

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).

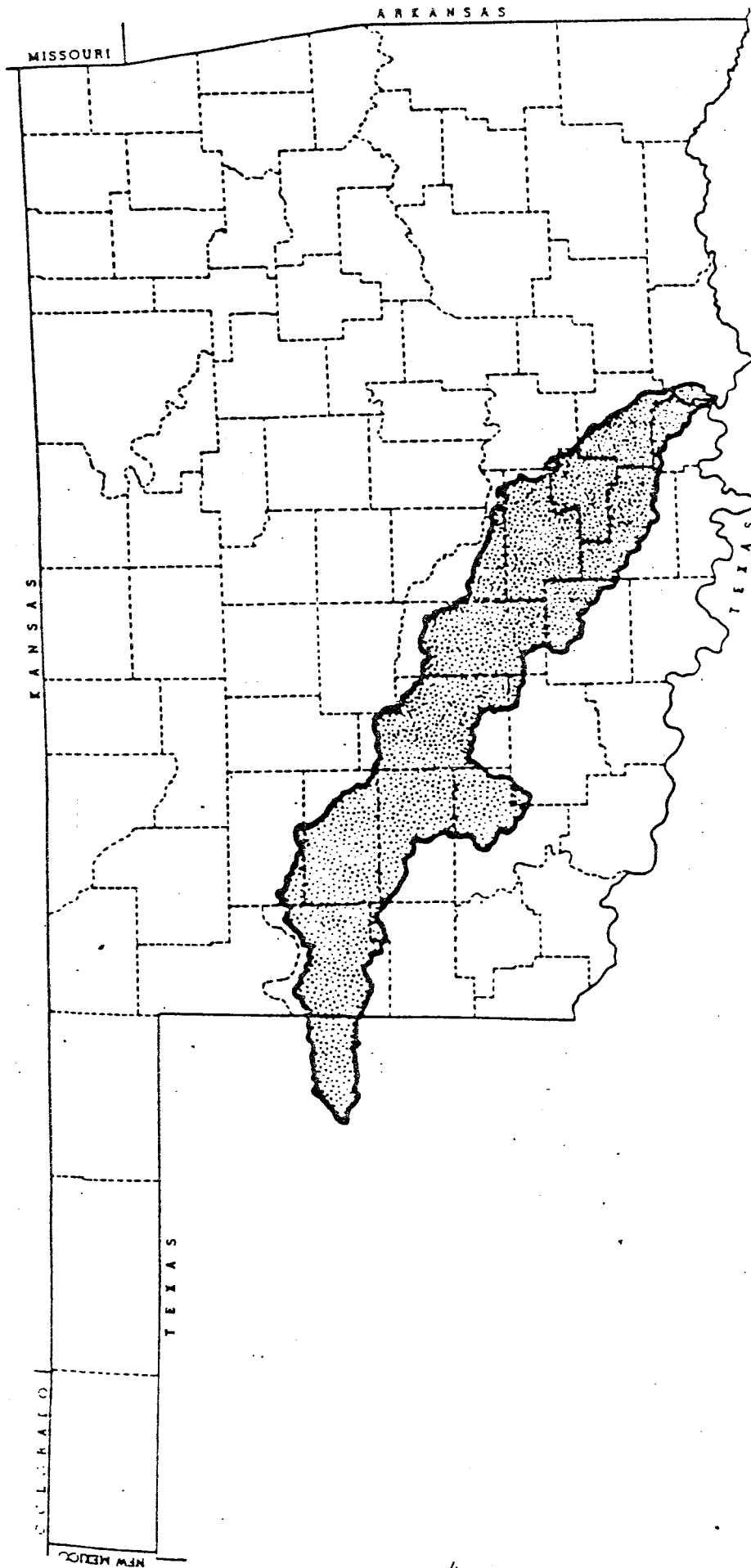


Figure 1. Map Showing The Washita River Drainage Basin Within Oklahoma.

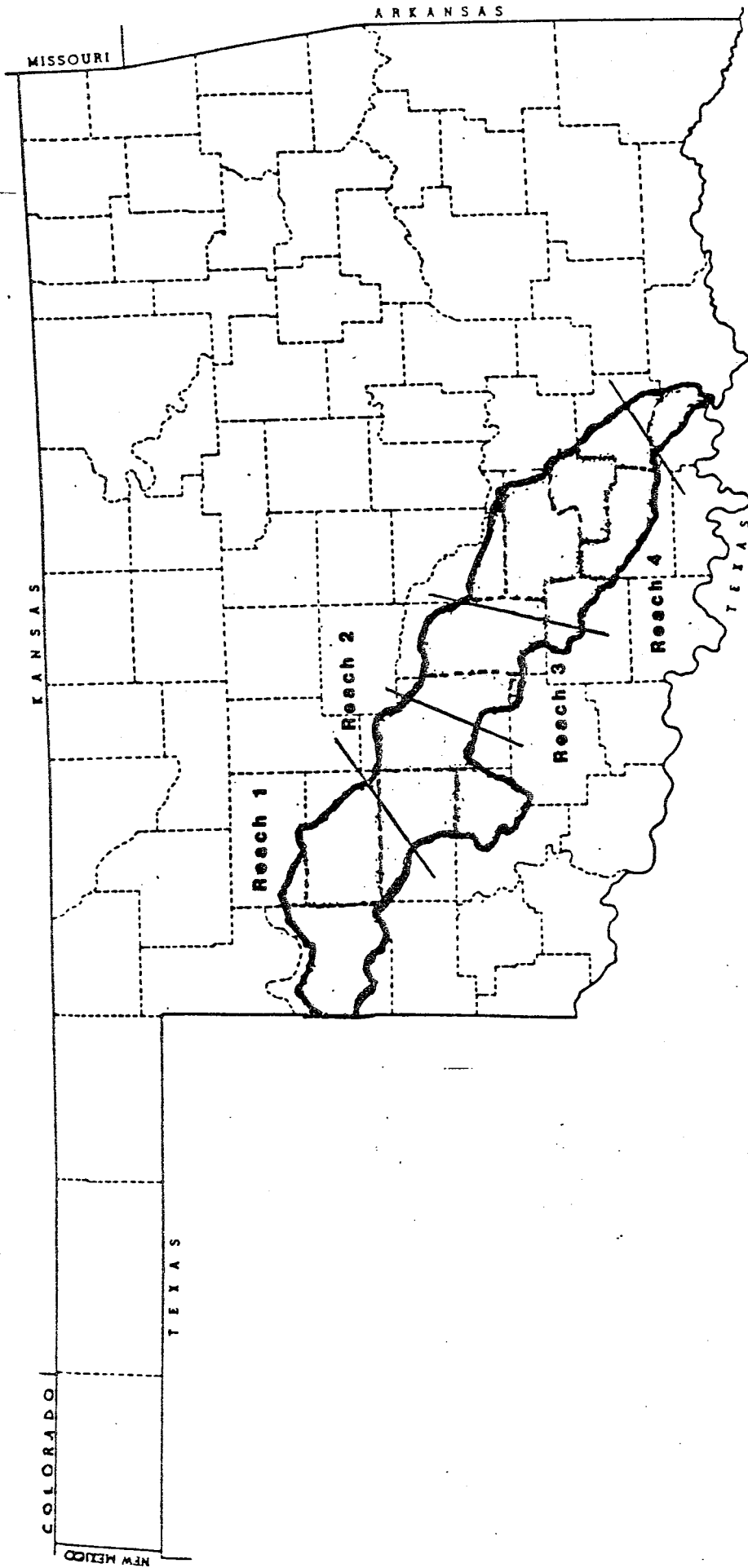


Figure 2. Reach Division Of The Washita River Drainage Basin.

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 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.

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 transmissivity 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.

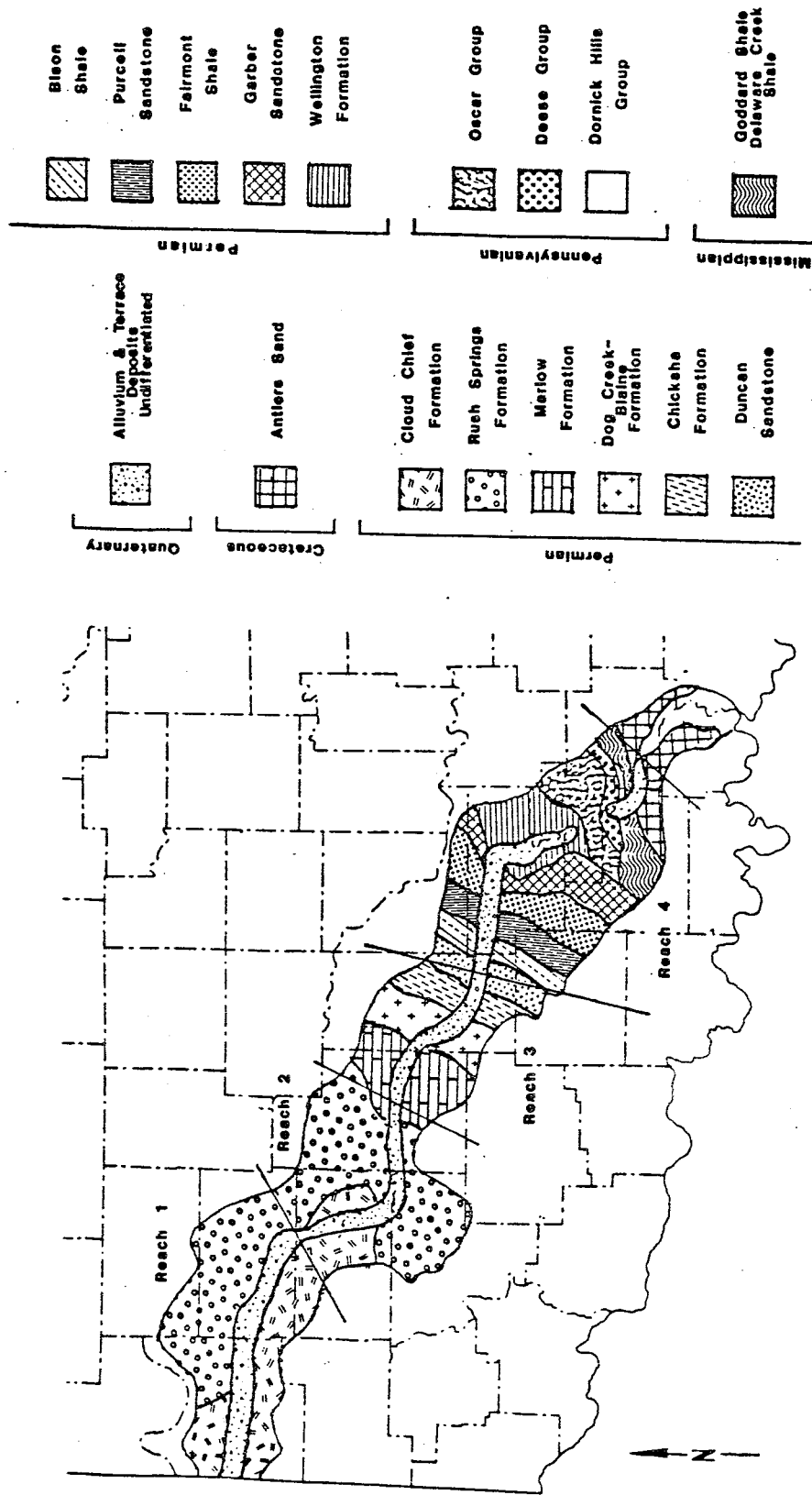


Figure 3. Geologic Map Showing The Formations That Underlie The Washita River Alluvial Aquifer.

TABLE 1

Summary Parameters Used To Determine Allocations By Reach

	Average Depth To Water (ft)		Average Saturatd Thickness (ft)		Average Permeability ₂ (gpd/ft)		Average Transmissivity (gpd/ft)		Average Annual Precipitation (in/yr)		Percent of Total Precipitation (%)		Average Annual E.T (in/yr)	
	1973	1993	1973	1993	1973	1993	1973	1993	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*	
Reach 2 B (not modeled)			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 variables 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

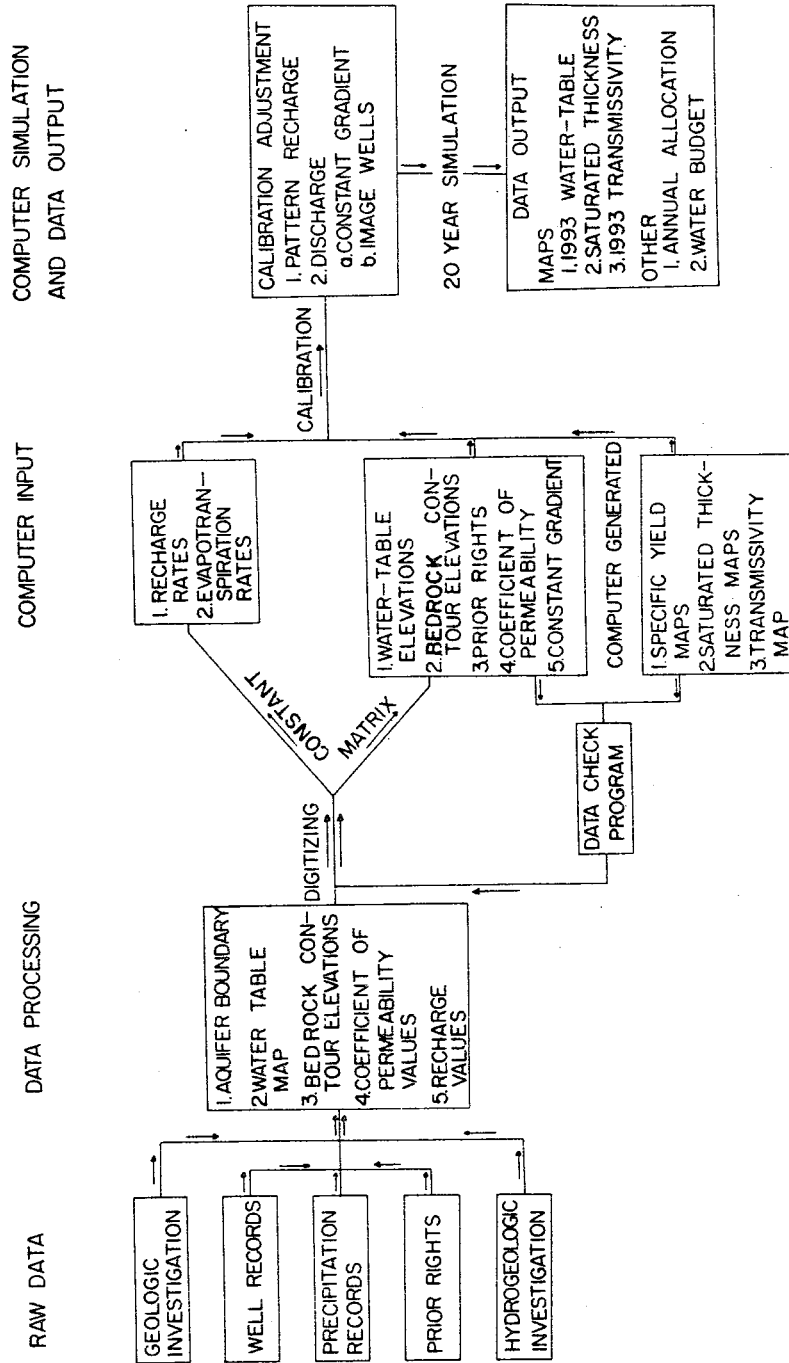


Figure 4. Flow Diagram of Data Processing for Model Simulation.

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.

20 YEAR GROUND WATER BUDGET

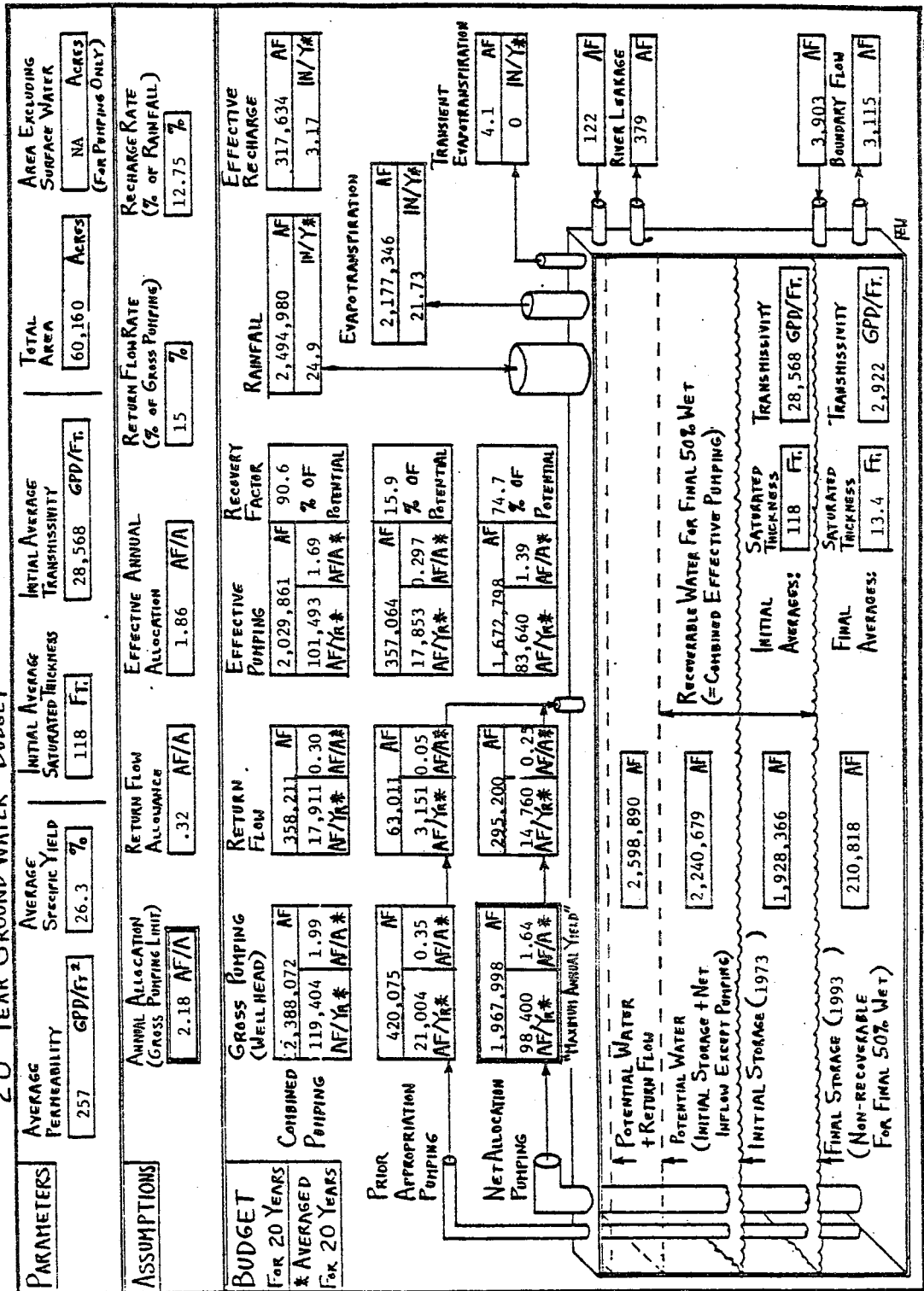


Figure 5. Ground-water Budget For Modeled Reach 1.

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	1973	1978	1983	1988	
Subreach A	150	113	75	39	0	0.4	1.4	8.0	
Subreach B	91	68	45.	27	0	0	9.3	31.4	
Subreach C	93	69	46	27	0	0	14.8	23.6	
									49.9
									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 preceding data is summarized in the ground-water budget for Reach 1 in Figure 5. Prior appropriate 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/l. 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	<u>0.56</u>
Total aquifer area (acres)	60,160				Net allocation for total aquifer area	2.18
<u>Allocation by Modeled Reach</u>						
	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

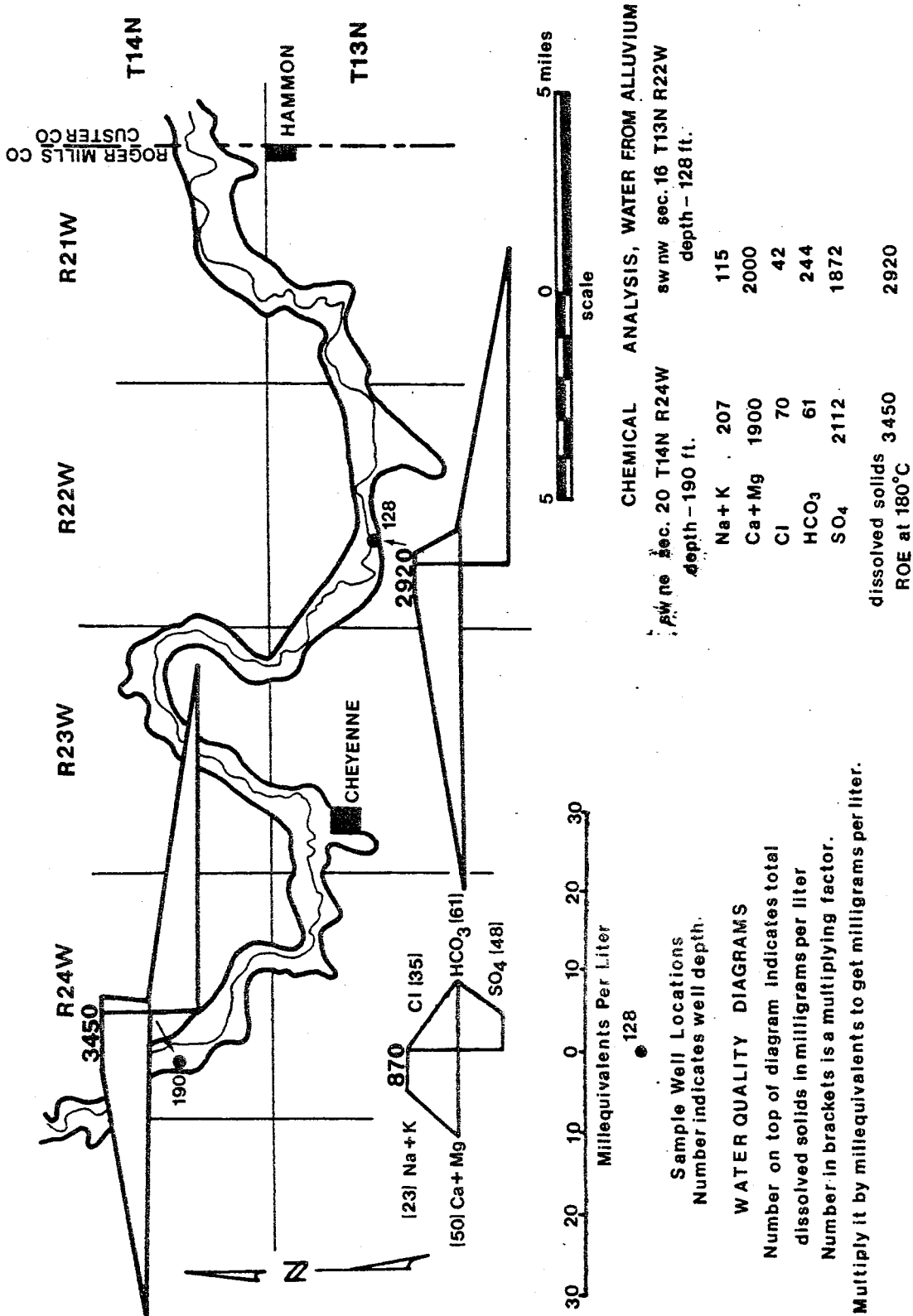


Figure 6. Ground-Water Quality Analyses For Modeled Reach 1.

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 (SO₄) are the main cause of the relatively high values of dissolved solids. The hardness and sulfate are probably related to the gypsum (CaSO₄ 2H₂O) 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.

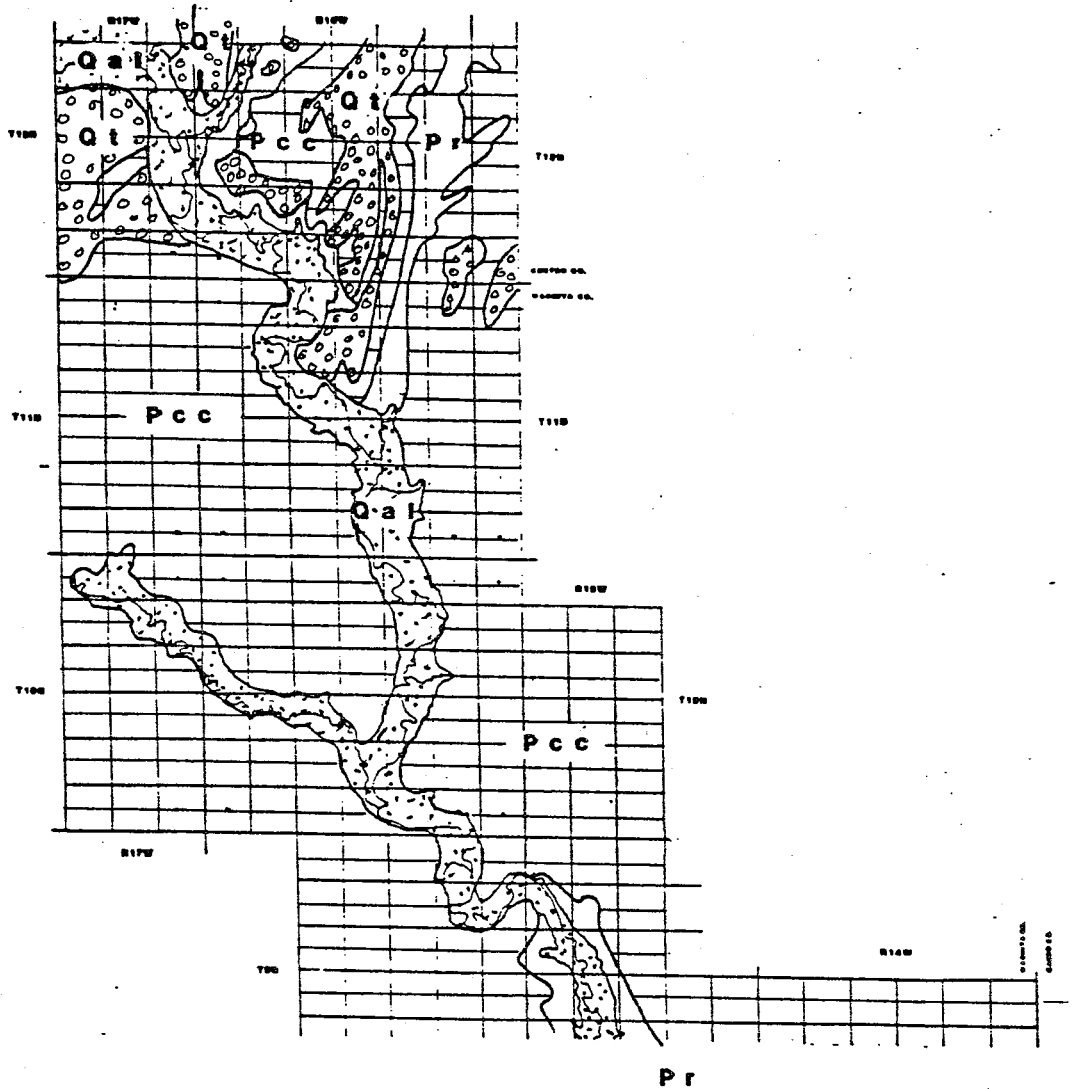


Figure 7.

Geologic Map

Reach 2 Subreach A

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

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miles



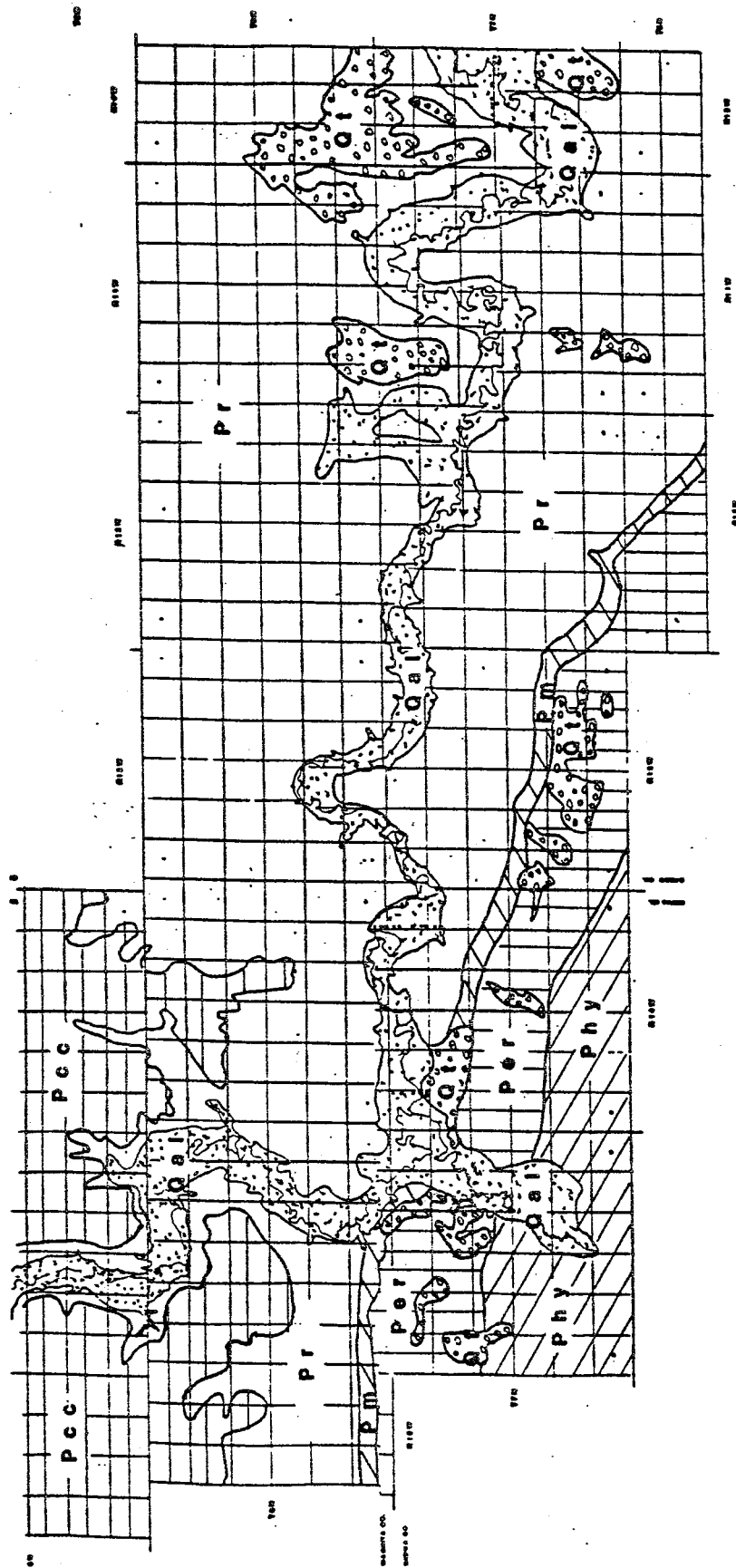


Figure 8.

Geologic Map

Reach 2 Subreach B

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

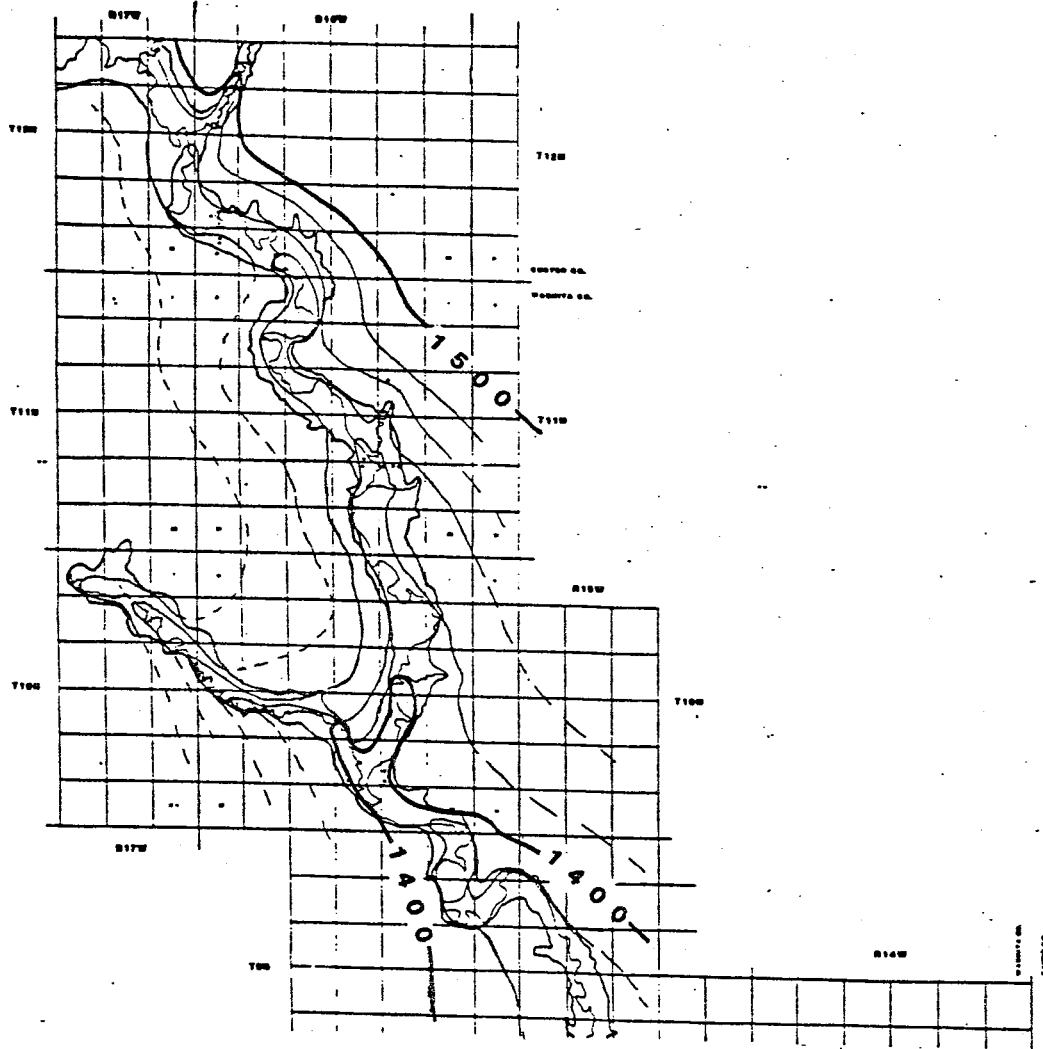
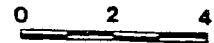


Figure 9. Water Table Map,

Subreach A, Reach 2.



