FINAL REPORT

O.W.R.R. A-055-OKLA.

O.R.A. 156-684

AN OPTIMAL WATER QUALITY MANAGEMENT TECHNIQUE FOR CONJUNCTIVE GROUND AND SURFACE WATER USE

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Submitted to

OKLAHOMA WATER RESOURCES RESEARCH INSTITUTE

Submitted by

Bureau of Water Resources Research
Oklahoma Research Administration
University of Oklahoma, Norman, Okla.

ACKNOWLEDGMENTS

This report presents the results of a research study sponsored by the Office of Water Resources Research, Title 1, Washington, D.C. Pertinent project numbers are as follows: O.R.A. No. 156-684, and O.W.R.R. No. A-055 OKLA.

The data for this study were collected from several different sources. Rainfall records were supplied by the Weather Bureau, the U.S. Department of Commerce, Environmental Science Administration, and by the City of Norman, and by the Oklahoma State Department of Health, Water Quality Service. Data regarding Lake Thunderbird was obtained from the Central Oklahoma Water Conservancy District. Maps and related materials were obtained from the U.S. Geological Survey. These offices were especially helpful and cooperative with respect to available data.

Norman, Oklahoma

June, 1975

The work upon which this report is based was supported in part by funds provided by the United States Department of the Interior, Office of Water Research and Technology, as authorized under the Water Resources Research Act of 1964.

NOTATIONS

B_n = Partial Regression Coefficients

B_o = A Constant

Q = Flow of Water, Million Gallons

R^2 = Correlation Coefficients

X = Quality Attribute

X_1 = pH

X_2 = Alkalinity, mg/1

X_3 = Hardness, mg/1

X_4 = Turbidity, Jackson Turbidity Units, J.T.U.

X_5 = Iron, mg/1

Y_2 = Monthly Average Rainfall, Inches

Y_3 = Monthly Average Lake Level, Feet

Y_4 = Monthly Total of Lake Water Used, Million Gallons

Y_5 = Monthly Total of Well Water Used, Million Gallons

ABSTRACT

The objectives of the research project were to determine time, season, and antecedent conditions when reservoir (impoundment) water and groundwater separately reach optimum quality. Further, the project was to compare the quality of these two water supply sources at any given time so as to establish quantified combinations from the two sources which would give optimum quality. Examination of water quality data from the wells which furnish a part of the water supply of the City of Norman was found to be essentially constant, which is to say that no significant water quality changes for the wells were noted during the period of record. Therefore, well-water quality, parameters for the purposes of this study were necessarily used as constant values. Water quality was measured at the City of Norman water treatment facility. The method used to evaluate data for this project was stepwise regression utilizing the IBM statistical subroutine package. This technique has been used on similar projects, and was found to give highly satisfactory results for this study as well. Water quality data was obtained from the water quality records of the City of Norman, and from the United States Geological Survey. Additional data was obtained from the Oklahoma State Department of Health. Rainfall records were obtained from the Oklahoma State Department of Health. Rainfall records were obtained from the City of Norman, and the U. S. Weather Bureau. Lake level readings for Lake Thunderbird were supplied by the Central Oklahoma Water Conservancy District. Regression analysis was performed on the data which was finally divided into the four seasons. The resulting linear equations are multiterm and establish correlation between the independent variables, rainfall, lake-level, surface water used, well-water used, and the water quality dependent variables deemed important in this study. The dependent

variables are pH, alkalinity, hardness, turbidity, and iron concentration. Only the regression equations of best fit, that is, the prediction equations having the highest correlation coefficient are presented.

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AN OPTIMAL WATER QUALITY MANAGEMENT TECHNIQUE FOR CONJUNCTIVE GROUND AND SURFACE WATER USE

CHAPTER I

INTRODUCTION

The City of Norman, Oklahoma, used groundwater as its only source of water supply until 1964. Since that time it has been combining groundwater and surface water from Lake Thunderbird, a nearby impoundment. Water quality records pertaining to the water wells indicate only minute changes in water quality during the period of record. Therefore, wellwater quality parameters were considered to be constants for this study. Water quality records pertaining to the mixture of ground and impoundment water were only available from January 1966 to the present time. Therefore, the basis of comparison will be the source time reference, namely, 1966 through 1974.

