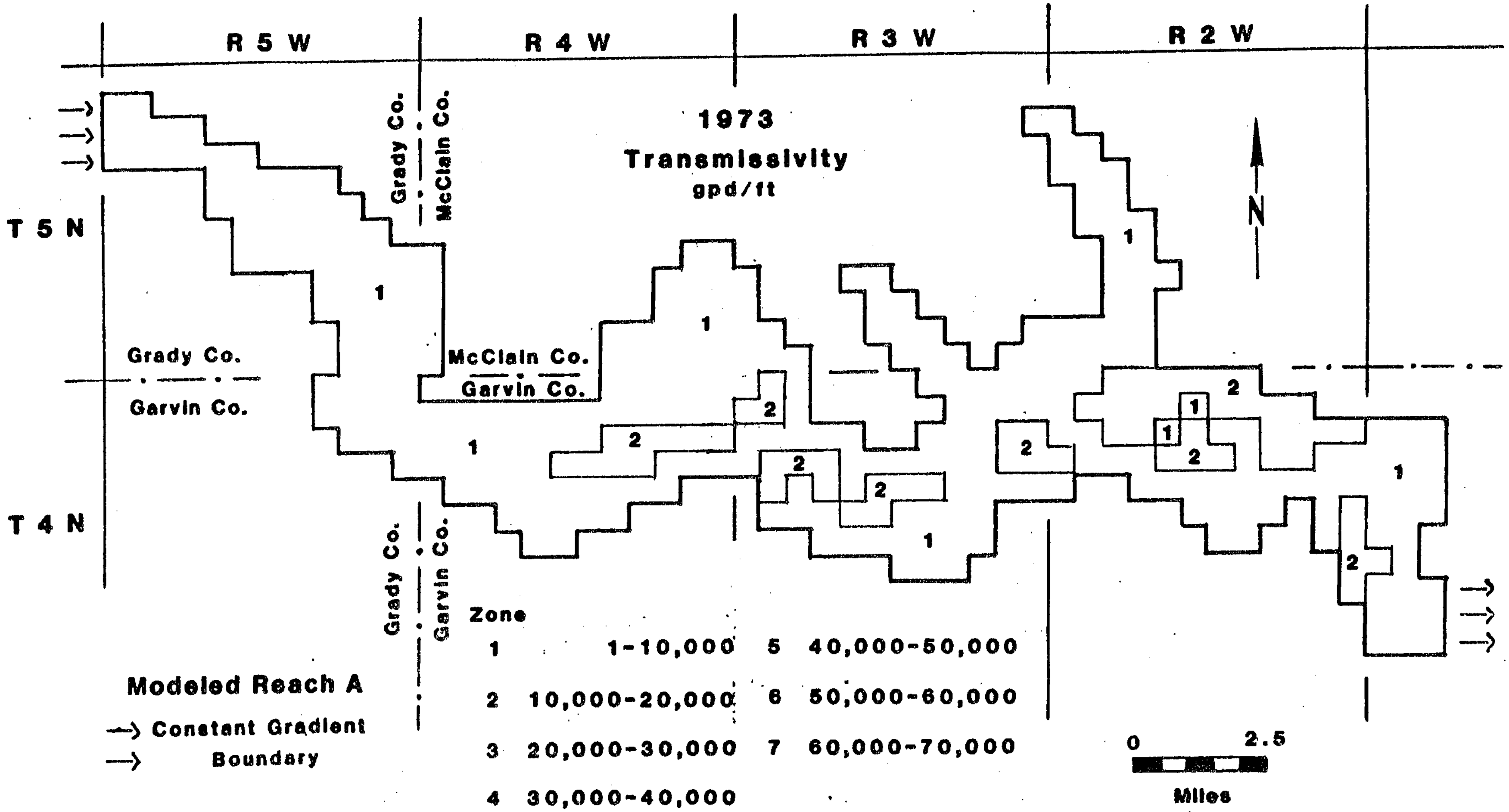
Saturated Thickness Map,

July 1, 1973, Subreach C, Modeled Reach 4.