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Cl. = 20 ft.

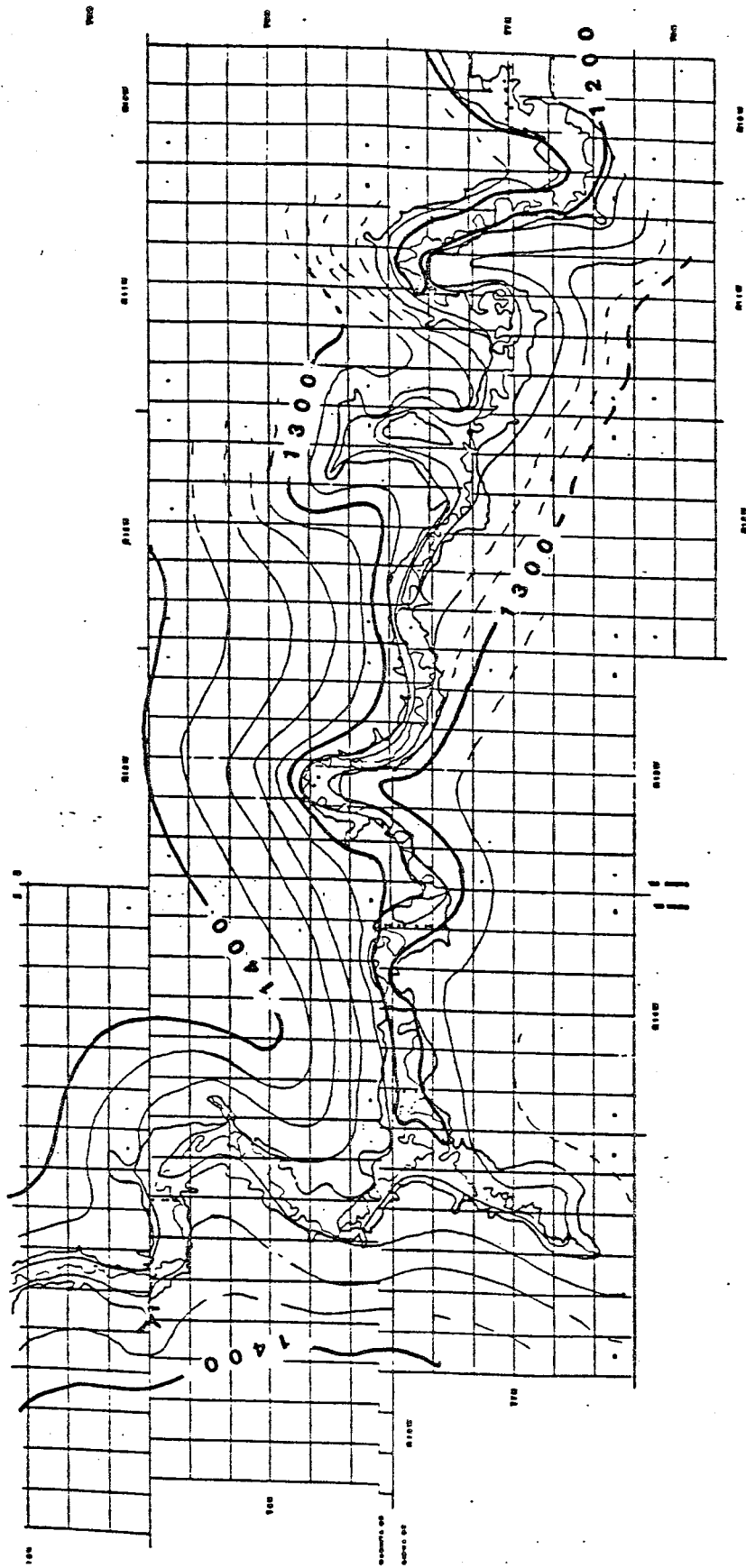
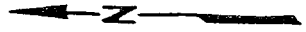


Figure 10. Water Table Map,

Subreach B, Reach 2.

Cl. = 20ft.



miles

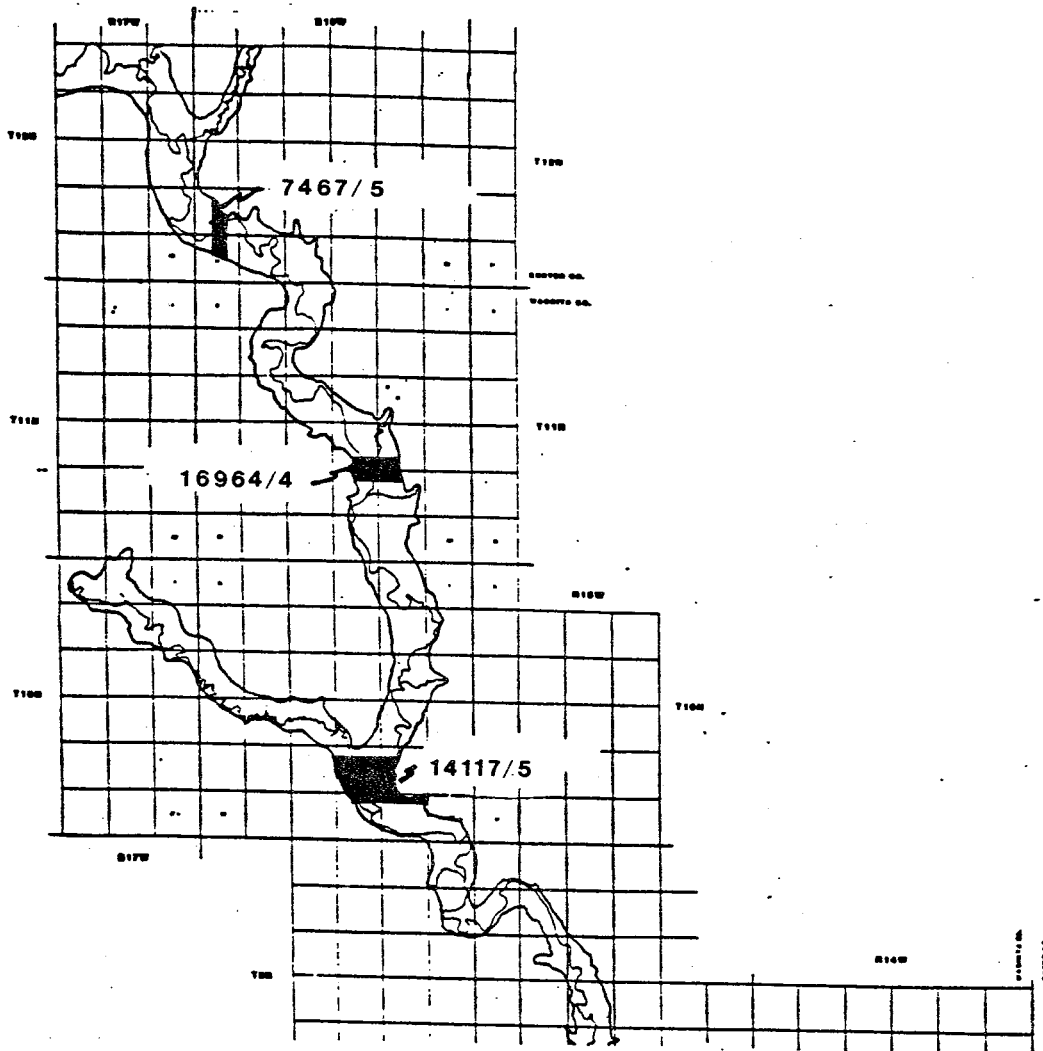
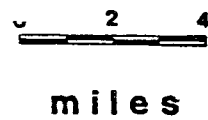


Figure 11. Saturated Thickness Map,

Subreach A, Reach 2.



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

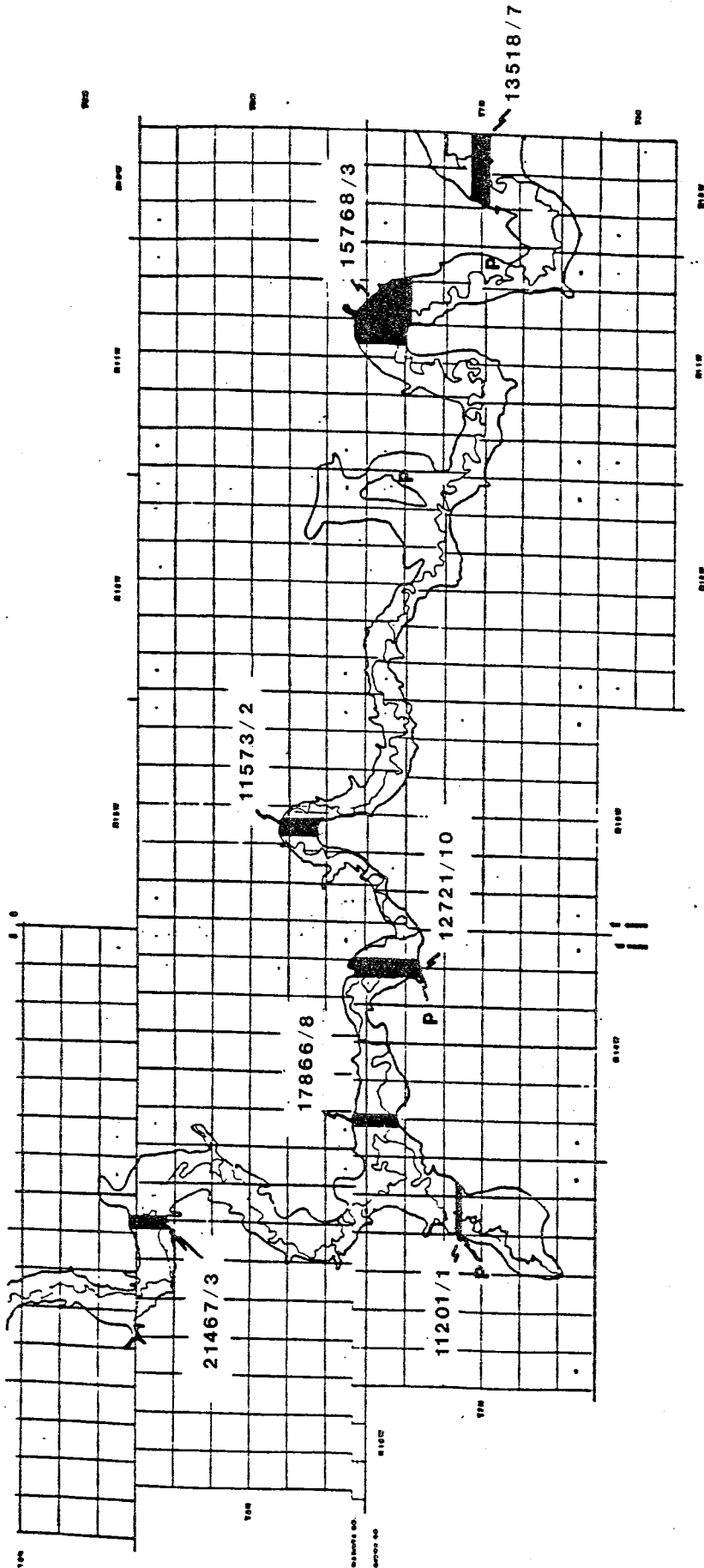


Figure 12. Saturated Thickness Map,

Subreach B, Reach 2.



miles

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

P - Prior Rights: Alluvium only

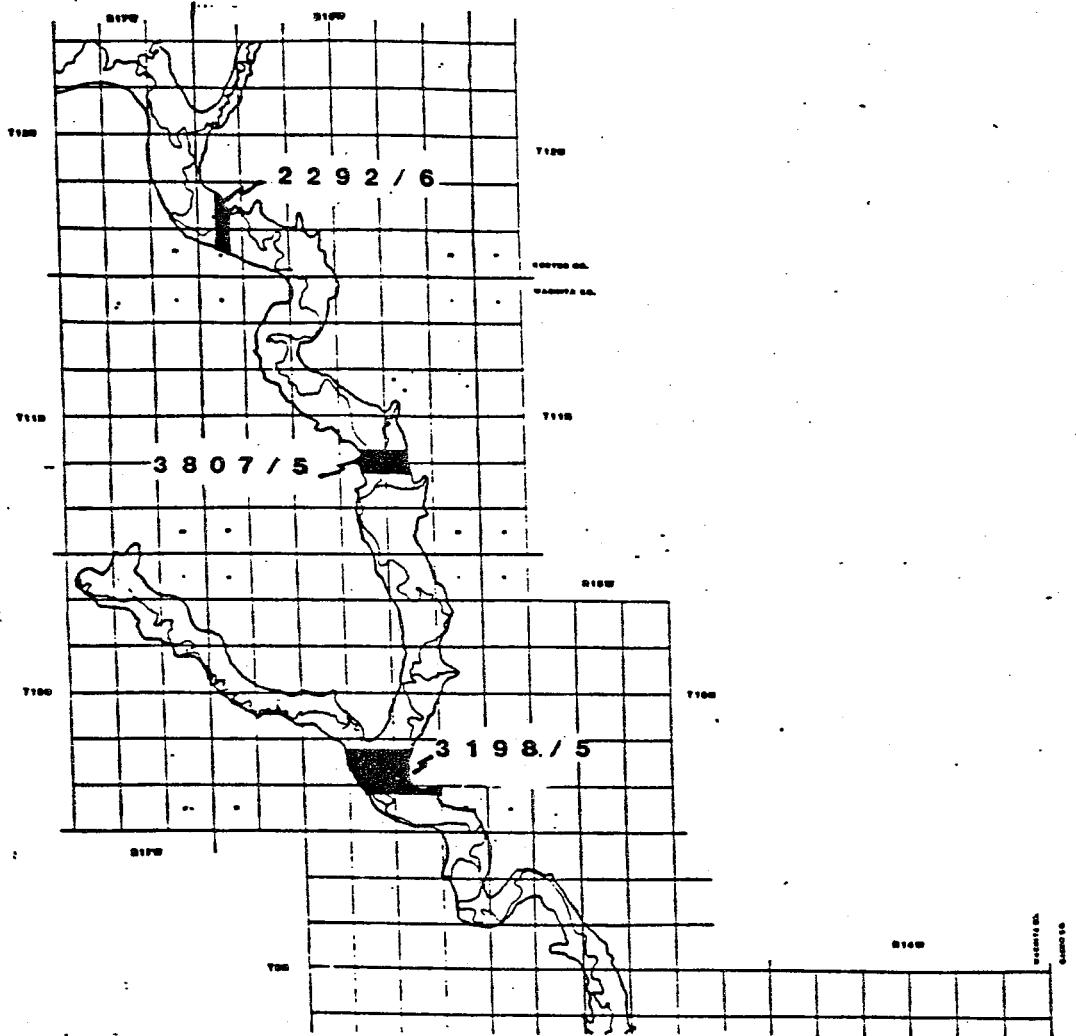


Figure 13. Transmissivity,

Subreach A, Reach 2.

0 2 4
 miles

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

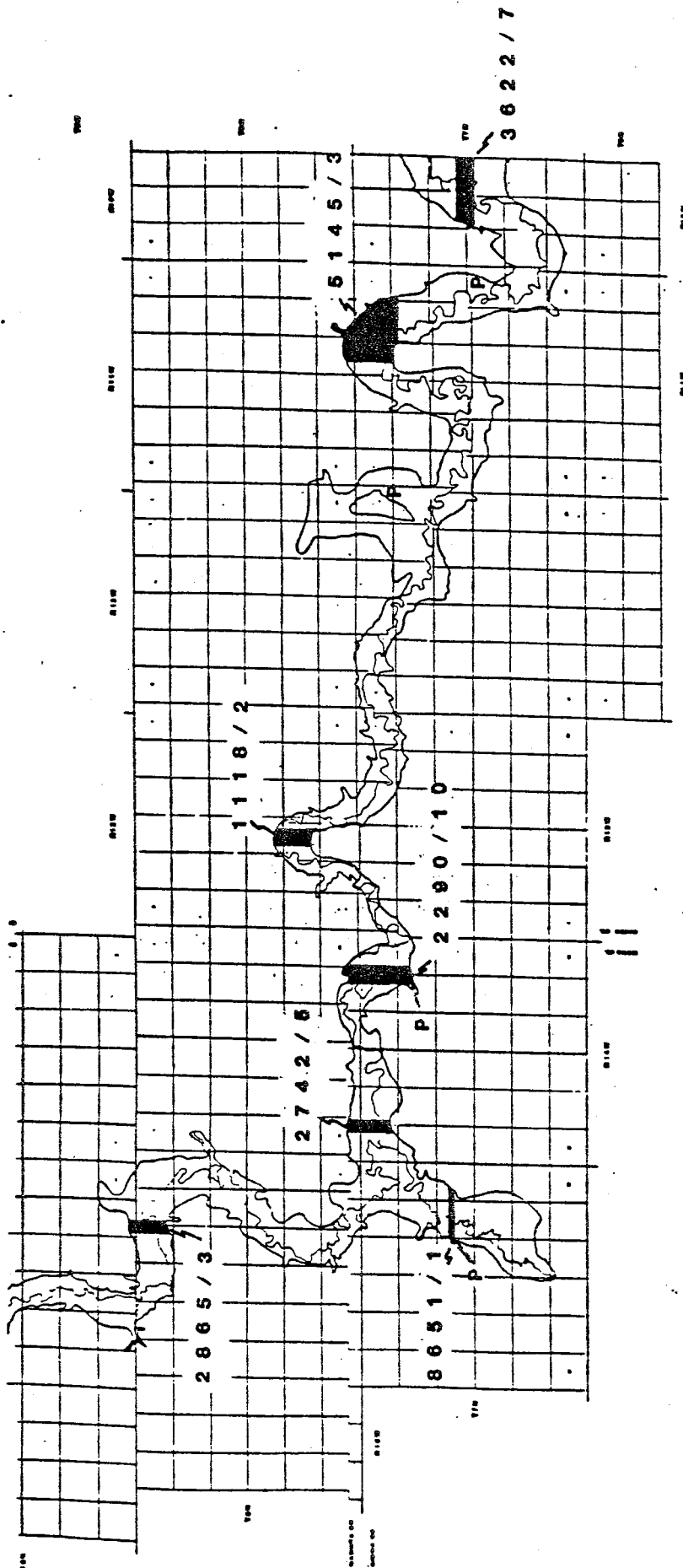
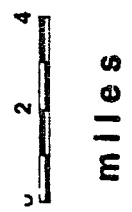


Figure 14. Transmissivity,
Subreach B, Reach 2.



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

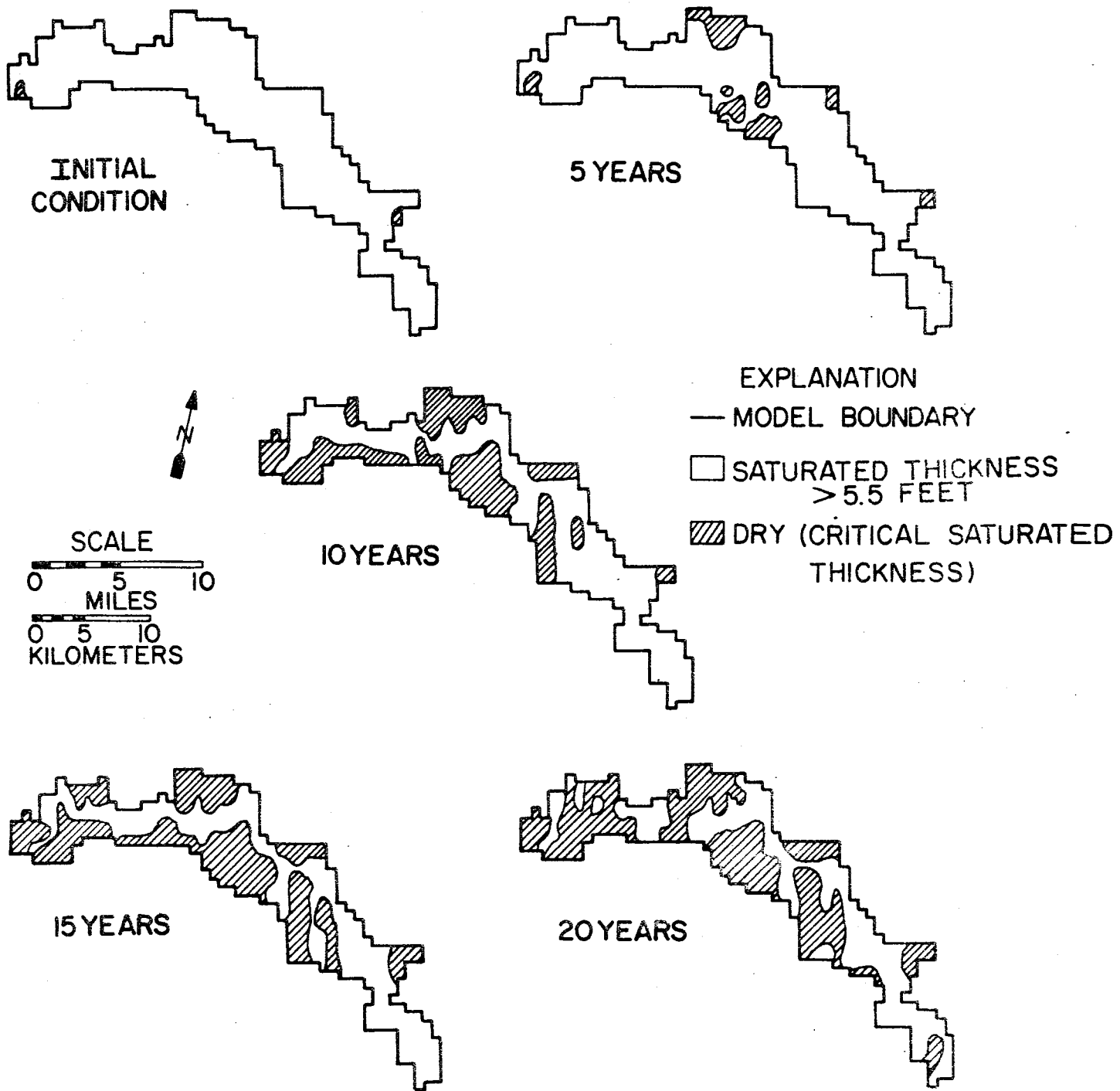


Figure 15. THE CRITICAL SATURATED THICKNESS FOR THE WASHITA RIVER ALLUVIUM BETWEEN ANADARKO AND ALEX, OKLAHOMA.

(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/ft², 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 in 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 preceding, 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 constituents map in Figure 18 represent patterns of occurrence which can be generalized for large portions of the study area.

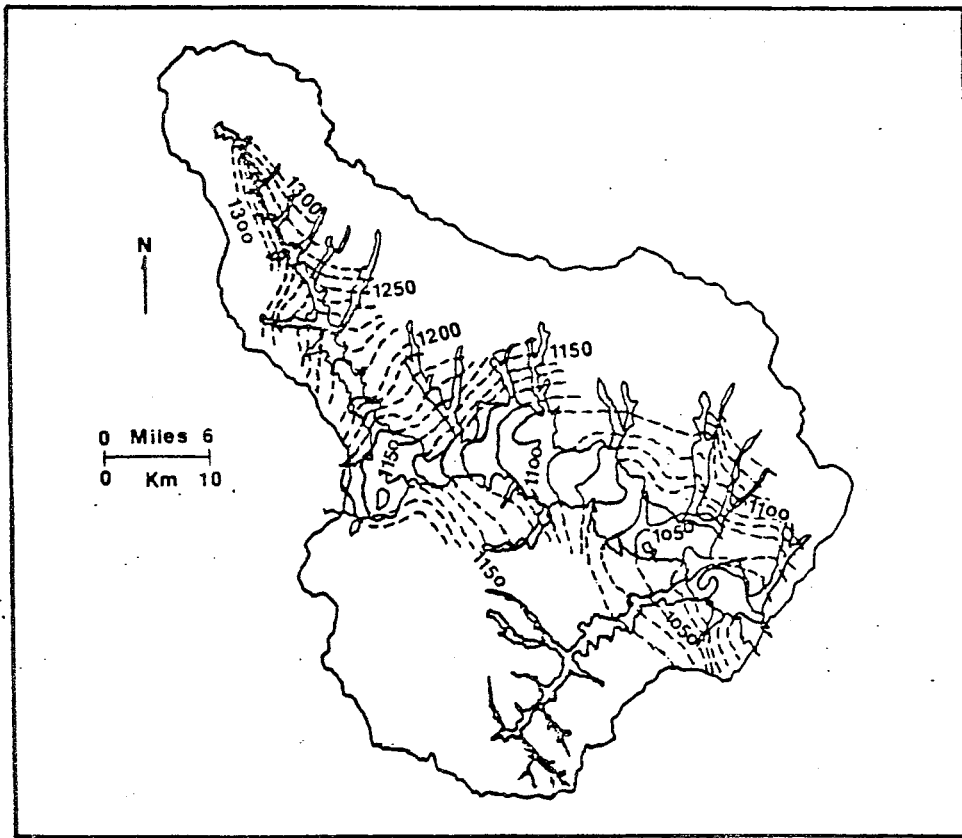


Figure 16. Water Table Map,
Modeled Reach 3.
(after Silka, 1975)

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	1978	1983	1988	1993	
67	38	16	0	2.3	19.5	47.0	52.0
		7					
		6					

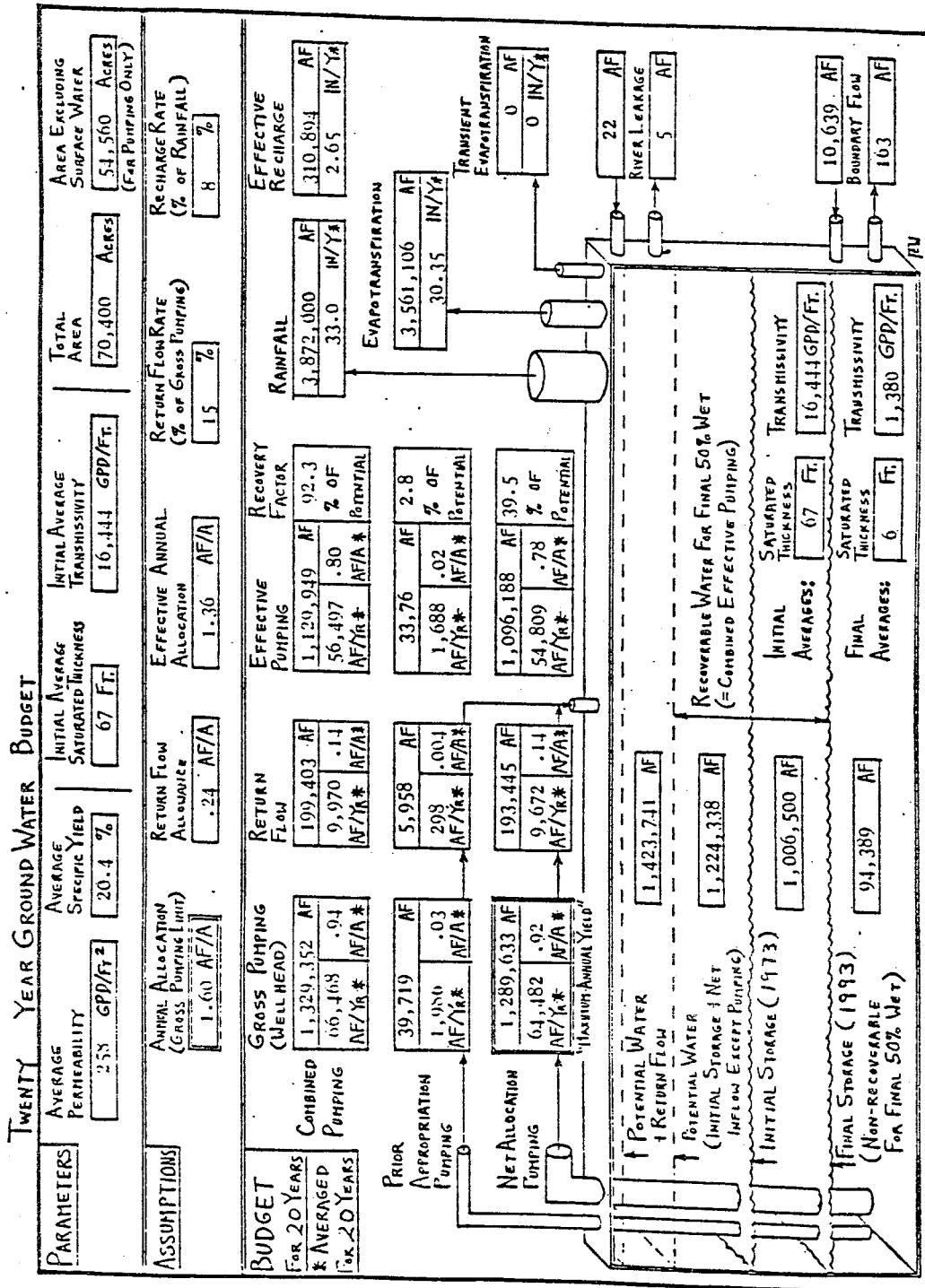


Figure 17. Ground-water Budget For Modeled Reach 3.

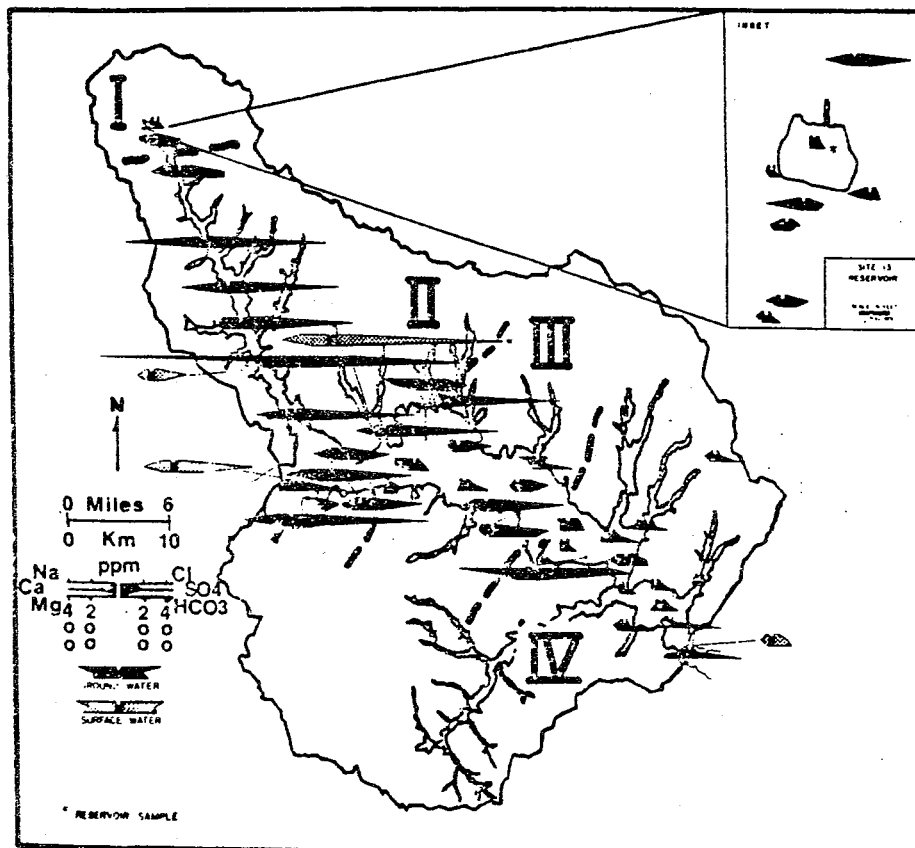


Figure 18. Ground-Water Quality Analyses For Modeled Reach 3.
(after Silka, 1975)

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 alluvium 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/ft² 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 preceding

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					Percent Dry Aquifer Area				
	Modeled Reach 4									
	Saturated Thickness					Saturated 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

YEAR GROUND WATER BUDGET

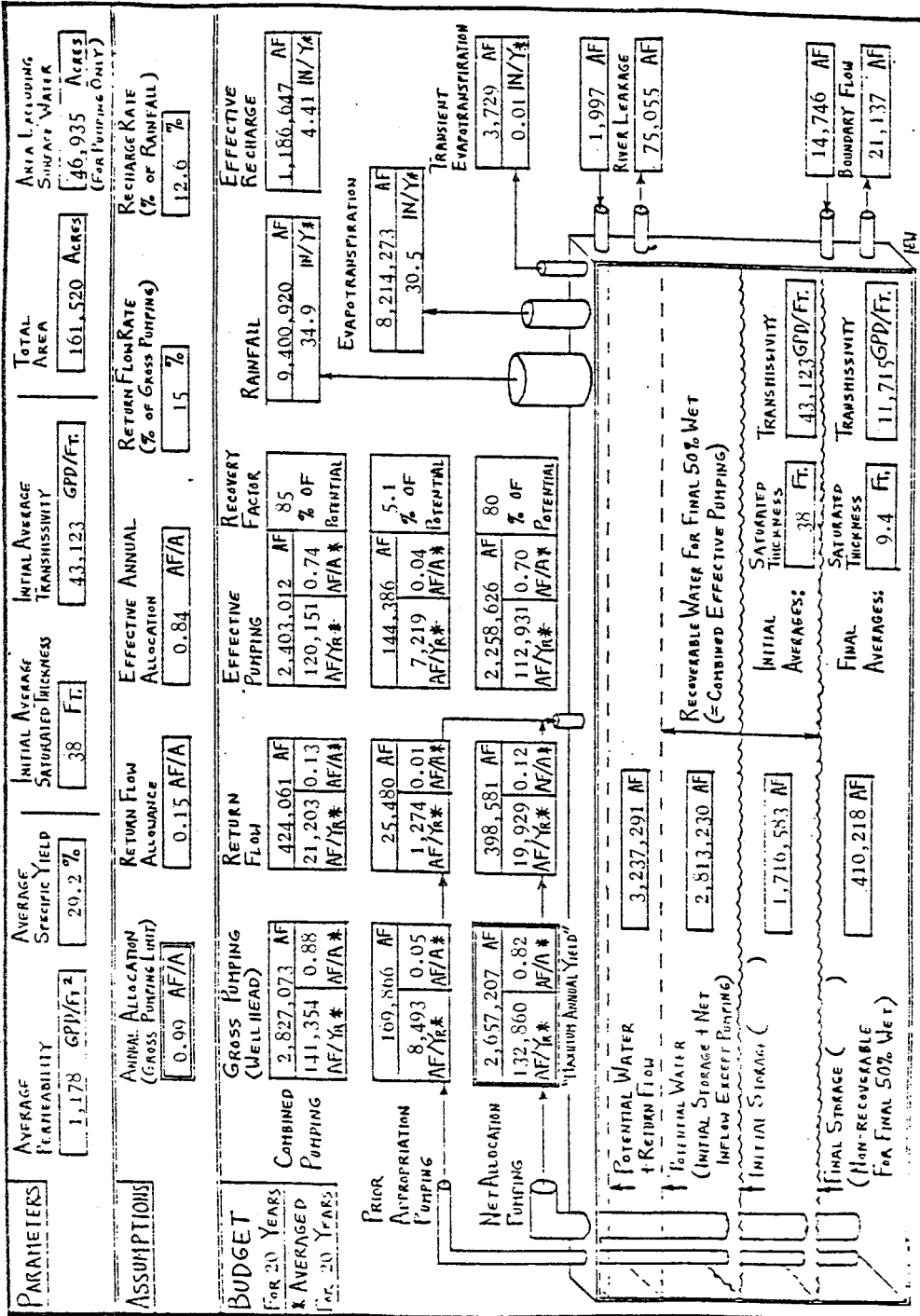


Figure 19. Ground-water Budget For Modeled Reach 4.