The methodology is essentially one of analyzing, comparing, and correlating data and information relative to the quality of the two water supply sources. Inasmuch as it has become standard practice to measure quality in terms of such attributes as hardness, dissolved solids, turbidity, pH, alkalinity, etc., and to identify the contributory parameters to qualify in terms of rainfall, antecedent moisture index, land use, land type, and aquifer properties, in the case of groundwater, a correlation can be established between a quality attribute and a set of contributory parameters or variables. This correlation, either numeric and/or logarithmic is of the form:

$$X_n = B_o + B_1Y_1 + B_2Y_2 + \ldots\ldots. B_nY_n$$

Where:

X_n = denotes a water quality attribute

B_o = a constant value

B_n = partial regression coefficients

Y_n = independent variable

Thus, a regression function will indicate which contributory parameters are significant in determining the quality attribute and the relative weights of these parameters. The resulting X_n values for the mixture of ground and impoundment water were determined using an arithmatic monthly average.

Since a quality parameter, X_n, is established only if there is a contributory parameter, Y_n, it becomes necessary, from an engineering point of view, to associate X_n and Y_n. A linear model will serve to describe the relationship between input flows and the desired water quality parameter, ie:

$$Q_{total} = Q_{lake} + Q_{groundwater}$$

$$Q_tX_t = Q_nX_n + Q_g\ (Xg)$$

Where:

Q = the flow of water

X = the concentration quality attribute

The prediction models, regression equations, were derived from monthly averages of the data.

This effort consisted of investigation of the influence of seasonal changes and antecedent precipitation conditions. The variables of land type and land usage were kept constant. The quality attributes measured were pH, alkalinity, total hardness, turbidity, and iron concentration. As expected, the prediction model has adequate sensitivity to be put into meaningful use. As is usually the case; however, the more extensive and variable the input data, the more realistic the model becomes. Consequently, this effort can serve as a later basis for a more in-depth study.

Water treatment practices in Oklahoma have varied widely across the state. This has been true because the quality of available water varies across the state. In most central and eastern Oklahoma regions, an abundance of high quality groundwater has presented a meaningful justification for the appropriate pumping of virtually untreated water for direct municipal use. The City of Norman, Oklahoma, may be cited as an example. Until 1964 Norman used 17 local wells as the sole source of water supply. However, the watertable elevation continually lowered, along with the general water quality, and it was decided that a new impoundment, Lake Thunderbird, should be used as an additional source of water. Presently, with two sources of water available, either source can be used alone or conjunctively. However, the initial condition of the water at the inflow source to the treatment plant dictates the degree of treatment that must be performed. Unfortunately, Norman, like many other cities, has haphazardly and randomly used the wells and the lake water as a mix, primarily because the qualities are not anticipated and are not being related to other parameters. Availability and not quality, has been the prime criterion for selection. It has been our experience that the quality of surface water varies widely with antecedent conditions, time of year, and land use activities around the lake. If municipal water could be used from the source where the quality is the highest, maximum cost-benefit ratios could be realized.