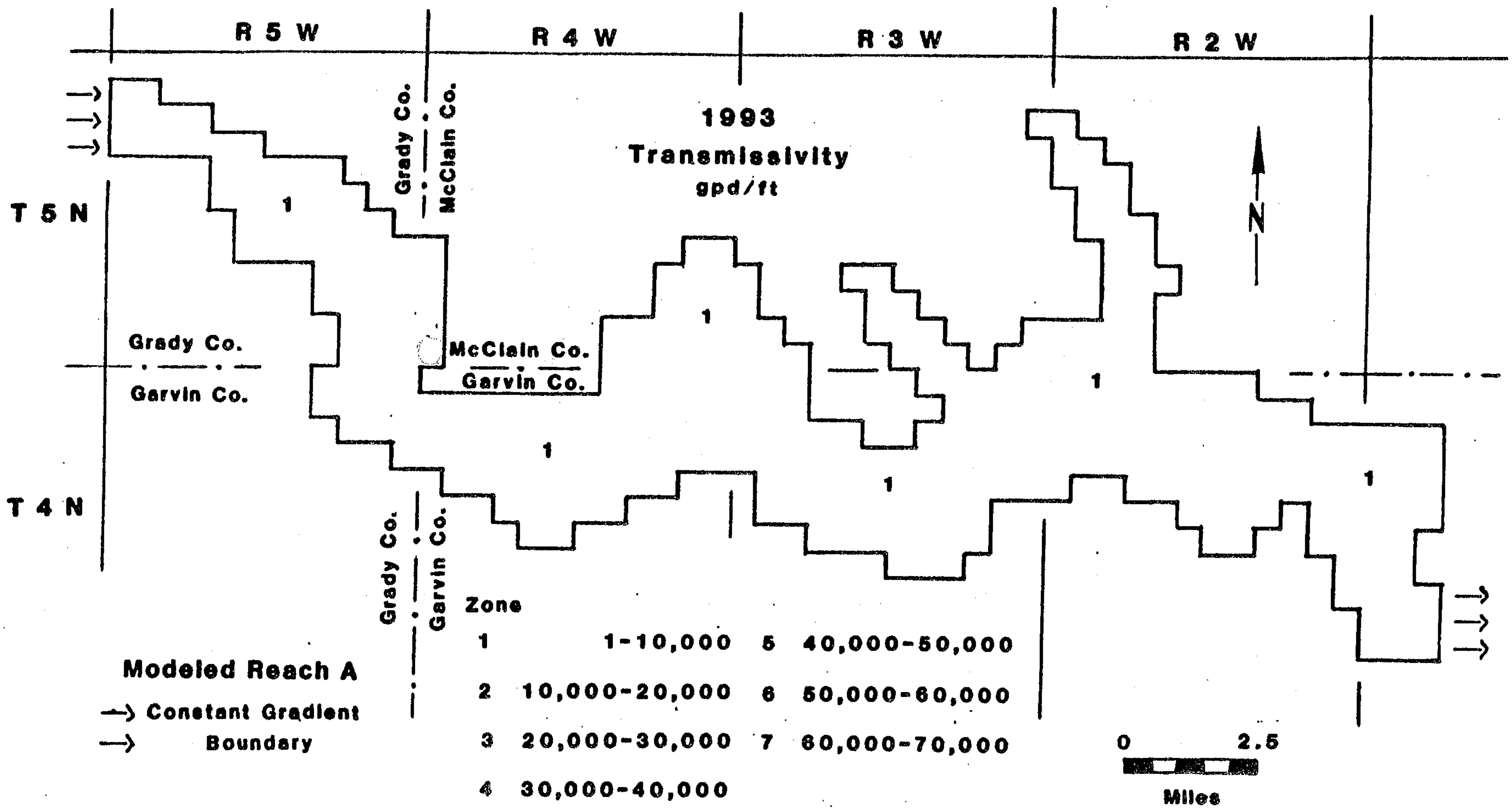
Saturated Thickness Map,

July 1, 1993, Subreach C, Modeled Reach 4.