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	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		
Allocation ac-ft/ac/yr		Upper Reach	Middle Reach	Lower Reach	Total area, A, B, and C	
	0.882	1.14	1.20	0.99	1.0	

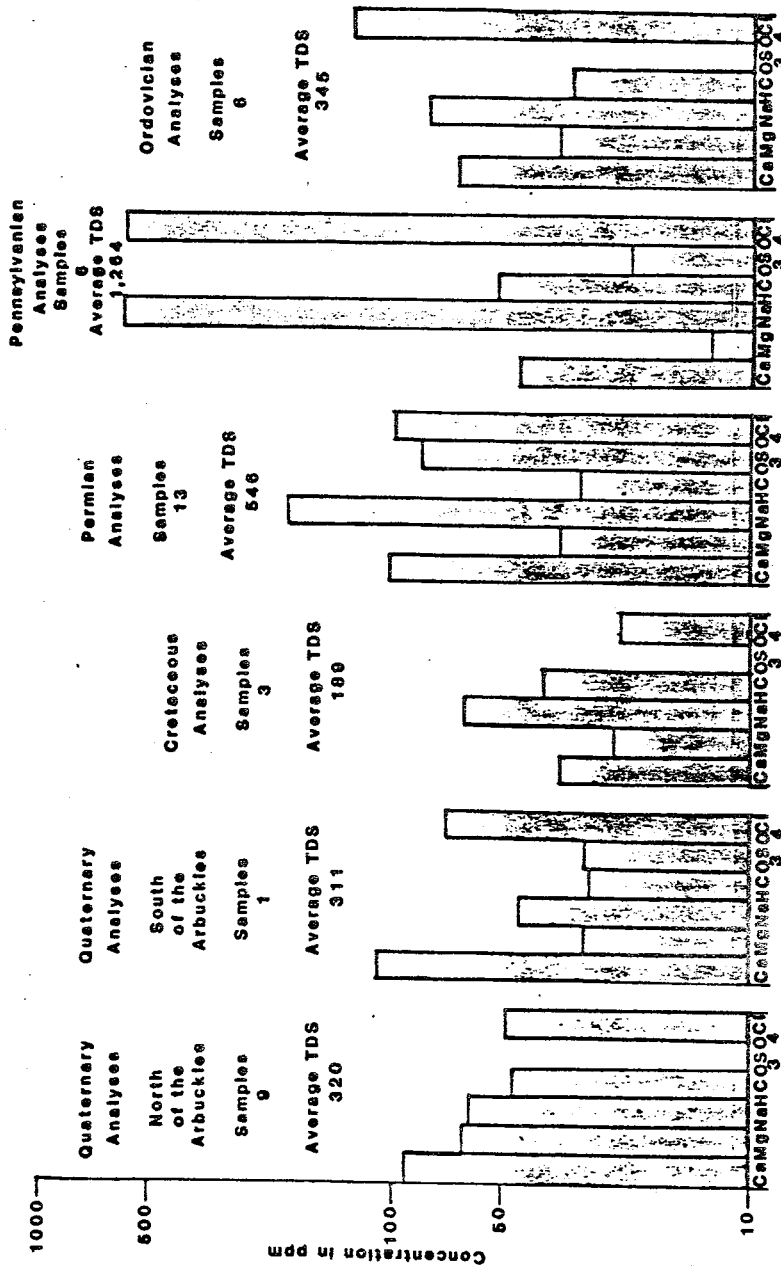


Figure 20. Ground-Water Quality Analyses For Modeled Reach 4.

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 *	≈ 2.0	= 0.442
Reach 2 Subreach A	4,160	296,240	$\frac{4,160}{296,240}$	1.4 *	≈ 1.50	= 0.022
Reach 3 (Neafus)	70,400	296,240	$\frac{70,400}{296,240}$	23.7 *	≈ 1.50	= 0.380
Reach 4 (Patterson)	161,520	296,240	$\frac{161,520}{296,240}$	54.5 *	≈ 1.00	= 0.539

Total weighted allocation = 1.38

≈ 1.4 ac-ft/ac

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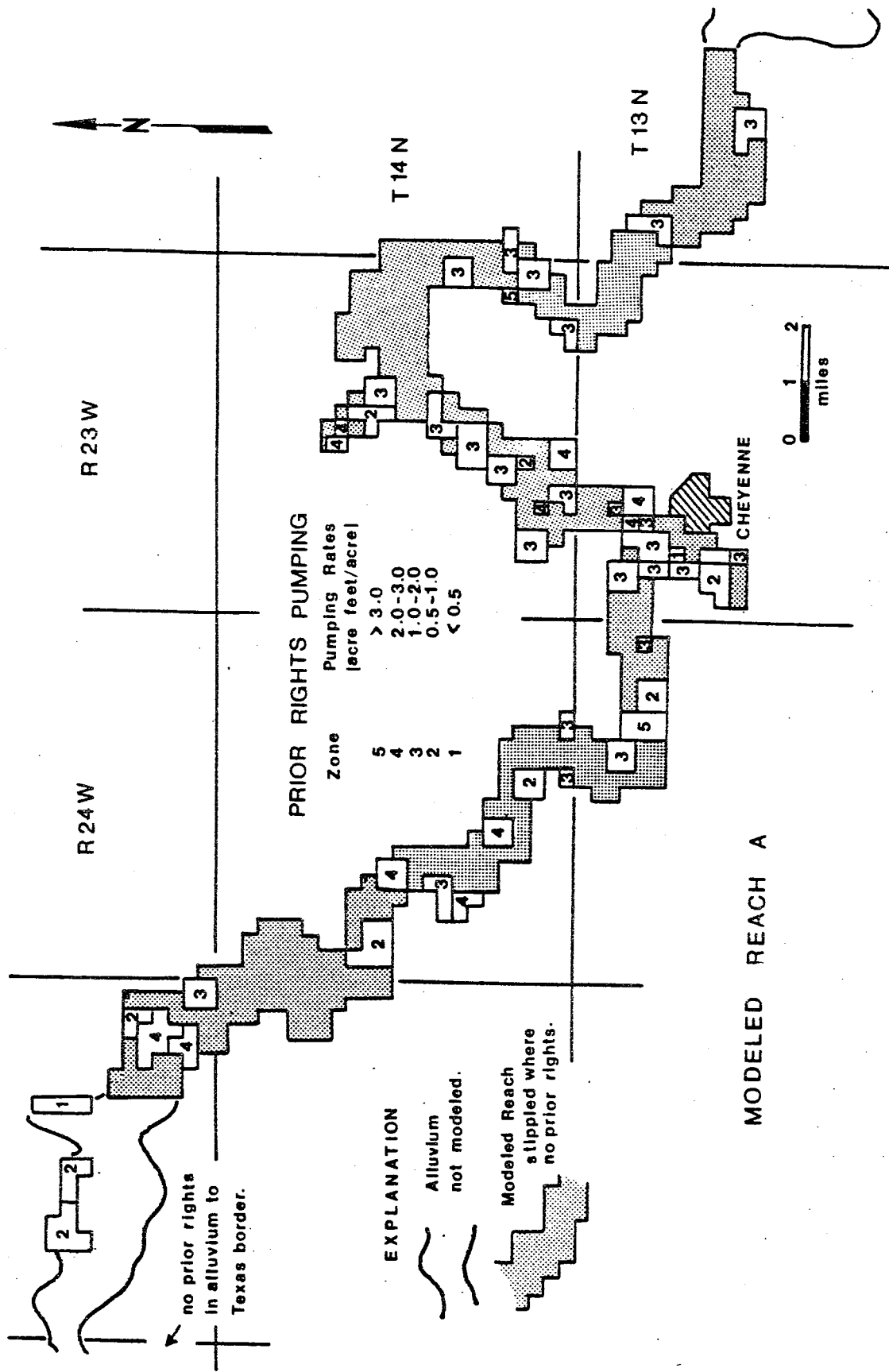
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APPENDIX
COMPUTER SIMULATION RESULTS

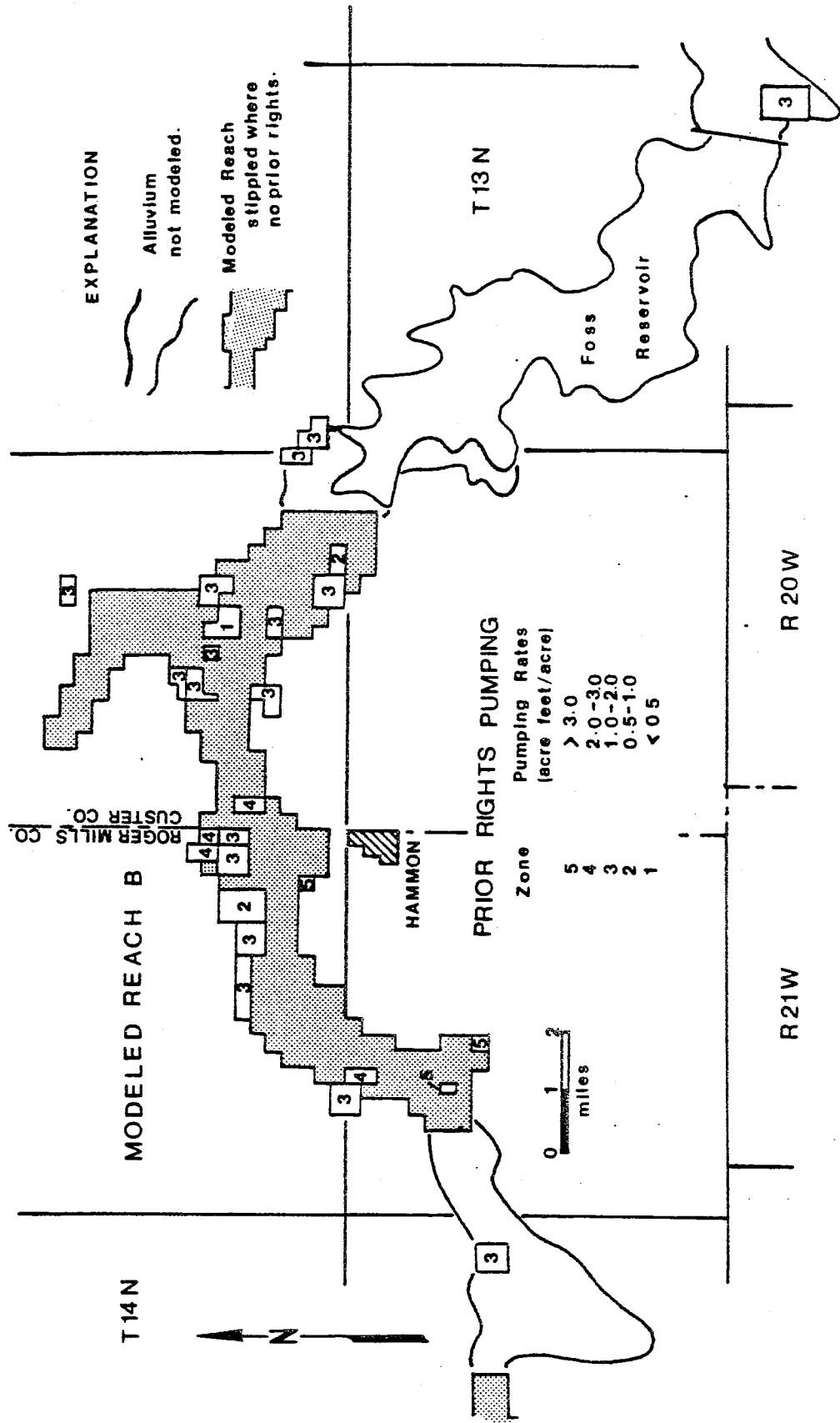
APPENDIX A

RESULTS FOR MODELLED REACH 1

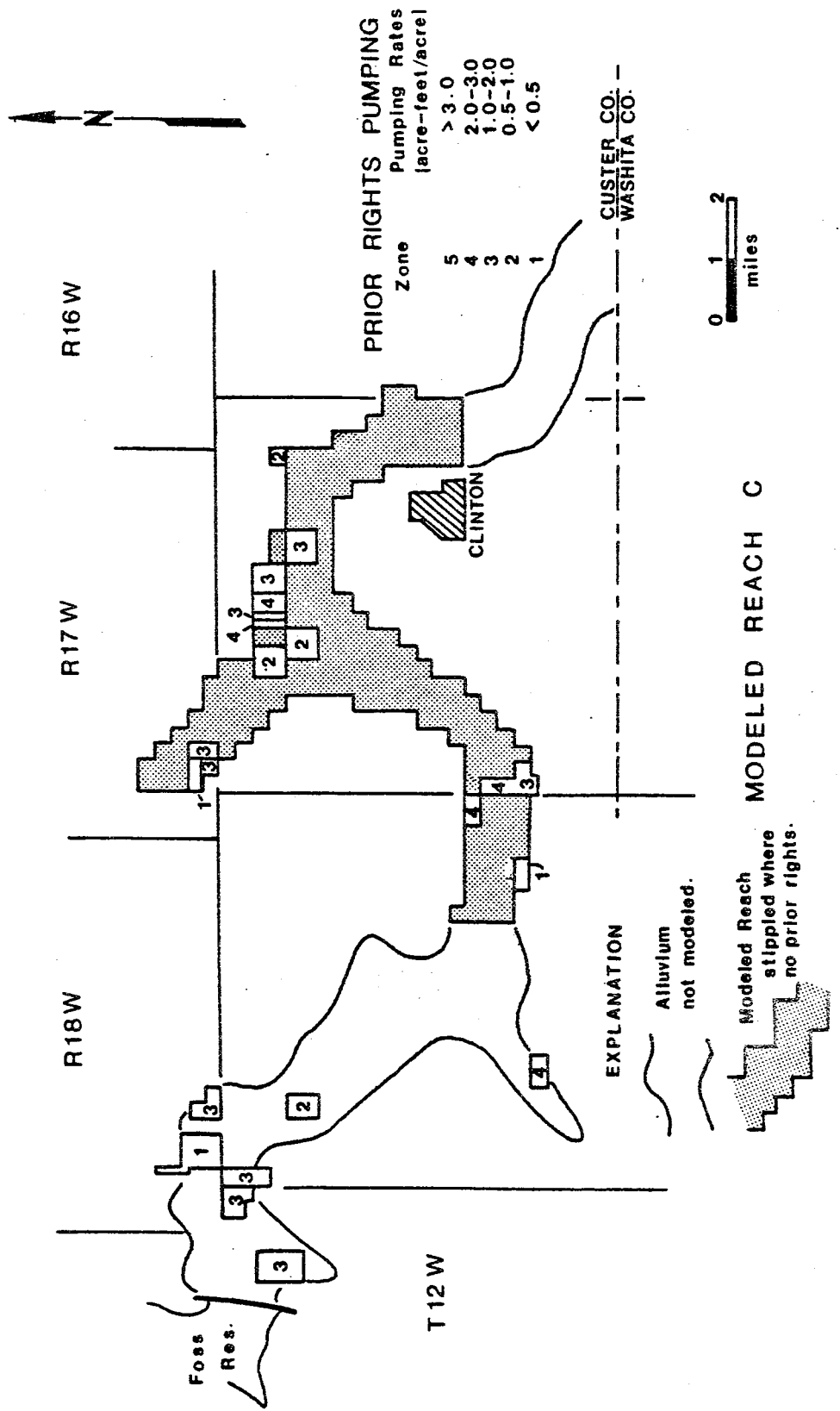
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Water Distribution Summaries.....	A-5 - A-7
Water Table Elevations.....	A-8 - A-9
Depth to Water.....	A-10 - A-13
Saturated Thickness.....	A-14 - A-17
Transmissivity.....	A-18 - A-21



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	18.5	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 (TOTAL)	100.0	19,960	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 (TOTAL)	100.0	19,960	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 (TOTAL)	100.0	11,600	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 (TOTAL)	100.0	11,600	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 OF TOTAL (PERCENT)	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 (TOTAL)	100.0	8,640	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

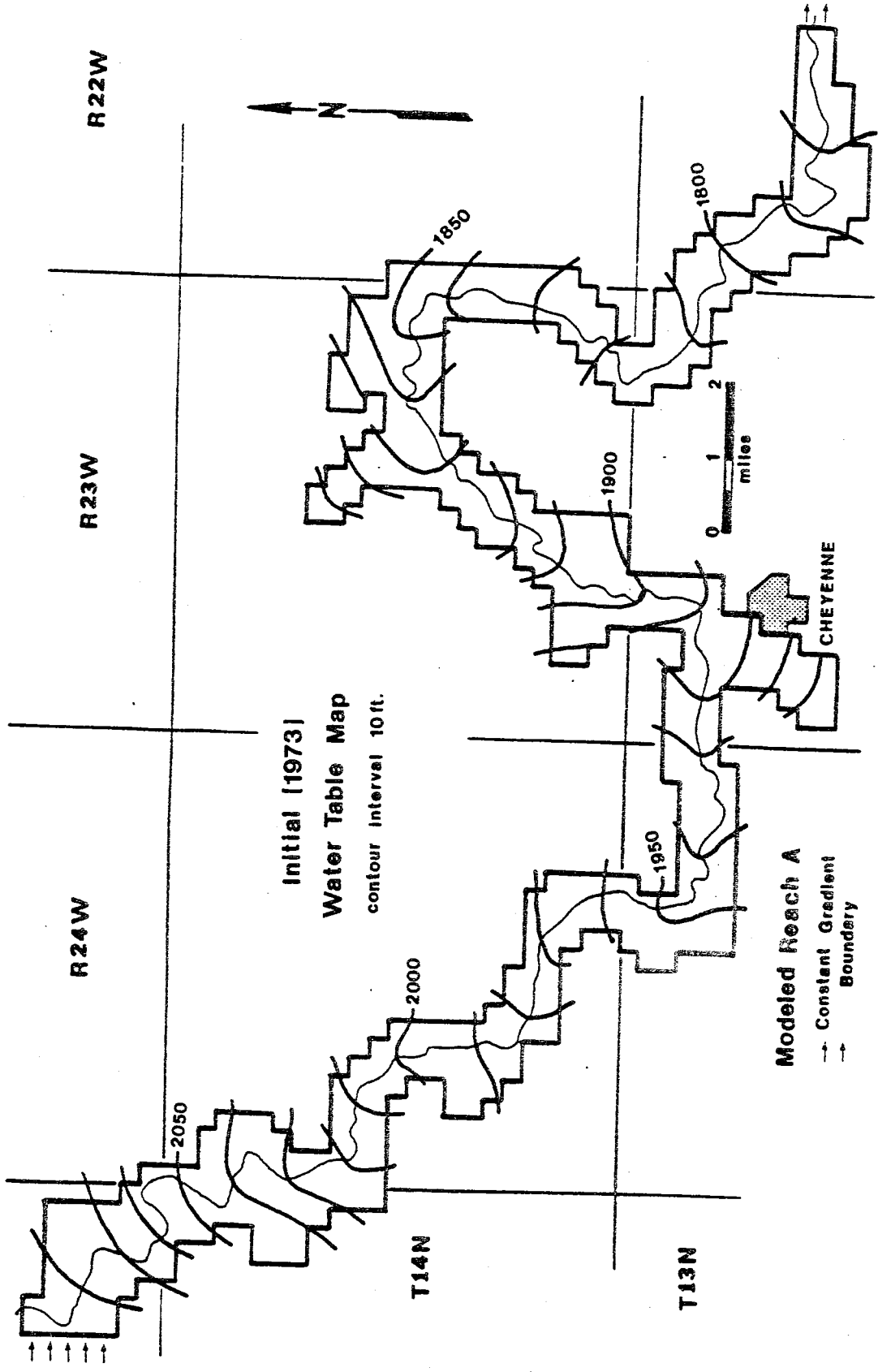
WATER DISTRIBUTION SUMMARY
 JULY 1, 1993

SATURATED THICKNESS RANGE (FEET)	AREA OF TOTAL (PERCENT)	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 (TOTAL)	100.0	8,640	11.1 (AVERAGE)	25.0 (AVERAGE)	23,919 (TOTAL)

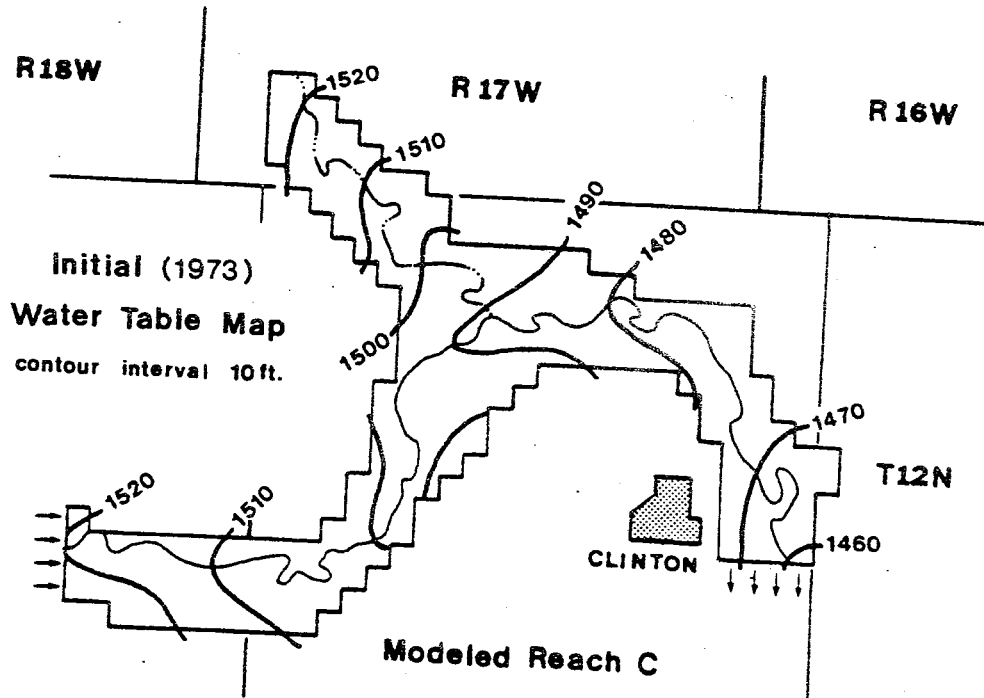
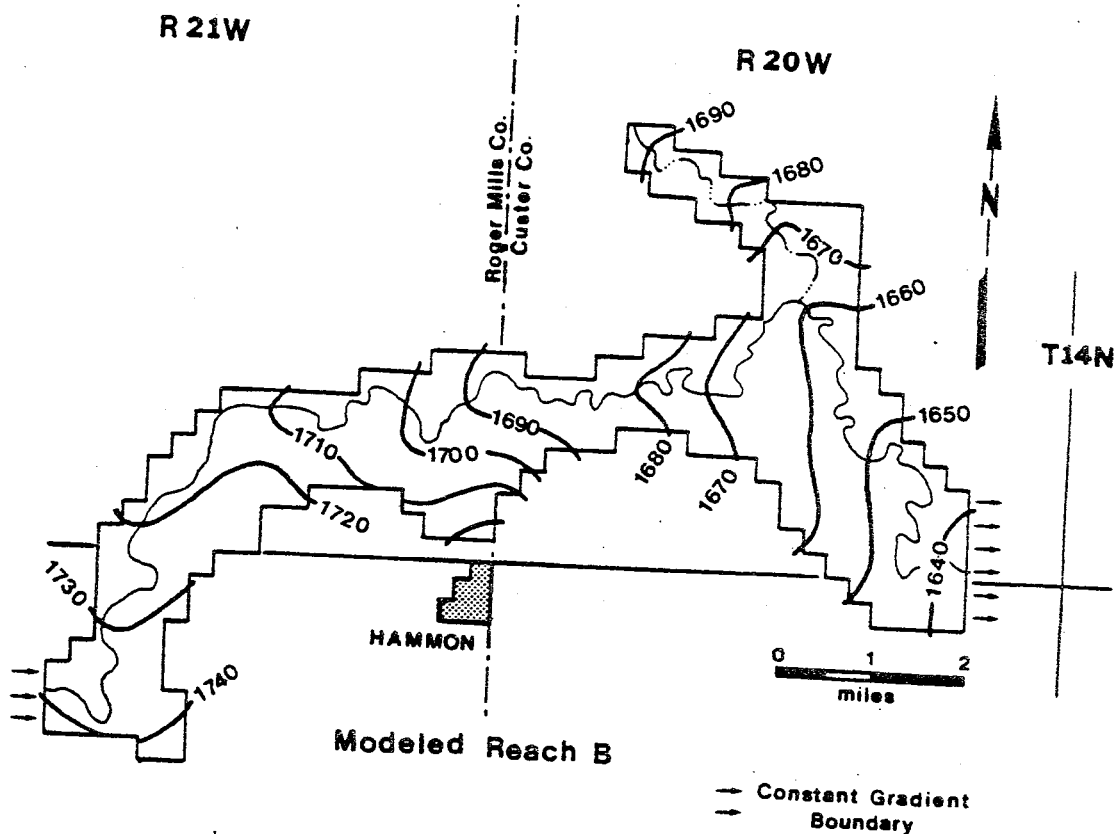
DATA FROM:
 A820902.0311 ALLOC=1.75AF/A;RATE=170GPD*.075;M=330;RIVER+1;RECH 3.4

Water Distribution Summaries,

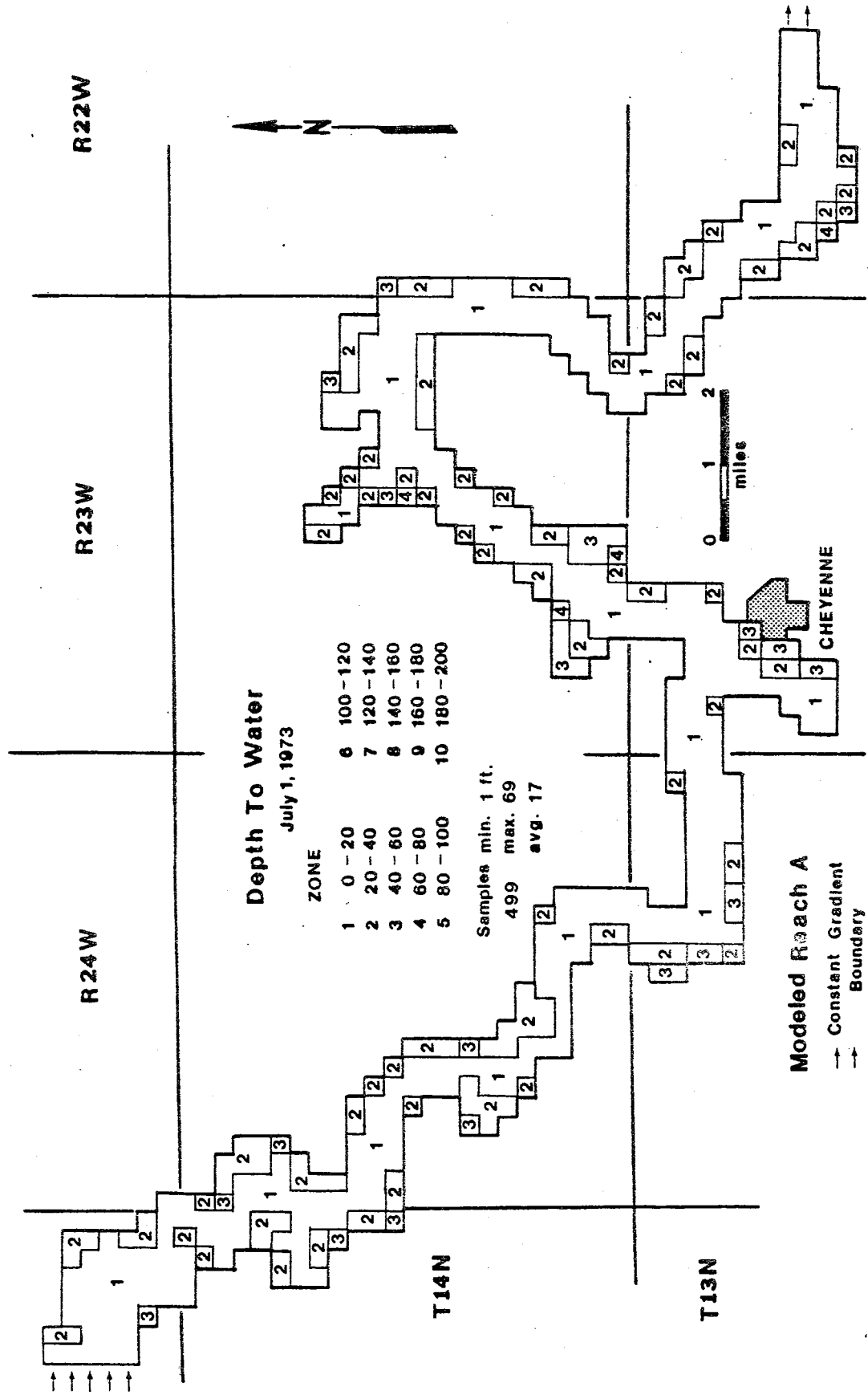
Subreach C, Modeled Reach 1.



