EVALUATION OF AQUIFER PERFORMANCE AND WATER SUPPLY CAPABILITIES OF THE ENID ISOLATED TERRACE AQUIFER IN GARFIELD COUNTY,OKLAHOMA

By

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Final Report

To

THE OKLAHOMA WATER RESOURCES BOARD

May, 1982

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Project Title: Evaluation of Aquifer Performance and Water Supply Capabilities of the Enid Isolated Terrace Aquifer In Garfield County, 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 Enid Isolated Terrace Aquifer in Garfield County, 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 combined maximum annual yield is 19,000 acre-feet proportioned as 0.50 acre-feet per acre over the total area. This was based on the following parameters: (1) the total land area overlying the Enid Isolated Terrace Aquifer is 52,000 acres (excluding surface water), (2) the amount of water in storage in the basin as of July 1, 1973 is 261,000 acre-feet, (3) the potential amount of water in storage plus return flow over the twenty-year life of the basin is 470,000 acre-feet, (4) the estimated rate of net recharge from rainfall is 2.30 inches per year and the assumed irrigation return flow rate is 25 percent, and (5) the initial average transmissivity is 9,500 gallons per day per foot and the average specific yield of the alluvium is 0.30. In addition, the predicted water table of July 1, 1993 indicates that the possibility of natural pollution due to ground-water withdrawal within the Enid Terrace

deposits is negligible.

INTRODUCTION

General

The objective of the study was to determine the maximum annual yield of fresh water that can be produced from the Enid Isolated Terrace deposits of the Cimarron River in Garfield County, Oklahoma. Under 82 Oklahoma Statute Paragraphs 1020.4 and 1020.5, enacted by the Oklahoma Legislature, the Oklahoma Water Resources Board is responsible for completing hydrologic surveys of each fresh ground-water basin or subbasin within the state of Oklahoma and for determining a maximum annual safe yield which will provide a 20-year minimum life for each basin or subbasin.

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

Location

The study area is located in the western half of Garfield County, in North Central Oklahoma. The location of the Enid Isolated Terrace Aquifer is shown in Figure 1. The aquifer extends over 52,000 acres in Garfield County and has an areal extent of 81 square miles.

Boundaries of the Enid Isolated Terrace Aquifer are controlled geologically. In the eastern half of the area, the boundary is defined by the Hennessey group - Quaternary terrace contact. The Cedar Hills Sandstone Formation - Quaternary terrace contact delineates the boundary

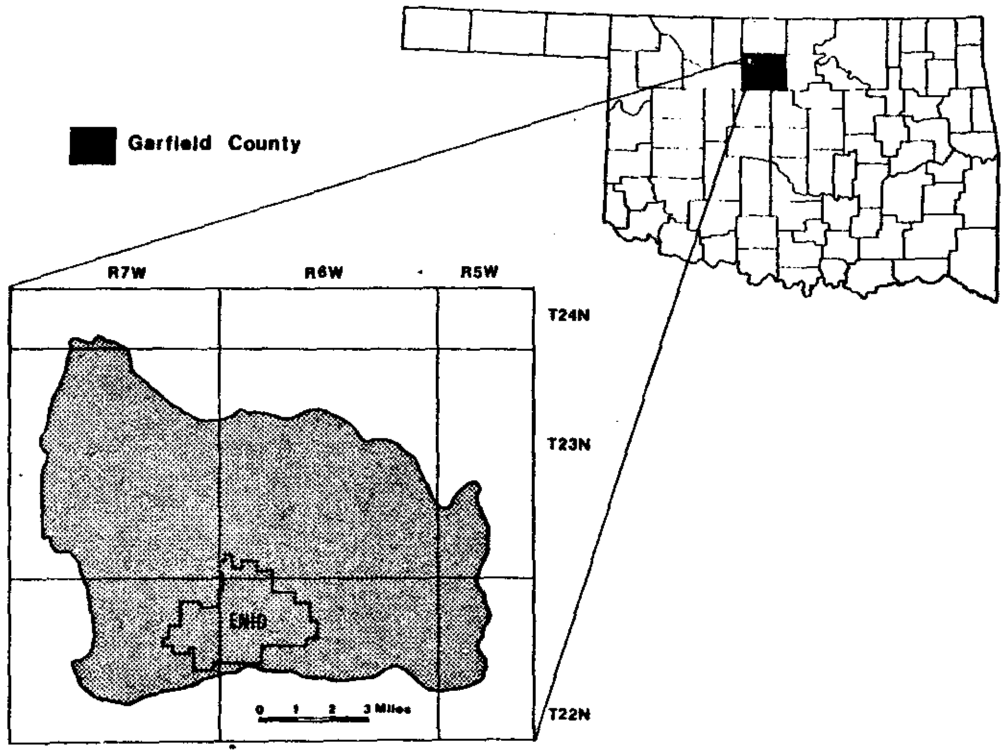

Figure 1. Location of Study Area by Township and Range

in the western half of the area.

Previous Work

Gould (1905) conducted a broad study of the water resources for the State of Oklahoma. Brief mention was made of the ground-water resources of Garfield County and pertinent published well records were included. Terrace deposits located along the Cimarron River and their nature were also discussed.

Schwennesen (1914) mapped and described the unconsolidated "Tertiary age" deposits surrounding Enid and made several conclusions concerning their ground-water potential. Published well records and logs were included as well as a preliminary geologic map. Well spacings and general recharge were discussed.

Renick (1924) followed Schwennesen's investigation with a more comprehensive study of the Enid Terrace deposits. A detailed analysis of the Terrace material as to lithology, origin, and thickness was undertaken and recommendations for future municipal well sites were made.

Clark (1927) mapped the Enid Terrace deposit along with the Permian bedrock units. In this study the Cedar Hills Sandstone Formation was identified as the Duncan Sandstone Formation of the Enid Group.

Reed (1952) proceeded with an extensive geologic, hydrologic study of a 600 square mile area located 5 miles southwest of the Enid Terrace deposits. A detailed geologic analysis of the Quaternary deposits and Permian strata was undertaken and published aquifer test data, well logs, and water quality data were included. The purpose of the study was to determine the occurrence, quantity, and quality of the ground-water resources found in the area and to analyze the effect of water withdrawals from the deposits. Recommendations were made as to the future development of these deposits with respect to irrigation, industrial, and municipal supplies. Because of the proximity of this investigation to the Enid study area and because of similar lithologies present, this report has been extensively used in the present analysis of the (Enid Terrace deposits).

In his study of Blaine and Major Conties, Fay (1962, 1965) describes many of the units found within the Enid study area. The Cedar Hills Sandstone Formation is classified by Fay as being uppermost in the Hennessey Group. Later Fay (1972) classifies the Cedar Hills Sandstone Formation as the lowermost formation of the El Reno Group. Information regarding climate, land use, and socio-economic information is also described in this report.

Bingham and Bergman (1980) described the ground and surface water resources of the Enid Quadrangle. The description includes ground-water quality, potential well yield, hydrology, and geology of the Enid area.

Kent (1978, 1980) studied the alluvium and terrace deposits along the North Fork of the Red River for water supply capability. Kent used the 1974 computer model version developed by the United States Geological Survey (USGS) to determine maximum annual yield and annual allocations for those aquifers. Many of the hydrogeologic and modeling techniques used by Kent (1980) were used in this investigation.

Bredehoeft and Pinder (1973) and Pinder (1970) designed a basic mathematic model to simulate two-dimensional aquifer problems. This model has been modified several times and described by Trescott, Pinder, and Larson (1976). Witz (1978) developed new input-output options for the IBM 370-158 computer. The 1974 version of this model developed by the United States Geological Survey plus the latter modifications were used in the study.

GEOLOGY

The Enid Isolated Terrace Deposits are located on the northern shelf of the Anadarko Basin and within the Central Red-bed Plains geomorphic province of Oklahoma (Johnson, 1972). The topography within this geomorphic province can be described as red Permian shales and sandstones that form gently rolling hills and broad, almost flat plains. These Permian shales are overlain by Quaternary terrace deposits, which form the topographic highs in the northern corner.

Reed (1952) notes that the Terrace deposits form a topographic feature that is not readily discernible more than two miles from the Cimarron River. Their full topographic expression has been obscured by subsequent erosion and dune formation. The geologic exposures in the area range in age from Lower Permian to Quaternary, with the Quaternary sediments lying unconformably on Permian bedrock.

The Permian units are classified as the Hennessey Group and the El Reno Group of the Cimarron Series. The Hennessey Group consists of the Kingman Formation, Salt Plains Formation, and the Bison Formation (Figure 2).

The Kingman Formation, which is the oldest of the Permian units, underlies the Terrace deposit and delineates the easternmost boundary of the study area. It is orange-brown to greenish-gray, fine-grained sandstone and siltstone, with some red-brown shale. Morton (1980) describes these shales as having thicknesses up to 70 feet thick.

The Salt Plains Formation is younger than the Kingman Formation and delineates the north-central and south-central boundaries of the Enid Terrace aquifer. It is characterized by a red-brown siltstone with

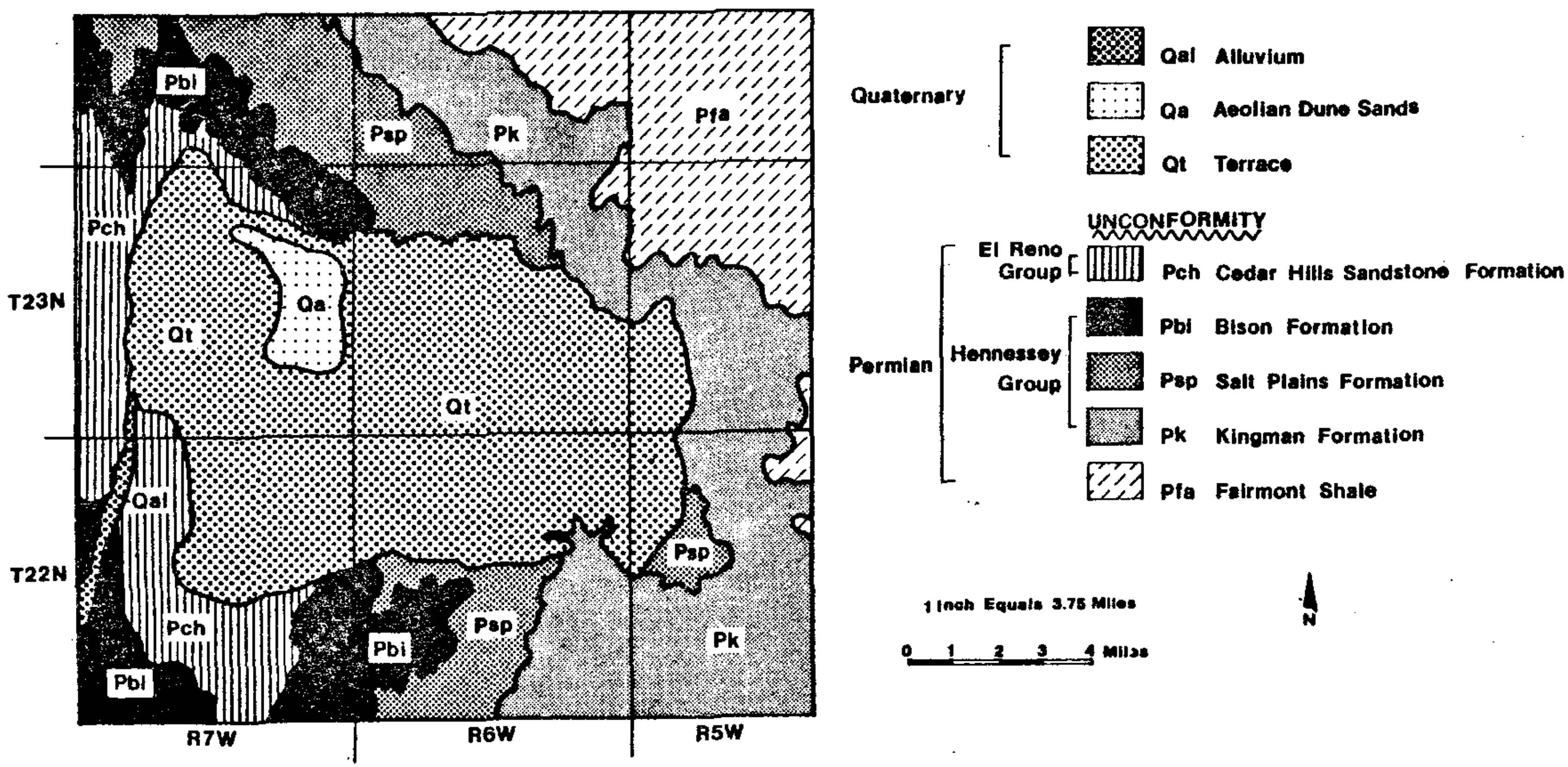

Figure 2. Geologic Map

several thin layers of greenish-gray and orange-brown calcitic siltstone.

The Bison Formation, which is uppermost and youngest in the Hennessey Group, is mainly a red-brown shale, with interbeds of greenish-gray and orange-brown calcitic siltstone present. The maximum thickness of the formation is 120 feet.

The Cedar Hills Sandstone Formation of the El Reno group rests conformably on the Bison Formation and underlies the Terrace material as a channel deposit in the western half of the study area. The northwestern, southwestern, and western boundaries of the aquifer are delineated by the Cedar Hills - Quaternary terrace contact. The Cedar Hills Sandstone Formation is a friable, well sorted, orange-brown to greenish-grey, fine grained calcitic sandstone. Grain size variations occur throughout the area. Siltstones and some soft red-brown shale units have also been recognized.

The Quaternary sediments vary considerably over the study area. These sediments are primarily composed of discontinuous layers of clay, sandy clay, sand, and gravel. The sand and gravels generally are not well sorted, although in the southeastern part of the area the Lower Quaternary material is extemely well sorted where it overlies the Permian formations. Color of the Terrace materials vary laterally and vertically within the deposits. The lower portion of the Terrace deposits are typically coarser grained. The Terrace materials which are directly in contact with the Permian bedrock contain rounded, reworked clasts of the Lower Permian units, varying in size from pebbles to cobbles. The Lower Quaternary material may also take on the characteristic calcitic nature of the underlying formation and may be difficult to differentiate from various Permian units in the area.

The distinction between the Terrace deposits and the Permian Cedar Hills Sandstone Formation has been made extremely difficult due to poor well records and similar characteristics in lithology. However, discrete color changes as well as grain size may be used as criteria for differentiation where gravel deposits of the Lower Quaternary material occur at the unconformable boundary. The thickness of the Terrace deposits change radically within the area due to the eroded Permian bedrock surface forming a channel which was subsequently filled by Quaternary deposits. The average thickness for the Quaternary age material is sixty feet.

The Terrace material can be separated into three distinct localized, geomorphic areas based on the topographic expression found in the area. The northeastern and southwestern regions can be characterized as a relatively flat area which has not been altered by extreme erosion or aeolian processes. Sands in this area thin toward the edge of the terrace deposits. Heavily incised, dendritic drainage systems prevail over the southeastern and north-central portions of the area. Permian units can be found in the stream beds and thicknesses of the Terrace material are extremely variable depending on location.

HYDROGEOLOGY

General

The Enid Isolated Terrace Aquifer is an unconfined system; the upper boundary of the aquifer is formed by the water-table and the lower boundary by the semi-permeable Hennessey Group. This condition is displayed in Figures 3 and 4. The water-table generally follows the topography of the area and subsurface flow is predominatly from the northwest to the southeast. The water-table gradient is fairly low except in the proximity of the aquifer boundary where seeps and springs are associated with steeper gradients.

The Terrace deposits and Cedar Hill Sandstone have been treated as an undifferentiated aquifer where they are in contact with each other. Although geologic time and environments of deposition most assuredly have differed in the laying down of these sediments, hydraulically they are very similar and together they make up the western half of the Enid Terrace deposits.

Morton (1980, 1981) recognized the Cedar Hills Sandstone Formation as having aquifer potential. In areas to the northwest of the study area, this unit has been used as a ground-water source; however, wells in that area were later abandoned due to the heavily mineralized quality of ground-water.