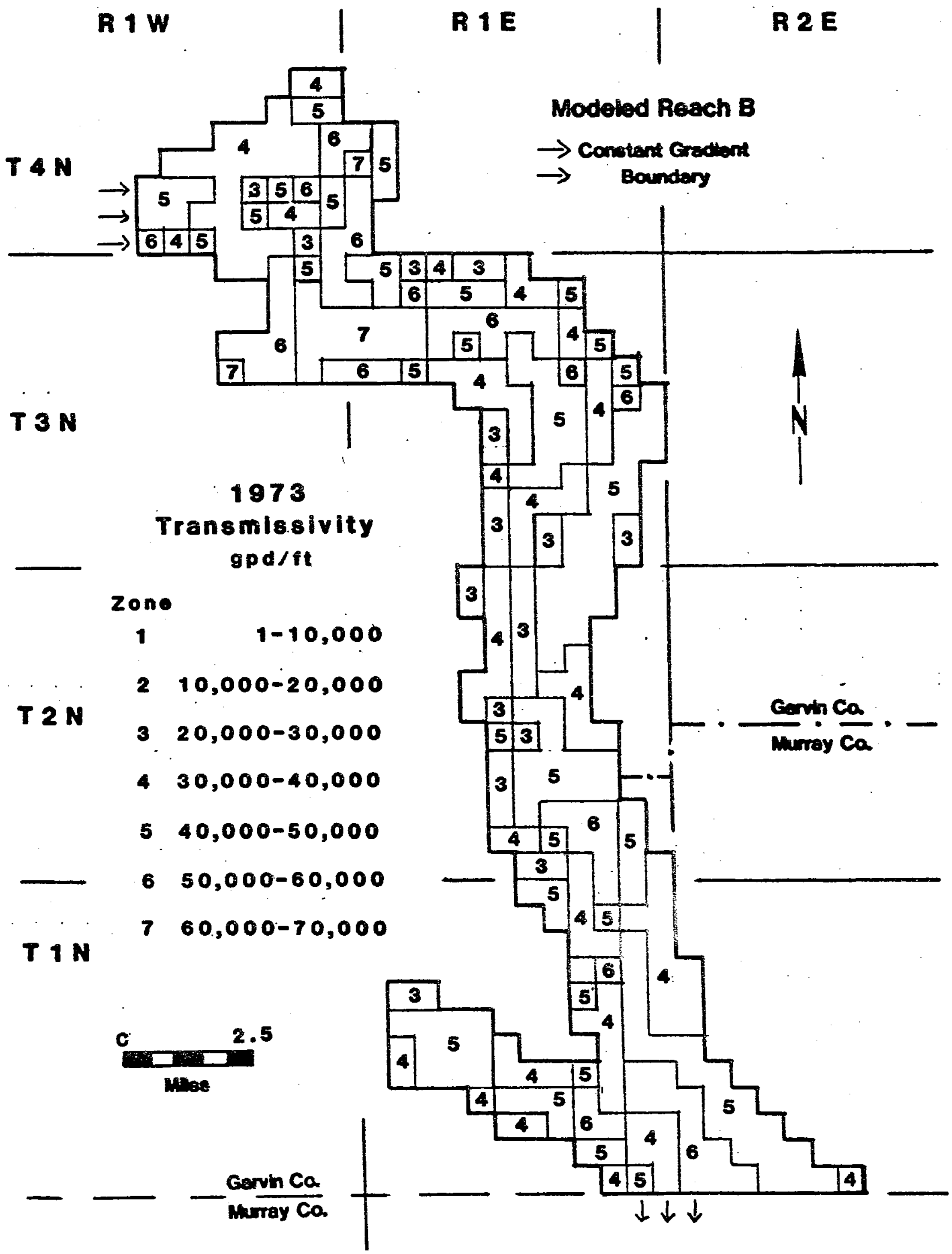
Transmissivity,

July 1, 1973, Subreach A, Modeled Reach 4.