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

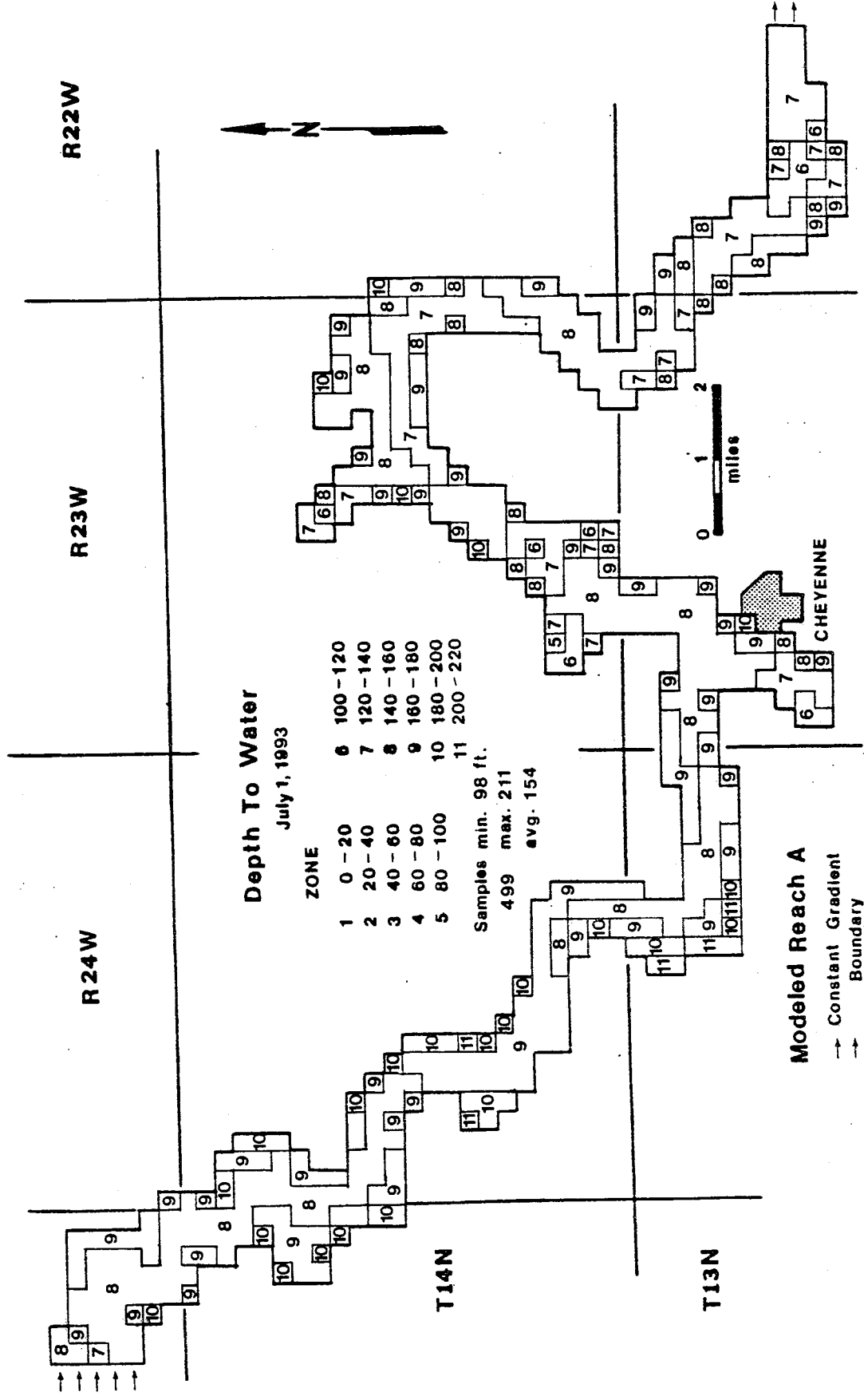
ZONE	1	2	3	4	5	6	7	8	9	10
	0 - 20	20 - 40	40 - 60	60 - 80	80 - 100	100 - 120	120 - 140	140 - 160	160 - 180	180 - 200

Samples min. 1 ft.
499 max. 69
avg. 17

Modeled Reach A

- Constant Gradient Boundary
- - - Boundary

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



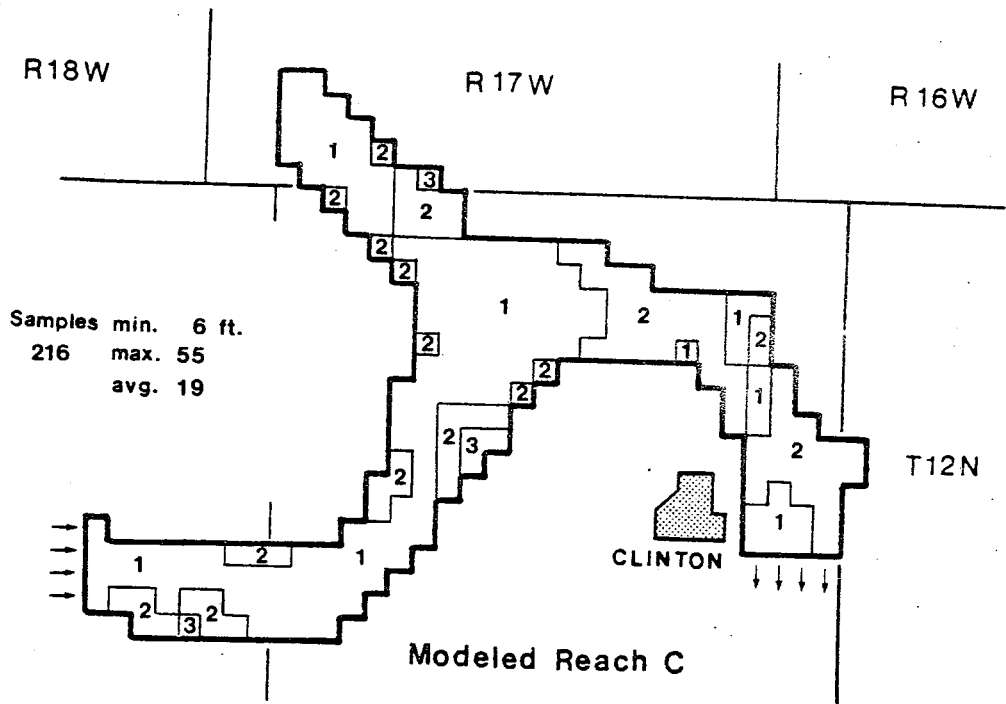
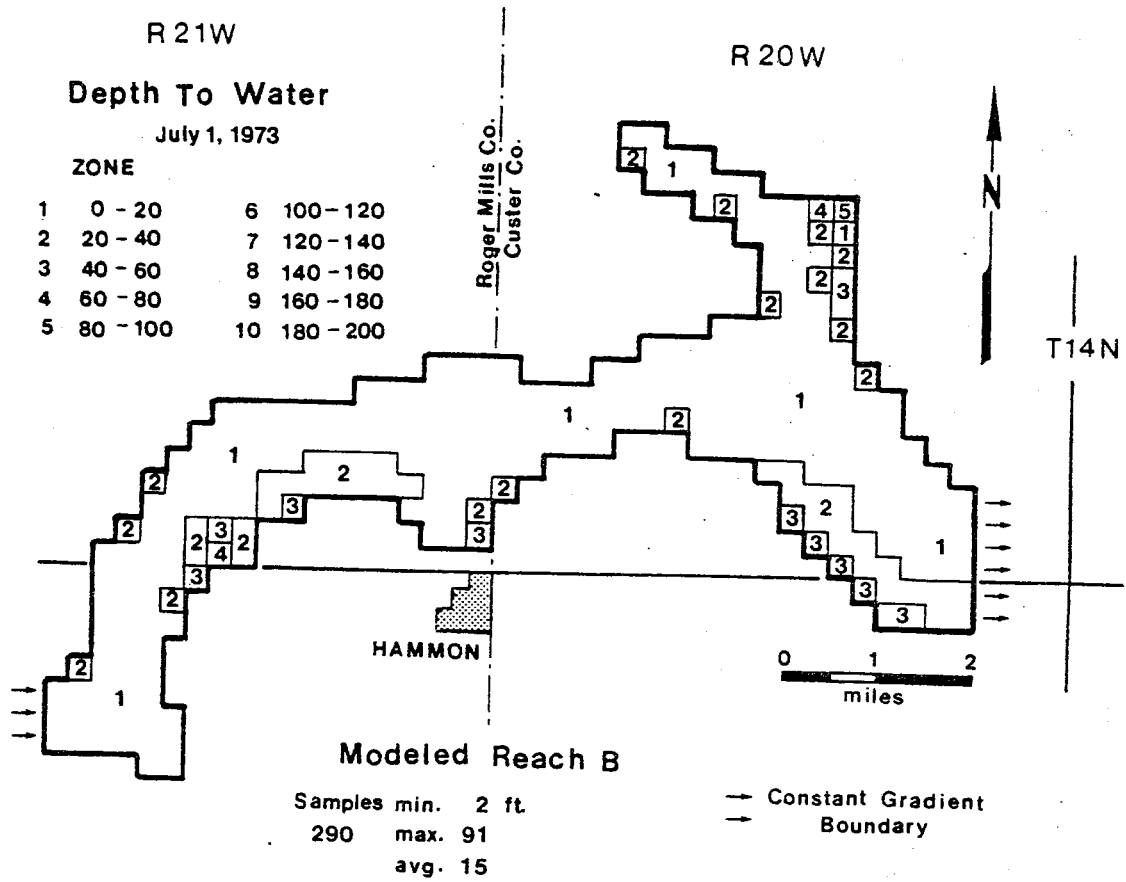
Depth To Water
July 1, 1993

ZONE	DEPTH RANGE
1	0 - 20
2	20 - 40
3	40 - 60
4	60 - 80
5	80 - 100
6	100 - 120
7	120 - 140
8	140 - 160
9	160 - 180
10	180 - 200
11	200 - 220

Samples min. 98 ft.
499 max. 211
avg. 154

Modeled Reach A
→ Constant Gradient
→ Boundary

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

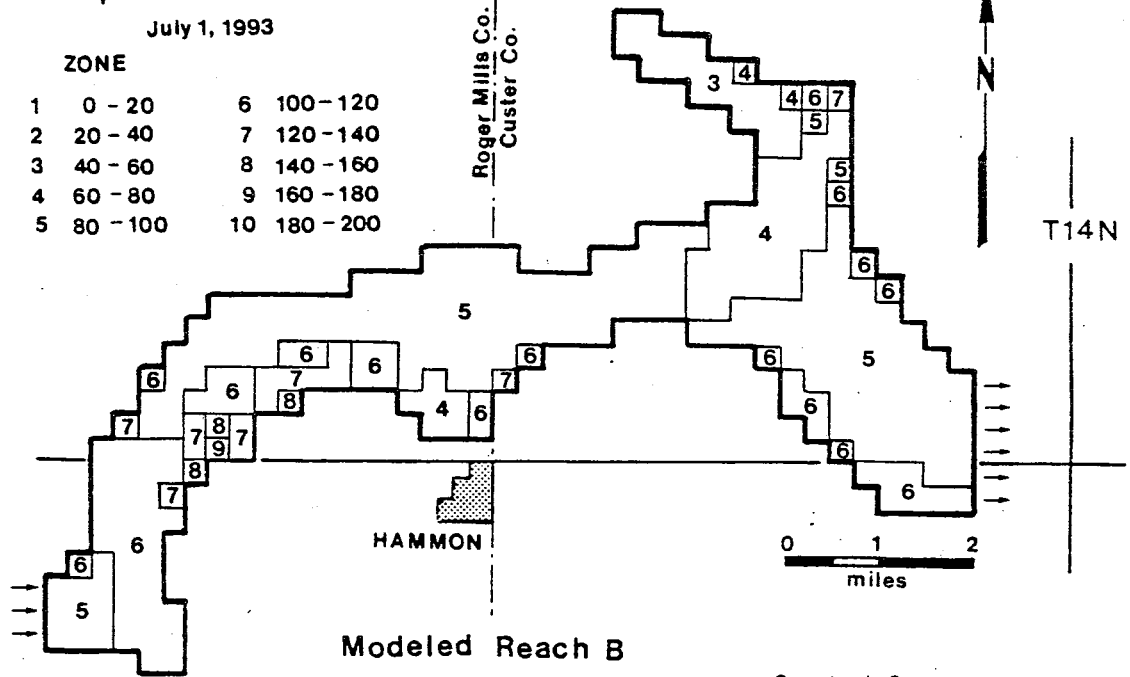


Depth to water, July 1, 1973, Subreaches B and C, Modeled Reach 1.

R 21W
Depth To Water
 July 1, 1993

ZONE

1	0 - 20	6	100 - 120
2	20 - 40	7	120 - 140
3	40 - 60	8	140 - 160
4	60 - 80	9	160 - 180
5	80 - 100	10	180 - 200



Modeled Reach B

Samples min. 45 ft
 290 max. 163
 avg. 92

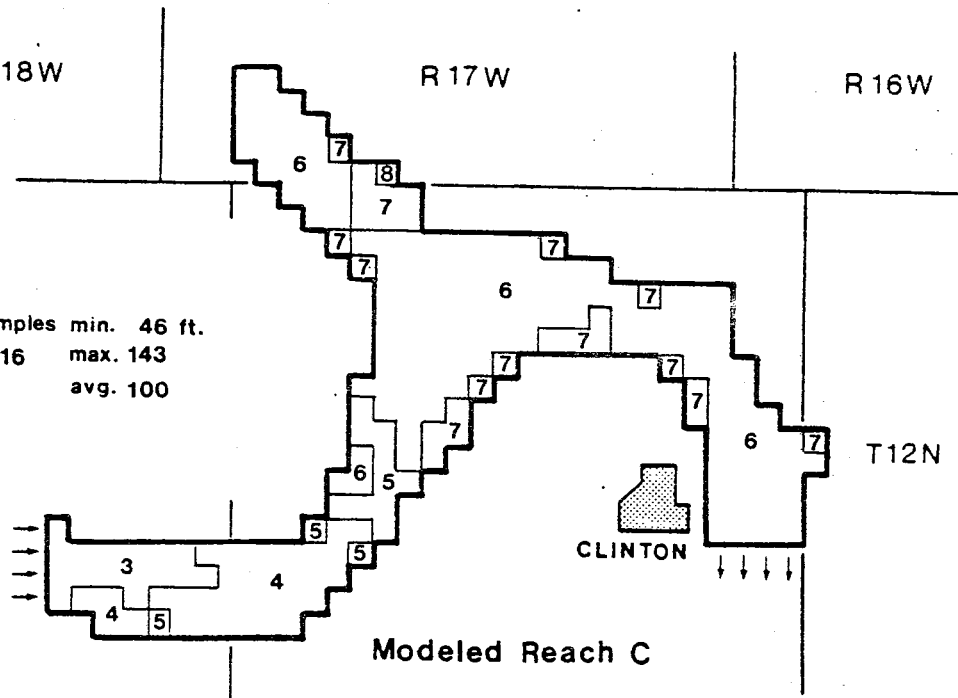
→ Constant Gradient
 → Boundary

R 18W

R 17W

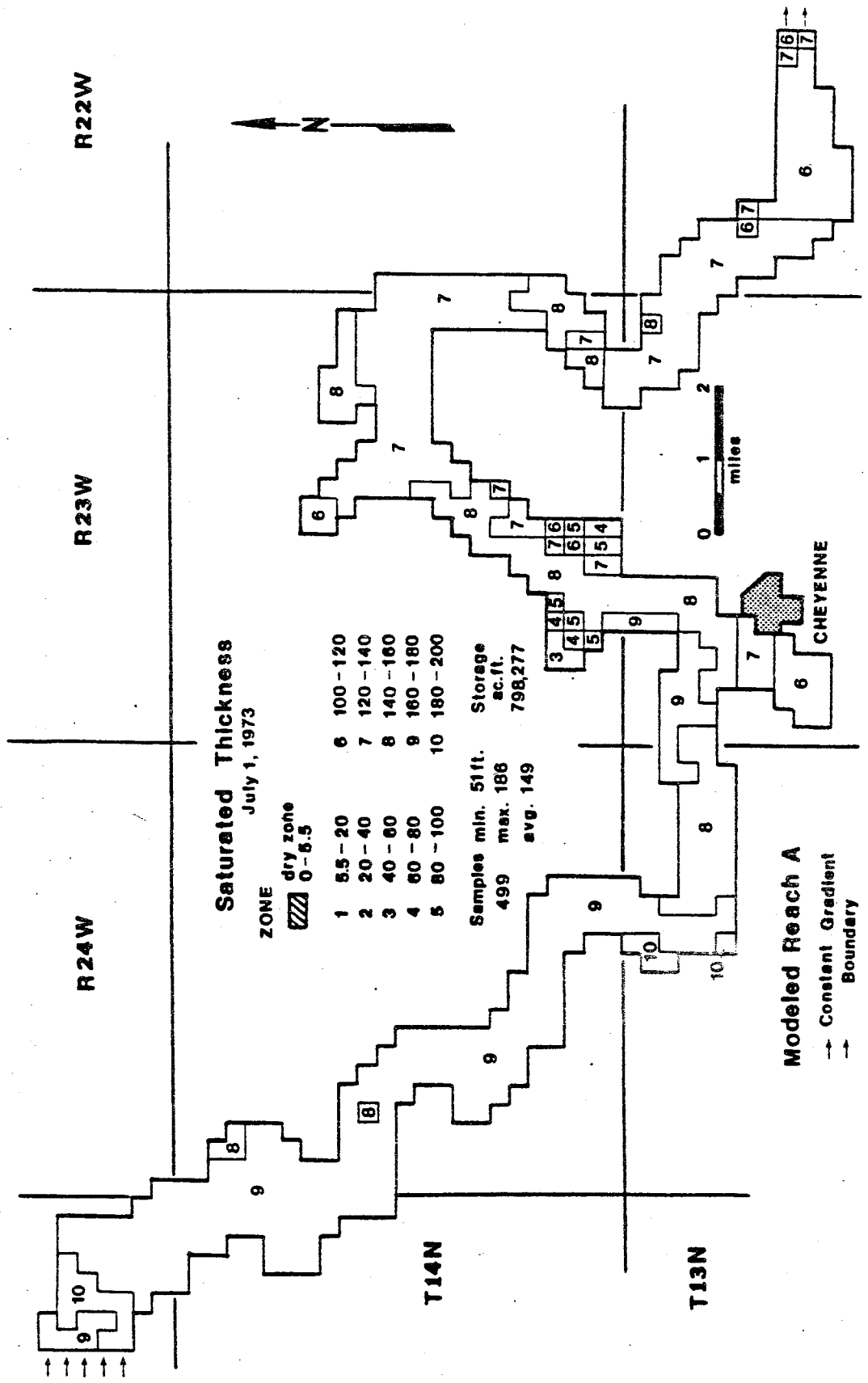
R 16W

Samples min. 46 ft.
 216 max. 143
 avg. 100

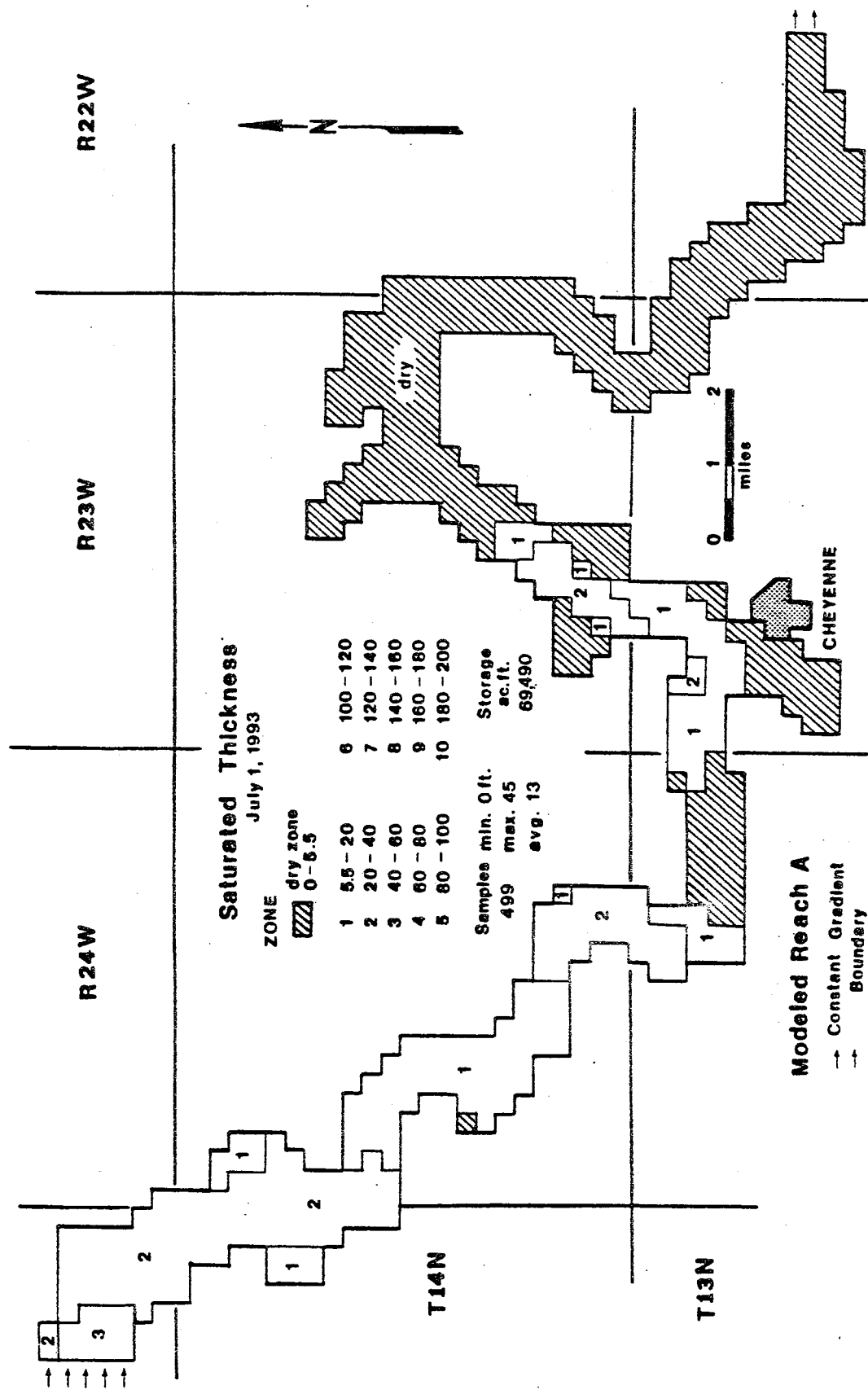


Modeled Reach C

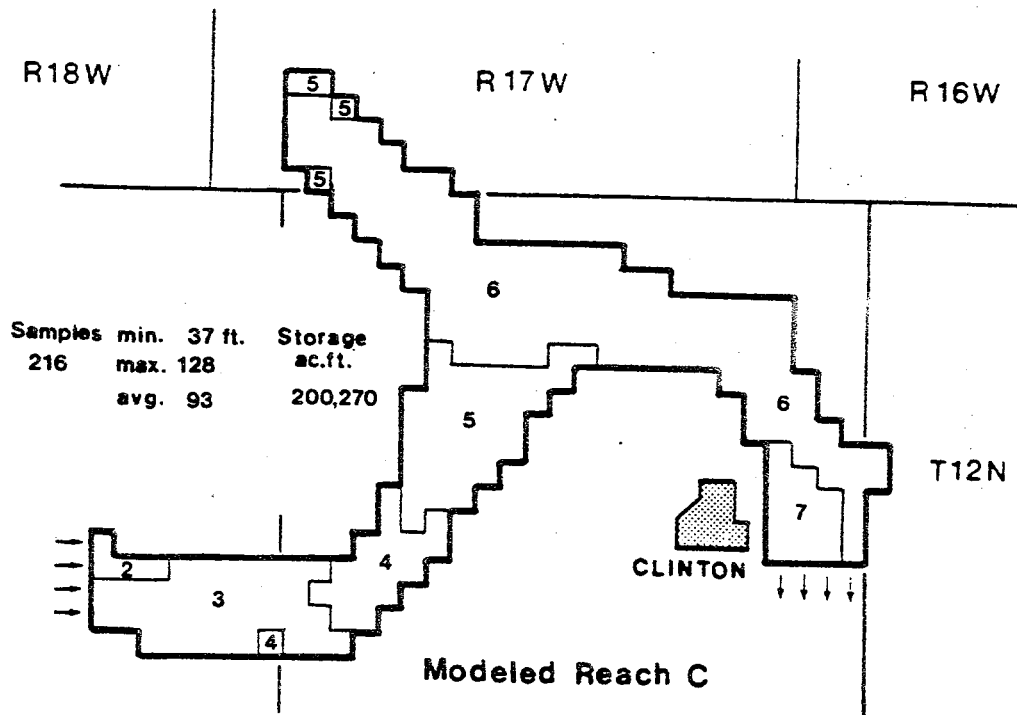
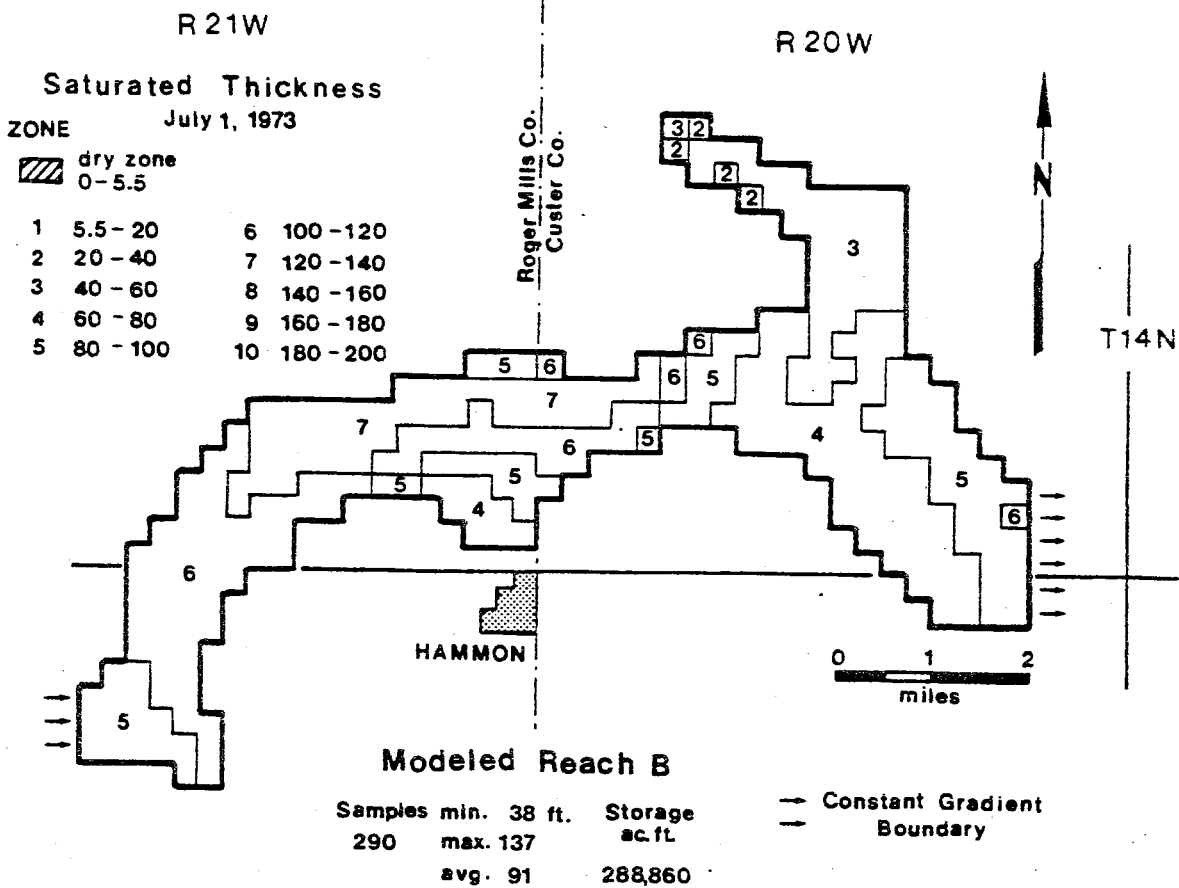
Depth to water, July 1, 1993,
 Subreaches B and C, Modeled Reach 1.



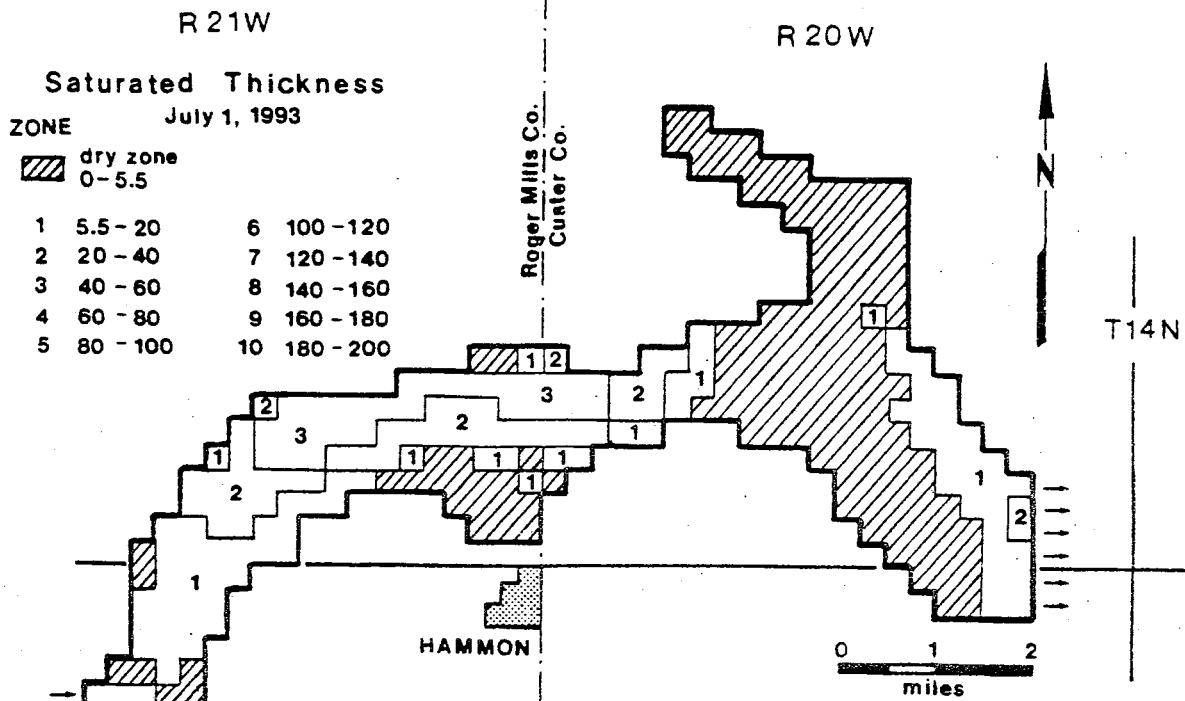
Saturated Thickness Map, July 1, 1973, Subreach A, Modeled Reach 1.



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

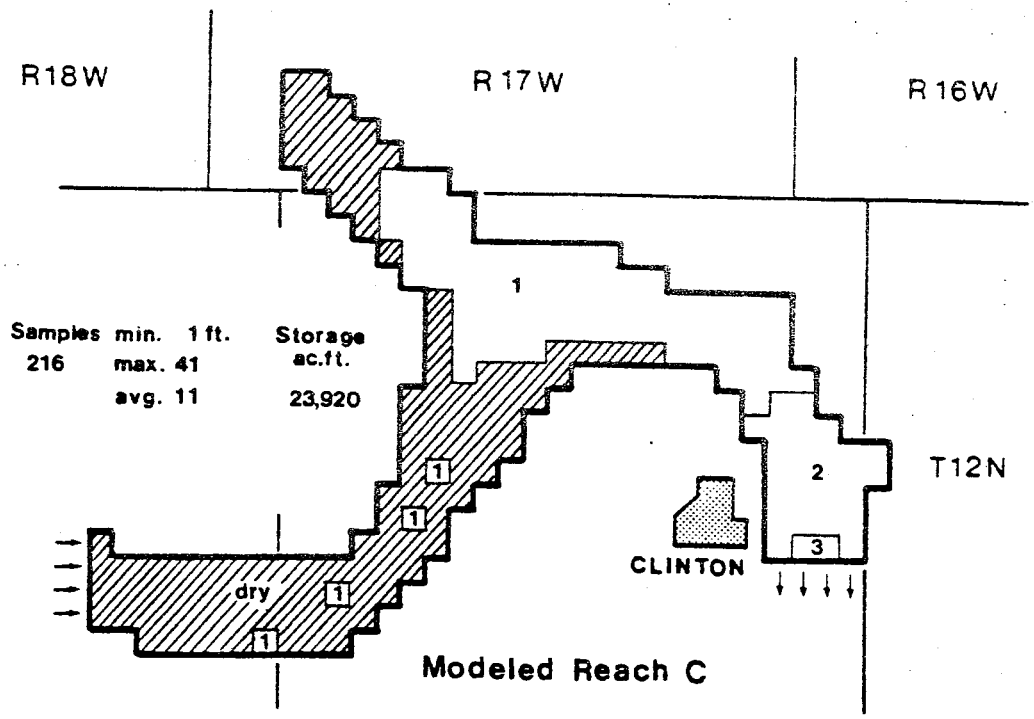


Saturated Thickness Map, July 1, 1973, Subreaches B and C, Modeled Reach 1.