CHAPTER 2

LITERATURE REVIEW

The School of Civil Engineering and Environmental Science at the University of Oklahoma has vigorously studied water quality for many years. The recent culmination of those efforts has been the Water Quality Standands Study (1) for the State of Oklahoma, wherein it was concluded that water quality is strongly affected by rainfall, land-use, and the hydrologic elements of the area. Another study by the School has dealt with water quality and land-use correlations (2). The recent study reported by Harp and Laguros (7) on Quality Variation has been a test of the study reported by Harp, et.al. (2,3) on six candidate cities. The result was that the methodology and model prediction techniques are indeed generally feasible and could be applied where applicable. Studies which are related to groundwater recharge and reservoir properties have generally indicated that quality and rate of recharge are interdependent. Surface and subsurface waters are largely inseparable. Activities in one would seem to affect the other. Wastes, for instance, frequently appear to be contained by the hydrogeologic environment making land disposal an attractive alternative for waste disposal activities. This leads many to view the groundwater system as an isolated independent body of water. The unfortunate truth becomes apparent when slow migration of subsequently contaminated groundwater eventually reaches the surface system (8). Care should be exercised to avoid a simplistic view of water quality problems as they exist today and will exist in the future. Even if waste treatment practices were improved beyond a level attainable with current technology, problems in water quality and water resource allocation would still exist. Reference is made to increased demand for water, and of the attendent rise in cost of water treatment for an expanding population. Characteristically, that portion of a typical region's total water resource which is required for municipal supply is often rather small in relation to other uses such as agriculture, industrial cooling, and waste dilution. In the economic sense, however, municipal water supply represents the largest portion of the total investment in water resource facilities. Because of quality parameters, the costs per gallon for municipal water supply are typically at least an order of magnitude greater than those, e.g., of agricultural water (9).

Water allocation and management techniques are directly linked with land use planning. Mathematical programming models have been used to determine municipal optimal water and land allocation and agricultural needs to the year 2000. The existing models encompass the whole of the nation's agriculture and include restraints and detail for 223 producing areas and 51 water regions. Because of the large supply capacity and loss income of agriculture in previous times, the nation implemented a supply control program based on land retirement. Through payments to farmers for keeping land idle, cropland retired under federal programs averaged 56,000,000 acres over the decade 1961-1970. Food crops can be grown on non-irrigated land presently retired from production and can replace crop yield decreases caused by decreased irrigation. With elimination of farm programs withholding land from production, the nation could free water from agriculture for other uses long before the year 2000. Pricing policies could be important as a means to lessen water demand in the western states. These possibilities exist as land management and technology is substituted for increases in water demand. Without farm programs and with a population of 300,000,000 in the year 2000, irrigated acreage could decline by 13% over the 1964 values. The problem facing the nation is not water shortage for agriculture but an improved allocation of this resource (10). This demonstrated need for resource planning leads us to the purpose of the work presented here.

A careful study of Volume 9, the current Water Resources Catalog, and WRSIC has been made. Ongoing studies related to this research effort are indicated in references (12) through (27). The ongoing projects listed appear to be related to the present research effort, but do not appear to duplicate efforts.

CHAPTER 3

COLLECTION OF DATA

The data for this study were collected from several different sources. Rainfall records were supplied by the Weather Bureau, the U.S. Department of Commerce, Environmental Science Services Adminstration, and by the City of Norman. Water quality data were supplied by the City of Norman, and by the Oklahoma State Department of Health, Water Quality Service. Data regarding Lake Thunderbird were obtained from the Central Oklahoma Water Conservancy District. Maps and related materials were obtained from the U.S. Geological Survey.

The rainfall data covers the appropriate span of ten years and is typical of rainfall for the area of the City of Noramn. The water quality data used in this research effort include pH, alkalinity, hardness, turbidity, and iron content. Additionally, the data includes well water quality, and amounts of both well water and lake water used in a given month. Lake levels and other information pertinent to Lake Thunderbird cover the period of record from 1964 to the present time. The data is further elucidated in the form of graphical presentation.

Figure 1 presents a diagramatic view of the major water mains within, and projected for the City of Norman within the near future. You will note that where the arrows point toward the mains, water inflow into the system is indicated. Conversely, if the arrows point away from the water mains, withdrawals of water in the amounts indicated are shown.

Figure 2A represents three water quality parameters, pH, alkalinity, and iron content. pH, of course, is expressed as a dimensionless number. Alkalinity and iron concentrations are expressed in mg/l. Subsurface water values for pH, alkalinity, and iron content are expressed as straight lines on the graphical presentation. This is because subsurface water quality is considered to be constant for purposes of this study. Figure 2B represents the remaining water quality parameters; hardness and turbidity. Each of these values is presented in mg/l. Figure 3 is a simplified graphical presentation of water levels in two test wells as compared with rainfall during the period 1942 through 1963. You will note that while a rough correlation exists, aquifer hydrographs necessarily lag behind rainfall due to the time required for water from precipitation to percolate down to the water table. In areas of heavy subsurface water usage aquifer levels and subsequent water quality values may be heavily dependent on withdrawals as well as recharge.