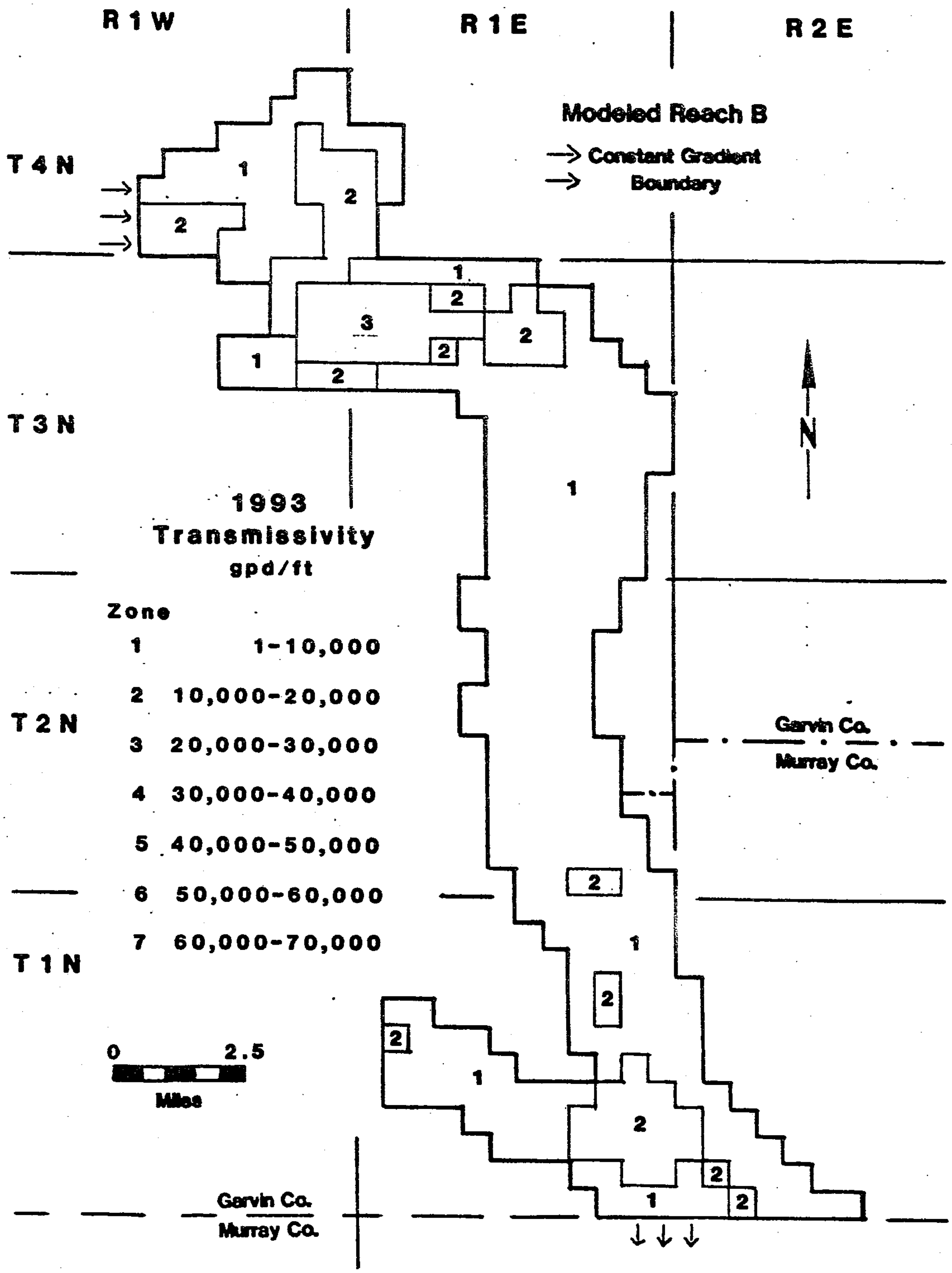
Transmissivity,

July 1, 1993, Subreach A, Modeled Reach 4.