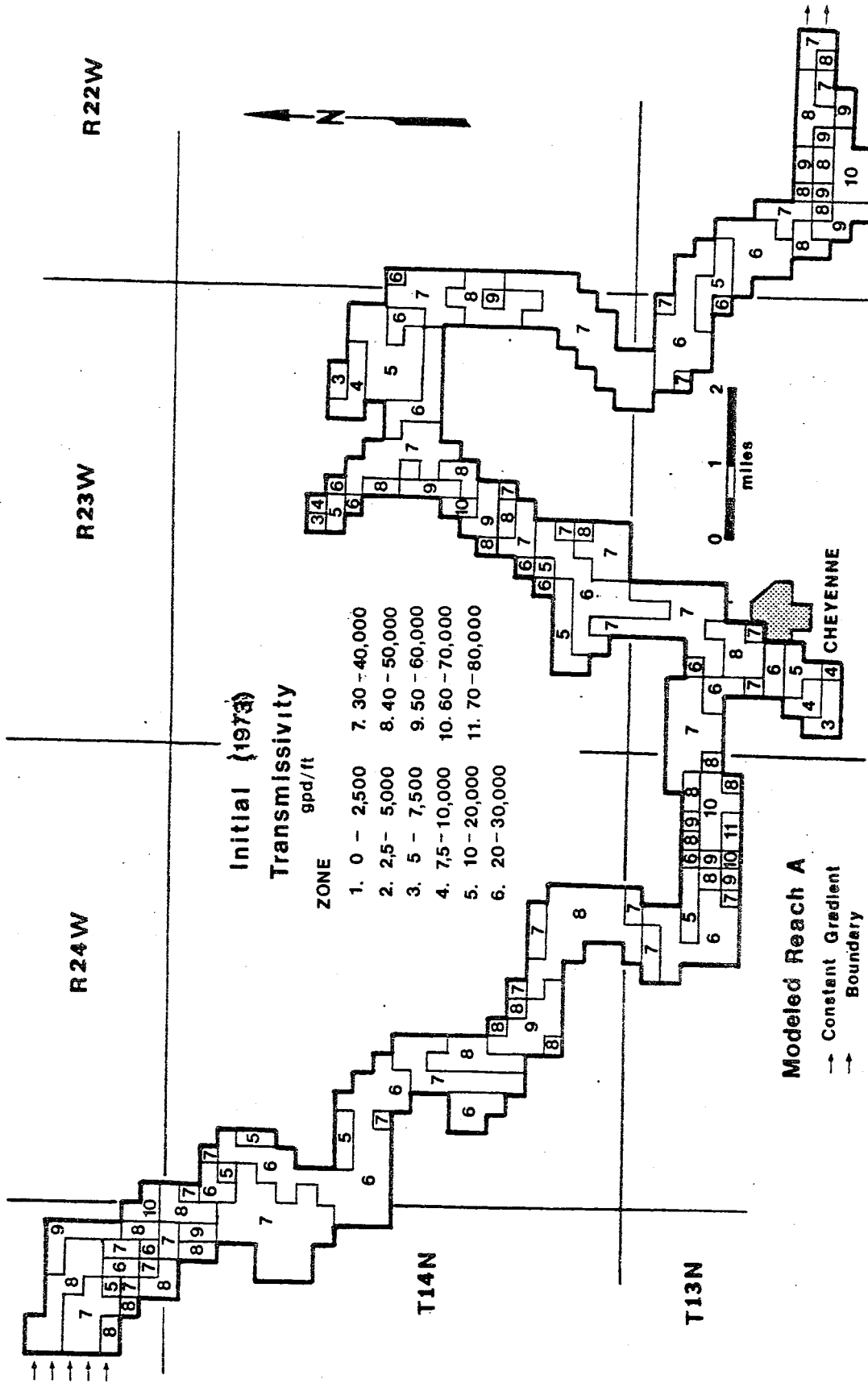


Modeled Reach B

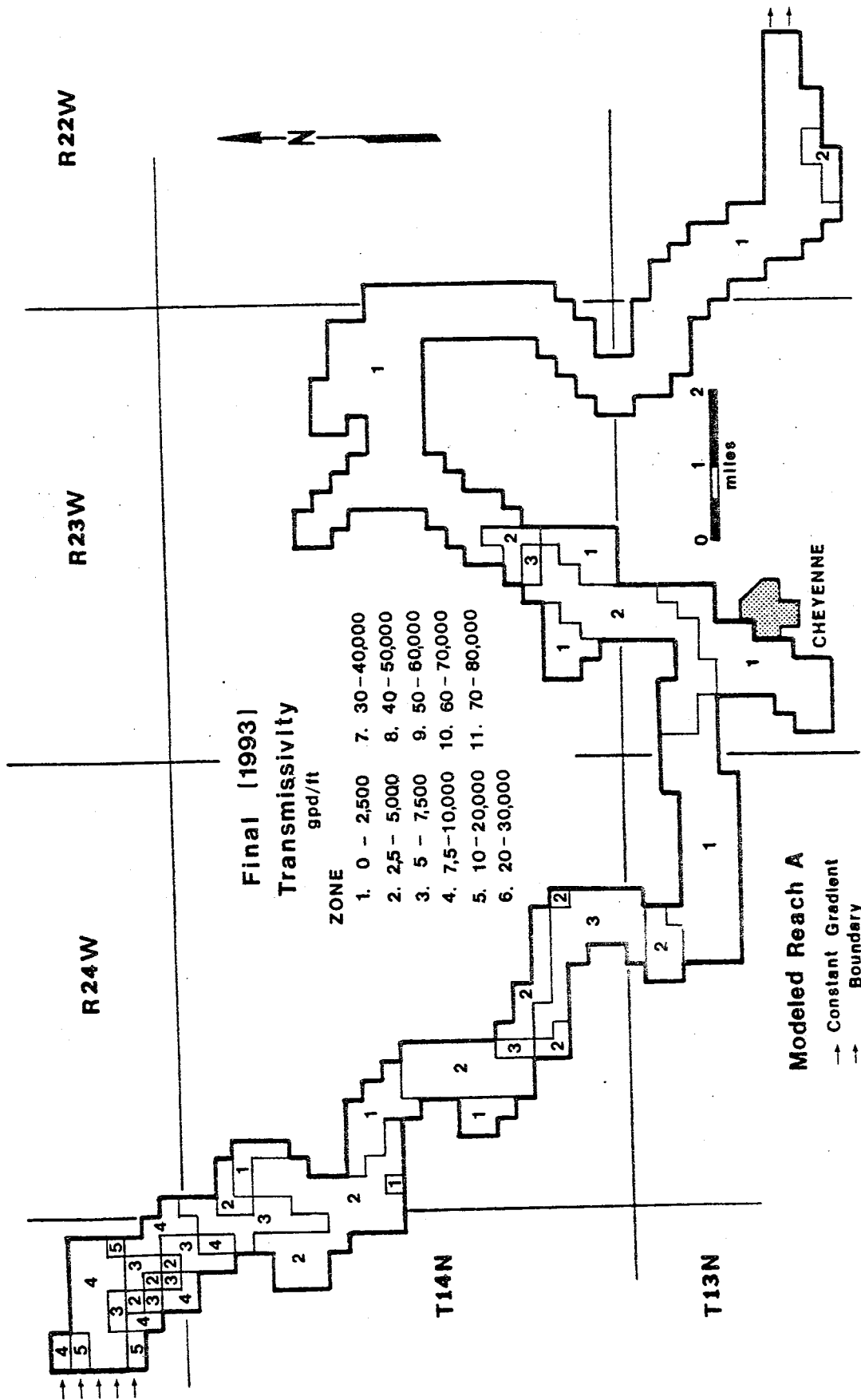
Samples min. 0 ft.	Storage	— Constant Gradient Boundary
290 max. 53	ac.ft.	
avg. 14	43,307	



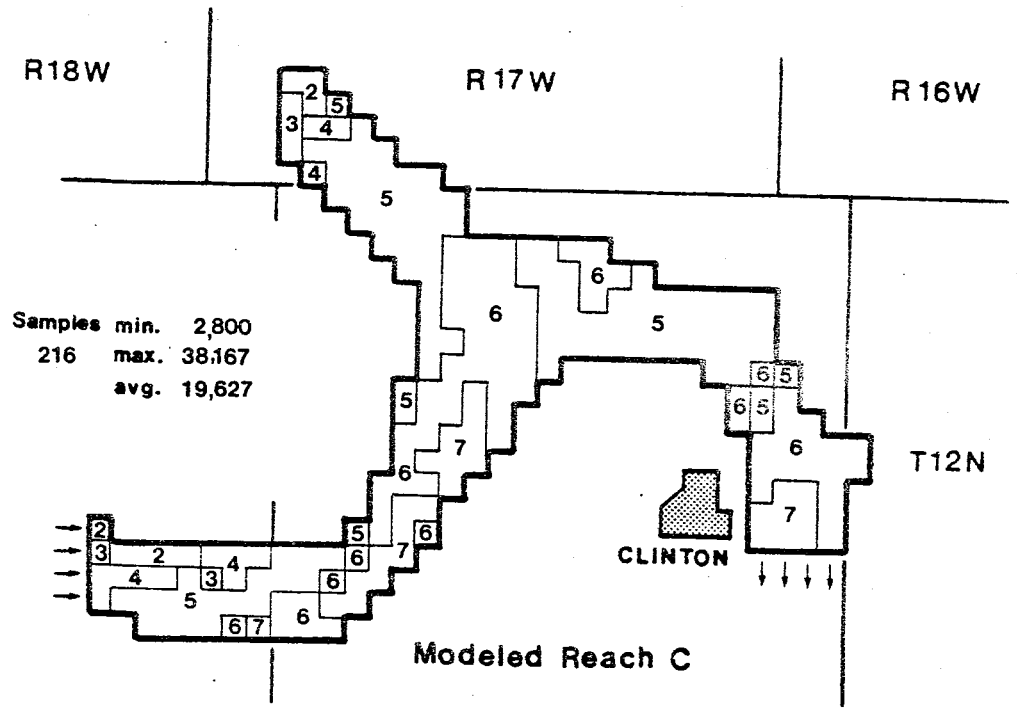
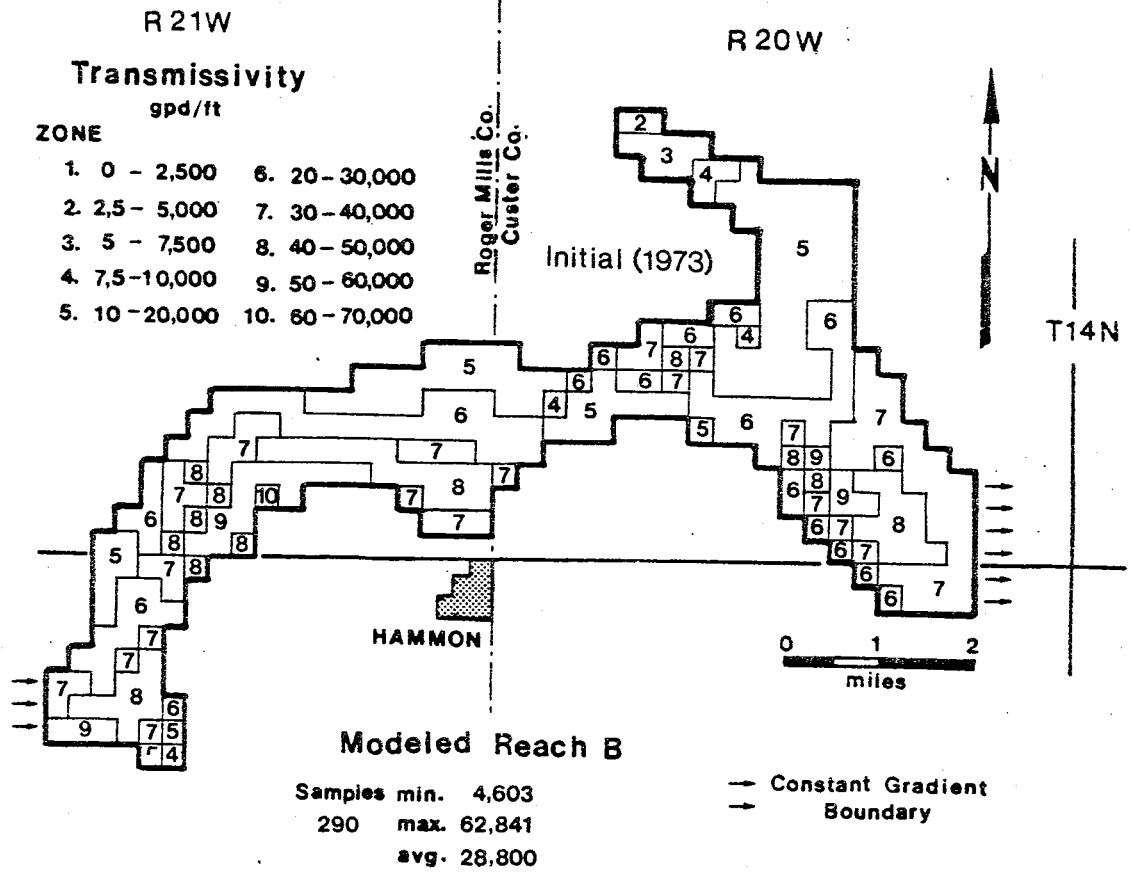
Saturated Thickness Map, July 1, 1993, Subreaches B and C, Modeled Reach 1.



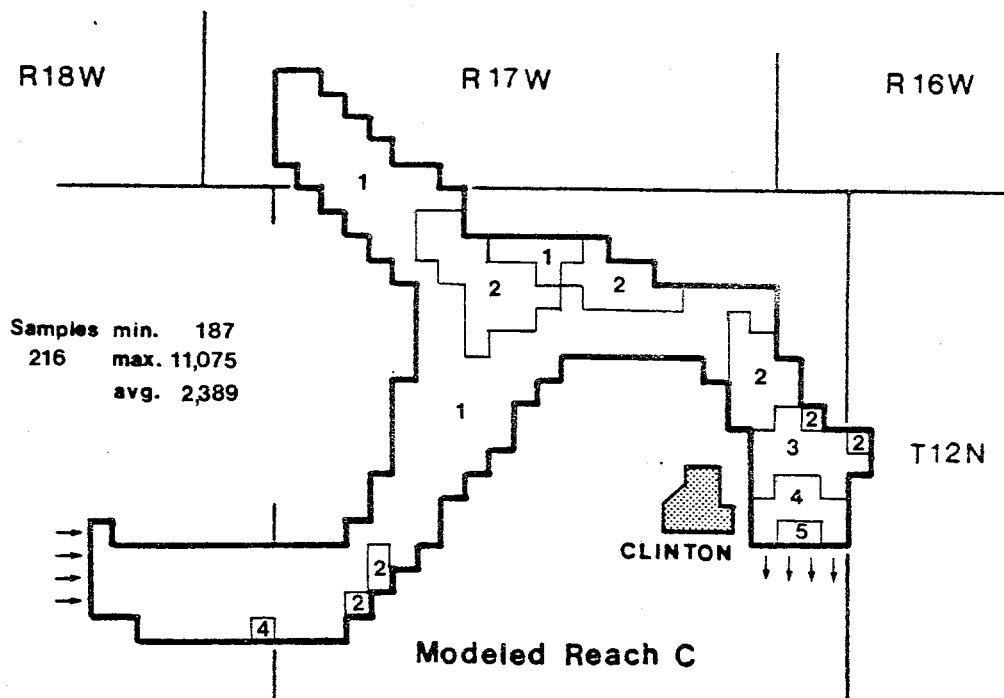
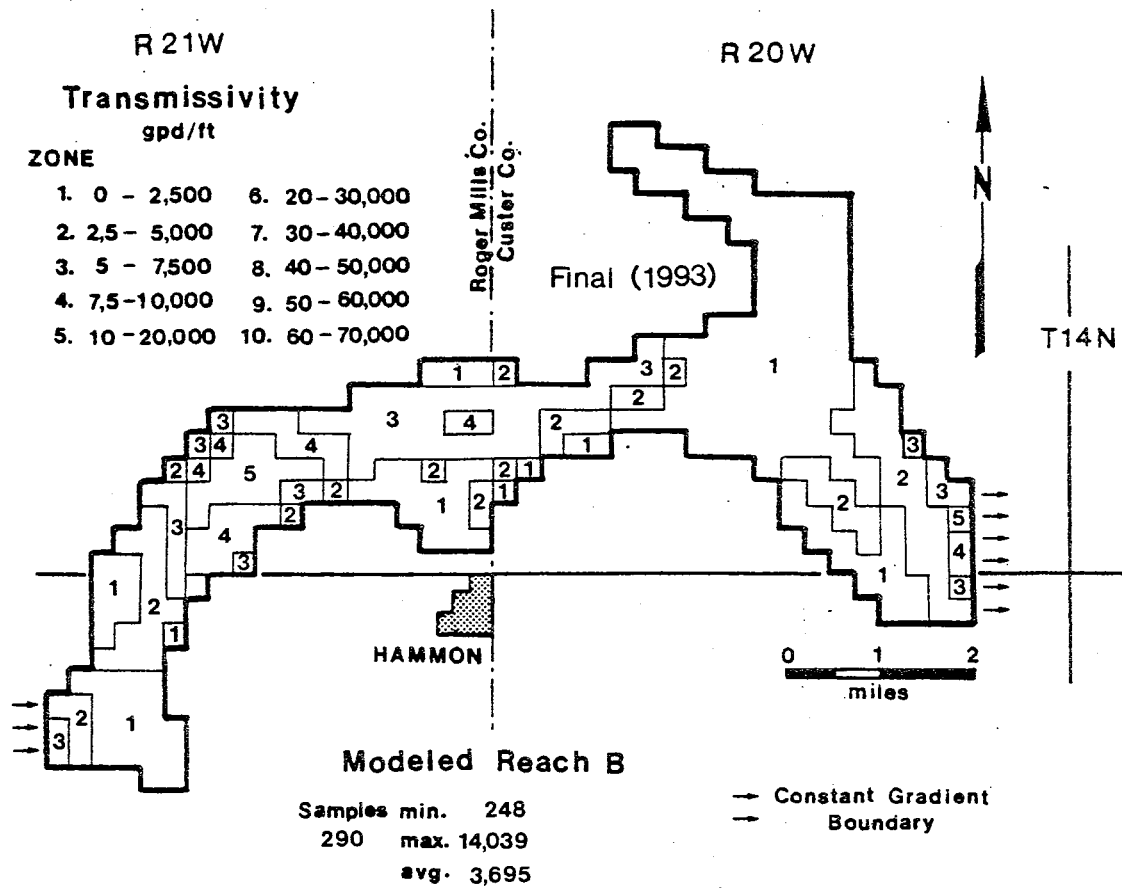
Transmissivity, July 1, 1973, Subreach A, Modeled Reach 1.



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



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

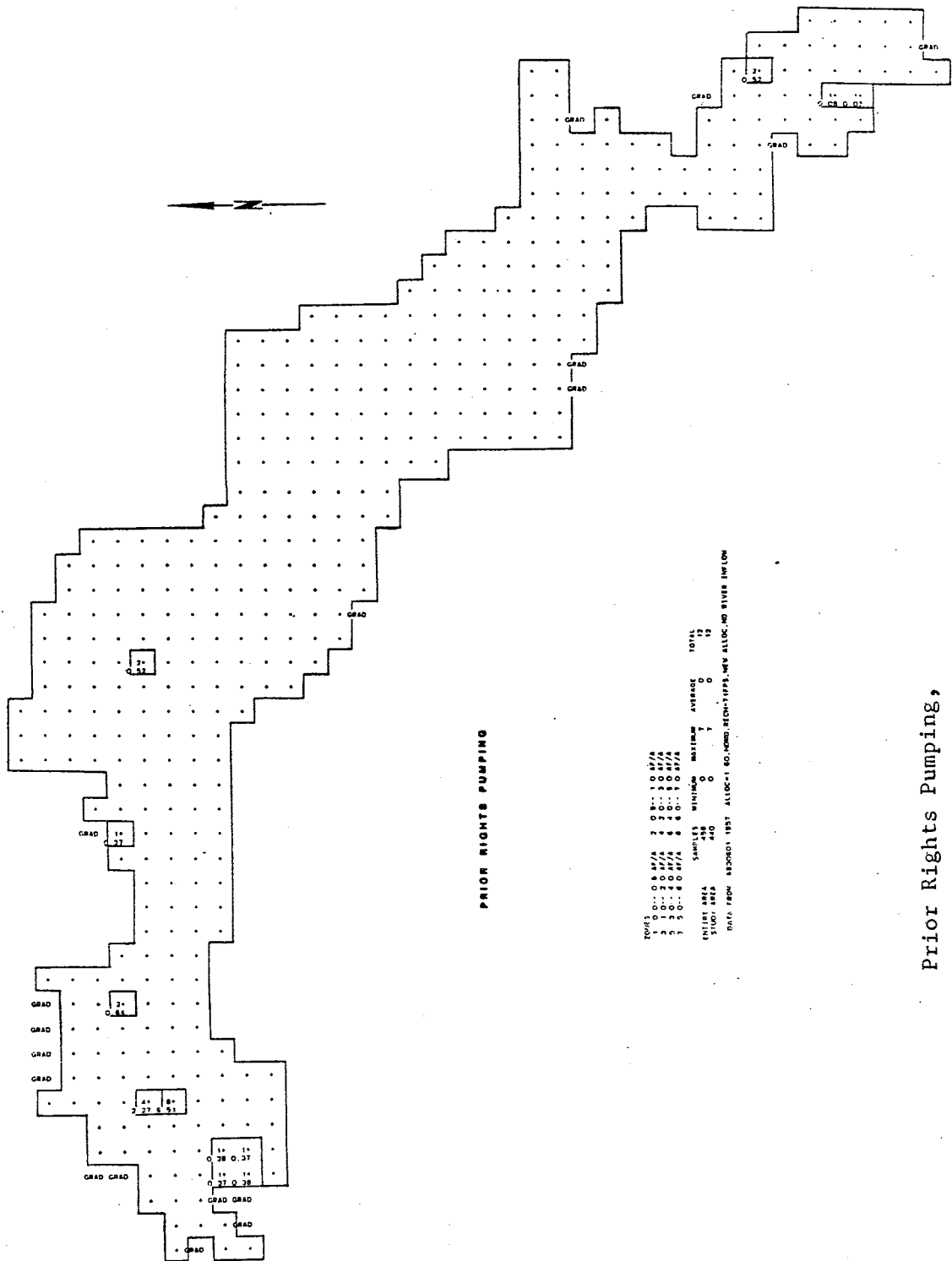


Transmissivity, July 1, 1993, Subreaches B and C, Modeled Reach 1.

APPENDIX B

RESULTS FOR MODELLED REACH 3

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Prior Rights Pumping.....	B-2
Water Distribution Summaries.....	B-3
Depth to Water.....	B-4 - B-5
Saturated Thickness.....	B-6 - B-7
Transmissivity.....	B-8 - B-9



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

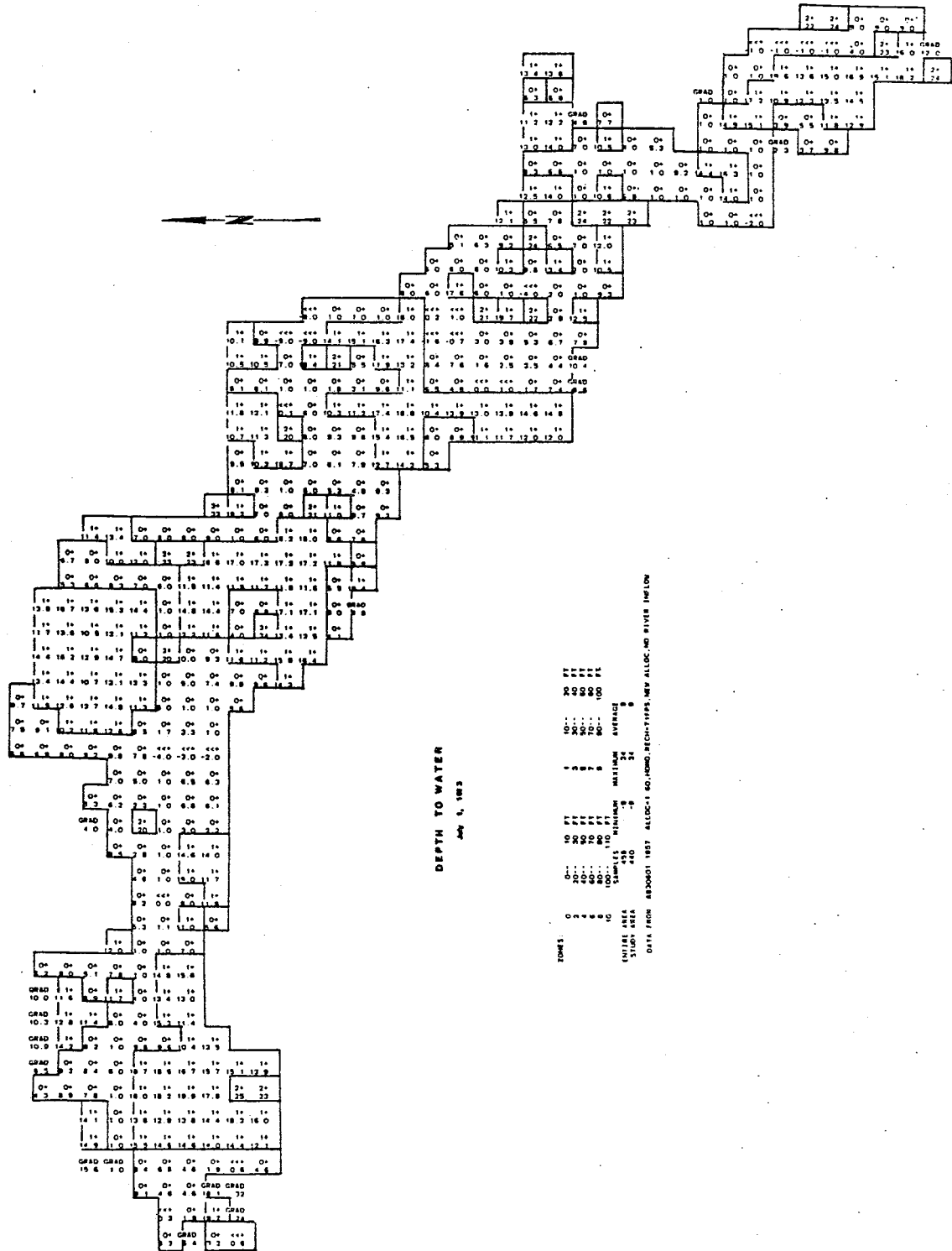
WATER DISTRIBUTION SUMMARY
 JULY 1, 1993

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,

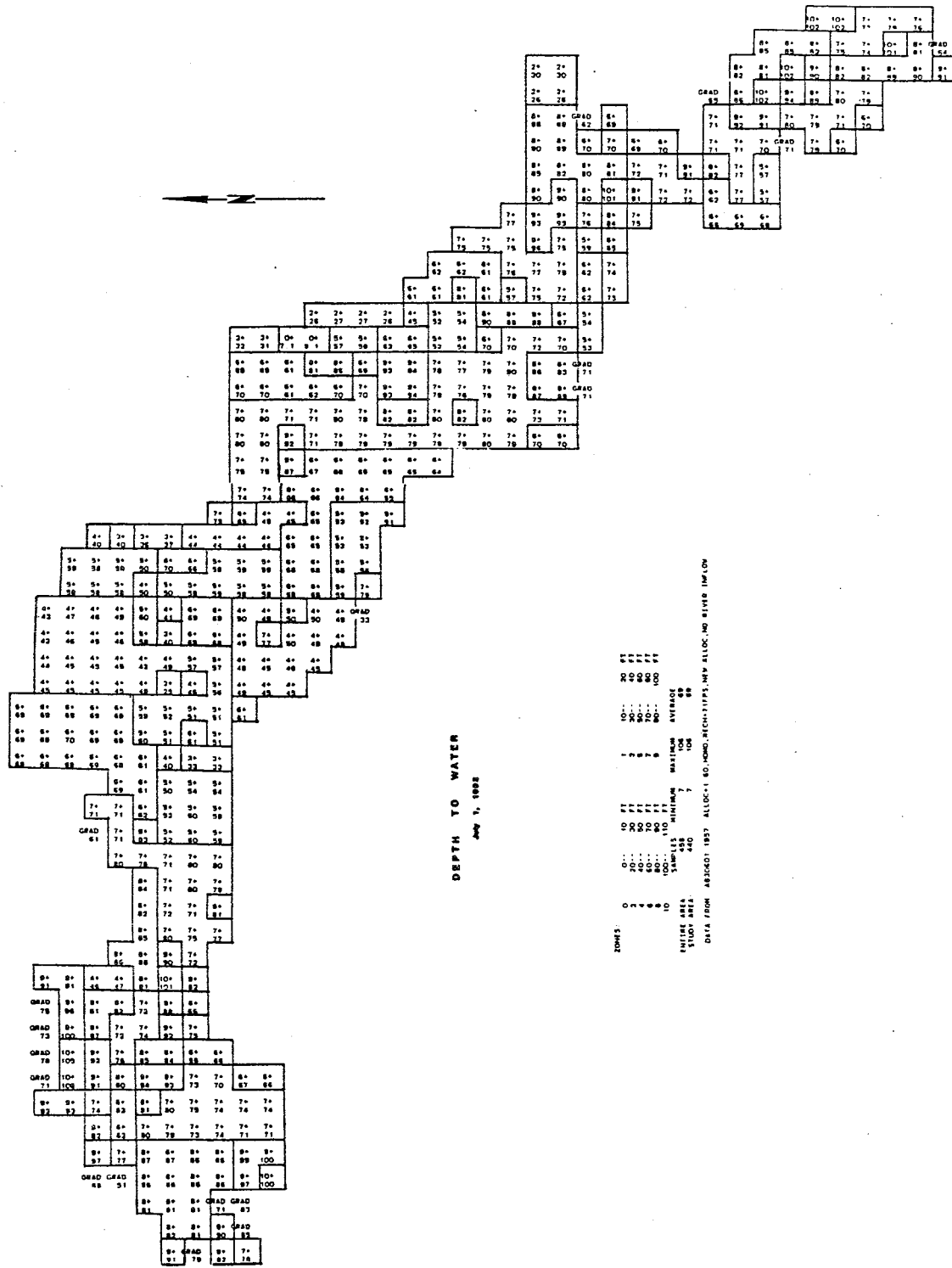
Modeled Reach 3.



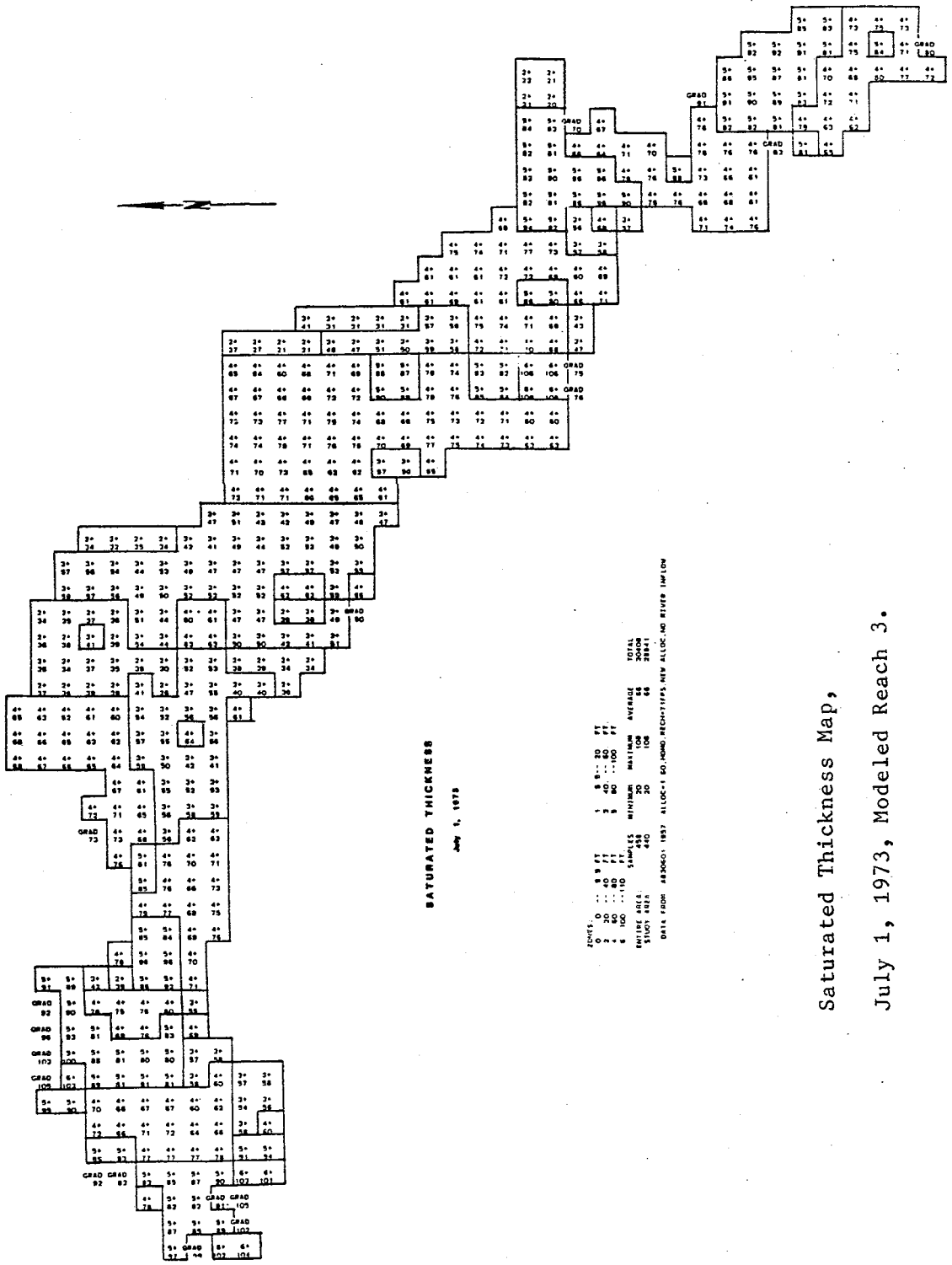
DEPTH TO WATER
July 1, 1973

ZONES: 2 20 20
 4 40 40
 6 60 60
 8 80 80
 10 100 100
 12 120 120
 14 140 140
 16 160 160
 18 180 180
 20 200 200
 22 220 220
 24 240 240
 26 260 260
 28 280 280
 30 300 300
 32 320 320
 34 340 340
 36 360 360
 38 380 380
 40 400 400
 42 420 420
 44 440 440
 46 460 460
 48 480 480
 50 500 500
 52 520 520
 54 540 540
 56 560 560
 58 580 580
 60 600 600
 62 620 620
 64 640 640
 66 660 660
 68 680 680
 70 700 700
 72 720 720
 74 740 740
 76 760 760
 78 780 780
 80 800 800
 82 820 820
 84 840 840
 86 860 860
 88 880 880
 90 900 900
 92 920 920
 94 940 940
 96 960 960
 98 980 980
 100 1000 1000

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



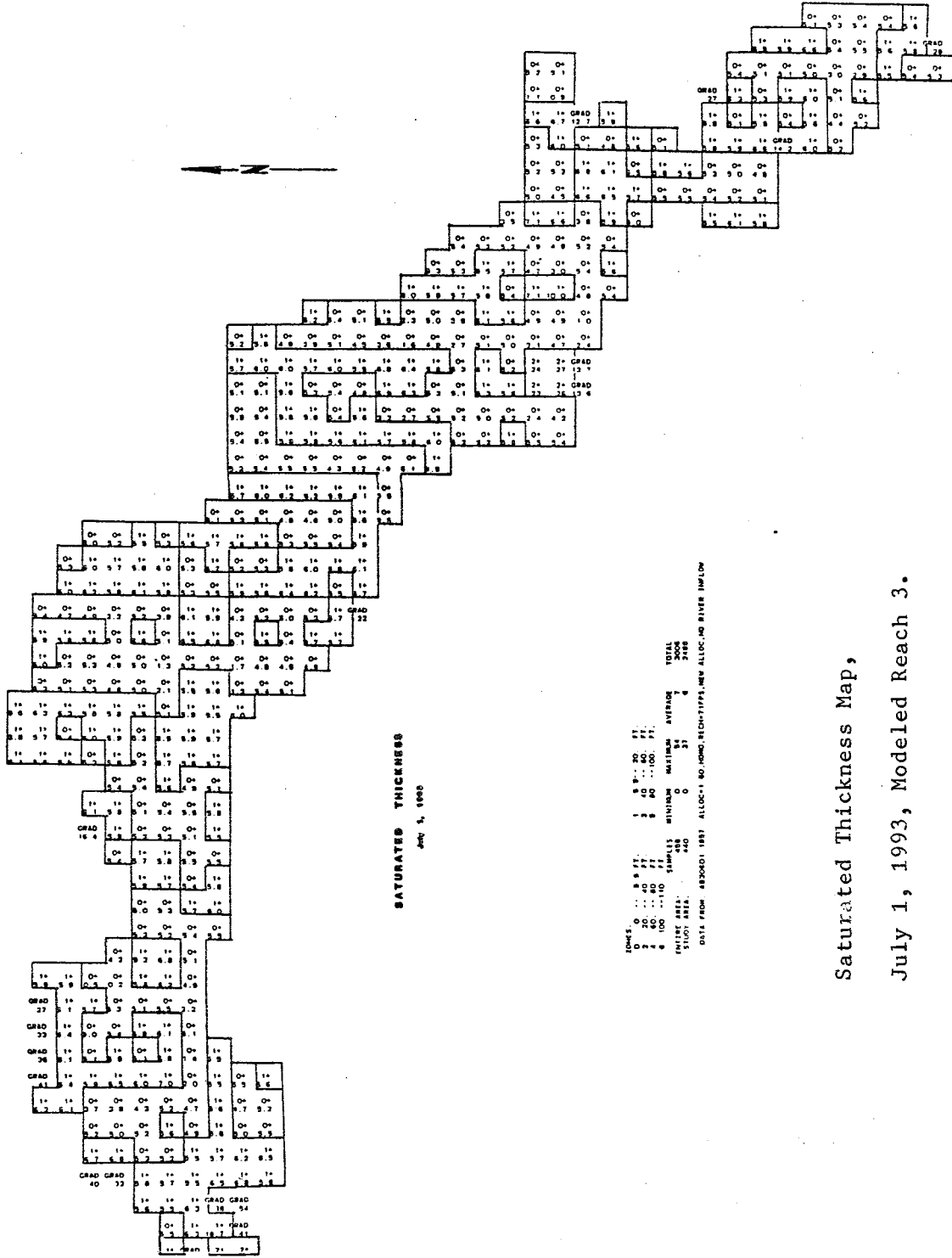
Depth to water, July 1, 1993, Modeled Reach 3.