Figure 4 is presented to acquaint the reader with the area under study. Additionally, types and locations of wells are presented.

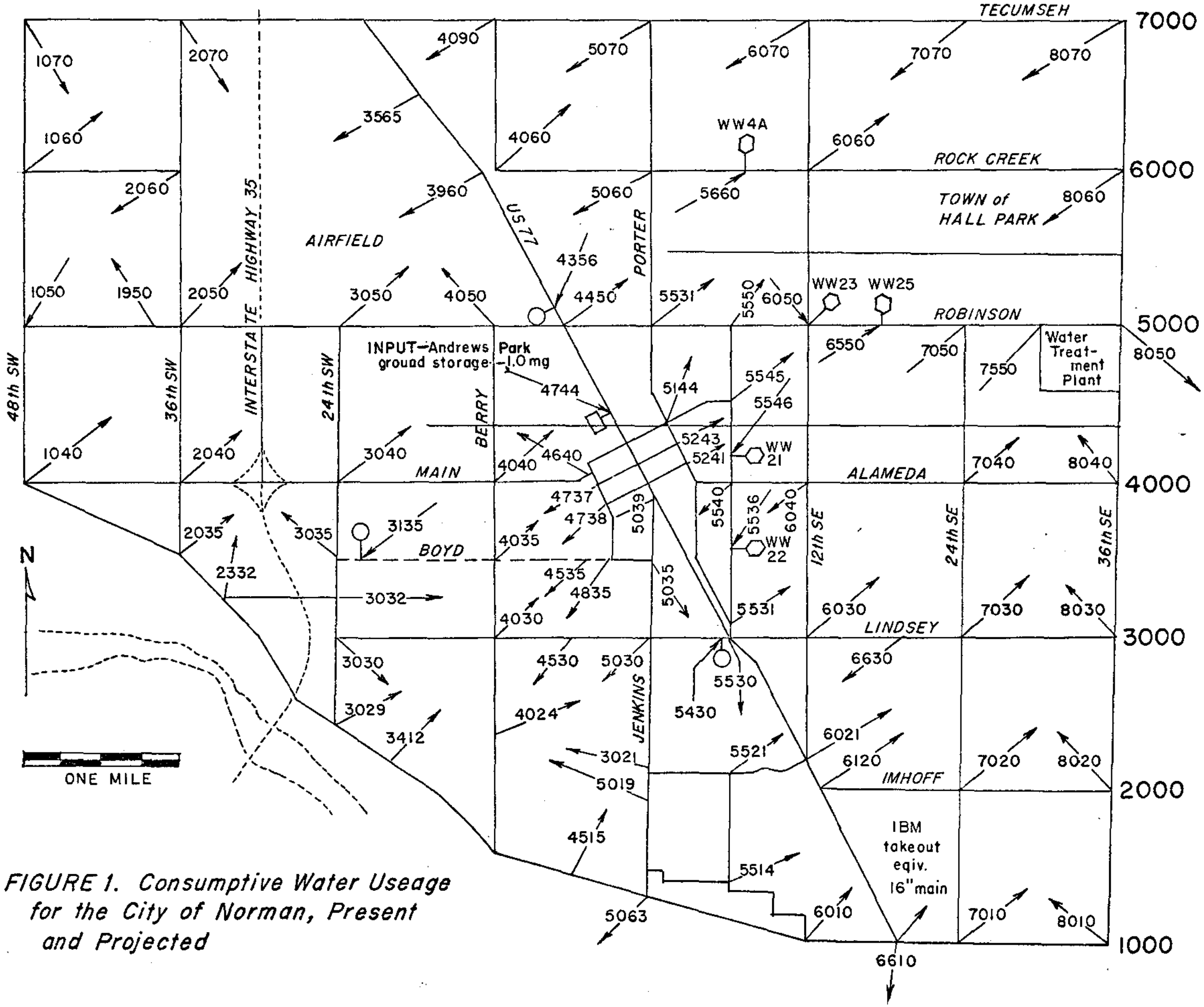

FIGURE 1. Consumptive Water Useage for the City of Norman, Present and Projected