Climate

Climate of the Red-Bed Plains region of north-central Oklahoma is continental, temperate, and subhumid. The mean annual temperature at Enid is 60.8°F (Swafford, 1967). The average annual precipitation of

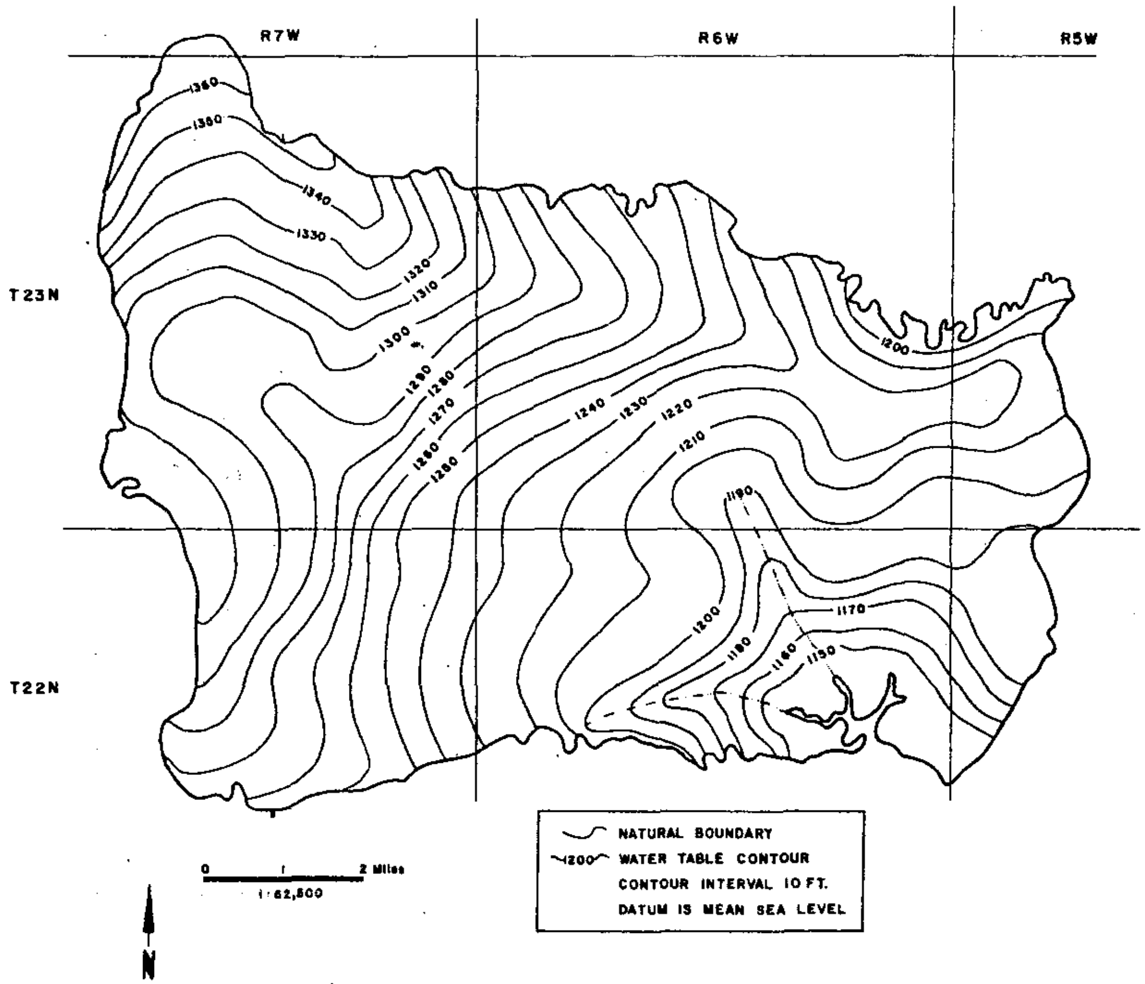

Figure 3. Water Table Map of the Enid Isolated Terrace Aquifer, 1973.

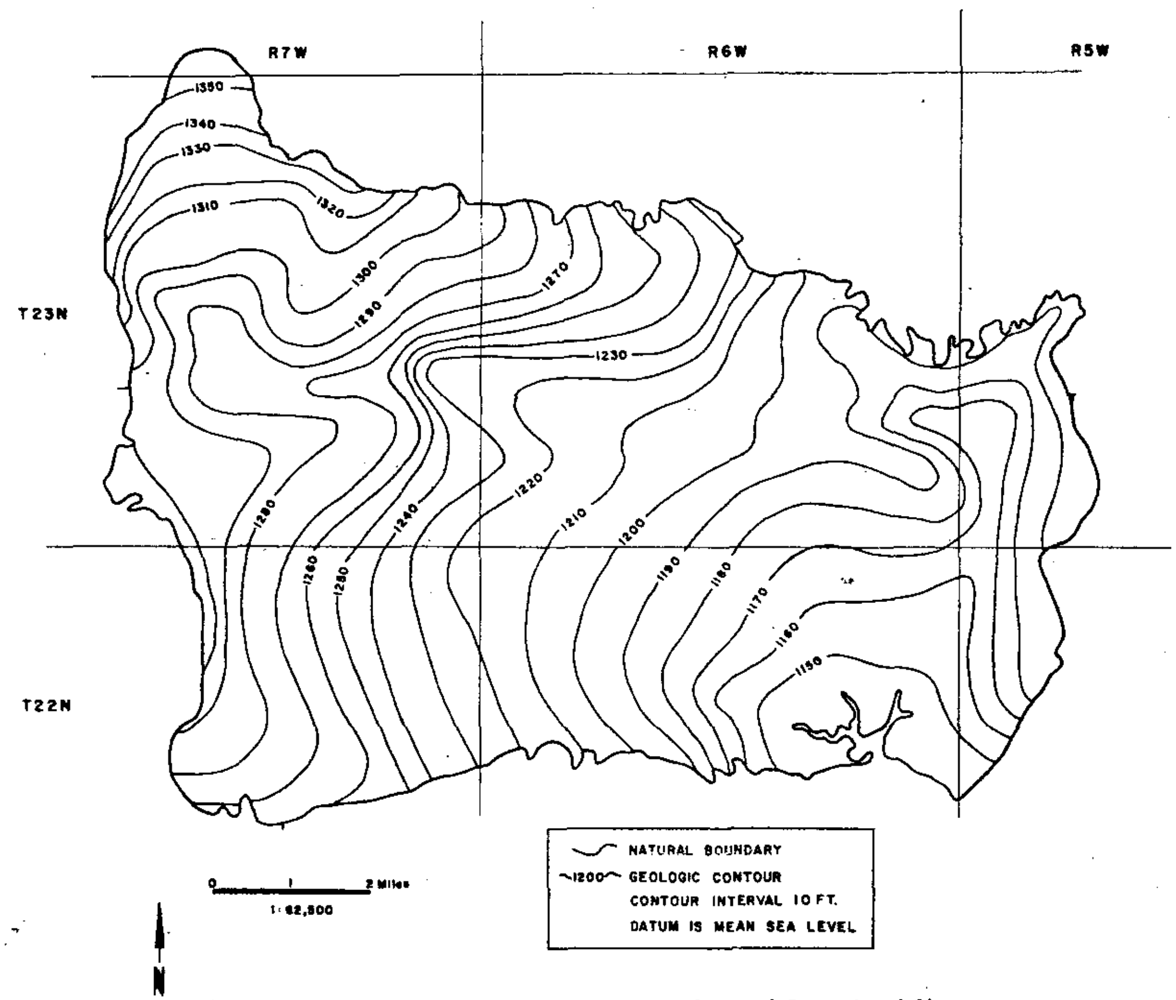

Figure 4. Topography at Base of Aquifer (Enid)

1950-1979 is 31.11 inches, with May, June, and September having the greatest concentration of precipitation. Annual and monthly precipitation for the City of Enid are presented as graphs in Figures 5 and 6.

Water Supply and Irrigation

Ranching, farming, and oil refining are the three main industries. Wheat, oats, barley, grain sorghum, and alfalfa are the dominant crops grown wihin the area. Pasture grasses are grown during the fall, spring, and summer months.

Farm cultivation takes place in those areas devoid of aeolian dunes and not deeply incised by the dendritic drainage of the area. The greatest concentration of cultivation occurs in the west-central, southwestern, east-central, and northeastern parts of the study area. The irrigation period for the above mentioned crops is June through September.

The City of Enid makes up the greater portion of the south-central portion of the study area. Enid, with a population of 45,000, is characterized by one-family dwellings with light industry interspersed throughout this region.

The main source of water for the City of Enid is from municipal wells located in the isolated terrace and also from wells located on the Cimarron terraces southwest of Enid. Of the 90 wells used for data collection, fifty percent of these were municipal wells used by the City of Enid.

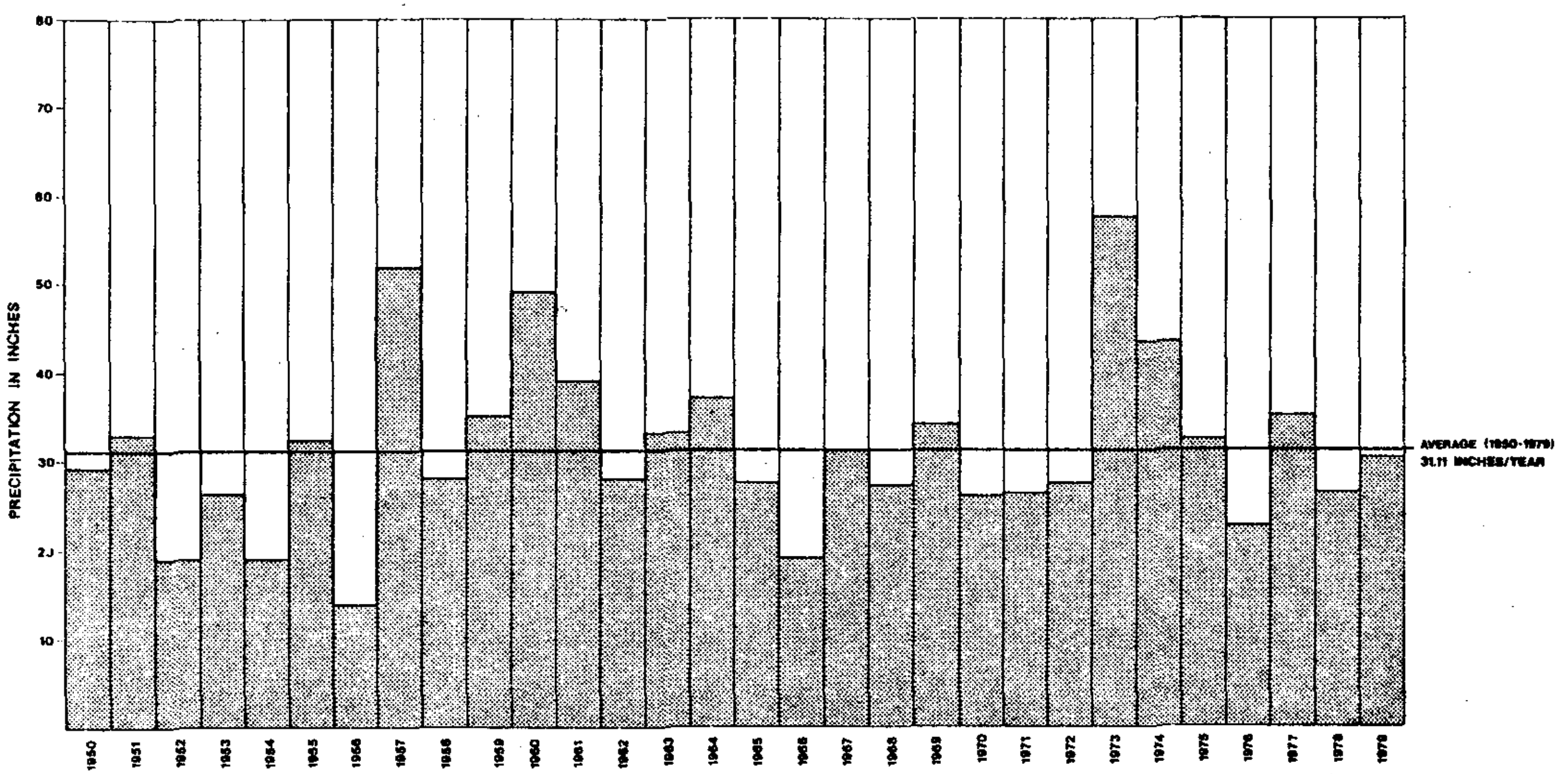

Figure 5. Annual Precipitation at Enid, Oklahoma 1950-1979

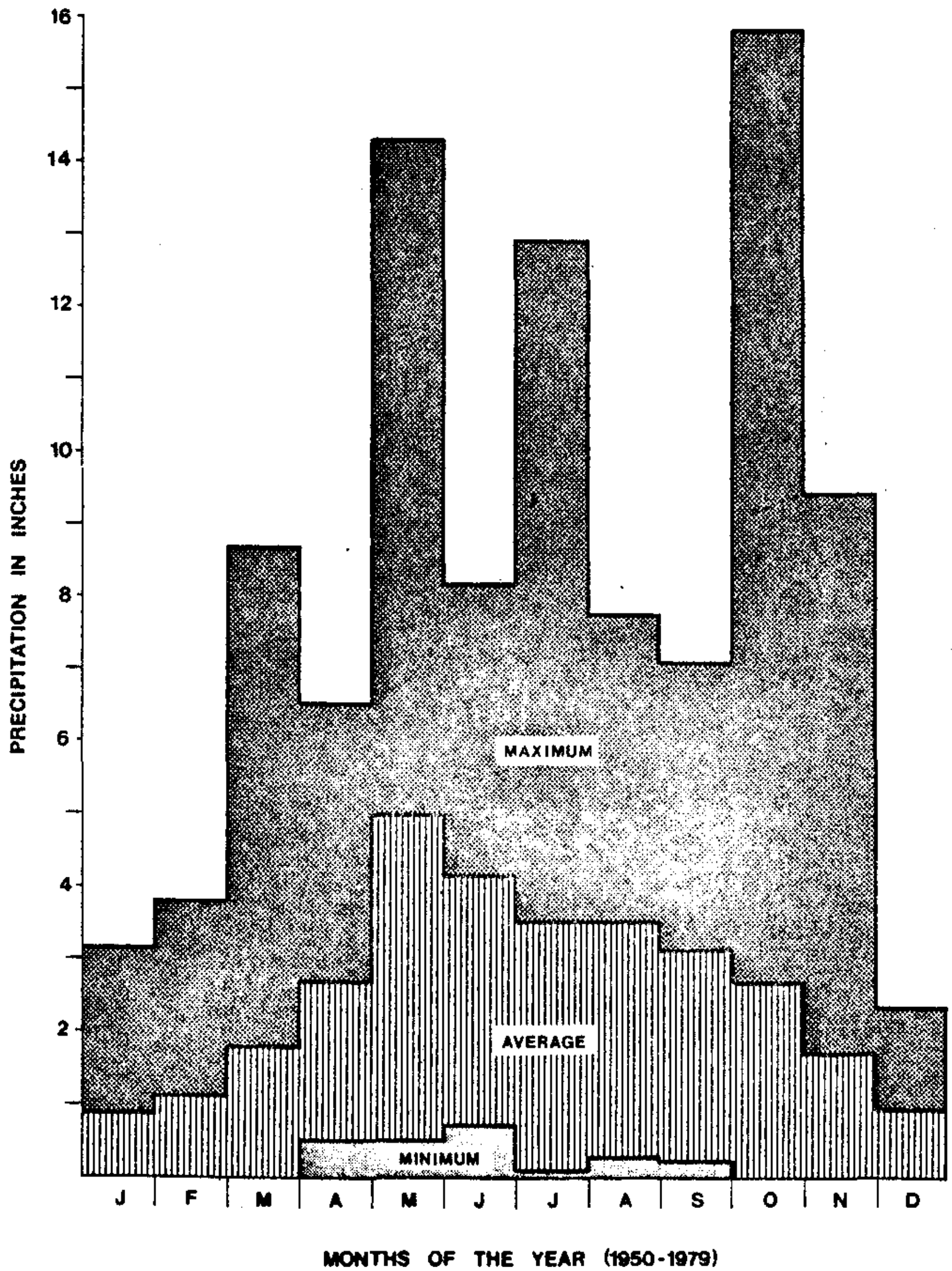

Figure 6. Monthly Precipitation at Enid, Oklahoma 1950-1979

Prior Appropriative Pumping Rights

Prior rights pumping is the right established by the State of Oklahoma for landowners who have pumped ground-water prior to July 1, 1973 at a rate for which a beneficial use can be shown. Final prior rights pumping rates (acre ft./year) were acquired from the Oklahoma Water Resources Board. These rates were assigned to nodes with respect to their quarter-mile location and are shown in Figure 7.