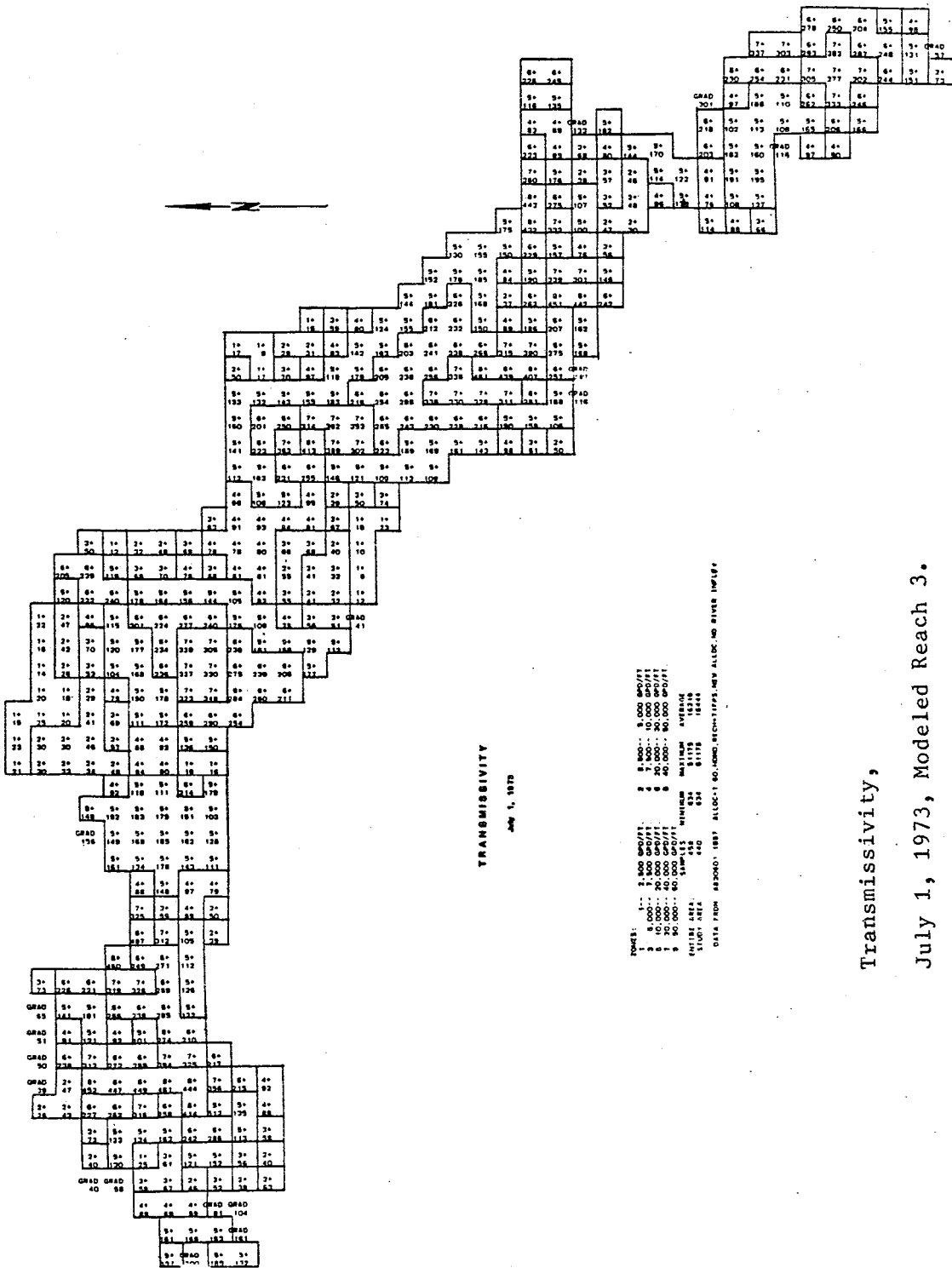
SATURATED THICKNESS
July 1, 1973

INDEX: ... 8 9 11 ... 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000

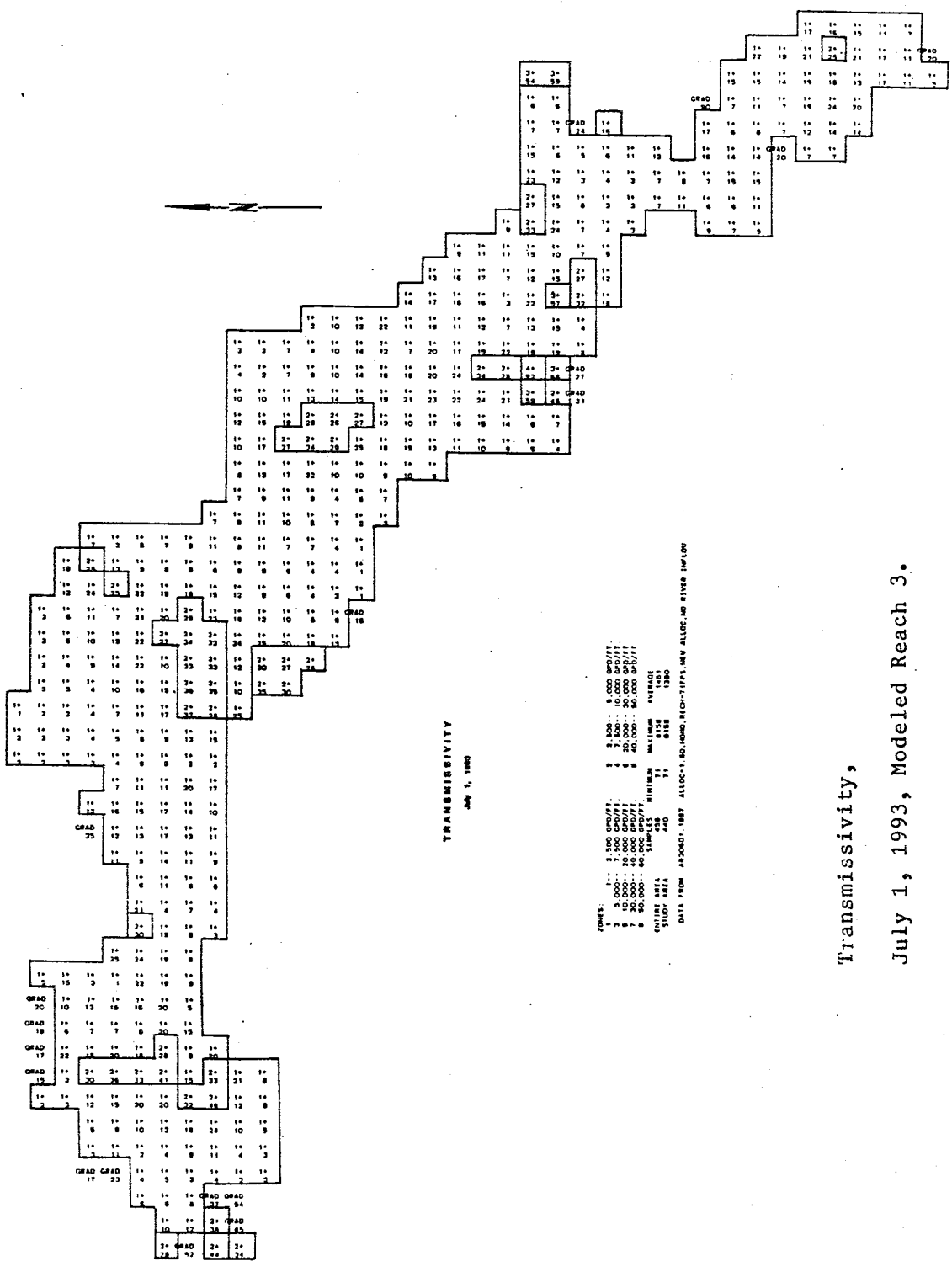
Saturated Thickness Map,
July 1, 1973, Modeled Reach 3.



Saturated Thickness Map,
July 1, 1993, Modeled Reach 3.

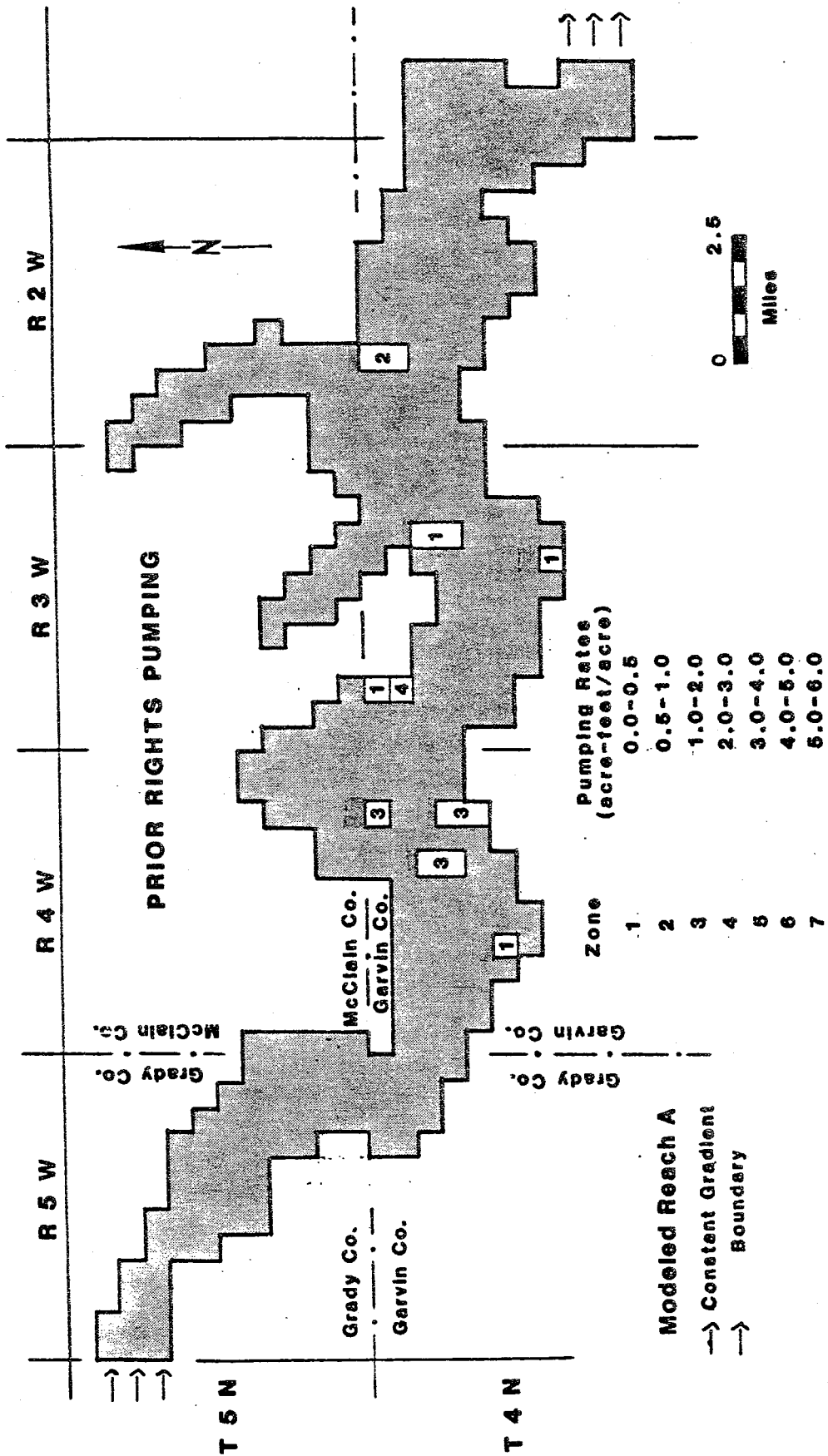


Transmissivity,
July 1, 1973, Modeled Reach 3.



Transmissivity,

July 1, 1993, Modeled Reach 3.

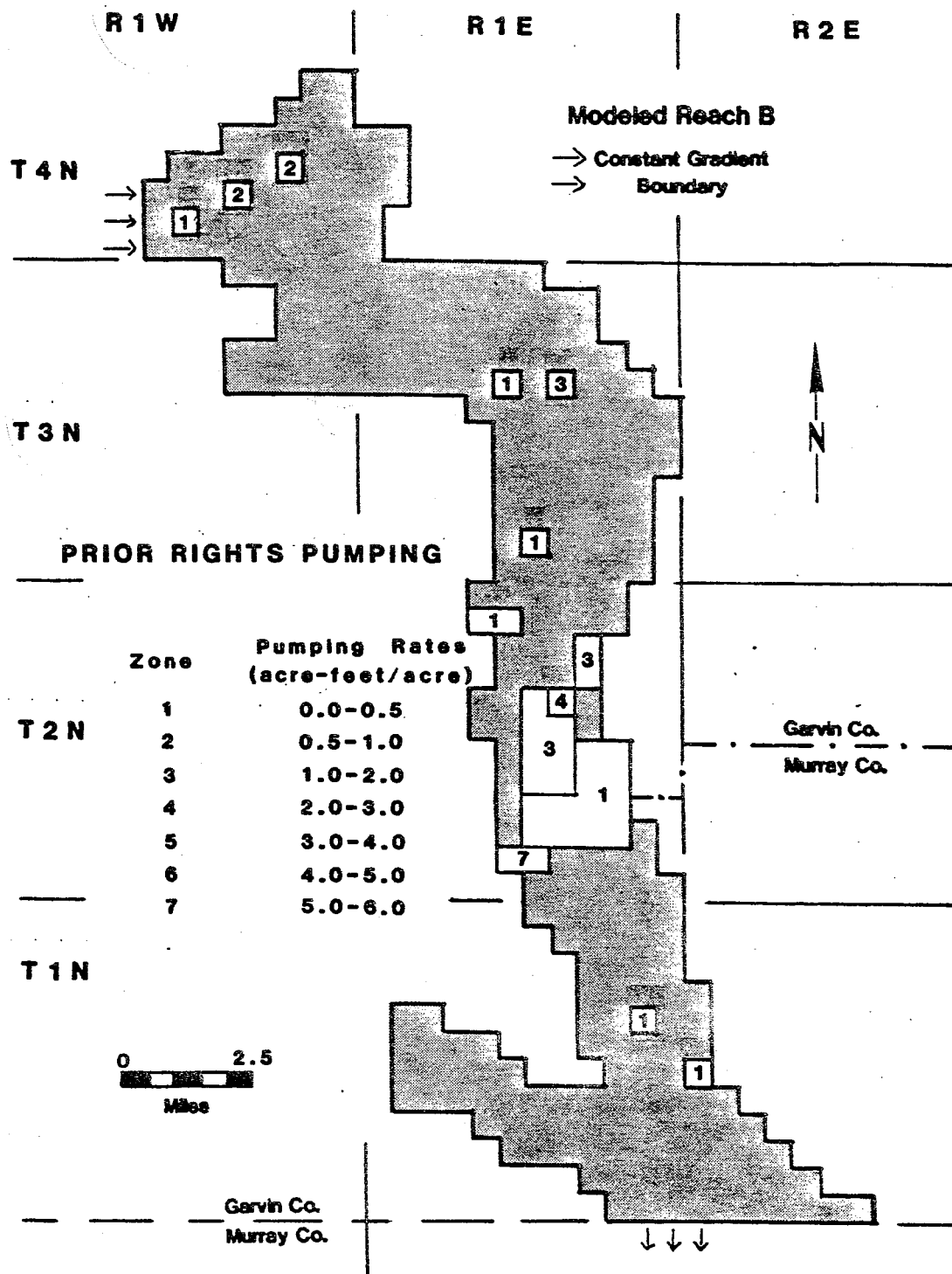


Prior Rights Pumping,
Subreach A, Modeled Reach 4.

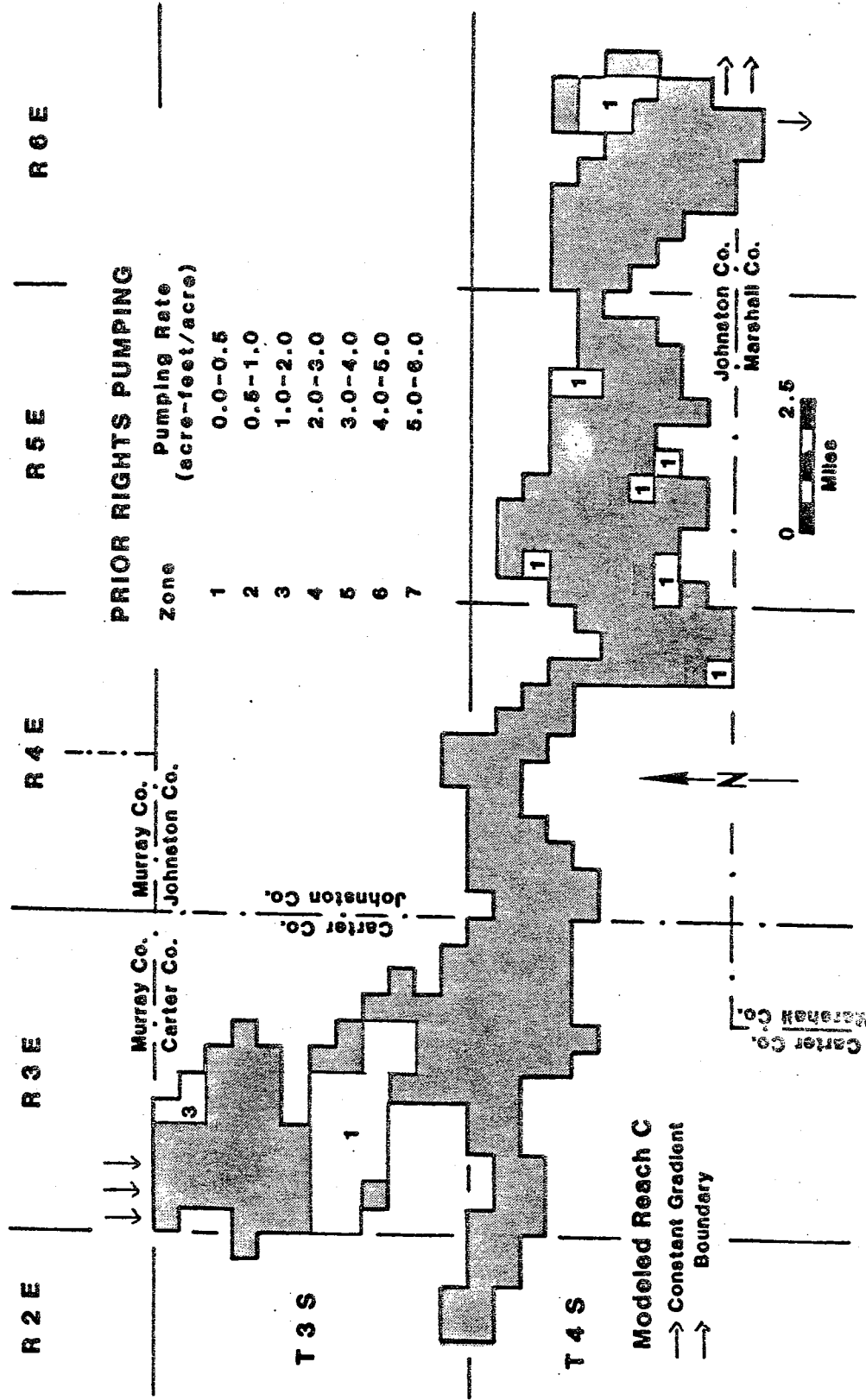
APPENDIX C

RESULTS FOR MODELLED REACH 4

	Page
Prior Rights Pumping.....	C- 2 - C- 4
Water Distribution Summaries.....	C- 5 - C- 7
Water Table.....	C- 8 - C-10
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Saturated Thickness.....	C-17 - C-22
Transmissivity.....	C-23 - C-28



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 OF TOTAL (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)	
10.0-- 20.0	9.3	5,120	17.3	22,752	
20.0-- 30.0	15.7	8,640	24.9	55,353	
30.0-- 40.0	33.0	18,240	35.3	166,335	
40.0-- 50.0	27.8	15,360	44.5	176,418	
50.0-- 60.0	11.6	6,400	54.4	90,312	
60.0-- 70.0	2.6	1,440	63.1	23,460	
ALL RANGES (TOTAL)	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 OF TOTAL (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (PERCENT)	STORED WATER (AC.FT.)	
0.0-- 5.5	50.7	28,000	5.2	37,296	
5.5-- 10.0	19.1	10,560	7.4	20,272	
10.0-- 20.0	25.5	14,080	13.7	49,867	
20.0-- 30.0	4.6	2,560	23.2	15,383	
ALL RANGES (TOTAL)	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 OF TOTAL (PERCENT)	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	51,840	41.4	30.0	643,185
	(TOTAL)	(TOTAL)	(AVERAGE)	(AVERAGE)	(TOTAL)

DATA FROM:
 A830725.2308 RUN 20YR,ALLOC1.14,RIVER-10.,RATE=9.265E-9,ORE=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 OF TOTAL (PERCENT)	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	51,840	7.6	30.0	118,913
	(TOTAL)	(TOTAL)	(AVERAGE)	(AVERAGE)	(TOTAL)

DATA FROM:
 A830725.2308 RUN 20YR,ALLOC1.14,RIVER-10.,RATE=9.265E-9,ORE=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 OF TOTAL (PERCENT)	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 (TOTAL)	80.6	44,480	35.7	32.0	507,927

DATA FROM:
 A830726.2210 RUN 20YR,ALLO1.2,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

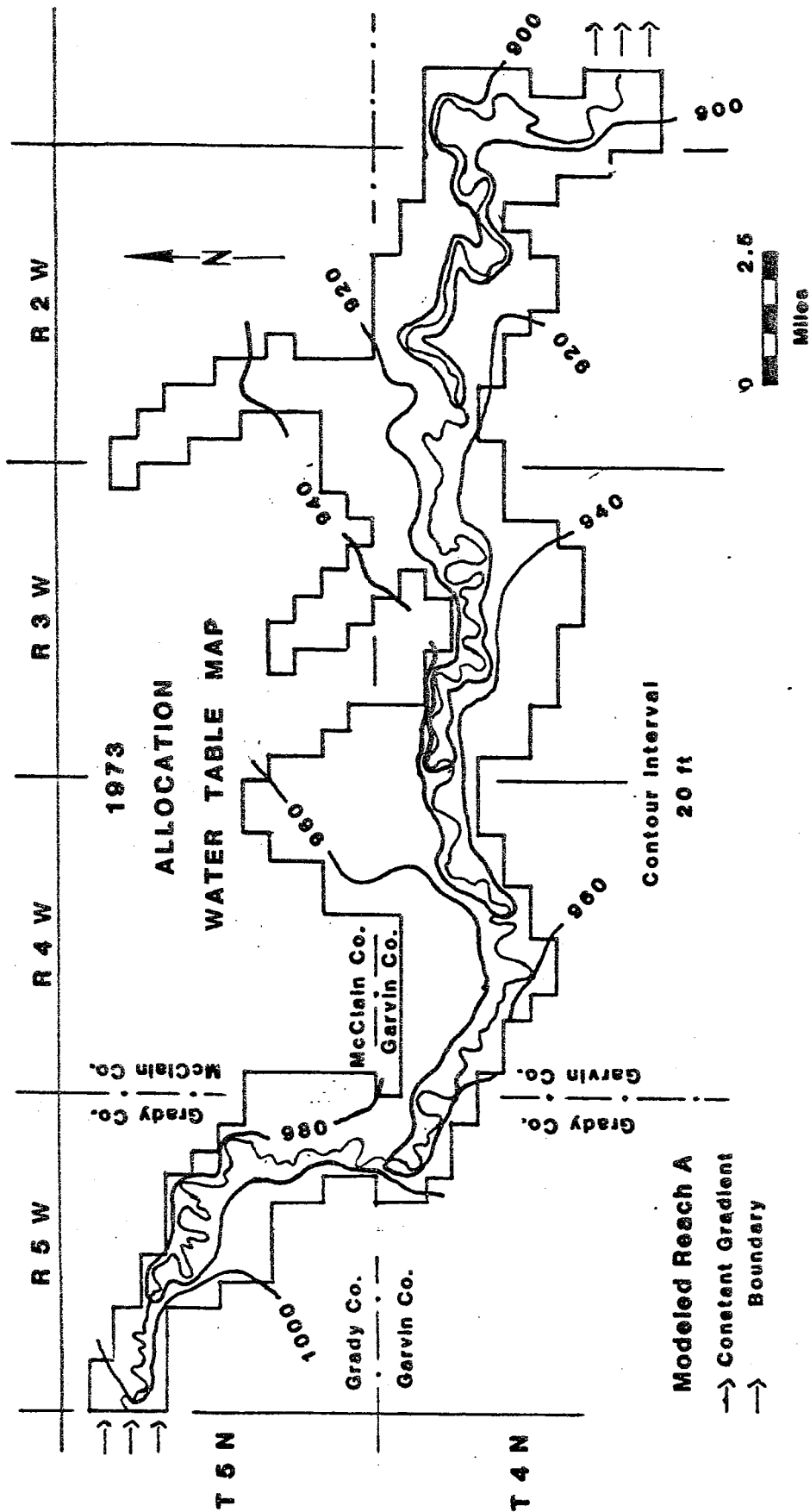
WATER DISTRIBUTION SUMMARY
 JULY 1, 1993

SATURATED THICKNESS RANGE (FEET)	AREA OF TOTAL (PERCENT)	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 (TOTAL)	80.6	44,480	11.0	32.0	157,267

DATA FROM:
 A830726.2210 RUN 20YR,ALLO1.2,RIVER-3,RATE=9.8E-9,QRE=5.00IN/YR

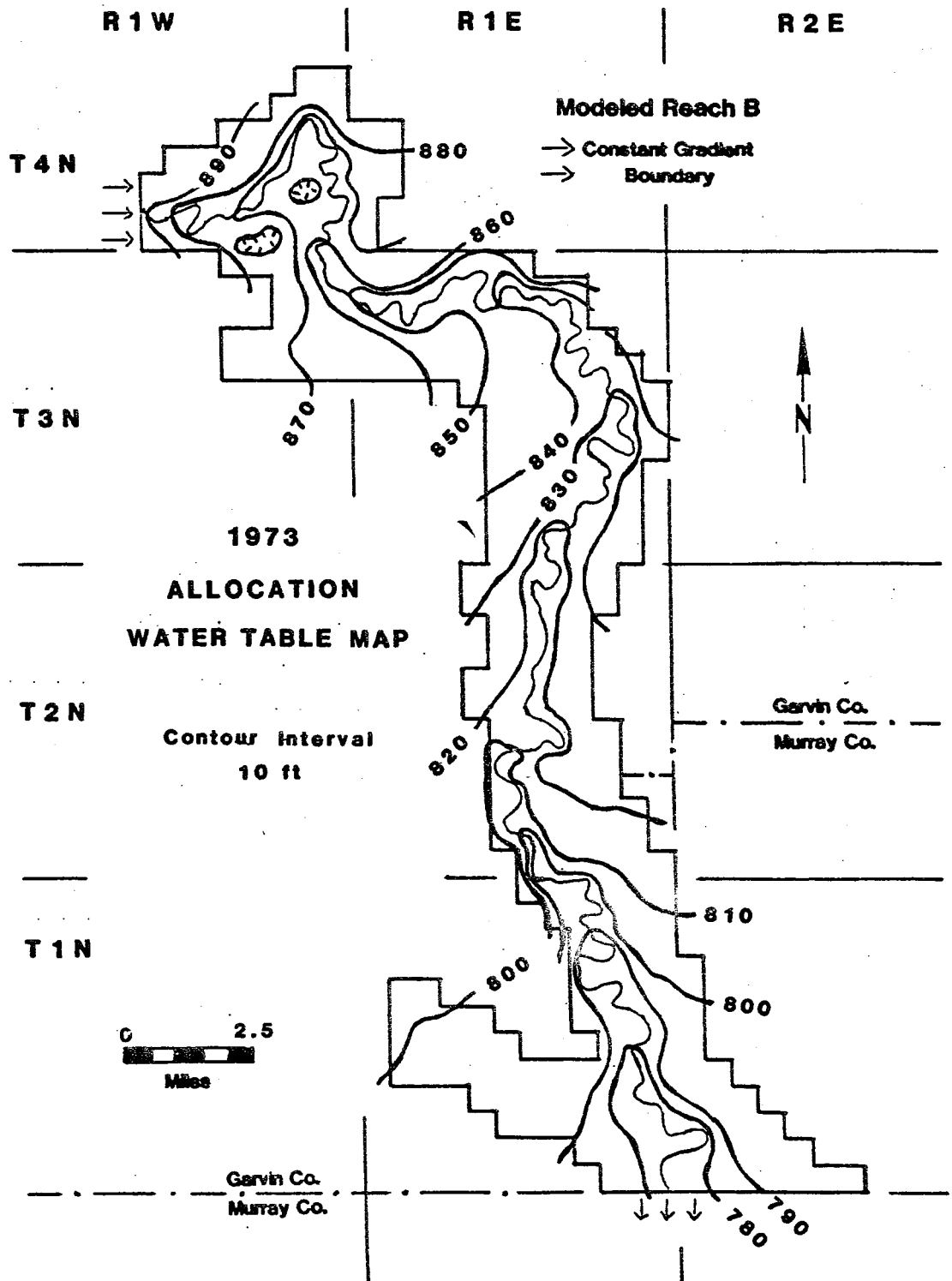
Water Distribution Summaries,

Subreach C, Modeled Reach 4.

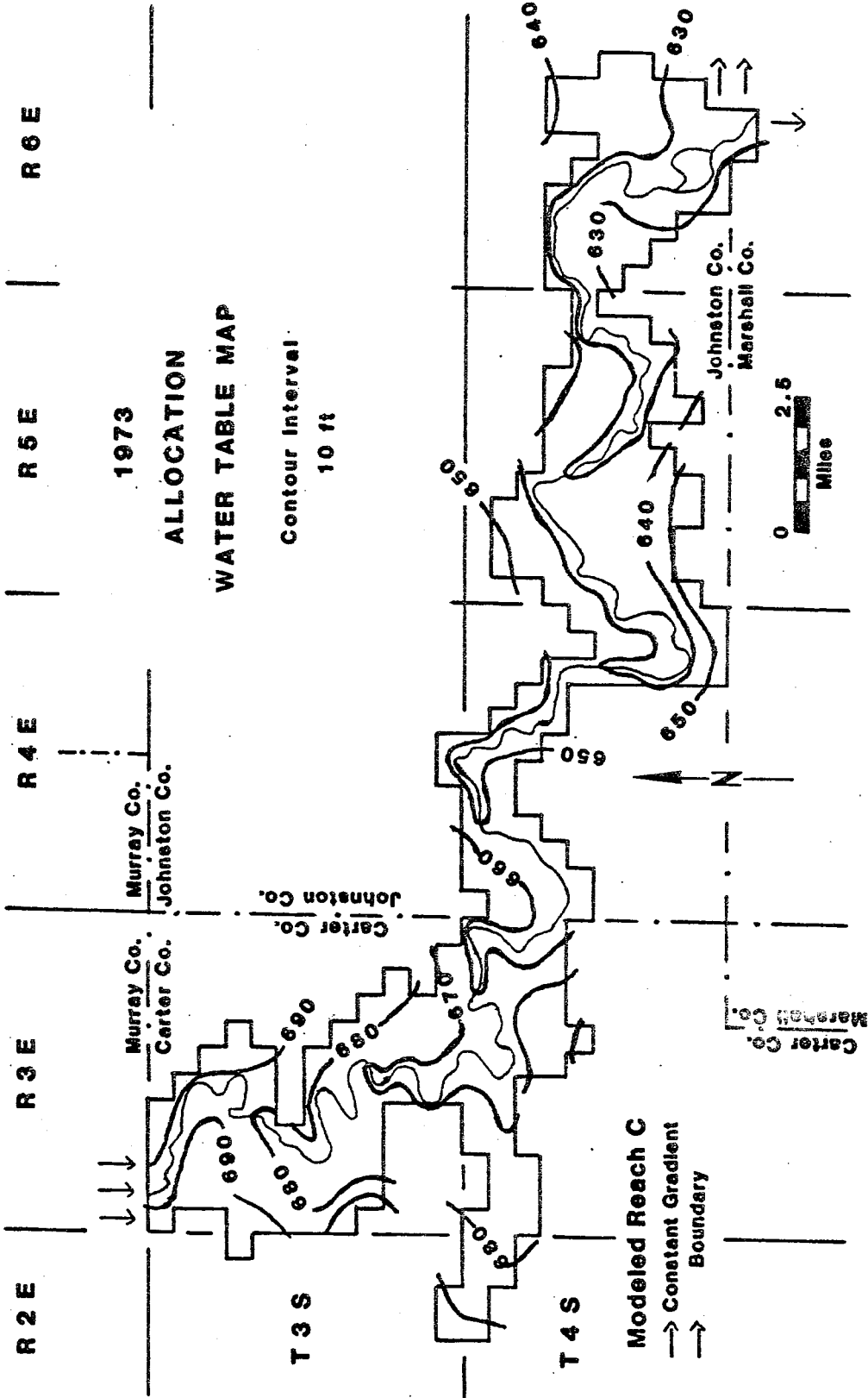


Water Table Map,

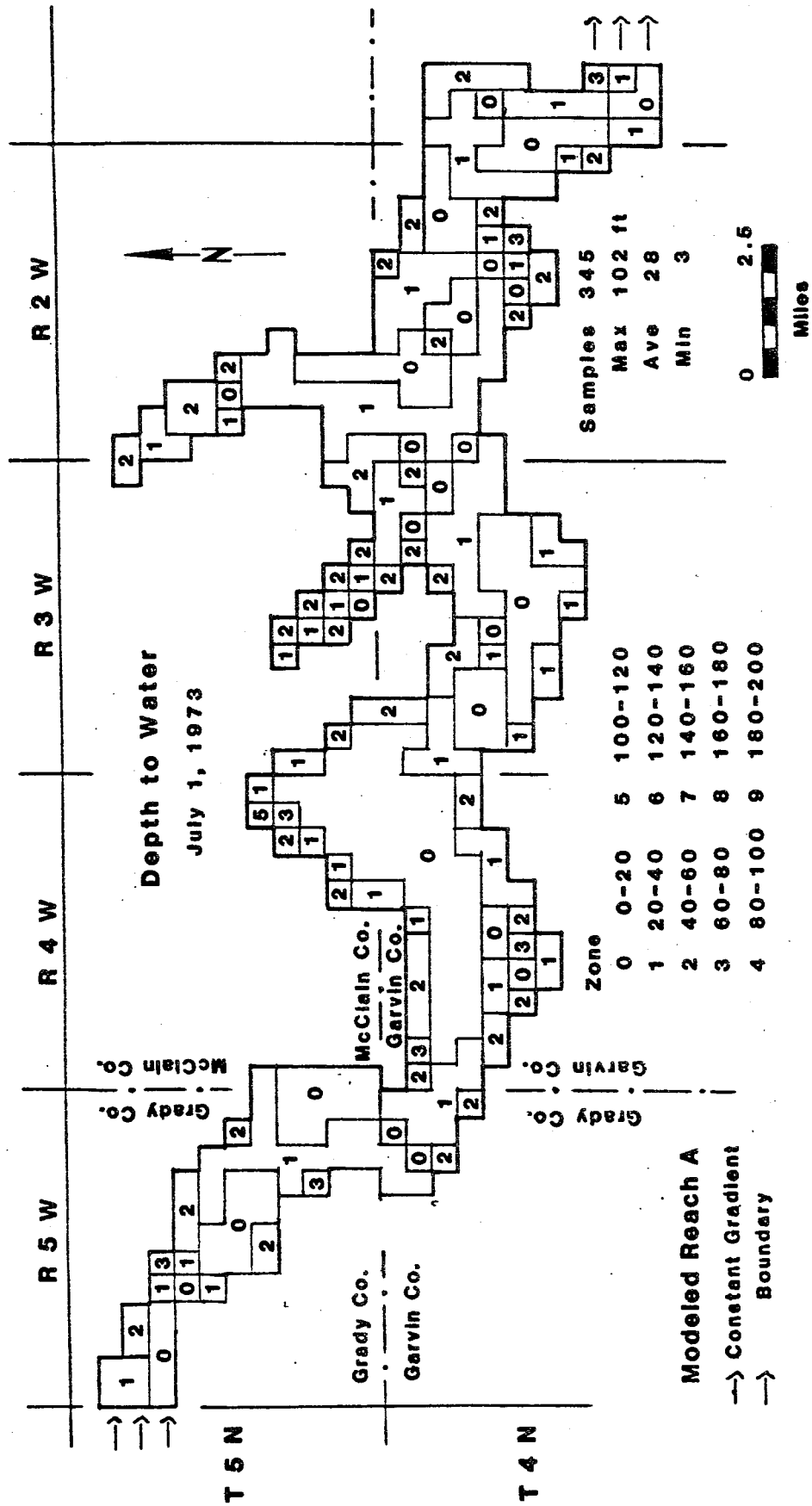
Subreach A, Modeled Reach 4.