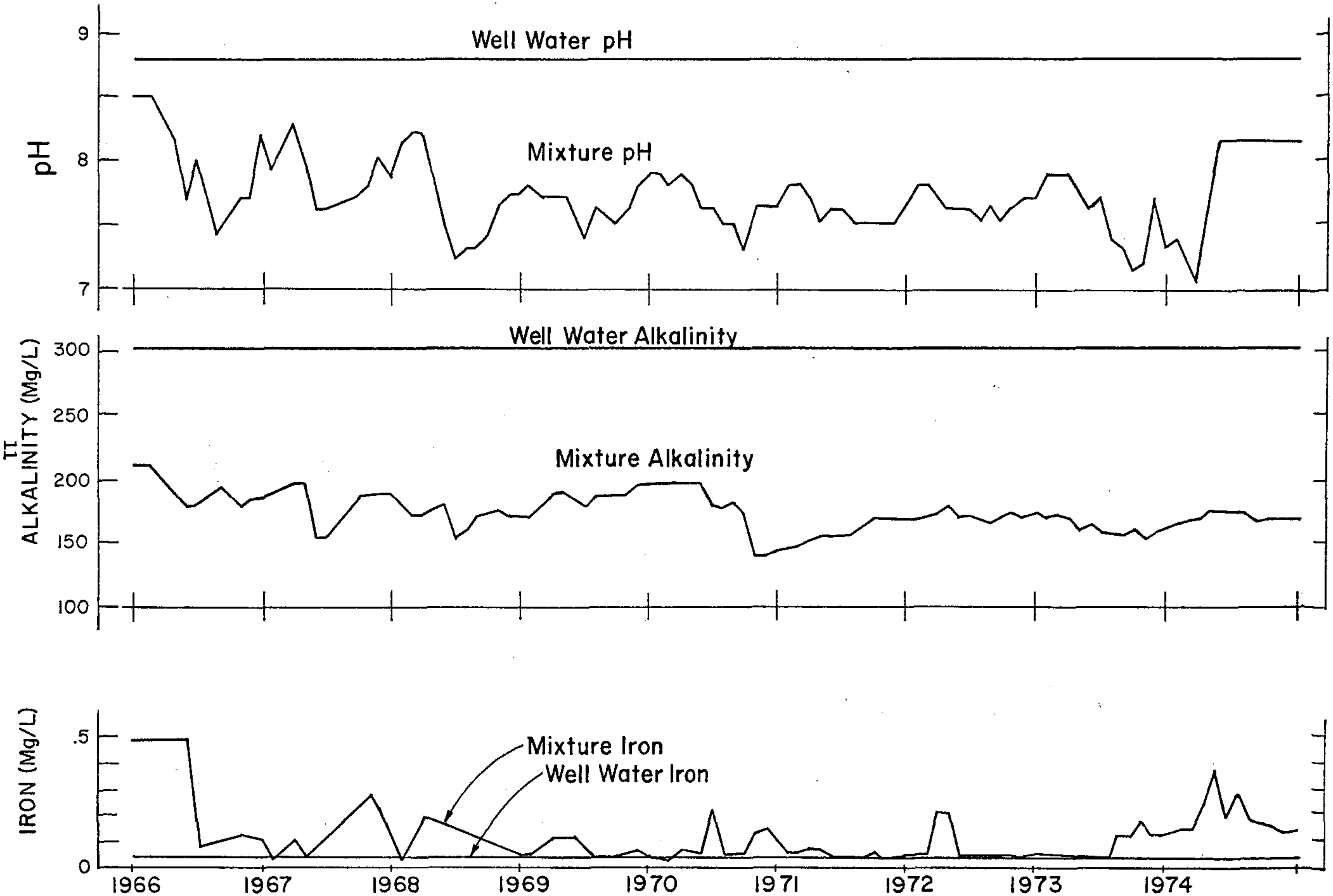

FIGURE 2A. Water Quality Parameters

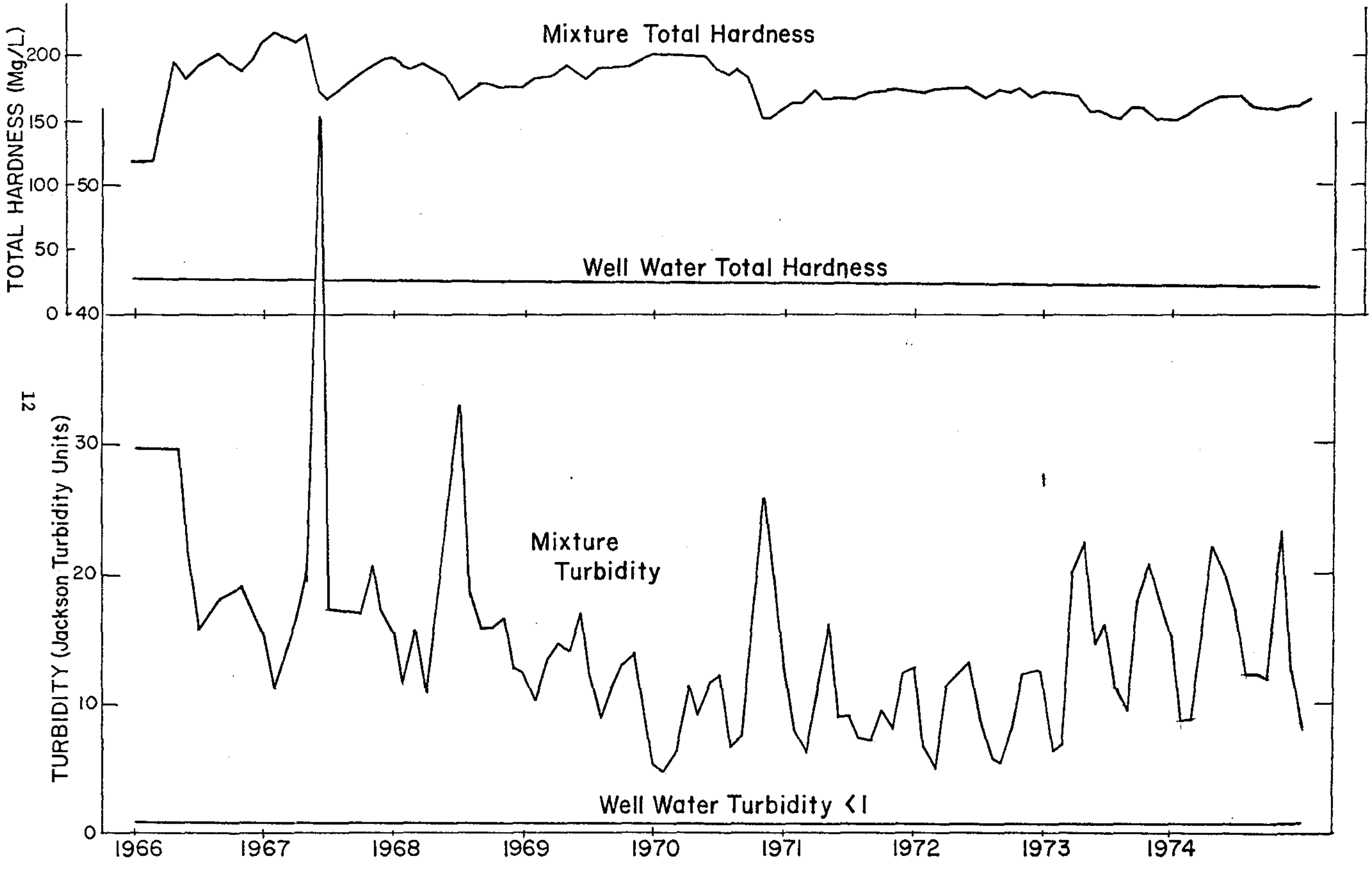

FIGURE 2B. Water Quality Parameters