Surface Recharge

Recharge is the major source of water to the aquifer in the area. Due to the sandy nature of the area a high infiltration rate can be expected. The recharge rate will vary depending upon many factors: rainfall intensity and duration, vegetation, soil type, permeability of unsaturated zone, temperature, wind, topography, and depth to water-table.

A value of 2.3 inches per year of recharge has been calculated for the area based on well hydrographs and precipitation hydrographs. The average annual rainfall for the area has been established at 31.11 inches per year as shown in Figure 5. The percentage of rainfall recharging the aquifer through infiltration and percolation has been estimated to be seven percent of the average annual rainfall. This estimate is based on well hydrographs and precipitation records for the area (Figure 8). The calculation of this recharge percentage is shown in Table 1. The percentage of rainfall as recharge for each given year was calculated by dividing the estimated recharge using the hydrograph by the total rainfall for the year. The seven percent estimate represents an average value which was determined by averaging the

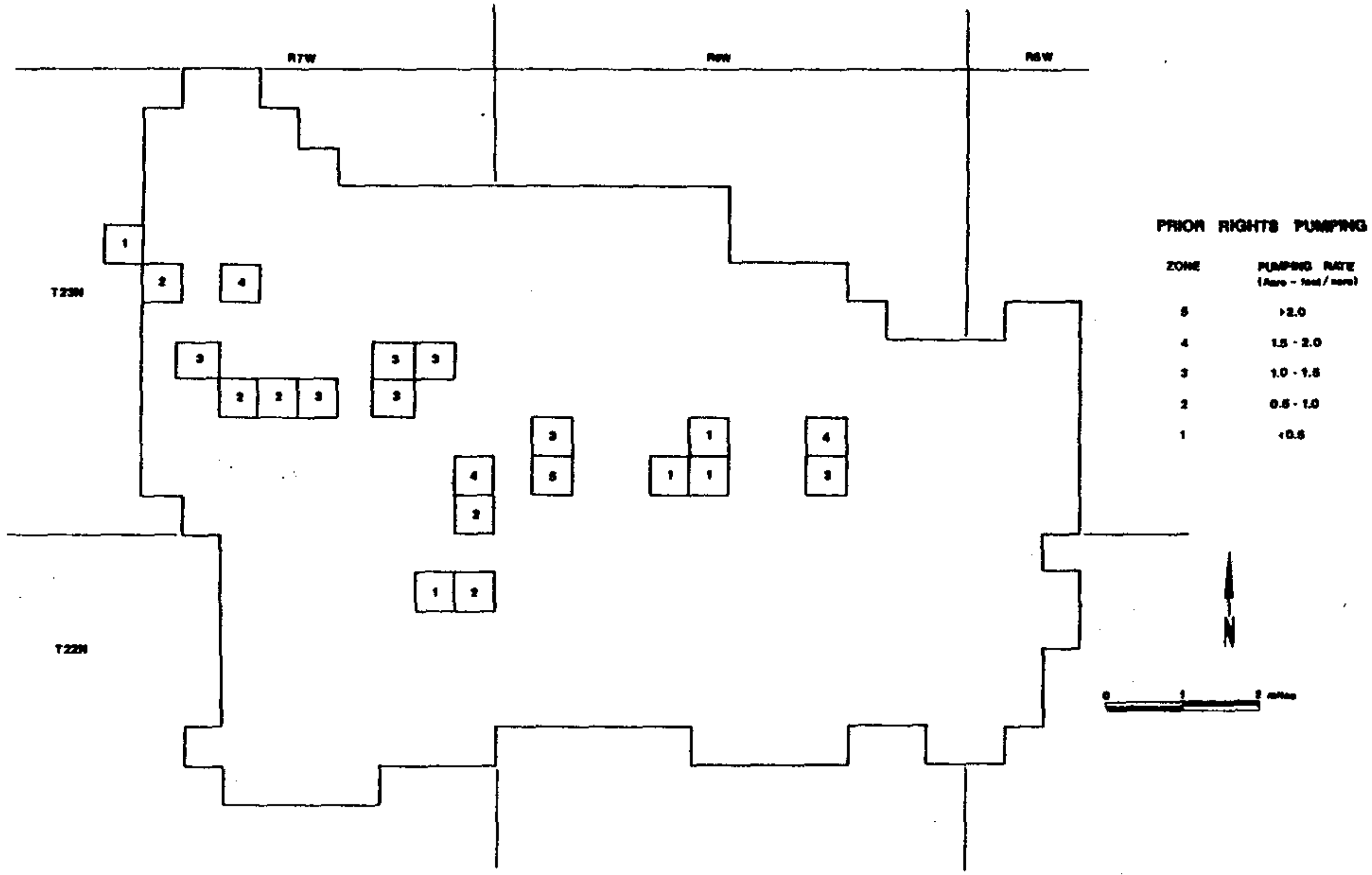

Figure 7. Prior Rights Pumping for Irrigation, Municipal and Industrial Use

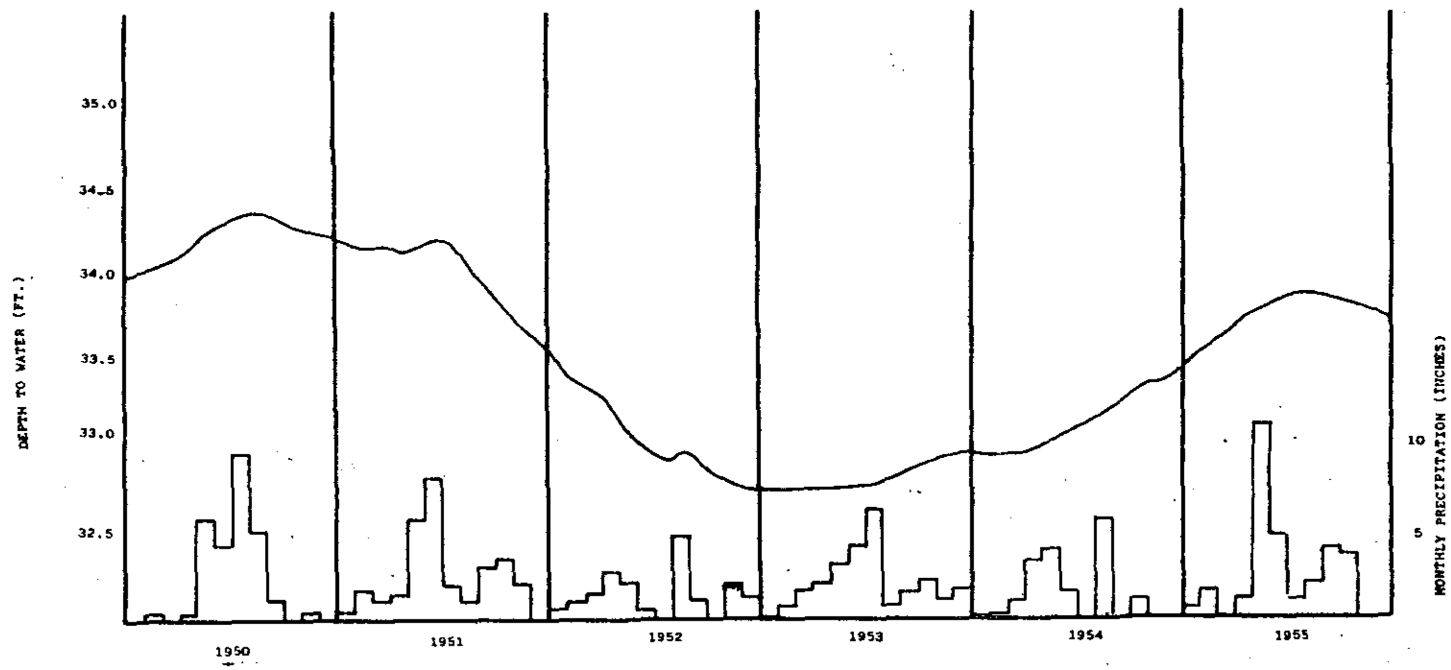

Figure 8. Well Hydrographs and Precipitation Data at Enid, Oklahoma 1950-1955

TABLE 1

CALCULATION OF GROUND-WATER RECHARGE AND RELATIVE PERCENT OF ANNUAL RAINFALL

Year	Change in Water Table (inches) (From well hydrograph)		Average Specific Yield (Sy)		Ground-water Recharge (inches)	Total Rainfall for Year (inches)	Percent of Rainfall as Ground-water Recharge
1950	4.2	x	.295	=	1.2	28.8	4.2
1951	7.8	x	.295	=	2.3	32.8	7.0
1952	9.6	x	.295	=	2.8	18.5	15.3
1953	2.4	x	.295	=	.7	25.8	2.7
1954	5.8	x	.295	=	1.7	18.8	9.1
1955	5.5	x	.295	=	1.6	32.1	5.1
						Mean Percent as Recharge	7.2

percent of rainfall for the years between 1950 and 1955.

Subsurface Recharge

Subsurface recharge to the aquifer represents a minor, yet significant element in maintaining aquifer equilibrium. The subsurface flow is most prevalent in the western half of the area where the Cedar Hills Sandstone Formation is adjacent to and in hydraulic continuity with the Quaternary terrace deposits.

Coefficient of Permeability

Under normal conditions, aquifer test data are used to determine the coefficient of permeability and related transmissivity values for the study area. Unfortunately, aquifer test data are unavailable for the 90 wells located within the area. Therefore, an indirect method was used to generate the coefficient of permeability and transmissivity (Kent et. al. 1973). Information related to thickness and lithology of the Terrace deposit was obtained from drillers logs of the 90 wells. The lithology is divided into four ranges: range one is associated with clay and silt; range two is very fine to fine sand; range three is fine to coarse sand; and range four is associated with coarse sand and gravel. A weighted average permeability was introduced by multiplying a weighting factor for the four size ranges by the percentage of saturated thickness for each range and summing up the total for all the ranges. The method is described for selected wells within the study area in Table 2. The weighting factors for each range were obtained from the coefficient of permeability grain-size envelope developed by Kent et. al. (1973) as shown in Figure 9.

TABLE 2

CALCULATION OF WEIGHTED COEFFICIENT OF PERMEABILITY (K)

Location of Well	Well Log	From	To	Saturated Thickness (ST)	Range	Multiplier (K)	Coefficient of Transmissivity (T=ST x K)
		ft.	ft.	ft.			gpd/ft
SW SE SE 28 21N 9W-2	Sand	0	10	0			
	Clay, gray	10	15	0			
	Clay, sandy	15	20	0			
	Sand, fine	20	35	11	2	300	3,300
	Clay, sandy	35	40	5	1	5	25
	Sand, Coarse	40	60	20	4	1,500	30,000
	Red beds	60	-				
				36			33,325

$$\text{Weighted } K = \frac{\Sigma\, T}{\Sigma\, ST} = \frac{33325}{36} = 925 \text{ gpd/ft}^2$$

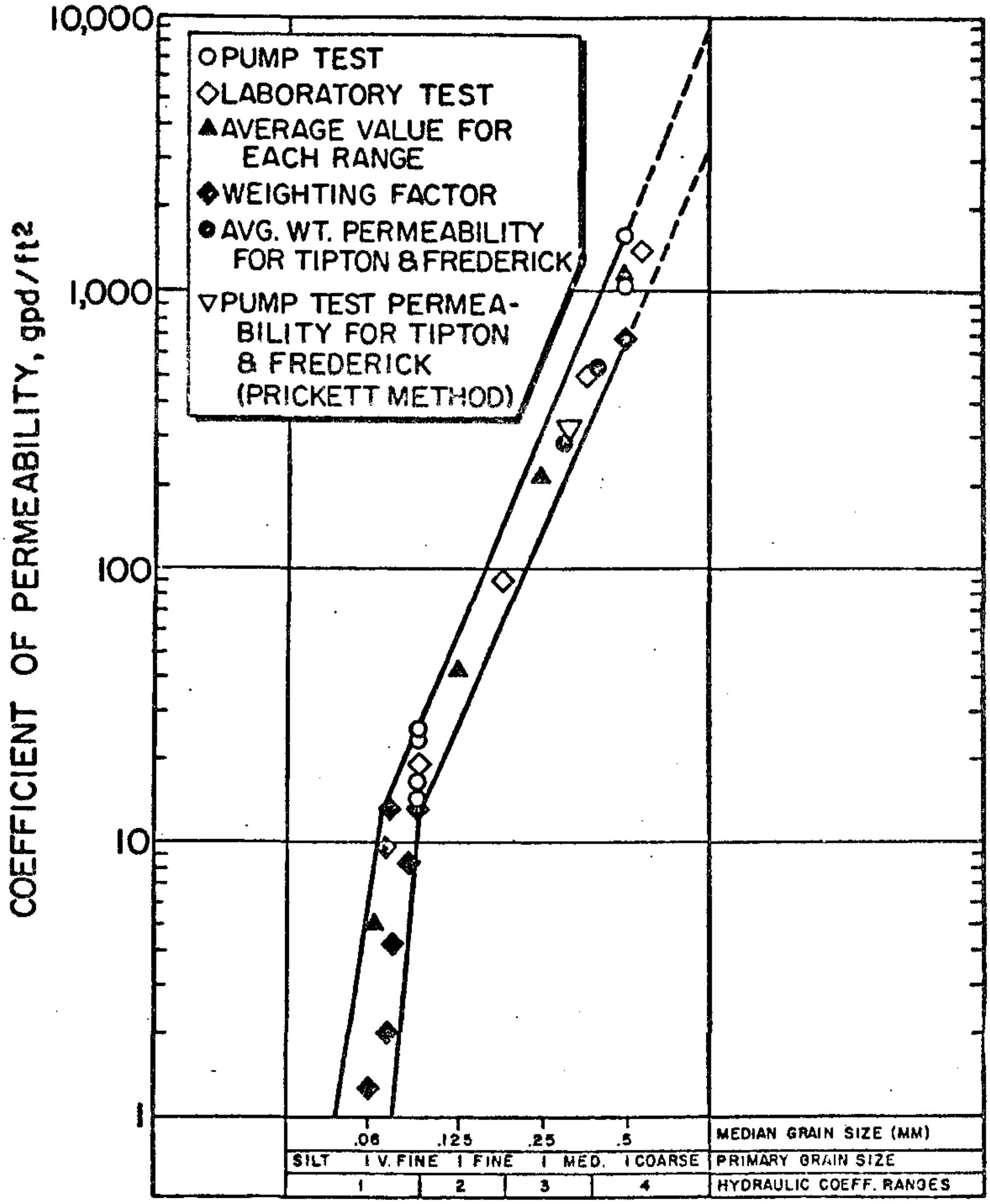

Figure 9. Coefficient of Permeability vs. Grain Size Envelope (after Kent, 1973).

In an attempt to ascertain that these values of permeability and transmissivity were correct for the envelope, (Figure 9) an analysis was run on several wells completed in the Cimarron River terraces outside the study area (Reed 1952). Aquifer test data and very complete well logs were available for selected wells. The lithology of these wells was very similar to those encountered in the Enid area. A comparison of these two methods is shown on Table 3. Kent's envelope method was shown to be very accurate in ascertaining transmissivity and permeabilities when compared with aquifer test data. Using these techniques, transmissivity values were computed for the area and are shown in Figure 10. The average transmissivity was computed to be 9,500 gpd/ft.

Two average values of permeability (Transmissivity x saturated thickness) were assigned to the Enid Terrace deposits based on subsurface geologic interpretation. These are shown in Figure 11. The Permian surface represents a highly eroded, unconformable surface. The extent of the Cedar Hills Sandstone Formation is based on the well log data and discussions with Fay (1981) and Morton (1981). A channel fill of Cedar Hills Sandstone appears to exist in the mid-western portion of the study area. This channel fill is included with the Terrace deposits because the sandstone is friable and therefore difficult to separate from the Terrace deposits. Based on wells which penetrate the channel, the sandstone is in hydraulic continuity with the Terrace deposits. The channel fill underlies the thickest sections of Quaternary terrace material. Permeability as well as transmissivity values appear to be characteristically higher within this central area.