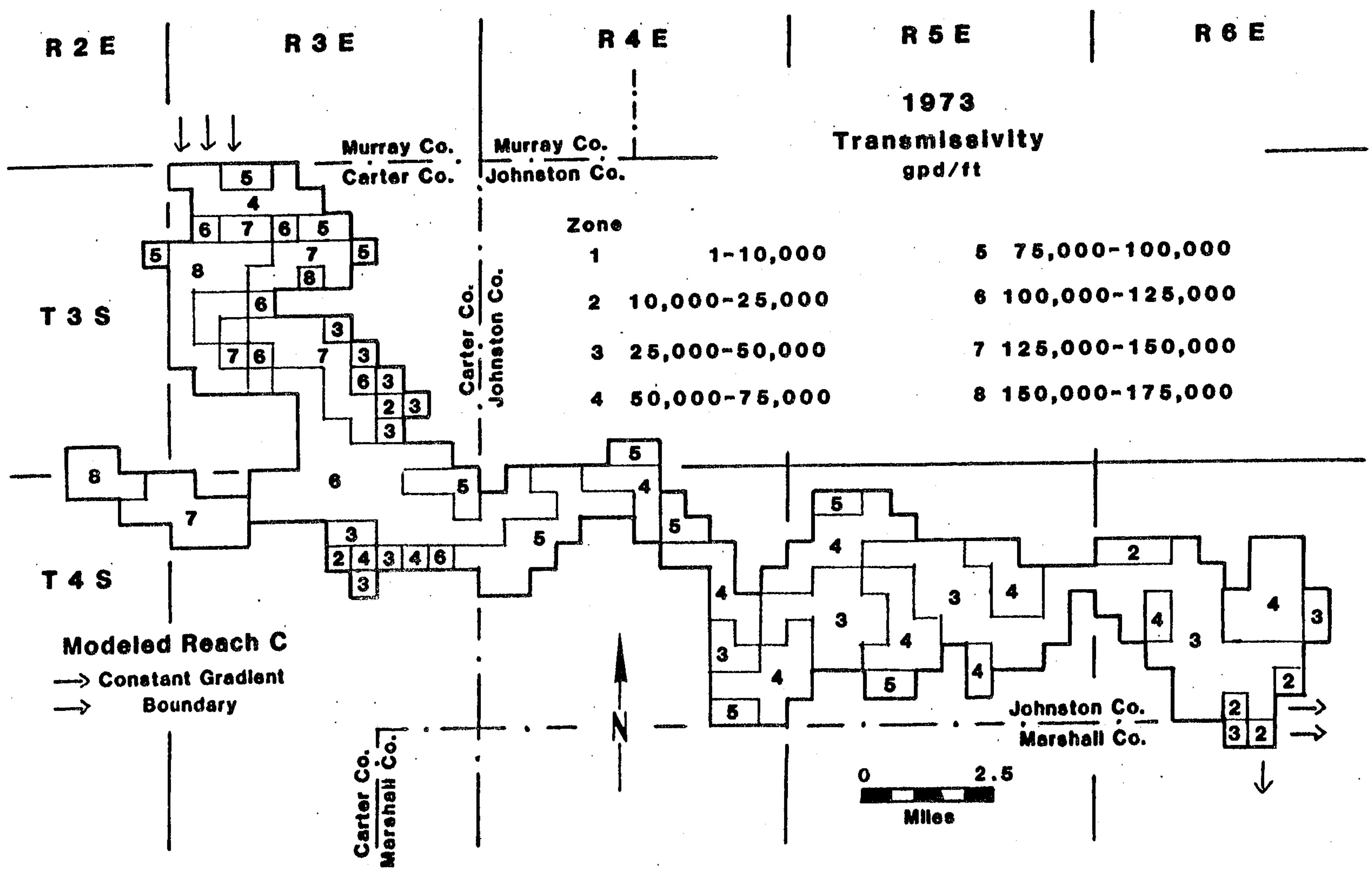
Transmissivity,

July 1, 1973, Subreach B, Modeled Reach 4.