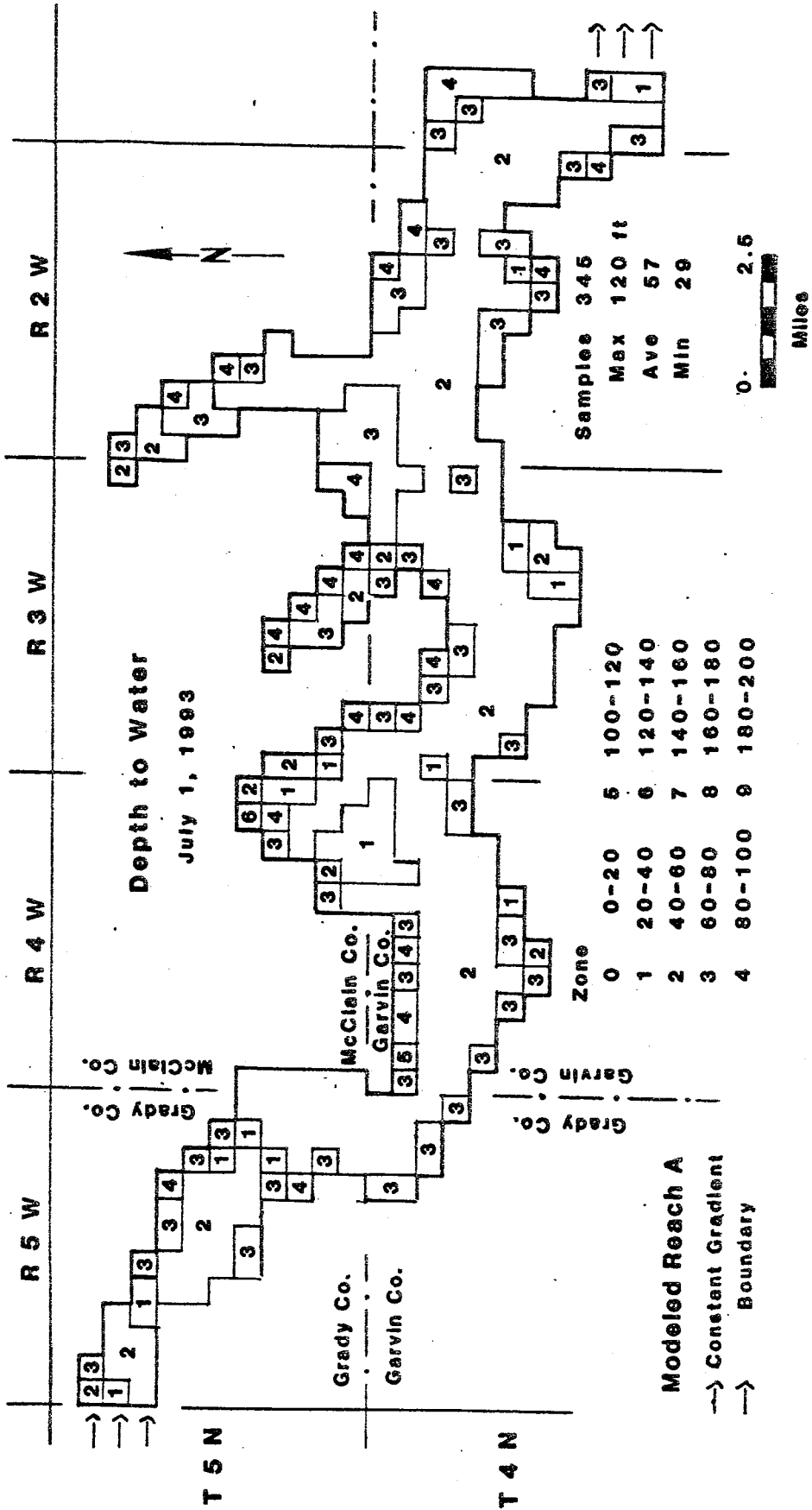
Water Table Map,
 Subreach B, Modeled Reach 4.



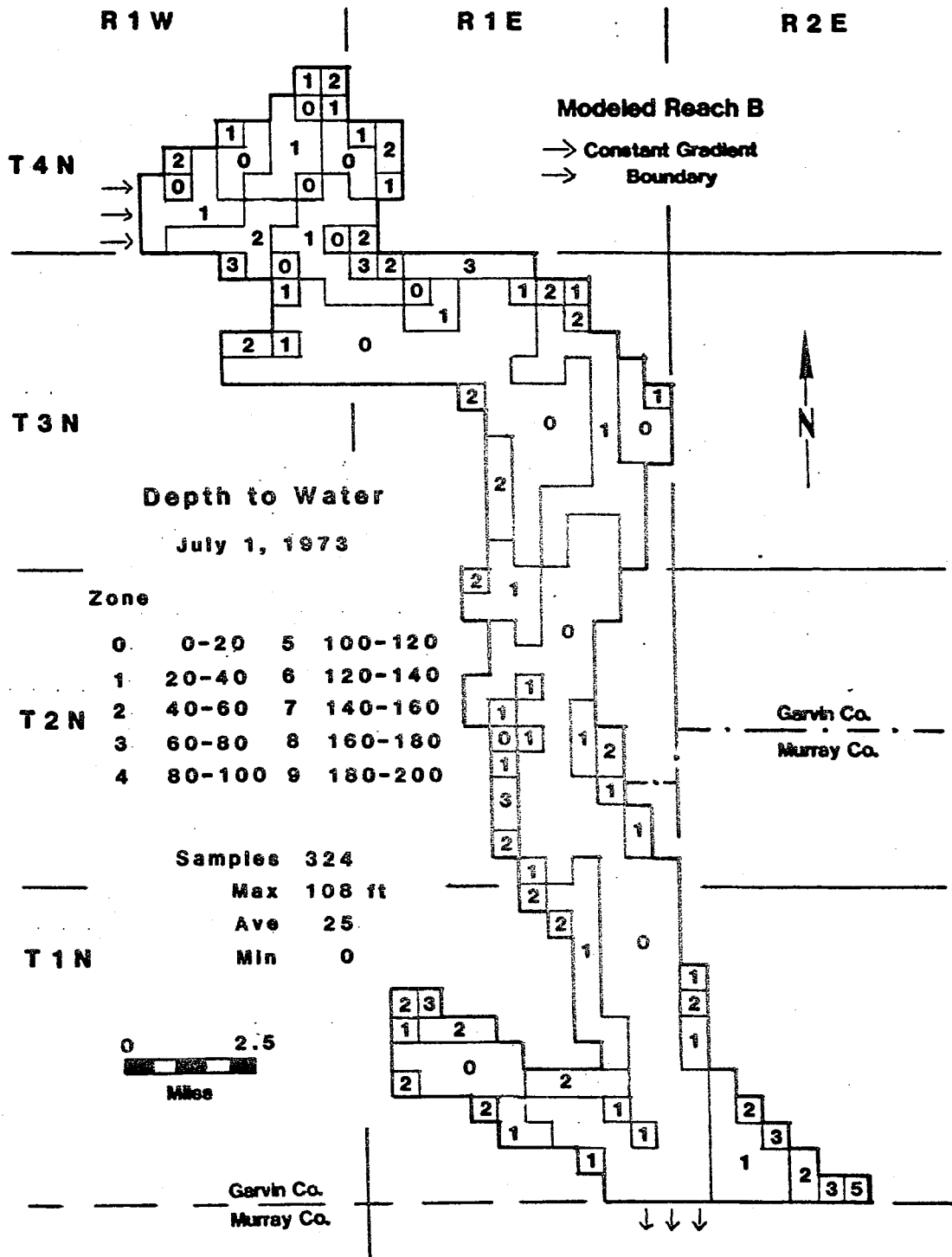
Water Table Map,
Subreach C, Modeled Reach 4.



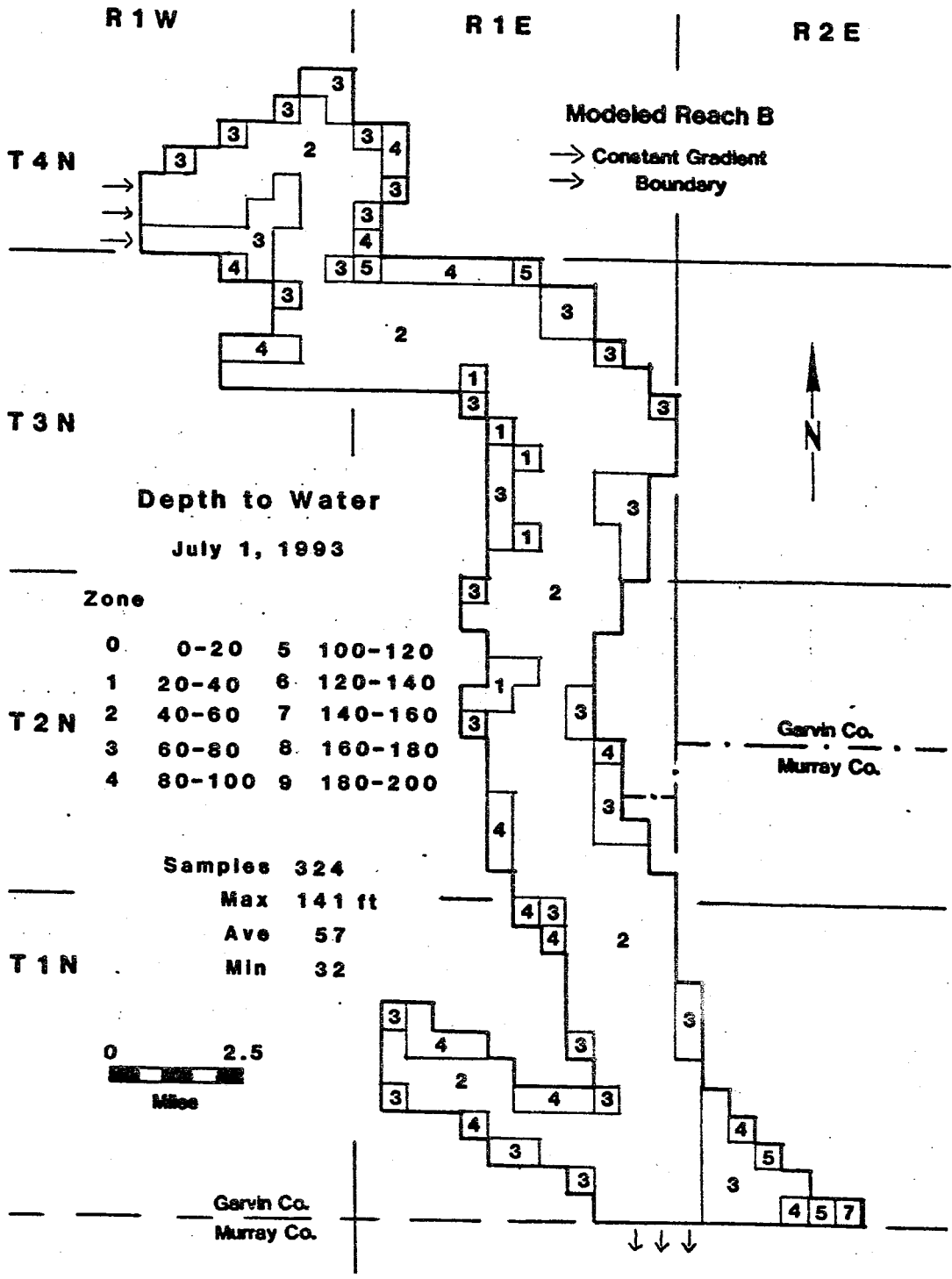
Depth to water, July 1, 1973, Subreach A, Modeled Reach 4.



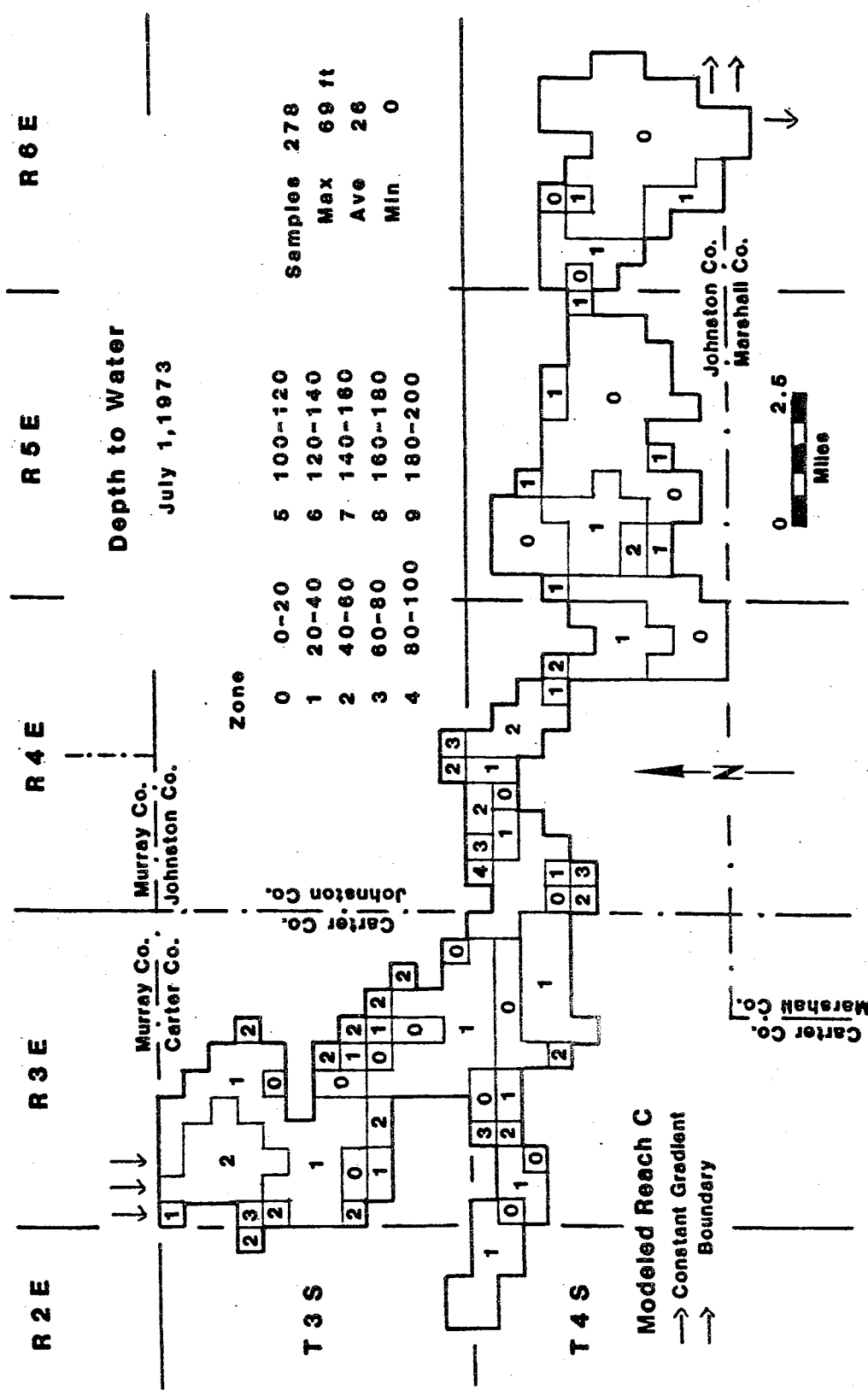
Depth to water, July 1, 1993, Subreach A, Modeled Reach 4.



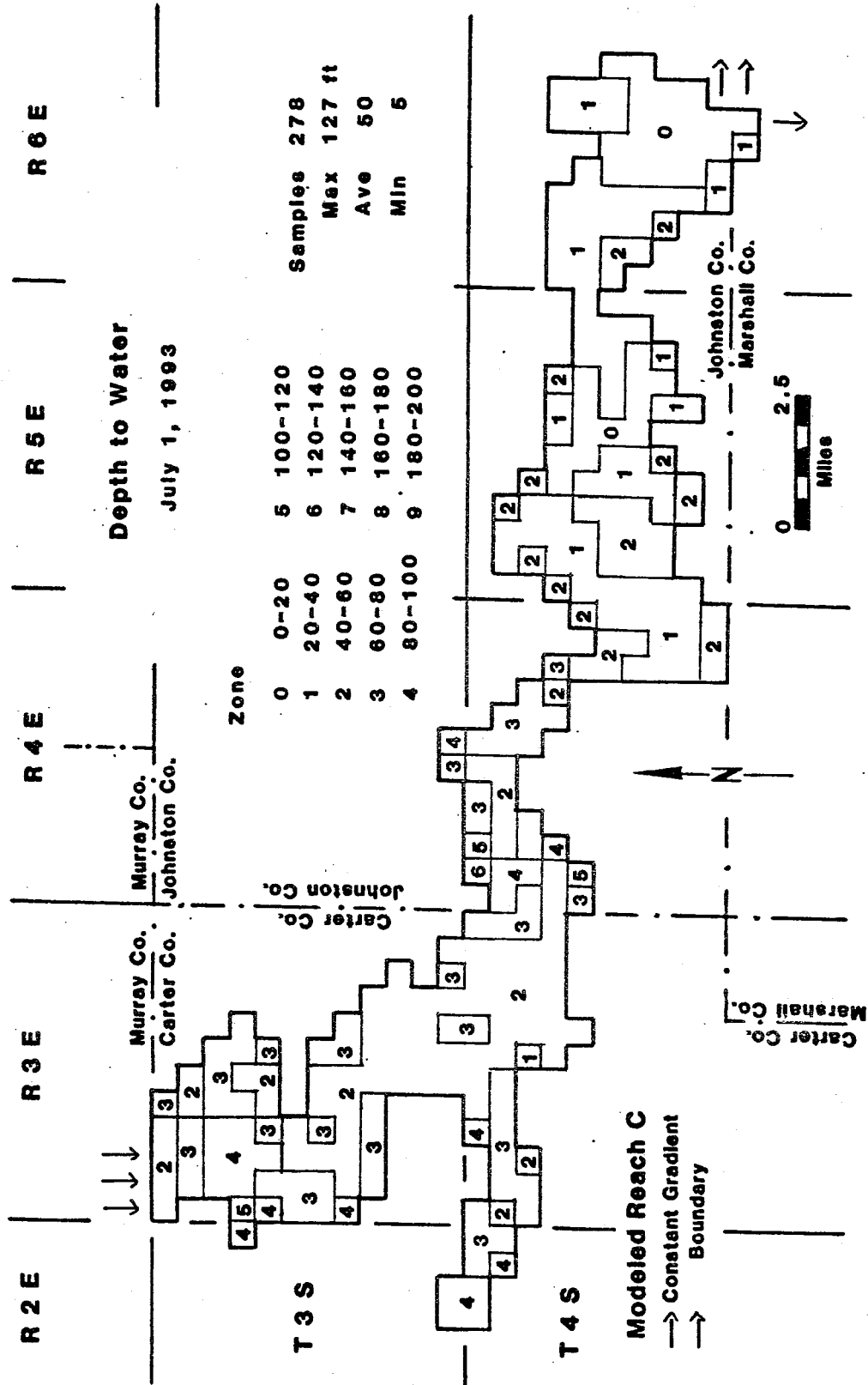
Depth to water, July 1, 1973, Subreach B, Modeled Reach 4.



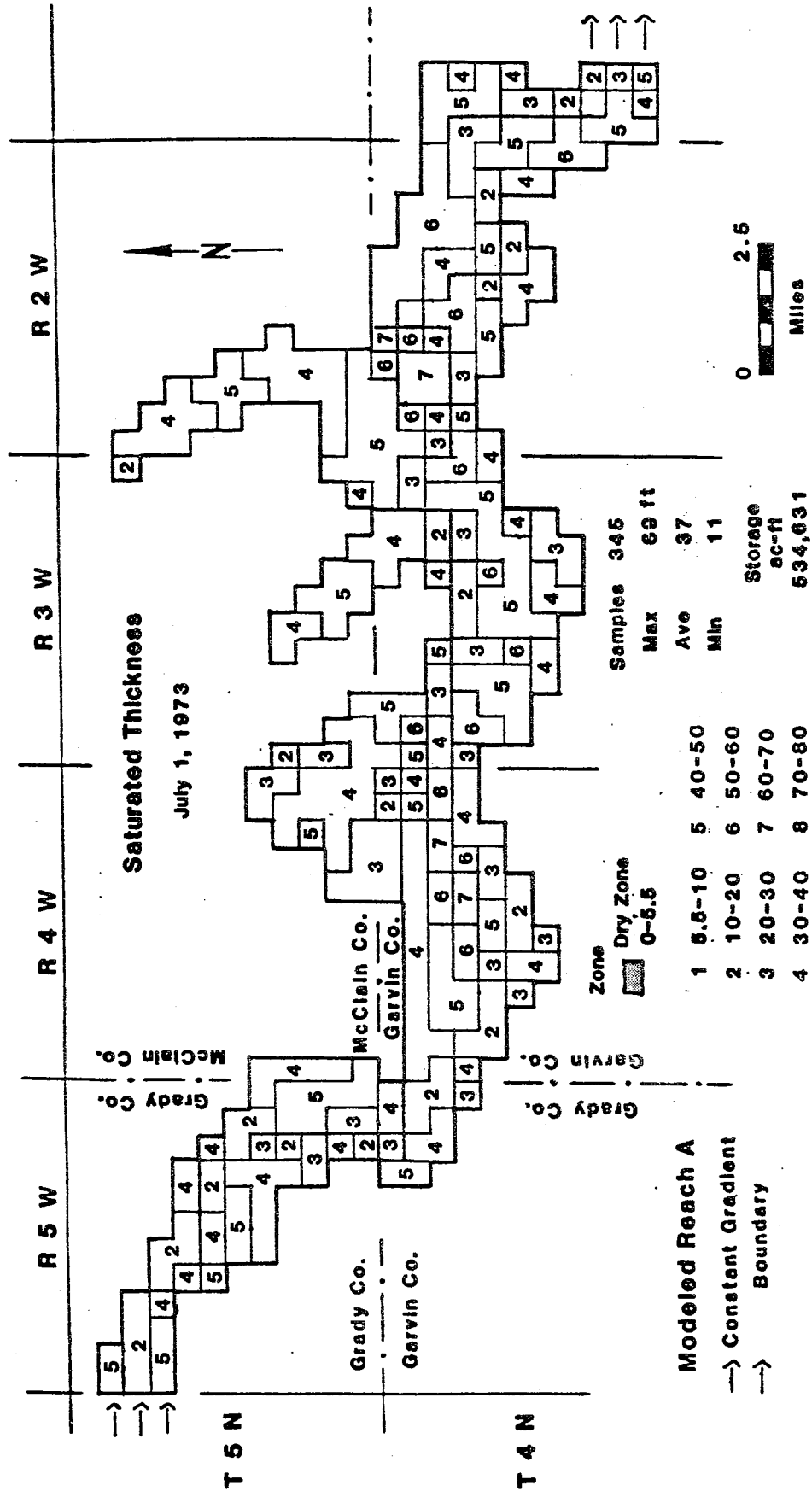
Depth to water, July 1, 1993, Subreach B, Modeled Reach 4.



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

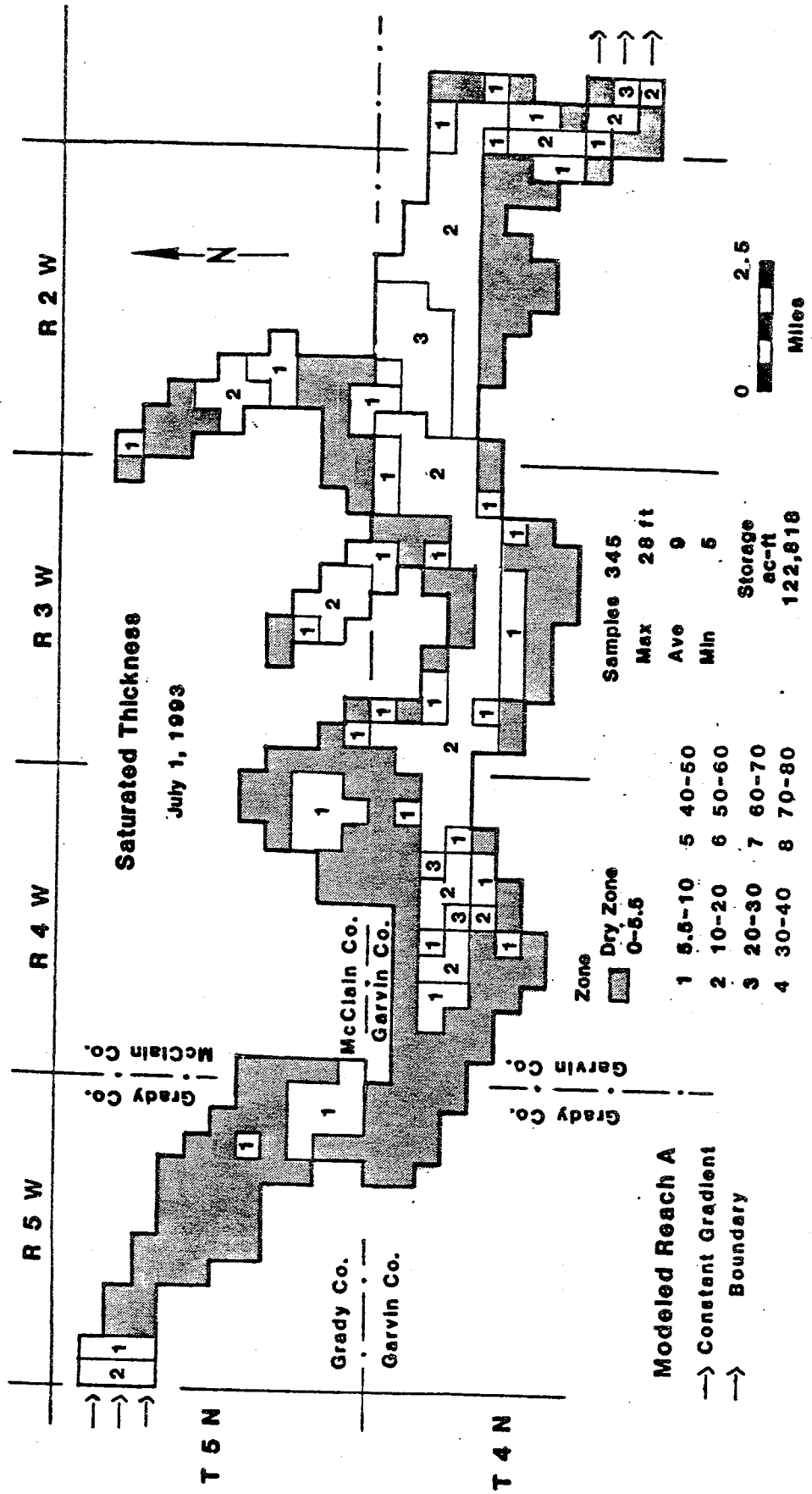


Depth to water, July 1, 1993, Subreach C, Modeled Reach 4.