In order to model the area, several assumptions concerning the aquifer were made. These are shown in Figure 12. The aquifer is

TABLE 3

COMPARISON OF AQUIFER TEST DATA (Reed, 1952) WITH WEIGHTED COEFFICIENT OF PERMEABILITY (K) (Kent, 1975)

Well Location	Aquifer Test Values from Reed (1952)		Envelope Method from Kent (1975)	
	Coefficient of Transmissivity (gpd/ft)	Coefficient of Permeability (gpd/ft^2)	Coefficient of Transmissivity (gpd/ft)	Coefficient of Permeability (gpd/ft^2)
SEC 27 19N 8W-2	60,000	1,100	56,700	1,000
SEC 5 20N 9W-2	46,000	800	46,000	800
SEC 28 21N 9W-2	31,000	900	33,000	900
SEC 20 21N 20W-3	52,000	800	49,000	700

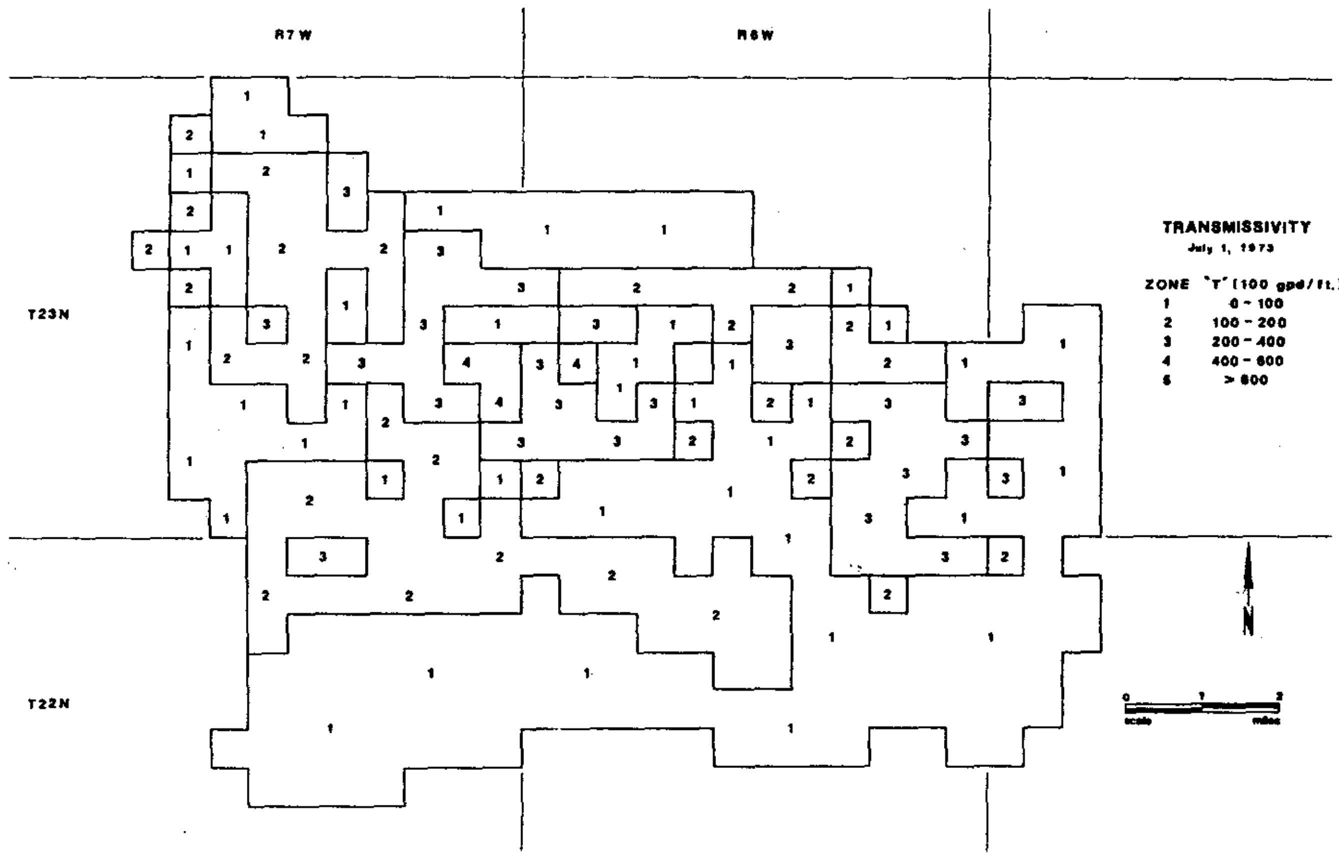

Figure 10. 1973 Transmissivity

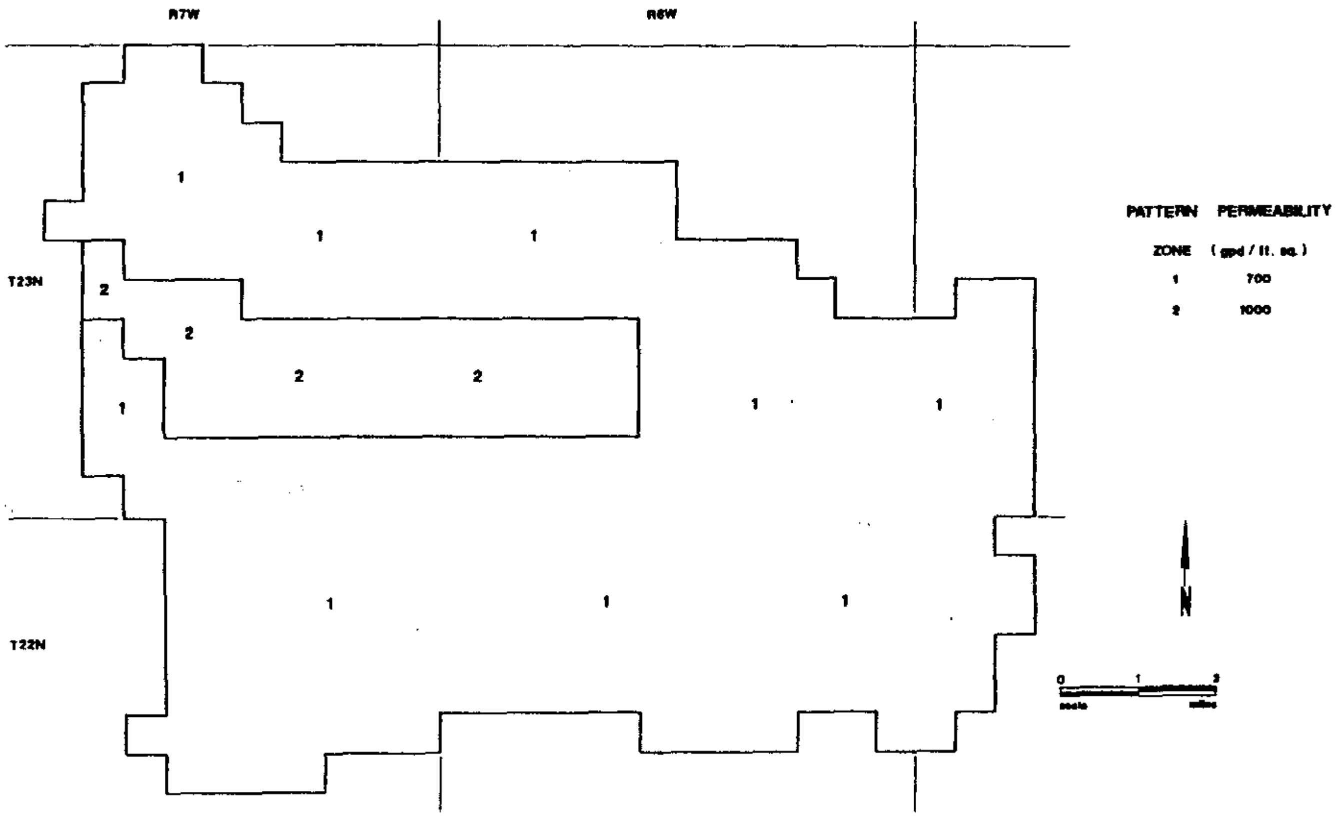

Figure 11. Patterned Permeability

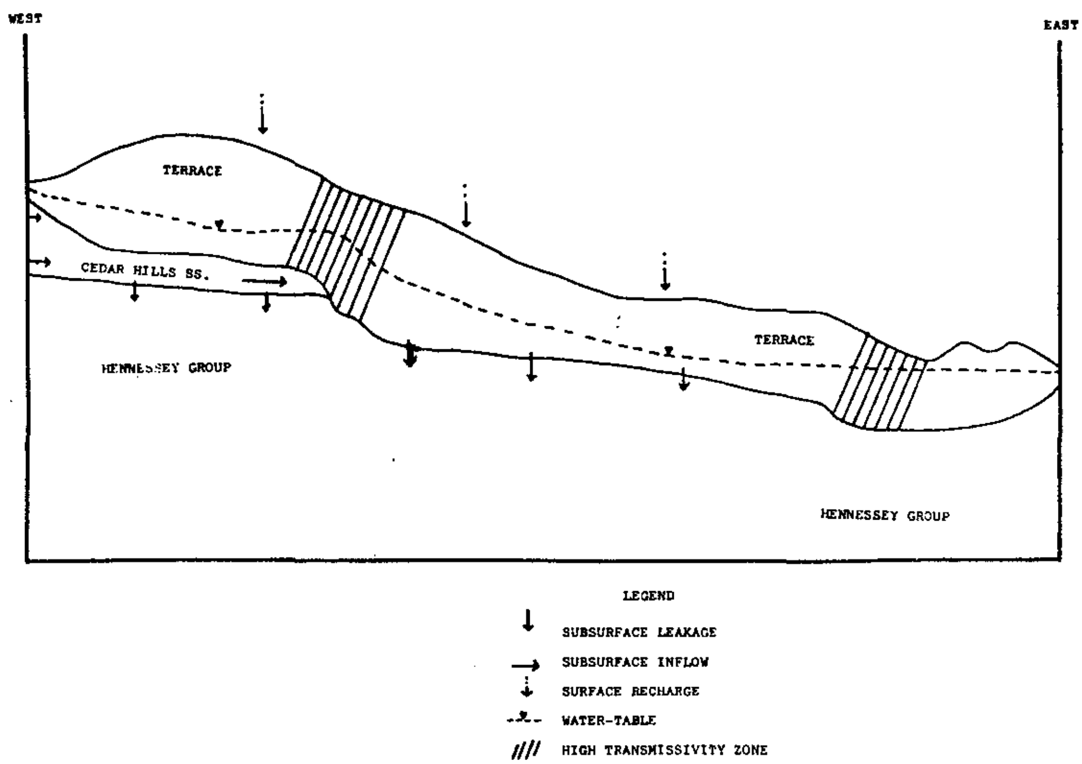

Figure 12. Conceptual Hydrogeologic Model

assumed to be a quasi-homogeneous, unconfined system. On a micro-scale, the Enid Terrace deposits are not homogeneous in a strict sense of the word. Vertical variations within the terrace occur throughout the area. Hydraulic characteristics also change as can be seen by noting the patterned transmissivity in Figure 10. Therefore, on a macro-scale the aquifer was subdivided into the two zones of permeability as shown in Figure 11, and the model area was divided into two regions based on permeability. Areas of the aquifer which overlie the channel fill were assigned a value of 1000 gpd/ft^2. All other areas were assigned a permeability value of 700 gpd/ft^2. These values represent average values based on the wells which occur within each of these subareas. Each zone is represented by an averaged value of permeability used to represent homogeneous conditions within that zone.

Another assumption made was that the bottom boundary represents an aquitard through which ground-water in the terrace leaks into the underlying fractured bedrock.

Recharge-Discharge and Water-Table Elevation

Historical water-level measurements for selected wells seem to reflect this phenomena by noting the negligible changes in water levels recorded in wells between 1950 and 1975.

GROUND-WATER QUALITY

All of the Permian units and the lower parts of the Quaternary material within the area contain some calcium carbonate ($CaCO_3$) which in turn provides the source for calcium (Ca^{++}) in the ground-water. The amount of Ca^{++} present in the water is reflected in total hardness. Waters containing a total hardness of less than 75 mg/l are moderately hard, 150-300 mg/l are hard, and greater than 300 mg/l are very hard. Mean total hardness for the study area has been established as 193 mg/l. Using these parameters, ground waters analyzed from the Enid Terrace are considered to be hard.

The mean total dissolved solids (TDS) for the area is 378 mg/l. This value represents the total quantity of dissolved mineral matter in the ground-water. A recommended maximum value of 500 mg/l has been established by the United States Environmental Protection Agency for drinking water containing total dissolved solids. Mean values for sulfate and chloride are 22 mg/l and 42 mg/l, respectively. The source of sulfate is associated with halite and gypsum deposits occurring in the Permian formations. Chloride is a common constituent of ground-water. Concentrations for sulfate and chloride fall well below the recommended maximum rejection limit of 250 mg/l, as set by United States Public Health Department. An areal distribution of these mean values is shown in Figure 13.

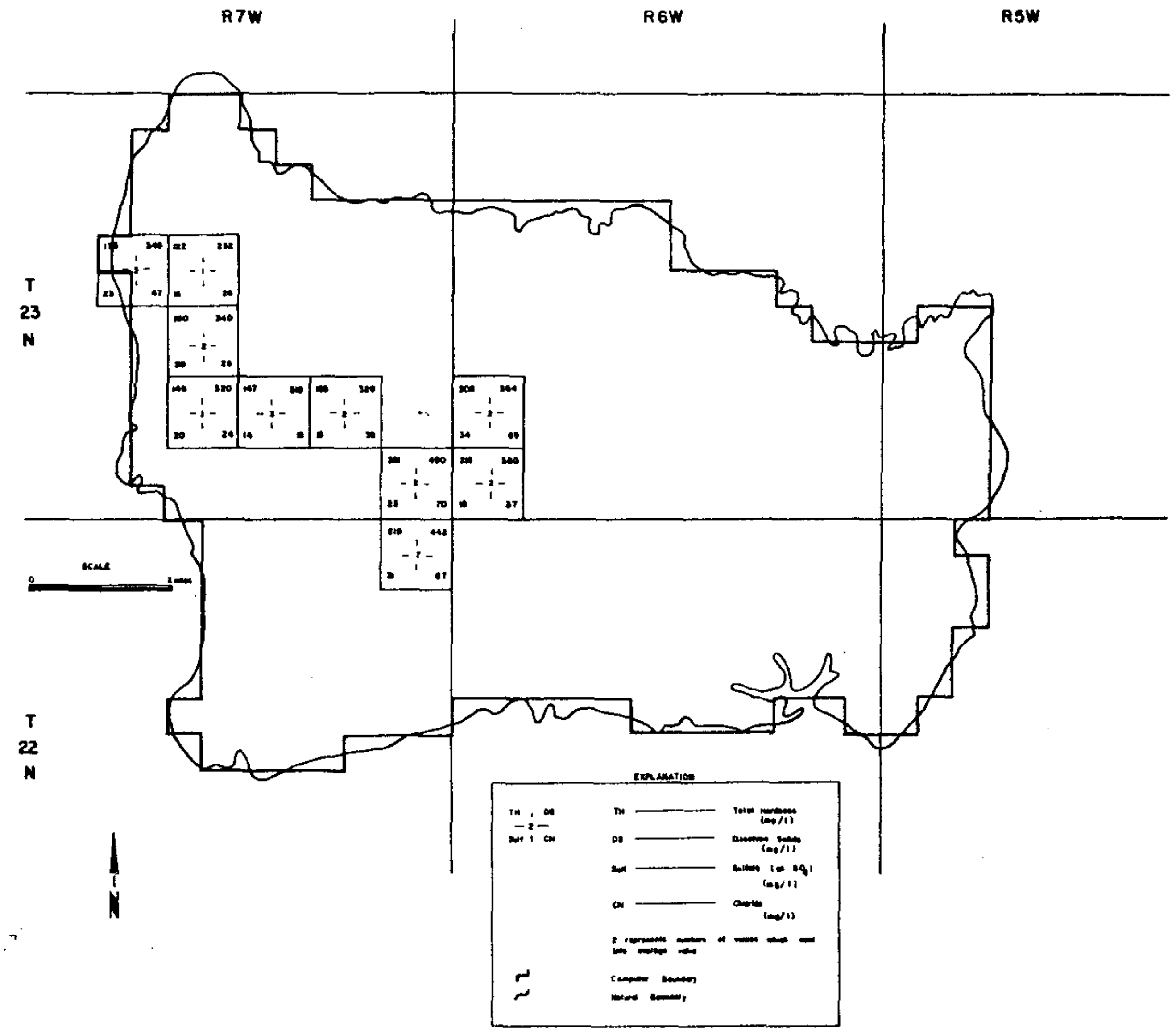

Figure 13. Water Quality Distribution (Enid).