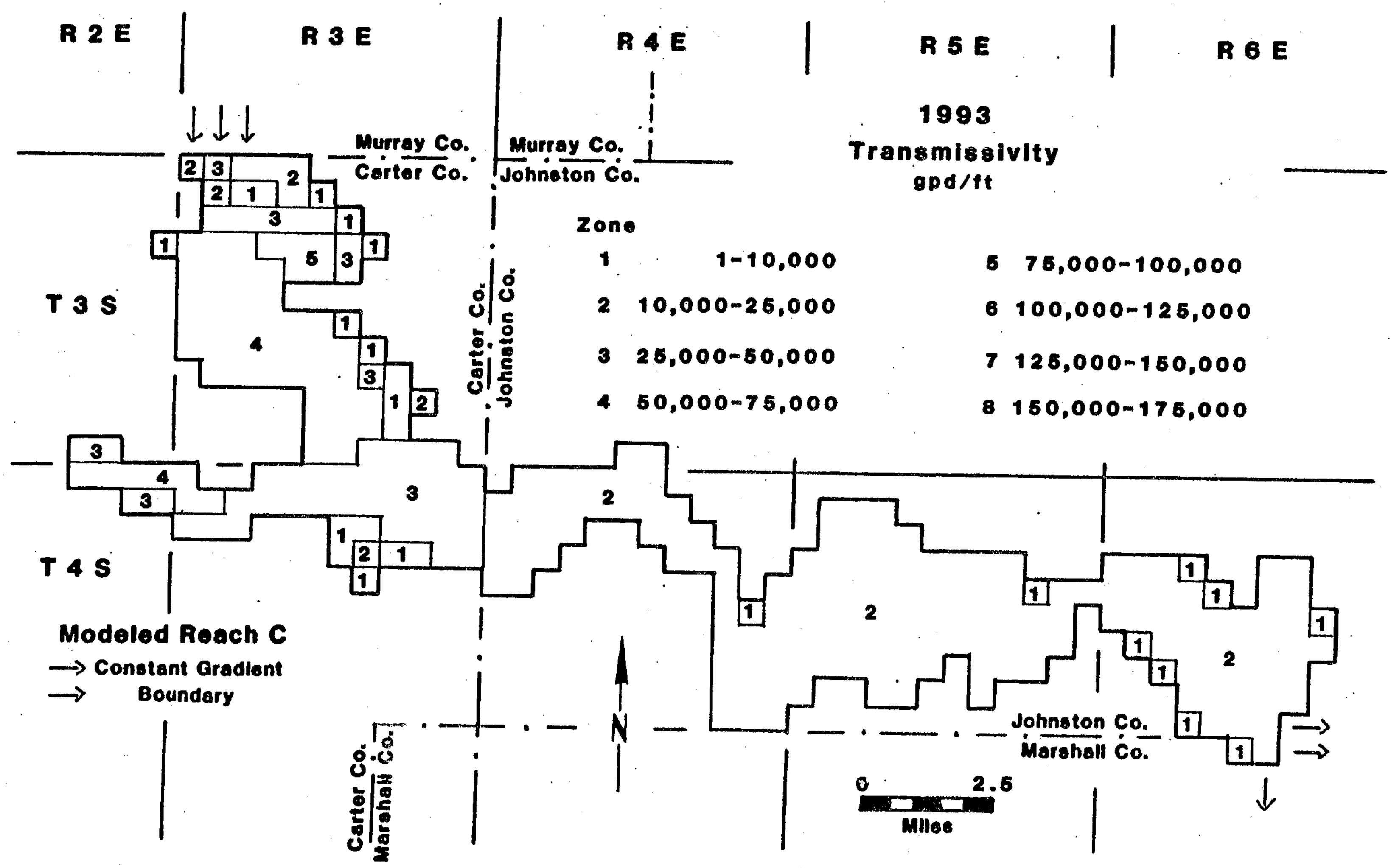
Transmissivity,

July 1, 1993, Subreach B, Modeled Reach 4.



Transmissivity,

July 1, 1973, Subreach C, Modeled Reach 4.



Transmissivity,

July 1, 1993, Subreach C, Modeled Reach 4.