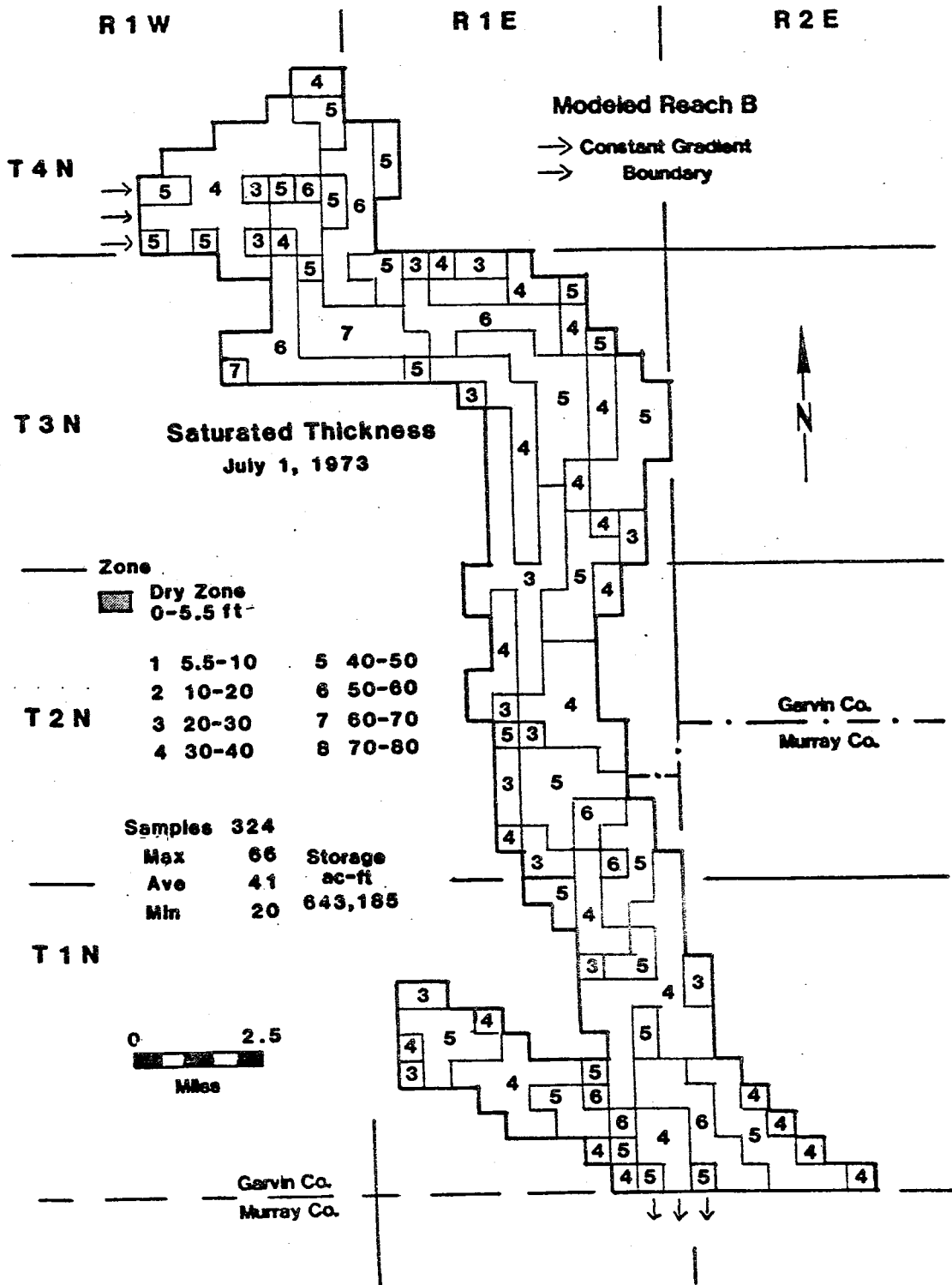
Saturated Thickness Map,

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



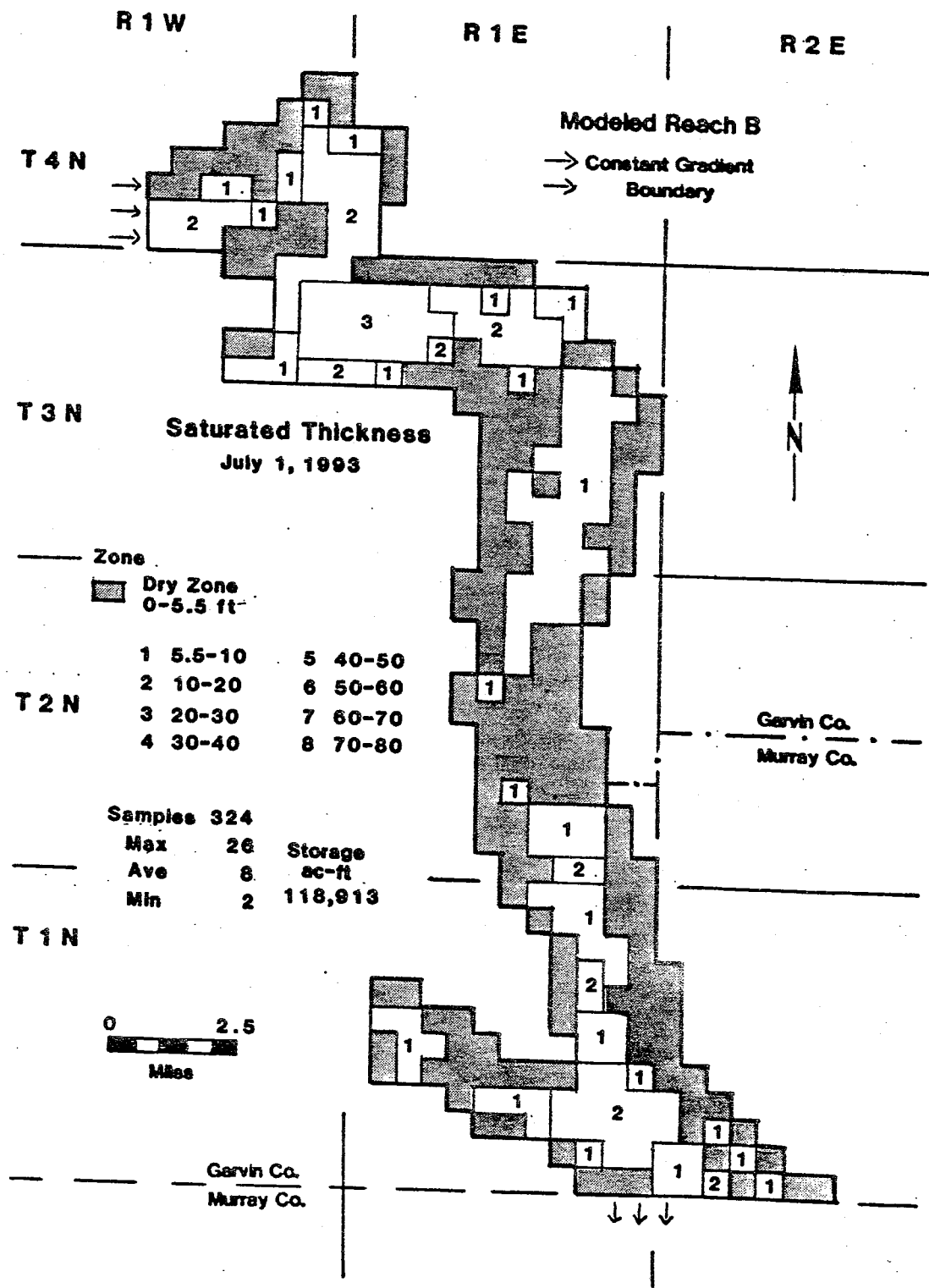
Saturated Thickness Map,

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

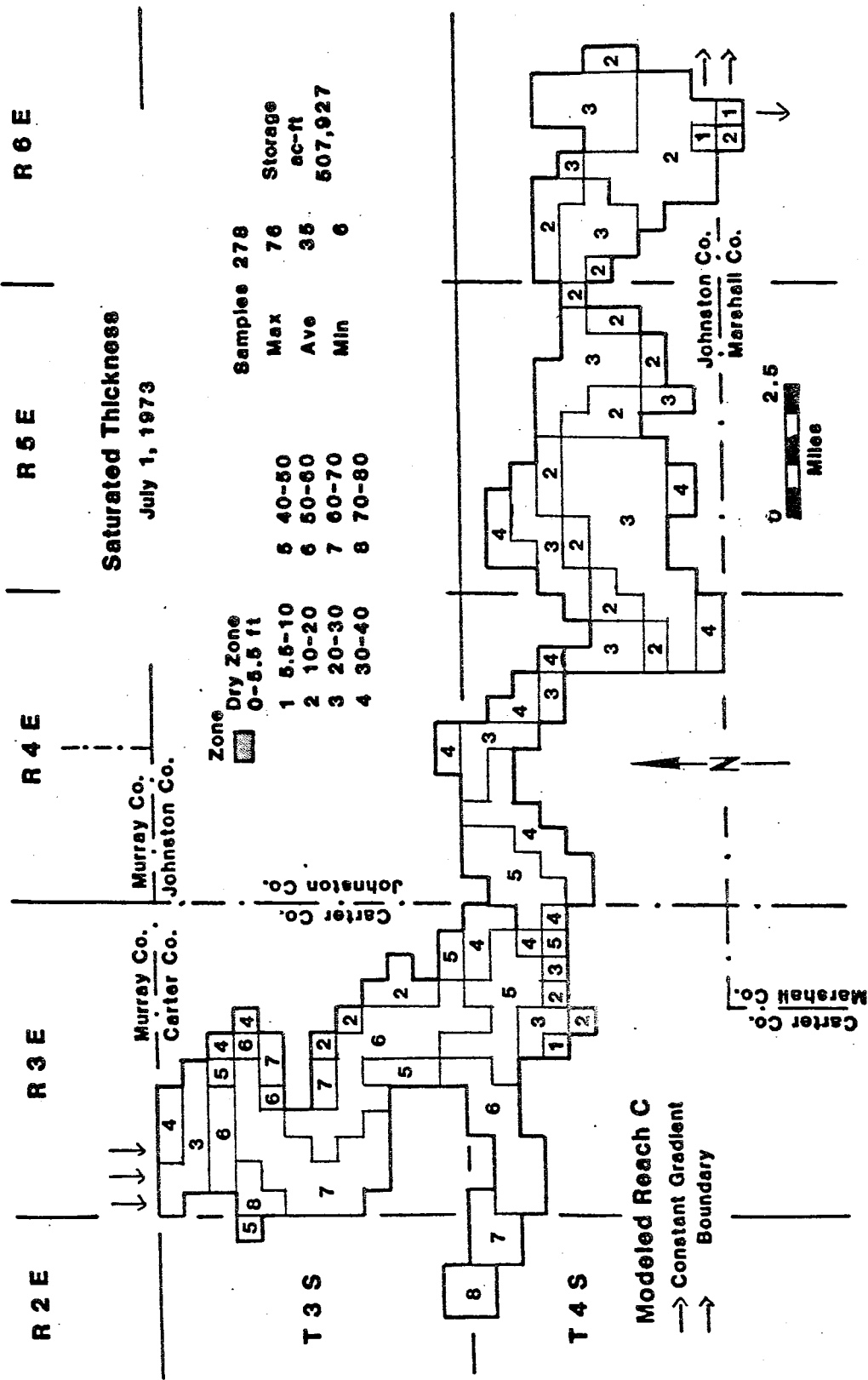


Saturated Thickness Map,

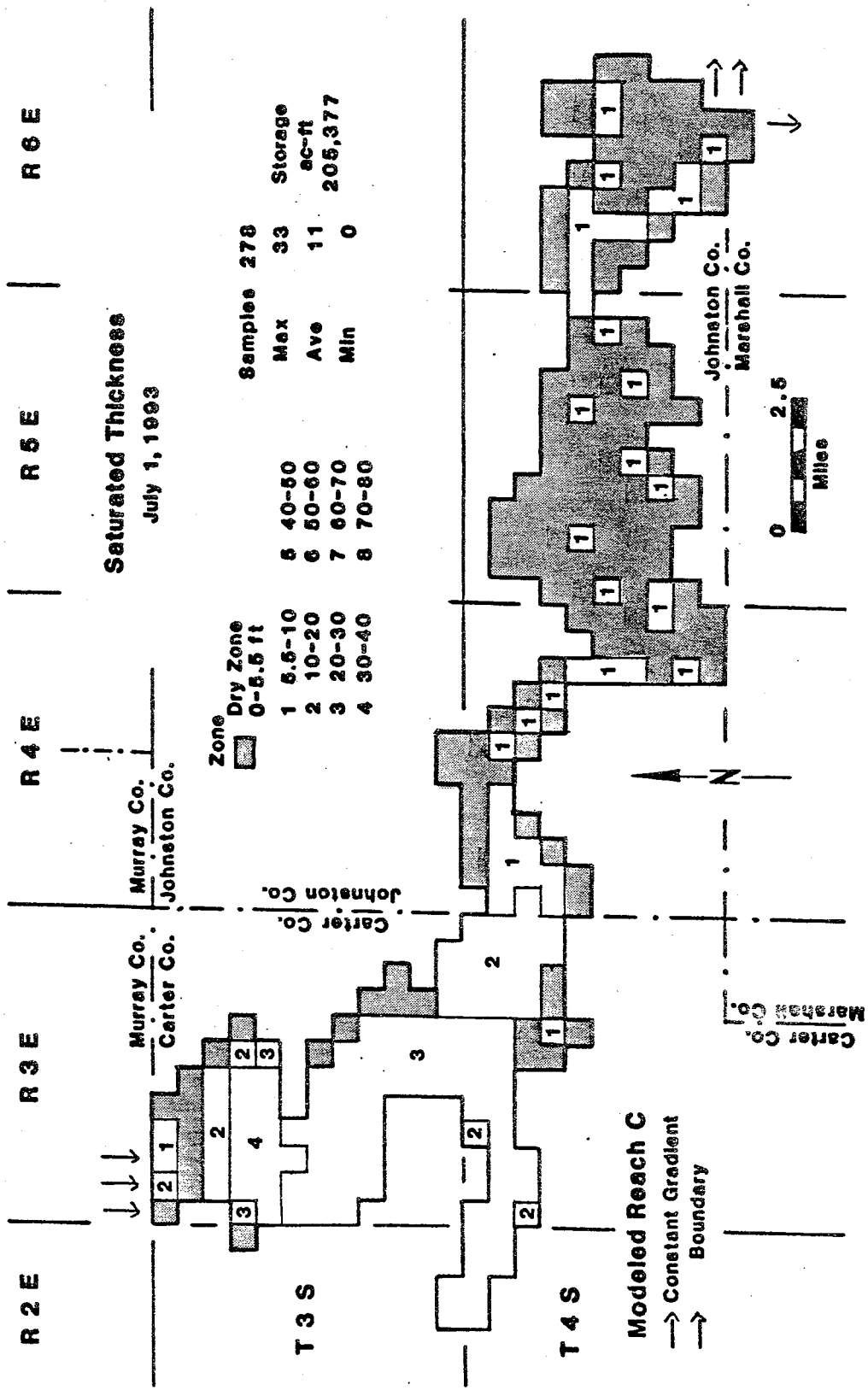
July 1, 1973, Subreach B, Modeled Reach 4.



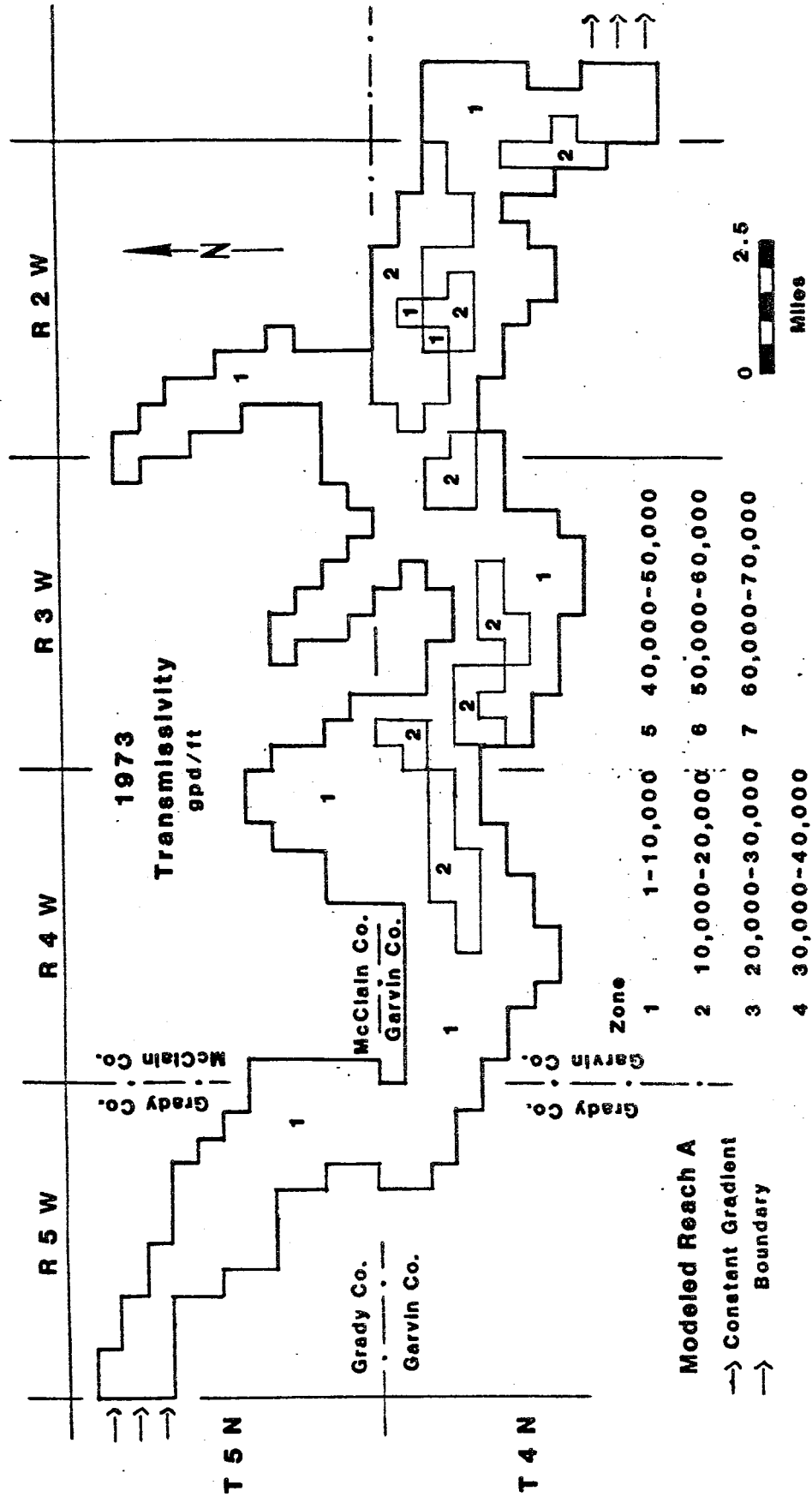
Saturated Thickness Map,
July 1, 1993, Subreach B, Modeled Reach 4.



Saturated Thickness Map,
July 1, 1973, Subreach C, Modeled Reach 4.

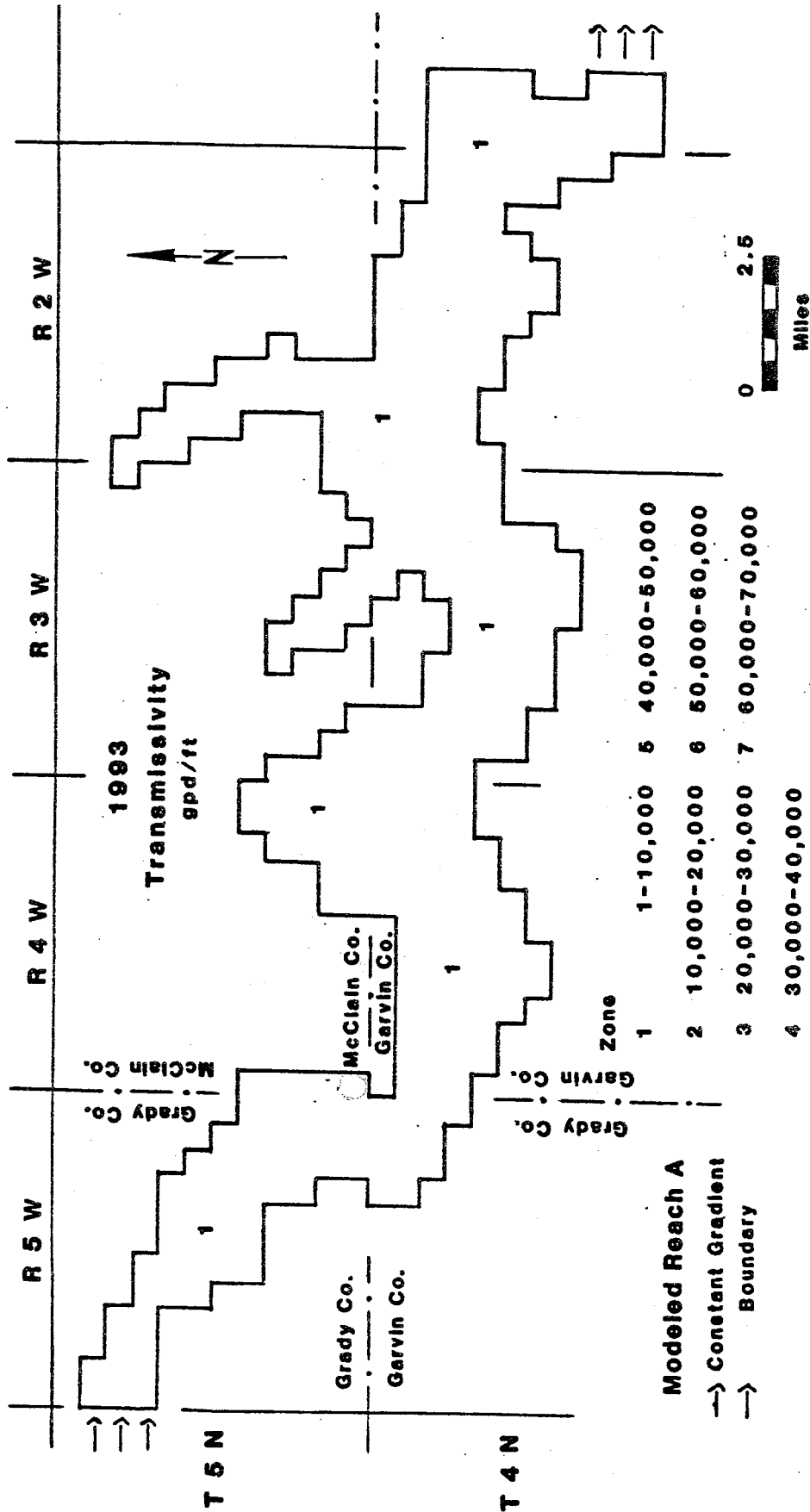


Saturated Thickness Map,
July 1, 1993, Subreach C, Modeled Reach 4.



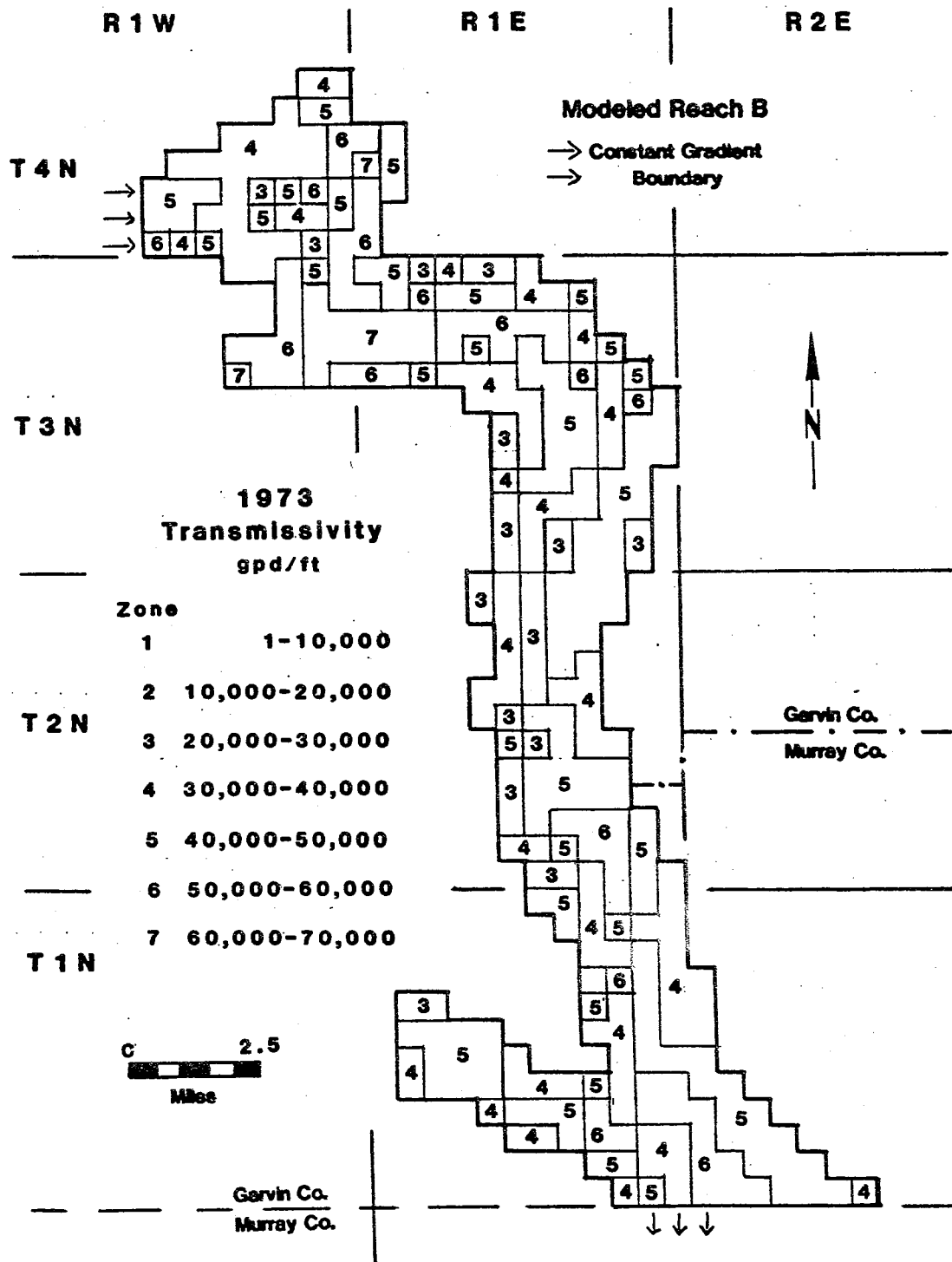
Transmissivity,

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



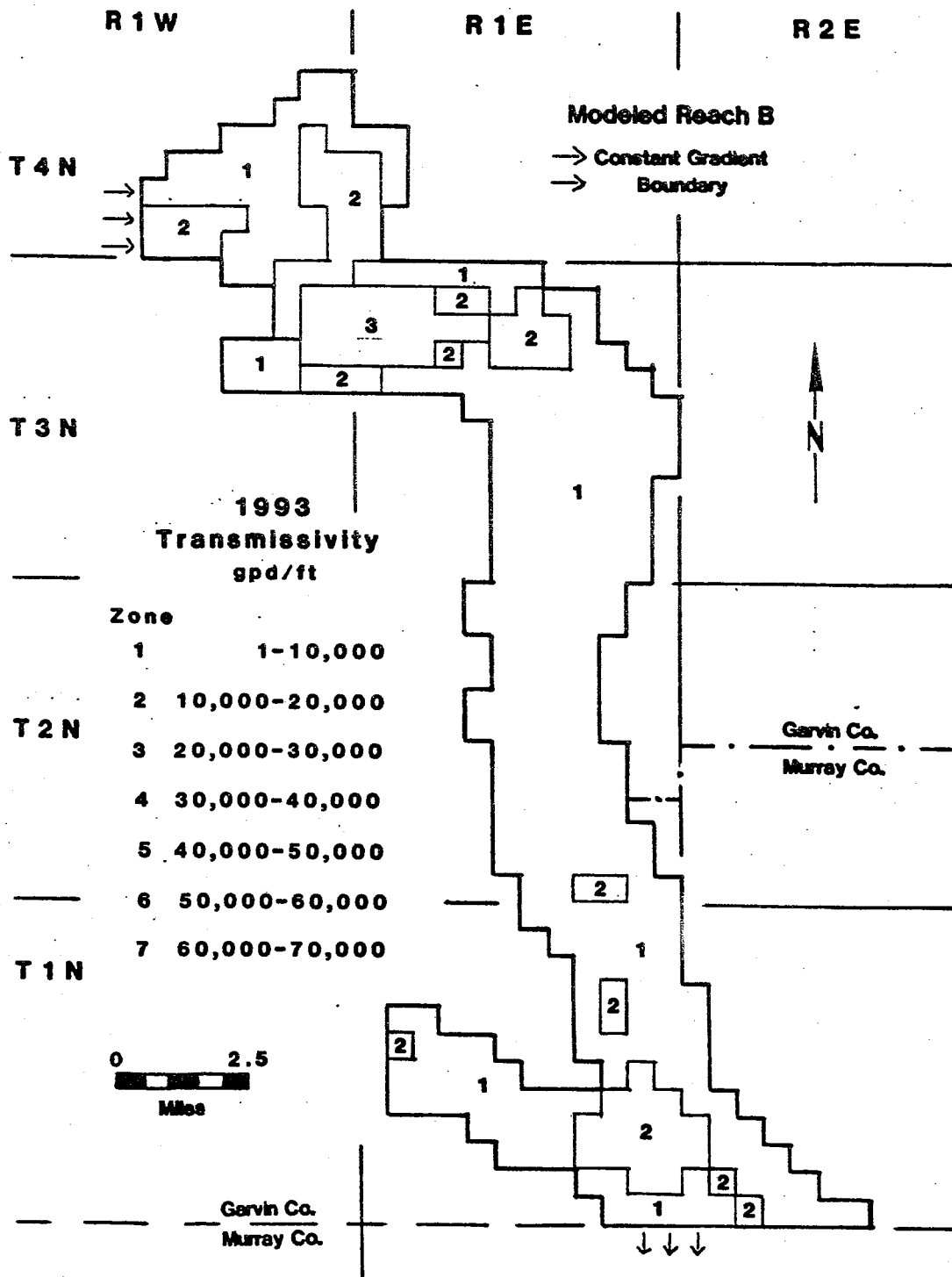
Transmissivity,

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



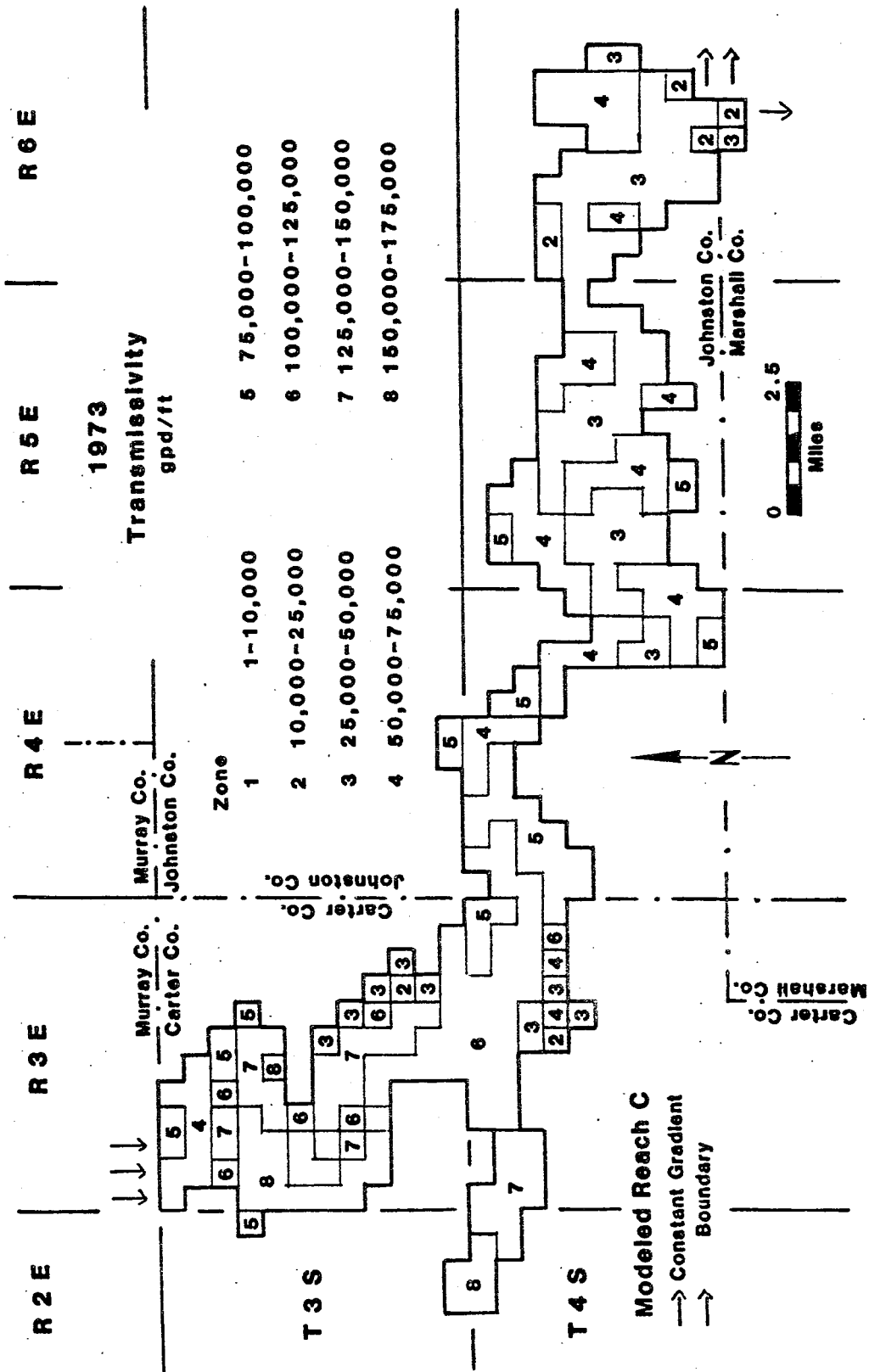
Transmissivity,

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



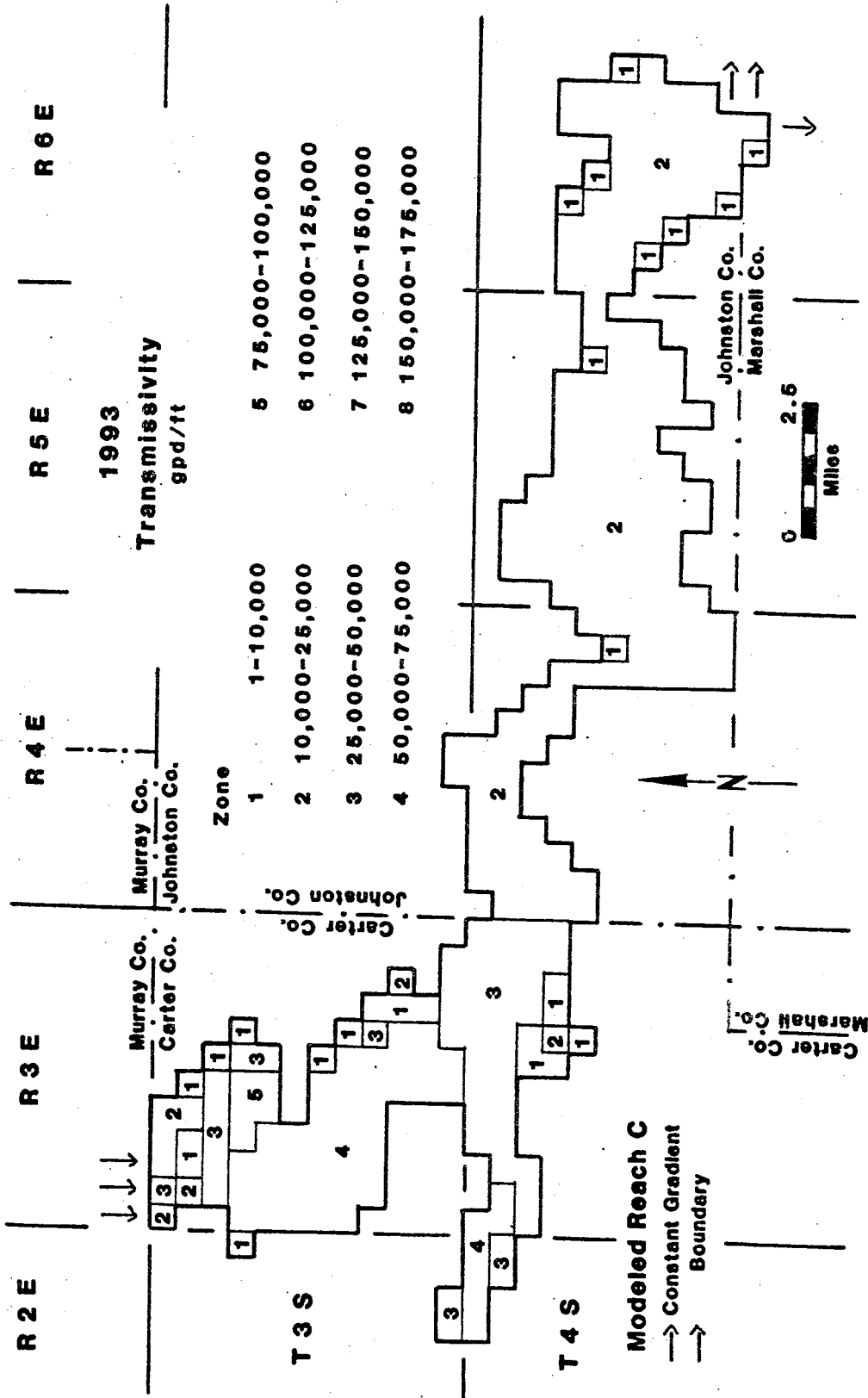
Transmissivity,

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.