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 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. The total aquifer area is 52,000 acres (81 square miles).

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. The water table version was used for the Enid Isolated Terace Deposits.

The approach used to process the data for model simulation is shown by the flow diagram in Figure 14. The input data were divided into matrix and constant parameters (Figure 14). The matrix parameters include: water-table elevations; land, top, and bedrock elevations; river bed thickness and hydraulic conductivity; and well pumping rate

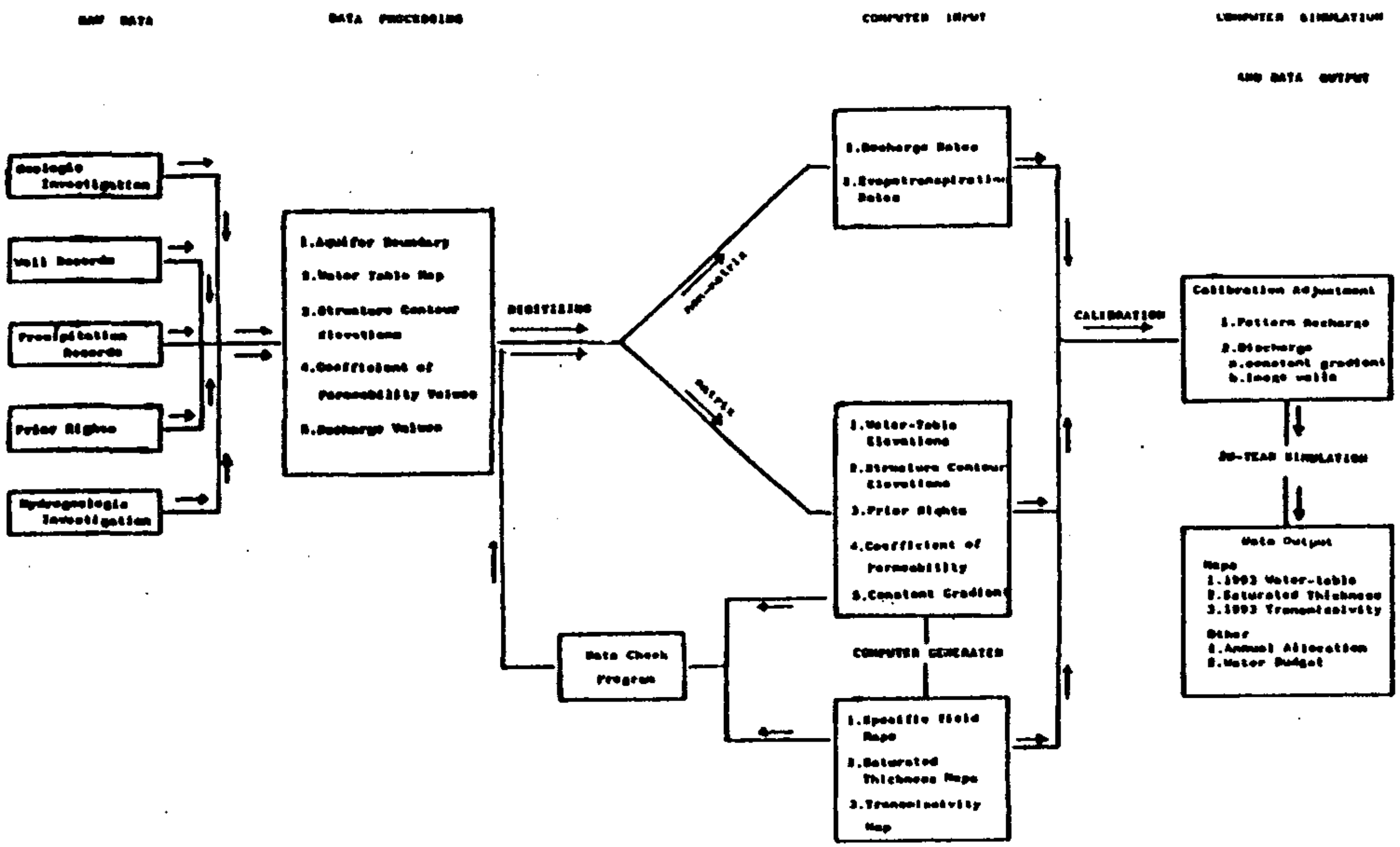

Figure 14. Flow Chart of Computer Modeling

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. The storage coefficient of the river bed is a constant parameter. Two coefficients of permeability were used as constants for the two zones shown in Figure 11.

Basic contoured data which was to be entered as a matrix was gridded and digitized for input into the computer model. A quarter mile 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 Isolated Enid Terrace 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 intricate network of intermittent streams which are present in the area. This river option was used as an alternative to setting transient evapotranspiration parameters or constant gradient discharge node values. The river was deemed to be more appropriate to the geologic setting and was therefore used to simulate boundary discharge through seepage as well as discharge into streams.

Because the river option only handles relatively shallow water, a problem arose in the mid-central portion of the study area. Using the river option, it was noted that a mound build-up occurred after a one-year simulation run. This mound created a water excess of 4,000 acre-feet. Assuming the Hennessey Group may represent a semi-permeable boundary, an attempt was made to program the model to remove this water excess by including a factor for bottom leakage. Evidence for bottom leakage was supplied by Fay (1981) and Reed (1952). Fay, in a personal communication, described collapse features occurring in the Hennessey Group. Reed (1952) comments on solution cavities found within the Permian units.

The result of calibration can be noted by comparing the existing and projected prior rights water-table maps for 1973 and 1993 (Figures 3 and 15); a negligible change in the two water-tables can be noted.

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 twenty-year simulation included two simulation runs: (1) prior appropriative rate only; (2) prior appropriative rate with allocation pumping.

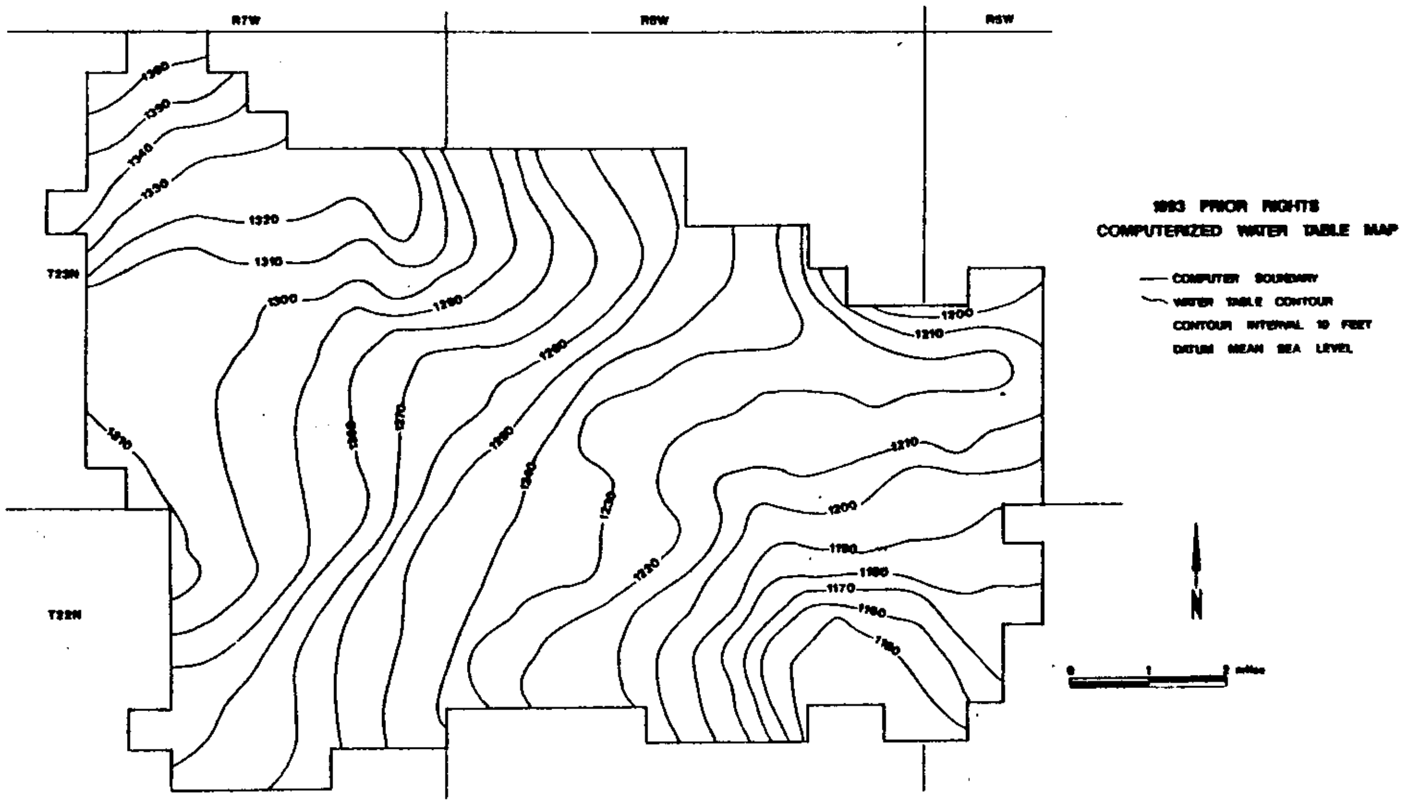

Figure 15. 1993 Prior Rights Computerized Water Table Map

RESULTS

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 150 gallons per minute. A maximum annual yield of 19,000 acre-feet and an average annual allocation of 0.50 acre-feet per acre were determined.

Each node (160 acres) was pumped continuously for a 4-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 average maximum legal limit (0.5 acre-feet per acre). This rate corresponds to an instantaneous pumping rate of approximately 150 gallons per minute continuously pumped for the 4-month period betwen 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% dry criteria was used to accommodate this variability. The wells are turned off in the model when the 5-foot saturated thickness is reached and will turn on periodically to remove accumulation due to recharge. The maximum annual yield is the resulting amount of water recovered over the 20-year period during which wells are being turned off and on as the aquifer is depleted and recharged. Because of these factors, the maximum annual yield does not simply equal the product of allocation rate times the area.

The computer simulation results are summarized in the ground-water budget shown in Figure 16. Simulated changes in saturated thickness and of areas that become dry for 1973, 1983, and 1993 are shown in Figures 16 to 18.

A 20-year ground-water budget was computed for the final computer allocation run of the entire aquifer area (Figure 19). In addition, a detailed ground-water budget analysis and ground-water distribution summaries for the aquifer area are shown in Appendix A. Other computer simulation results for the same period include transmissivity and water depth (Appendix A).

Ground-Water Quality

Ground-water quality is dependent on initial rain-water quality and chemical reactions which may occur during net recharge (downward percolation) into the aquifer. The ground-water was analyzed and tested at several sites in the Enid area for Total Hardness (TH), Total Dissolved Solid (TDS), Sulfate (SO_4^{--}) and Chloride (Cl^-). These data

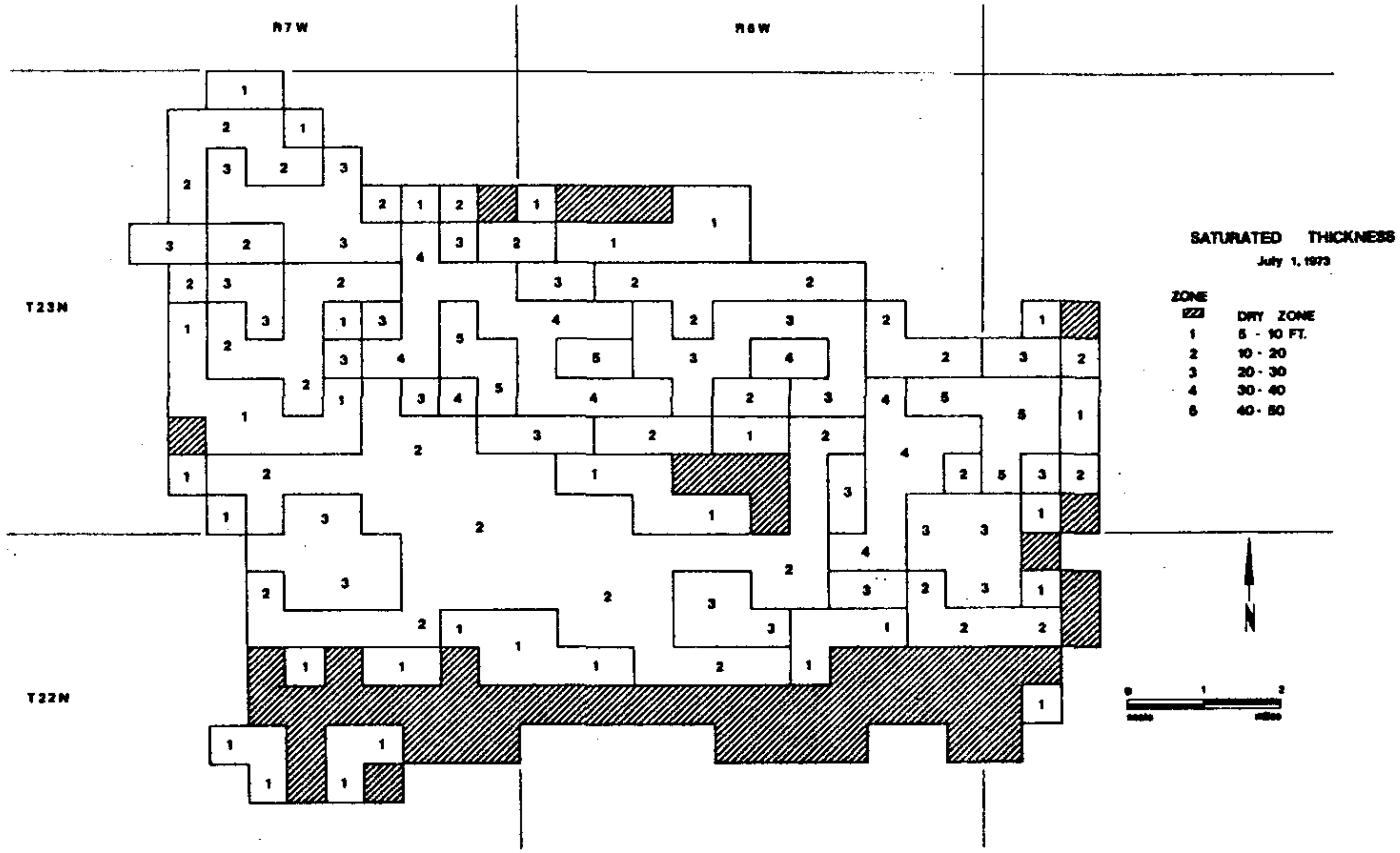

Figure 16. 1973 Saturated Thickness

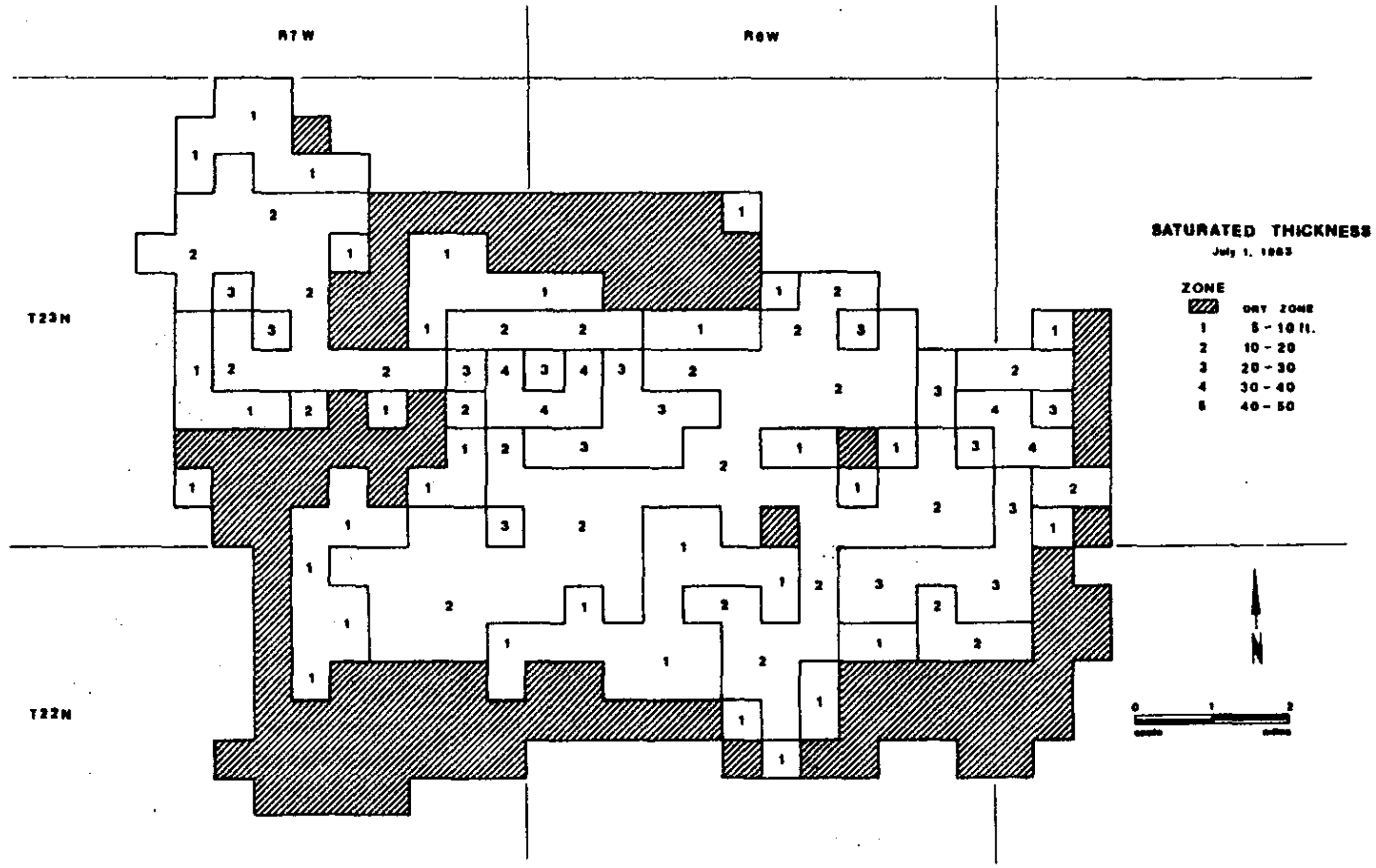

Figure 17. 1983 Saturated Thickness

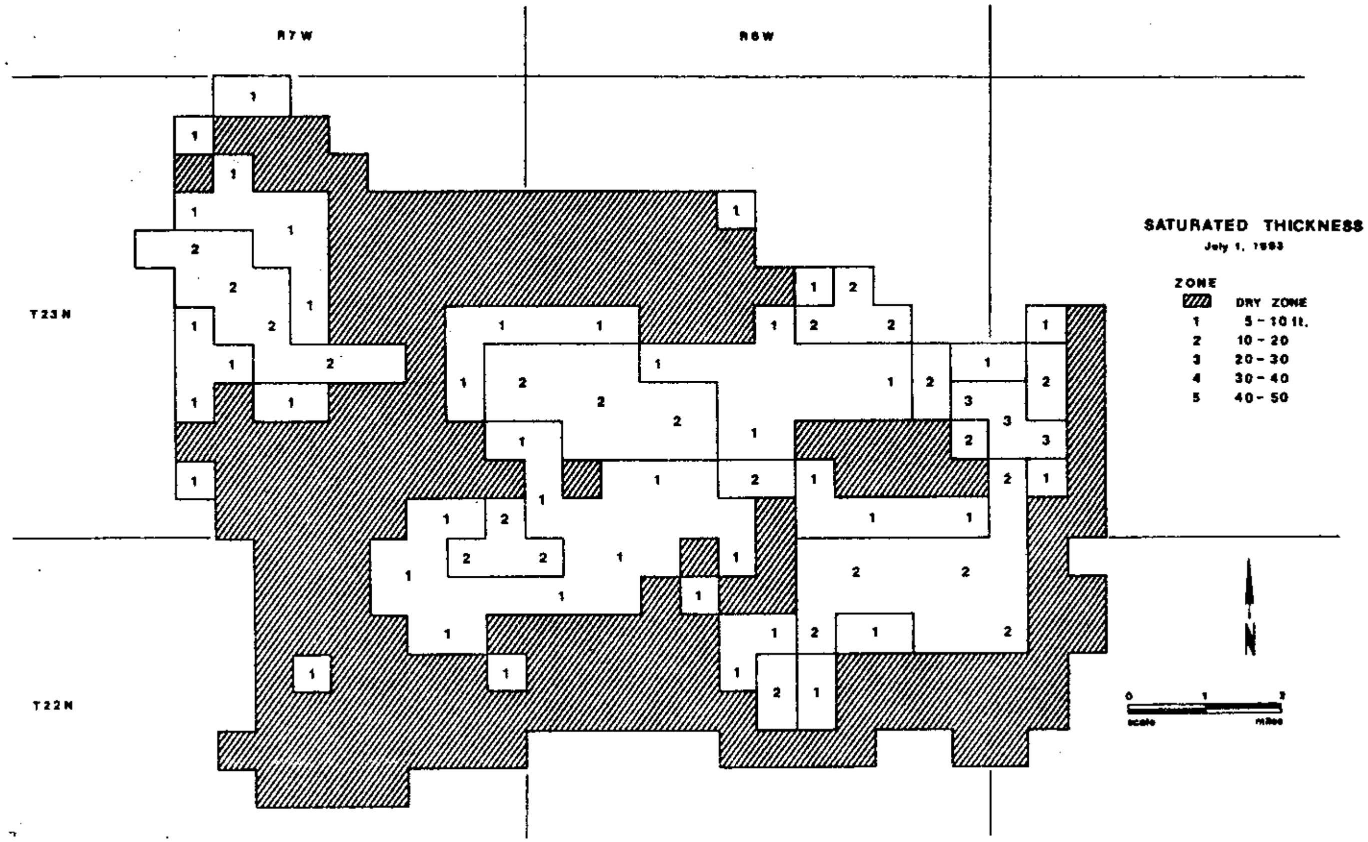

Figure 18. 1993 Saturated Thickness

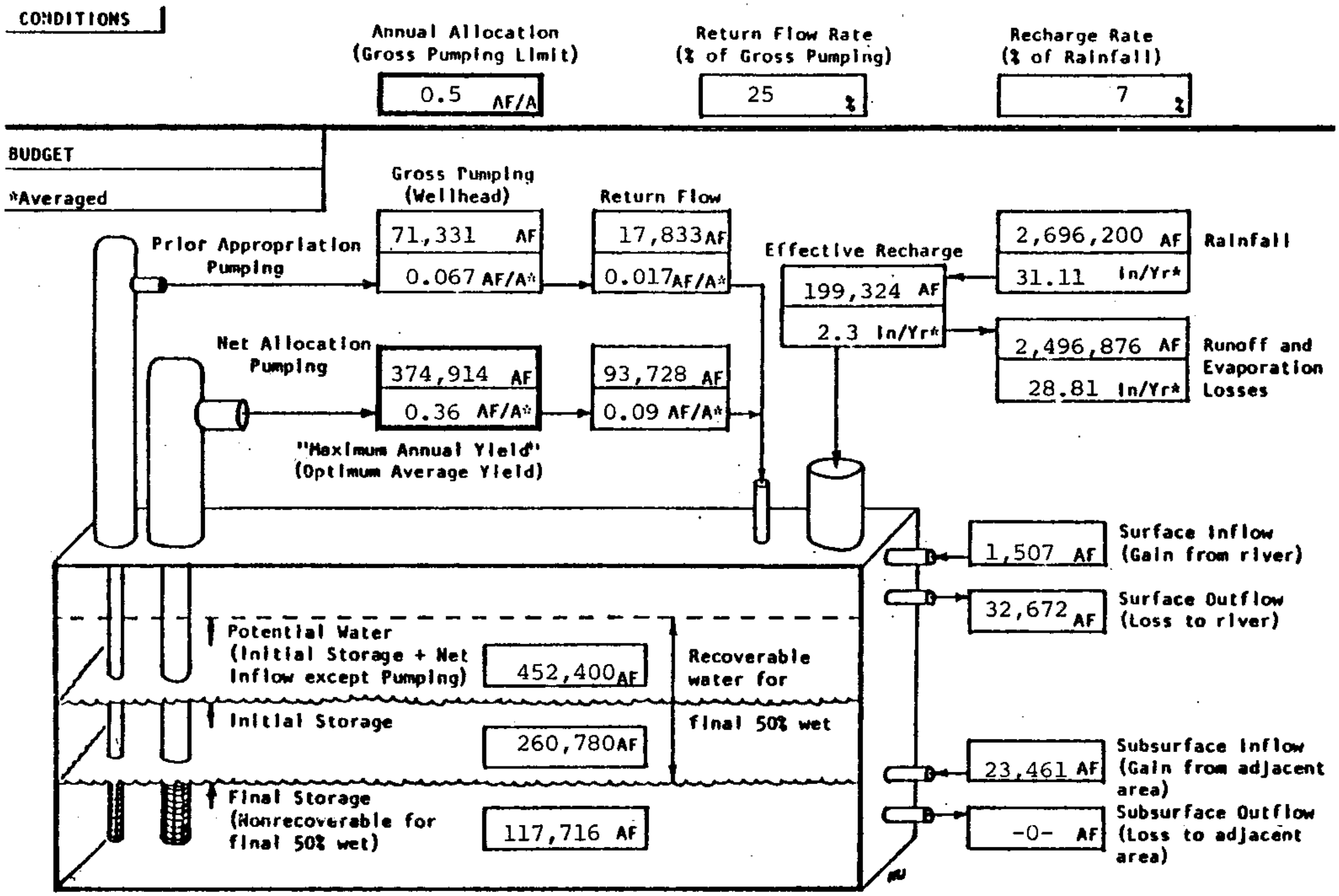

Figure 19. Twenty-year Ground-Water Budget
(after Kent, 1980)

are shown in Table 4. Concentration of these dissolved minerals are a result of the period of contact between the ground-water and geologic formations and as a result of natural and man-made pollution.

The headwaters of tributaries to the Cimarron and Salt Fork Rivers are located in the aquifer area. Because the drainages in the area originate over the aquifer, natural salt sources for surface runoff should not occur. This condition would contribute to the similarity between stream- and ground-water quality. This similiarity would suggest that there probably will not be any significant degradation of ground-water quality due to recharge from streams induced by aquifer depletion.

TABLE 4

WATER QUALITY FOR SELECTED WELLS

Location	Total Hardness (1)	Dissolved Solids (2)	Sulfate (as SO_4) (3)	Chloride (3)	Oklahoma Water Resources Board Sample Number (4)
		milligram per liter mg/l			
SW SW NE 31 23N 6W	212	388	16	29	0539
SW NW NE 31 23N 6W	221	372	20	45	0541
SW SW SW 30 23N 6W	211	344	15	29	0540
SE SW SE 30 23N 6W	205	384	19	40	0542
NW NE SW 1 22N 7W	164	300	15	21	0522
NW SW SE 1	192	468	26	37	0523
NE NW SE 1	217	408	27	83	0524
SE NW SE 1	265	594	48	110	0525
SE NE SE 1	246	512	52	70	0526
NE NE SE 1	204	400	23	37	0527
NE SE NE 1	247	412	28	40	0528
SE SE SE 16 23N 7W	122	232	16	26	0532
SW SE SW 21	126	252	16	23	0535
NW NW NW 21	194	428	34	36	0552
SE SE NW 17	168	316	22	52	0553
NE NE SE 17	122	220	12	12	0554
SW SW SE 17	236	508	36	78	0551
NE NE NE 26	143	288	13	18	0534
NW NW NE 26	188	368	18	52	0533
SW SW NW 27	187	368	17	14	0529
NE NE NW 27	120	304	13	17	0531
NE NE NE 27	135	284	12	24	0536
NE NE NE 28	146	320	20	24	0530
SW SE NE 36	339	652	33	114	0537
NE NE NE 36	224	328	14	26	0538
	$\bar{X}$=193	$\bar{X}$=378	$\bar{X}$=22	$\bar{X}$= 42	

1. Reported as $CaCO_3$
2. 500 mg/l recommended maximum rejection limit
3. 250 mg/l recommended maximum rejection limit
4. Sample period August 1973

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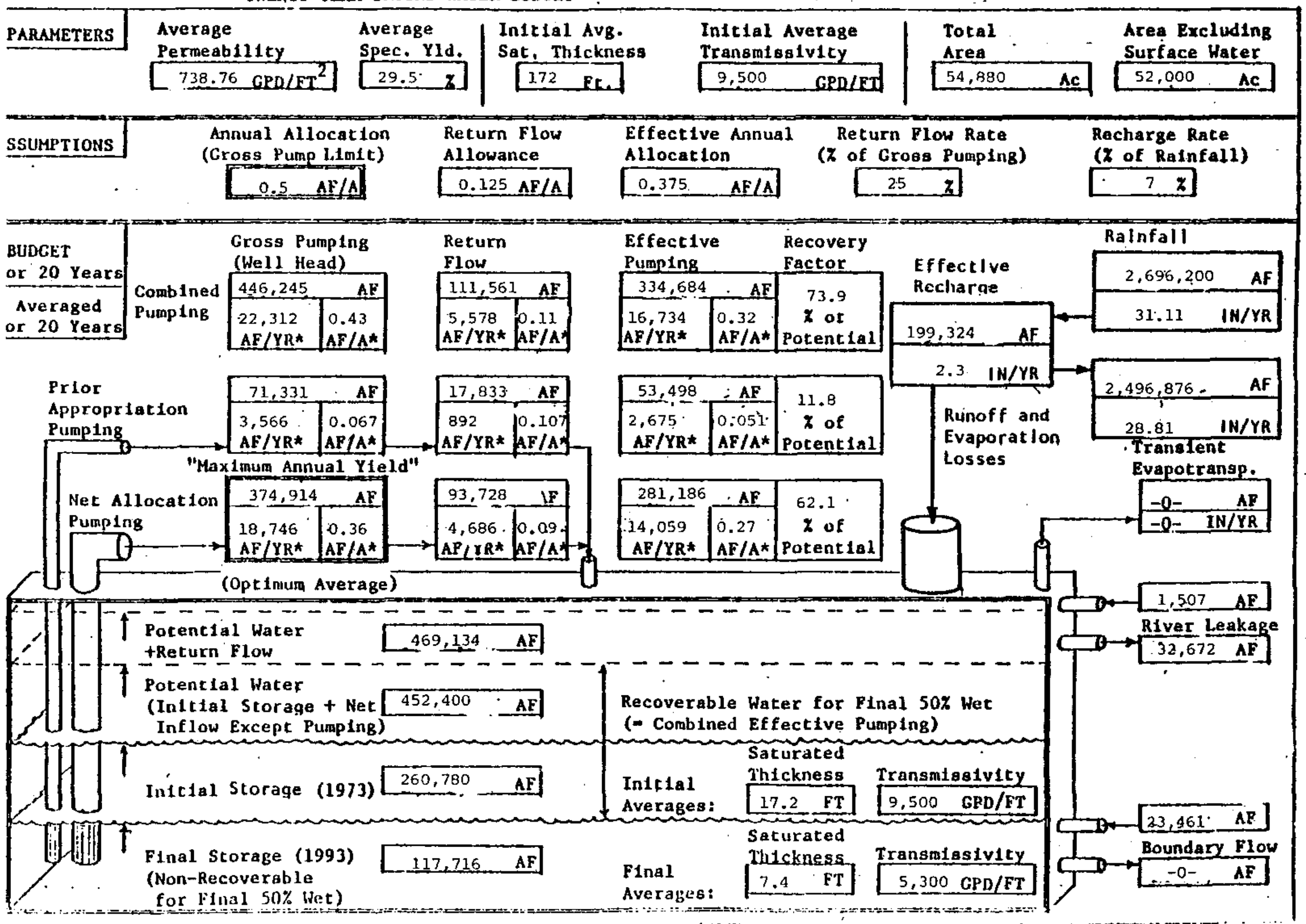
APPENDIX A
COMPUTER SIMULATION RESULTS

APPENDIX A-1

RESULTS FOR THE ENID TERRACE

TWENTY YEAR GROUND WATER BUDGET



MASS BALANCE OF PRIOR APPROPRIATIVE PUMPING
FROM JULY 1, 1973 TO JULY 1, 1993

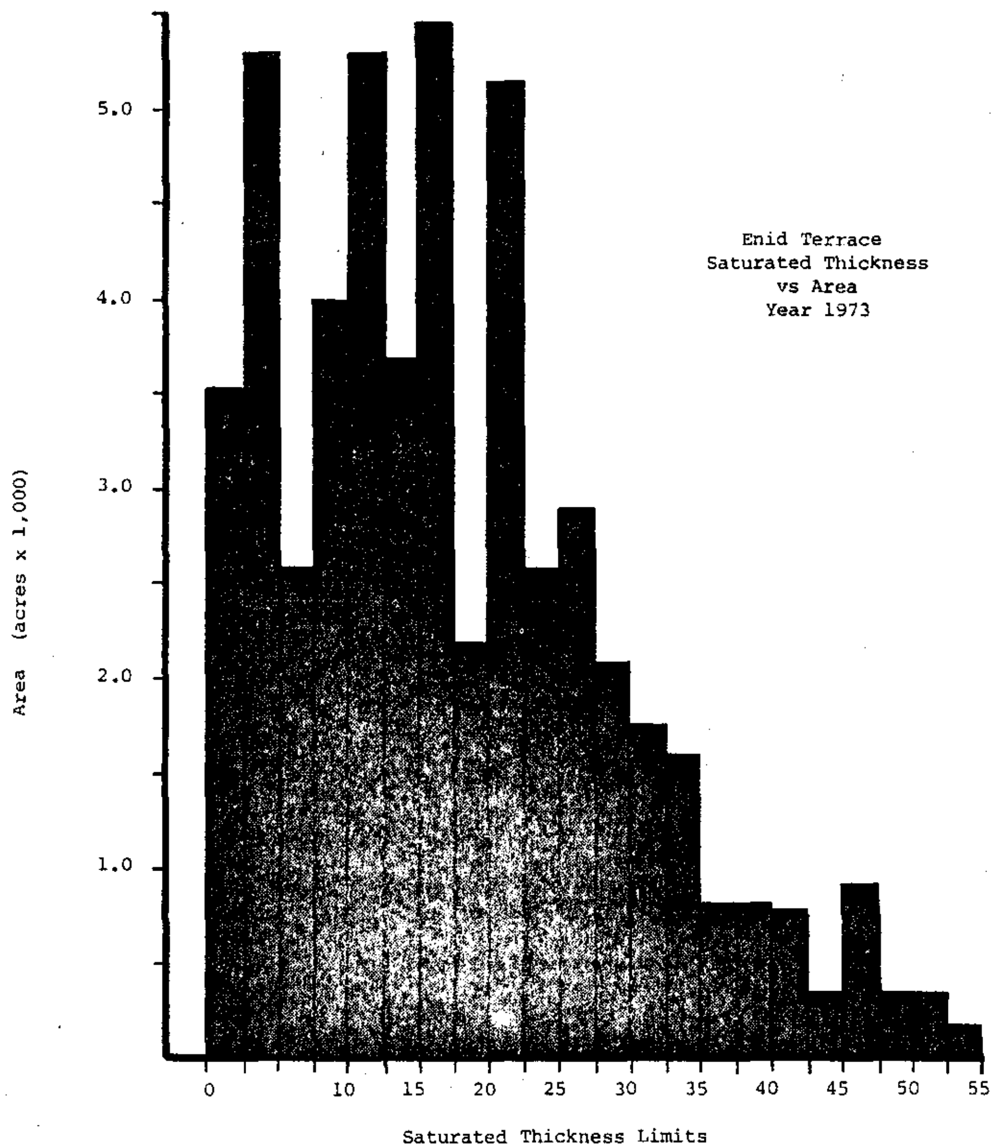
	Average Annual (Acre Feet)		Twenty Year Total (Acre Feet)	
	Inflow	Outflow	Inflow	Outflow
Recharge	+ 9,966		+199,324	
Pumpage		-16,734		-334,684
River Leakage	+ 75	- 1,634	+ 1,507	- 32,672
Subsurface Flow	+ 1,173		+ 23,461	
	-----	------	------	-------
TOTALS	+11,214	-18,368	+224,292	-367,356
Net Storage		- 7,154		-143,064

Water Distribution Summary
July 1, 1973

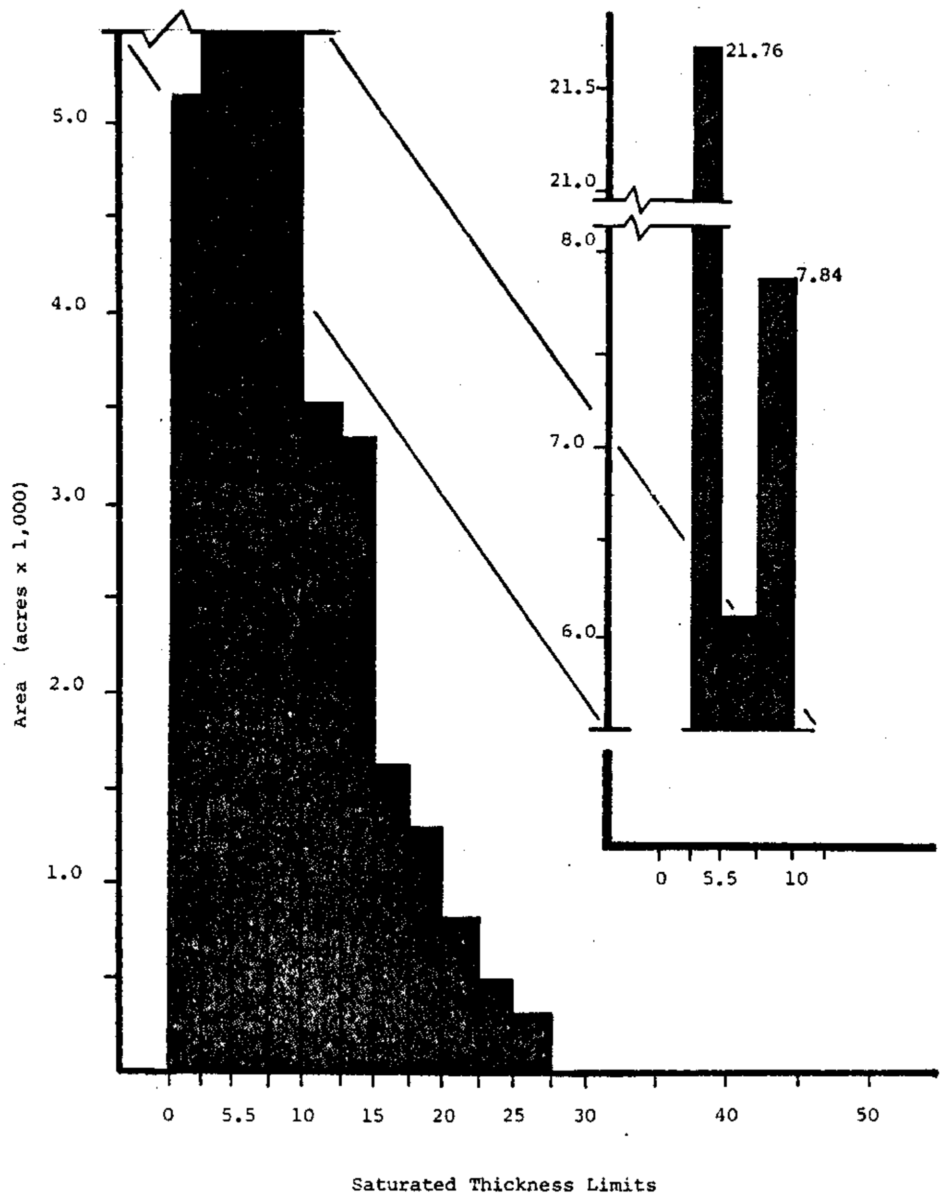
SATURATED THICKNESS RANGE (FEET)	AREA (% OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (%)	STORED WATER (AC.FT.)
0.0 - 2.50	6.8	3,520	1.6	29.5	1,711
2.50 - 5.50	10.2	5,280	4.5	29.5	7,022
5.50 - 7.50	4.9	2,560	6.3	29.5	4,759
7.50 - 10.00	7.7	4,000	8.7	29.5	10,266
10.00 - 12.50	10.2	5,280	10.8	29.5	16,867
12.50 - 15.00	7.1	3,680	14.3	29.5	15,504
15.00 - 17.50	10.5	5,440	15.7	29.5	25.245
17.50 - 20.00	4.6	3,400	18.8	29.5	13,281
20.00 - 22.50	9.8	5,120	20.7	29.5	31,205
22.50 - 25.00	4.9	2,560	23.9	29.5	18,032
25.00 - 27.50	5.5	2,880	25.4	29.5	21,606
27.50 - 30.00	4.0	2,080	29.1	29.5	17,866
30.00 - 32.50	3.4	1.760	30.9	29.5	16,046
32.50 - 35.00	3.1	1,600	33.8	29.5	15,951
35.00 - 37.50	1.5	800	36.0	29.5	8,491
37.50 - 40.00	1.5	800	39.0	29.5	9,192
40.00 - 42.50	1.2	640	41.1	29.5	7.750
42.50 - 45.00	0.6	320	43.6	29.5	4,117
45.00 - 47.50	0.9	480	45.4	29.5	6,423
47.50 - 50.00	0.6	320	48.4	29.5	4,567
50.00 - 52.50	0.6	320	50.1	29.5	4,728
52.50 - 55.00	0.3	160	54.3	29.5	2,564
	-----	------			-------
ALL RANGES	100.0 (TOTAL)	52,000 (TOTAL)	17.2 (AVERAGE)	29.5 (AVERAGE)	263,202 (TOTAL)

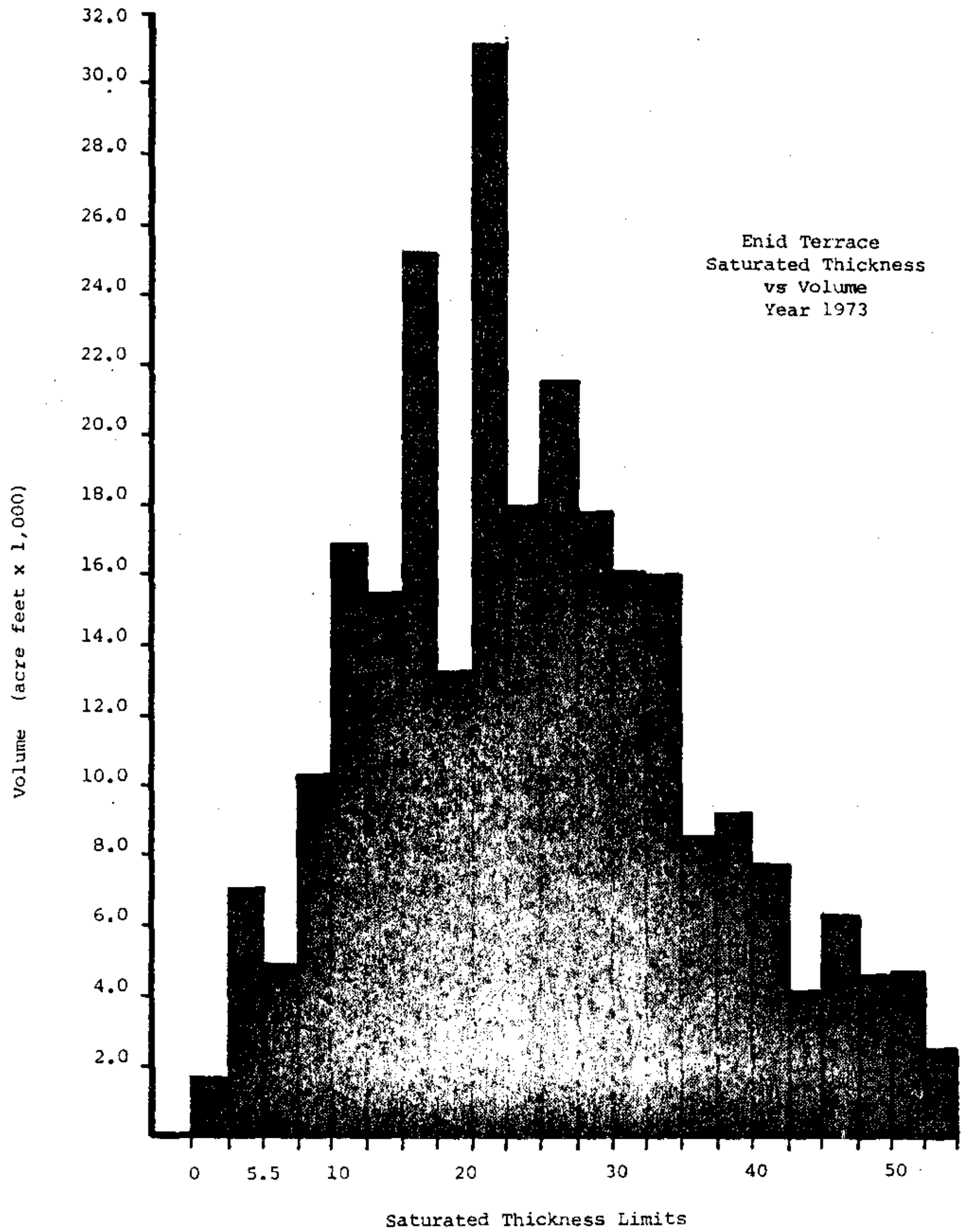
Water Distribution Summary
July 1, 1993

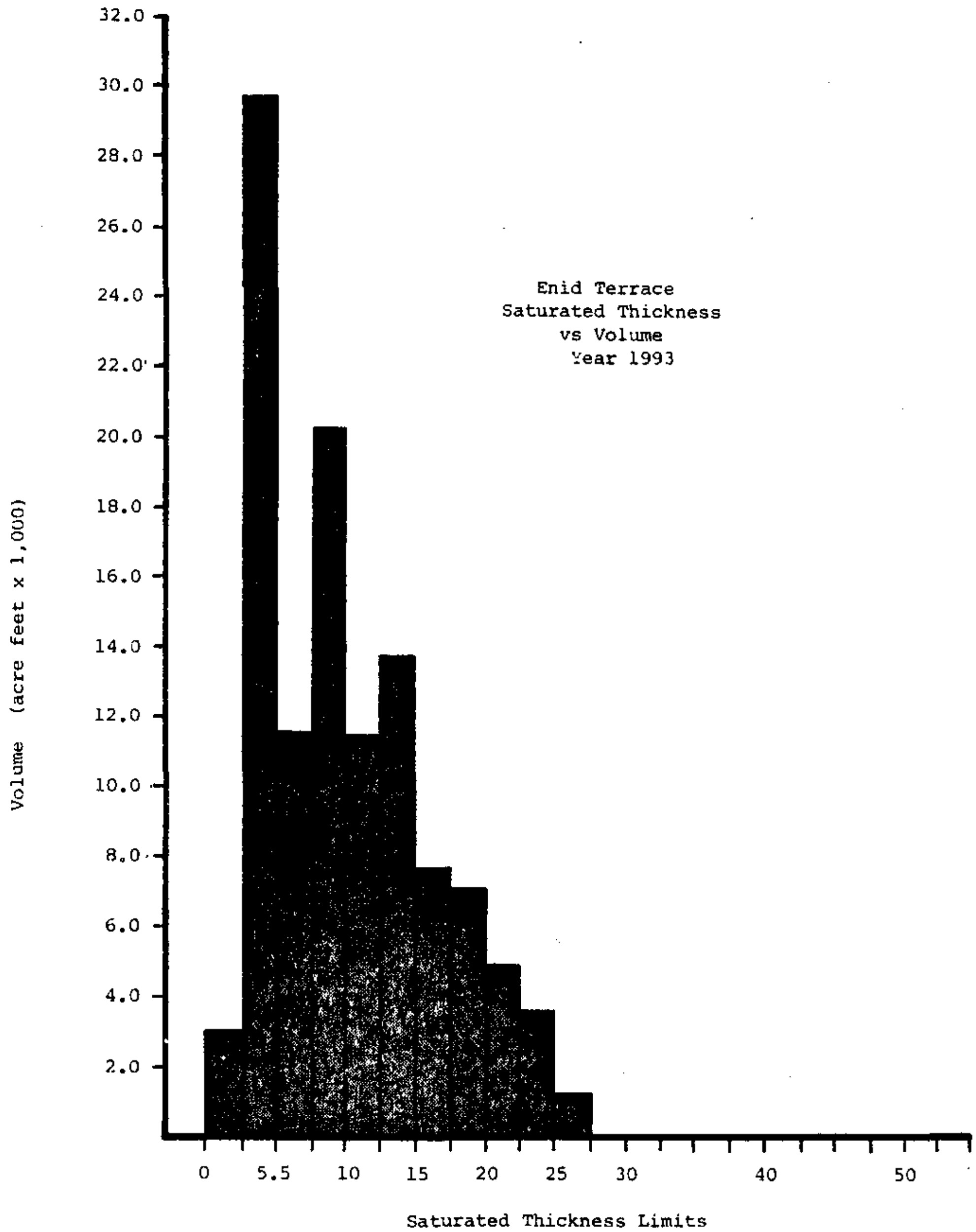
SATURATED THICKNESS RANGE (FEET)	AREA (% OF TOTAL)	AREA (ACRES)	AVERAGE SATURATED THICKNESS (FEET)	AVERAGE SPECIFIC YIELD (%)	STORED WATER (AC.FT.)
0.0 - 2.50	9.8	5,120	2.0	29.5	2,948
2.50 - 5.50	41.8	21,760	4.6	29.5	29,845
5.50 - 7.50	11.7	6,080	6.5	29.5	11,589
7.50 - 10.00	15.1	7,840	8.8	29.5	20,285
10.00 - 12.50	6.8	3,520	11.0	29.5	11,388
12.50 - 15.00	6.5	3,360	13.8	29.5	13,716
15.00 - 17.50	3.1	1,600	16.0	29.5	7,566
17.50 - 20.00	2.5	1,280	18.5	29.5	6,997
20.00 - 22.50	1.5	800	20.2	29.5	4,776
22.50 - 25.00	0.9	480	24.4	29.5	3,458
25.00 - 27.50	0.3	160	26.0	29.5	1,226
	----	------			------
ALL RANGES	100.0 (TOTAL)	52,000 (TOTAL)	7.4 (AVERAGE)	29.5 (AVERAGE)	113,799 (TOTAL)


Enid Terrace
Saturated Thickness
vs Area
Year 1973
Area (acres x 1,000)
5.0
4.0
3.0
2.0
1.0
0
10
15
20
25
30
35
40
45
50
55
Saturated Thickness Limits

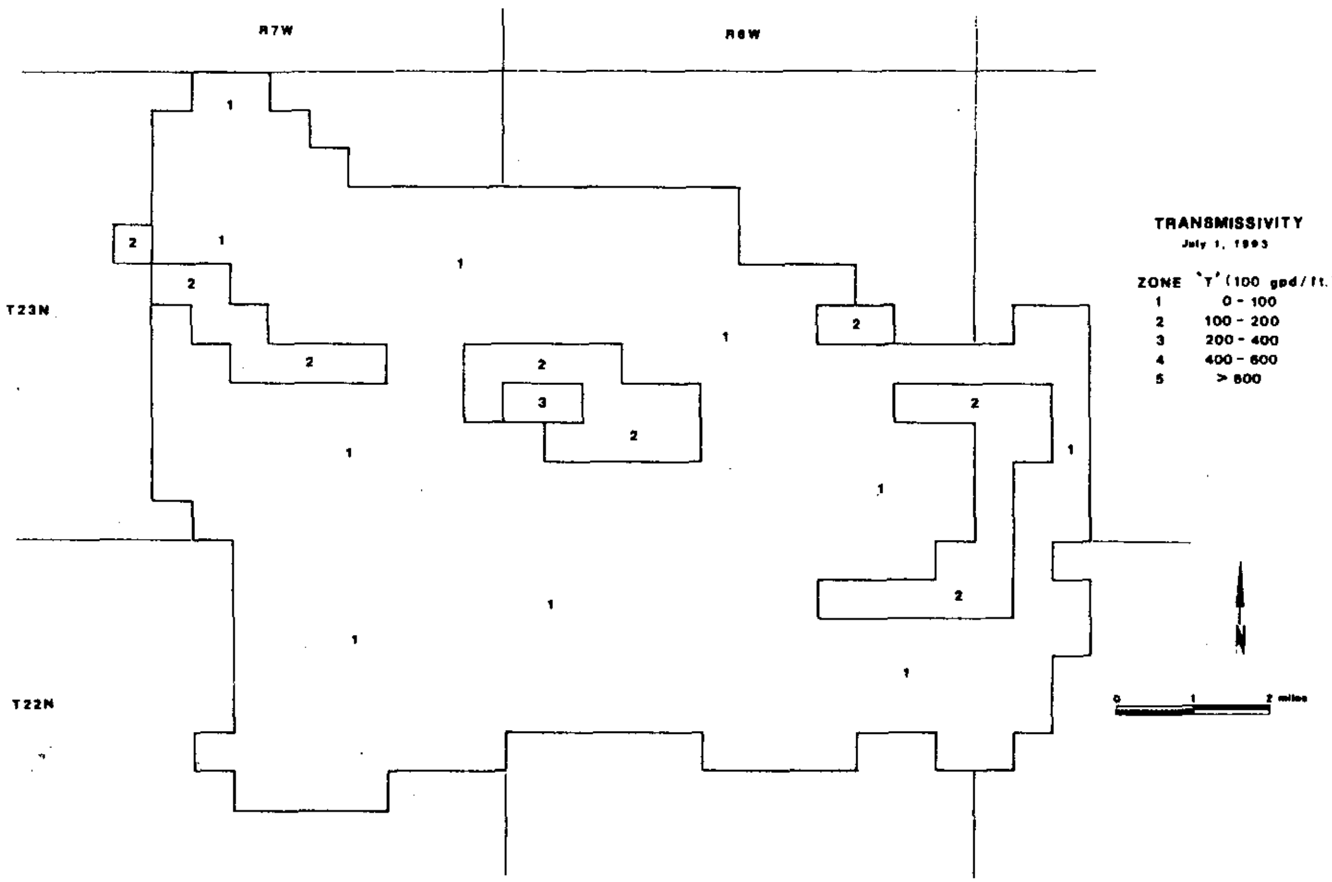
Enid Terrace
Saturated Thickness
vs Area
Year 1993



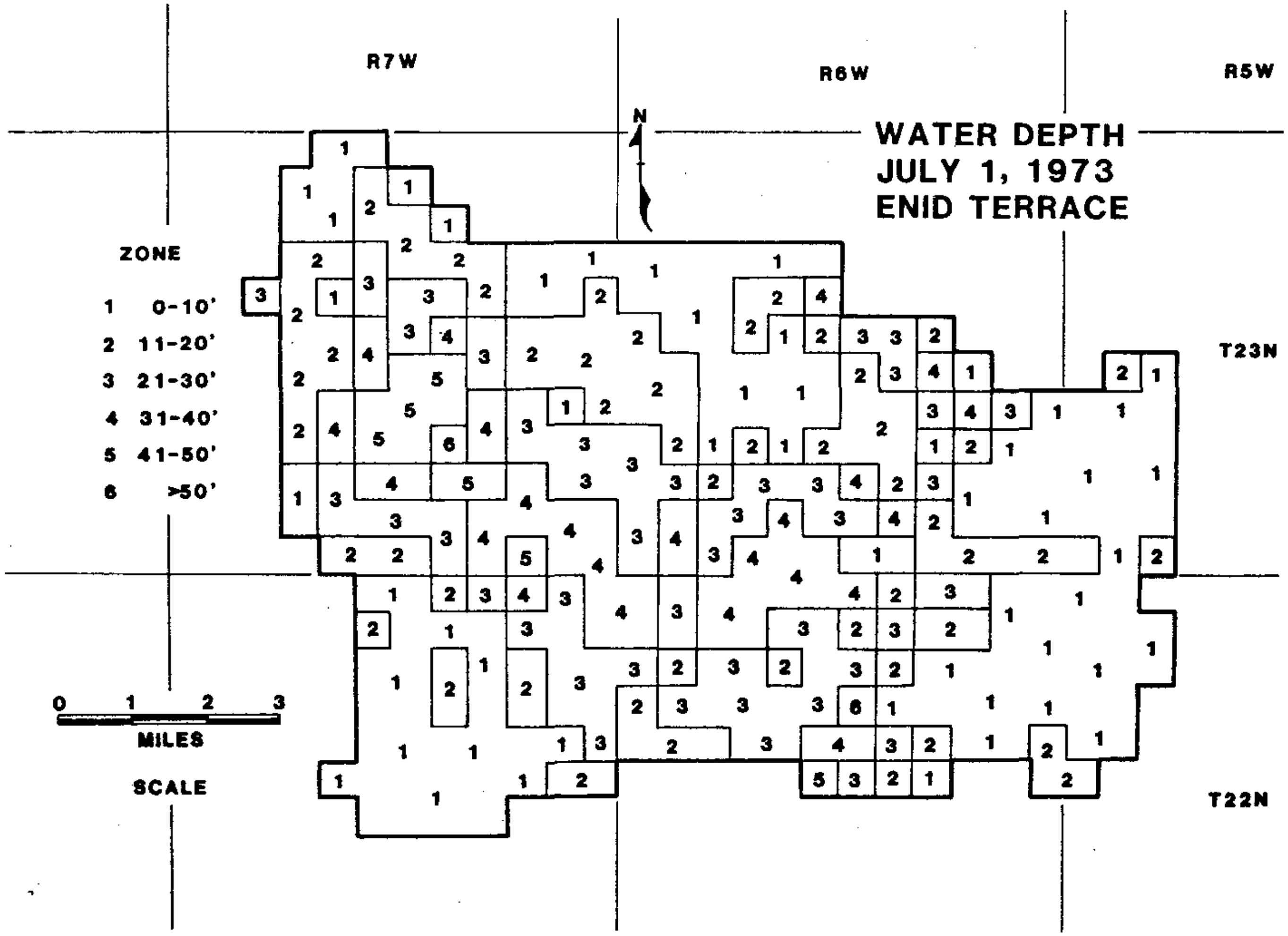

Enid Terrace
Saturated Thickness
vs Volume
Year 1973
Volume (acre feet x 1,000)
32.0
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0
5.5
10
20
30
40
50
Saturated Thickness Limits

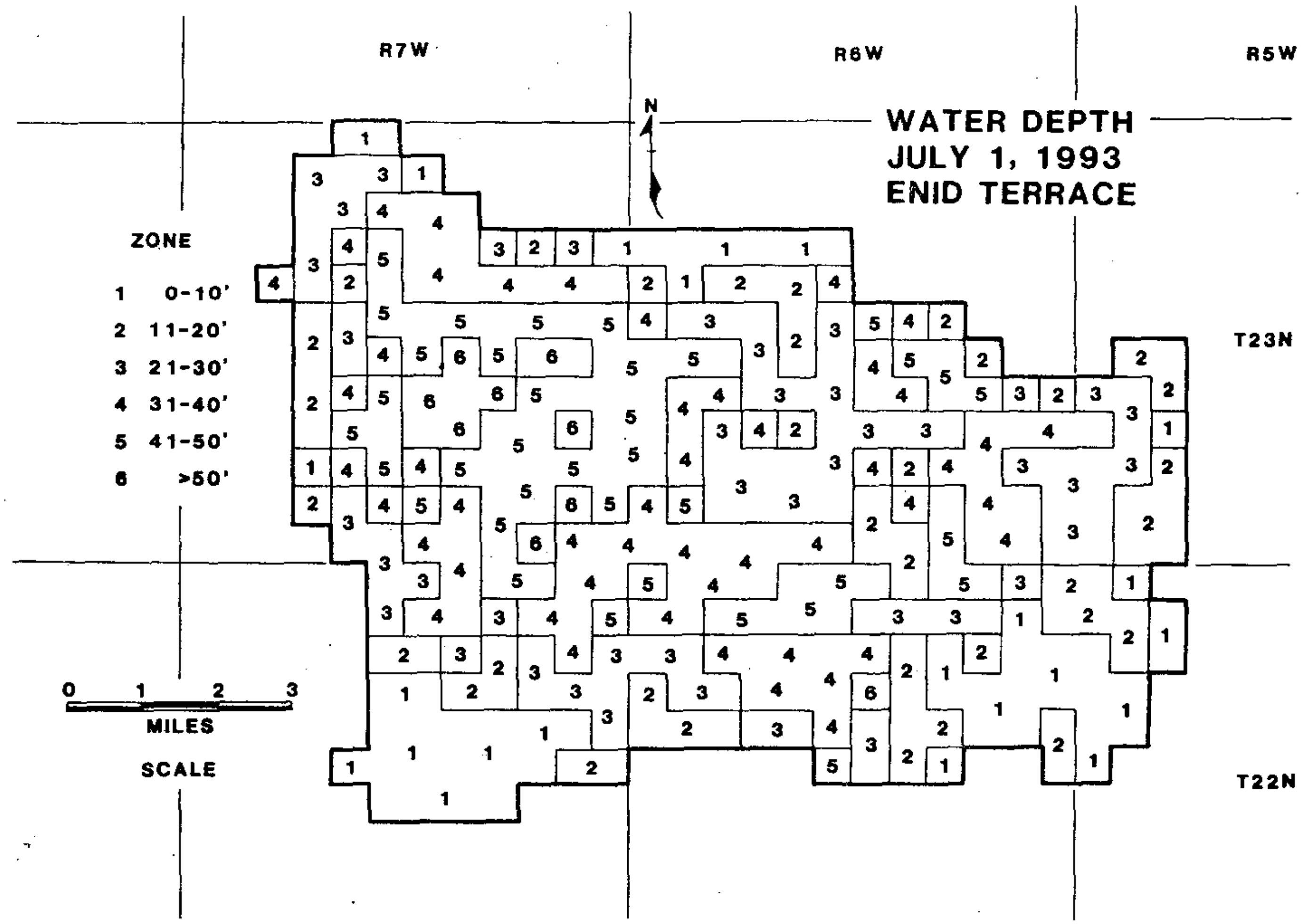


32.0
30.0
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
Volume (acre feet x 1,000)
Enid Terrace
Saturated Thickness
vs Volume
Year 1993
0
5.5
10
15
20
25
30
40
50
Saturated Thickness Limits



R7W
R6W
T23N
T22N
TRANSMISSIVITY
July 1, 1993
ZONE 'T' (100 gpd/ft.)
1 0 - 100
2 100 - 200
3 200 - 400
4 400 - 600
5 > 600
0 1 2 miles


WATER DEPTH
JULY 1, 1973
ENID TERRACE
R7W
R6W
R5W
T23N
T22N
N
ZONE
1 0-10'
2 11-20'
3 21-30'
4 31-40'
5 41-50'
6 >50'
0 1 2 3
MILES
SCALE


WATER DEPTH
JULY 1, 1993
ENID TERRACE
R7W
R6W
R5W
T23N
T22N
N
ZONE
1 0-10'
2 11-20'
3 21-30'
4 31-40'
5 41-50'
6 >50'
0 1 2 3
MILES
SCALE