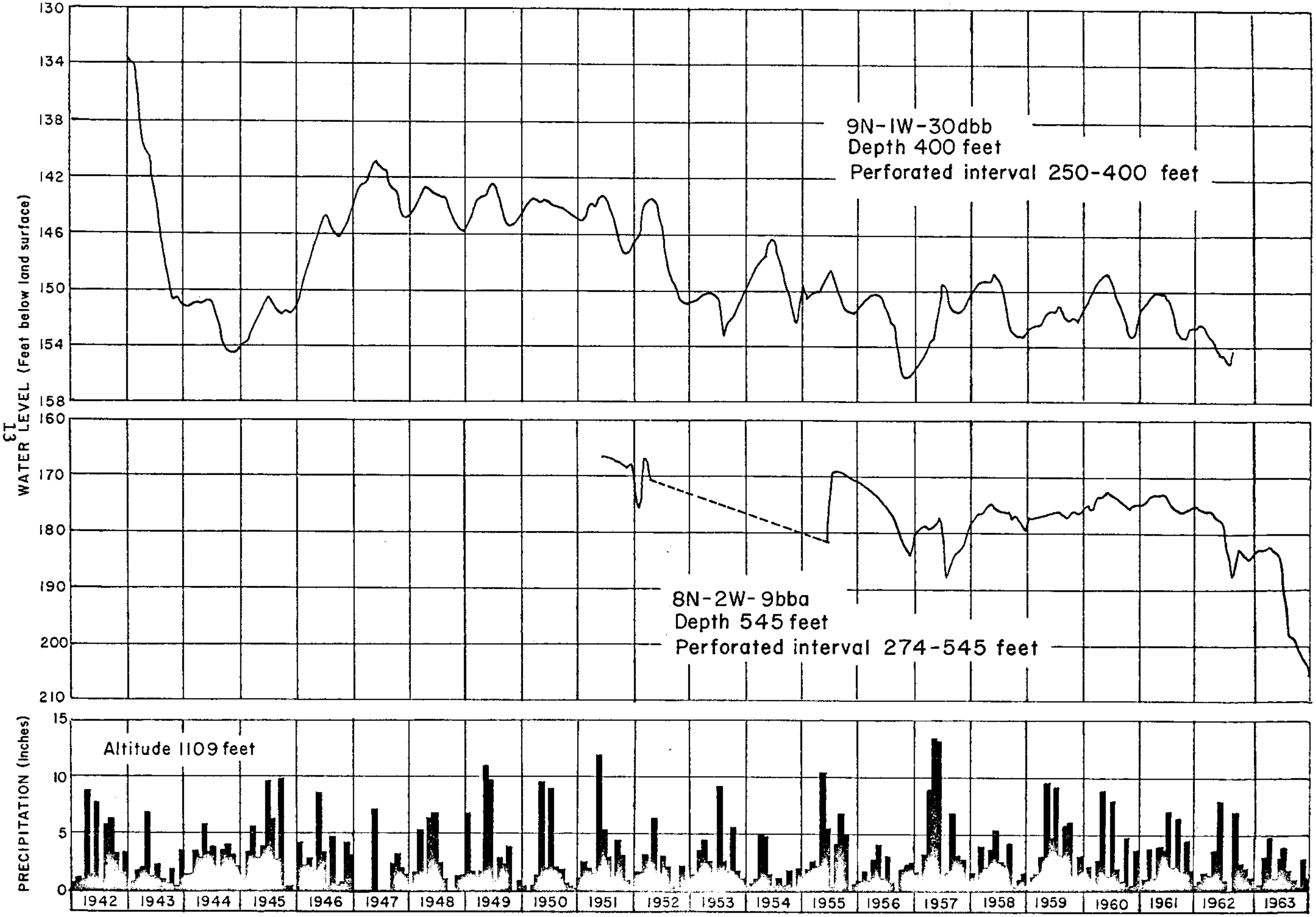

FIGURE 3. Hydrographs of Two Wells in Cleveland County and Monthly Precipitation at Norman

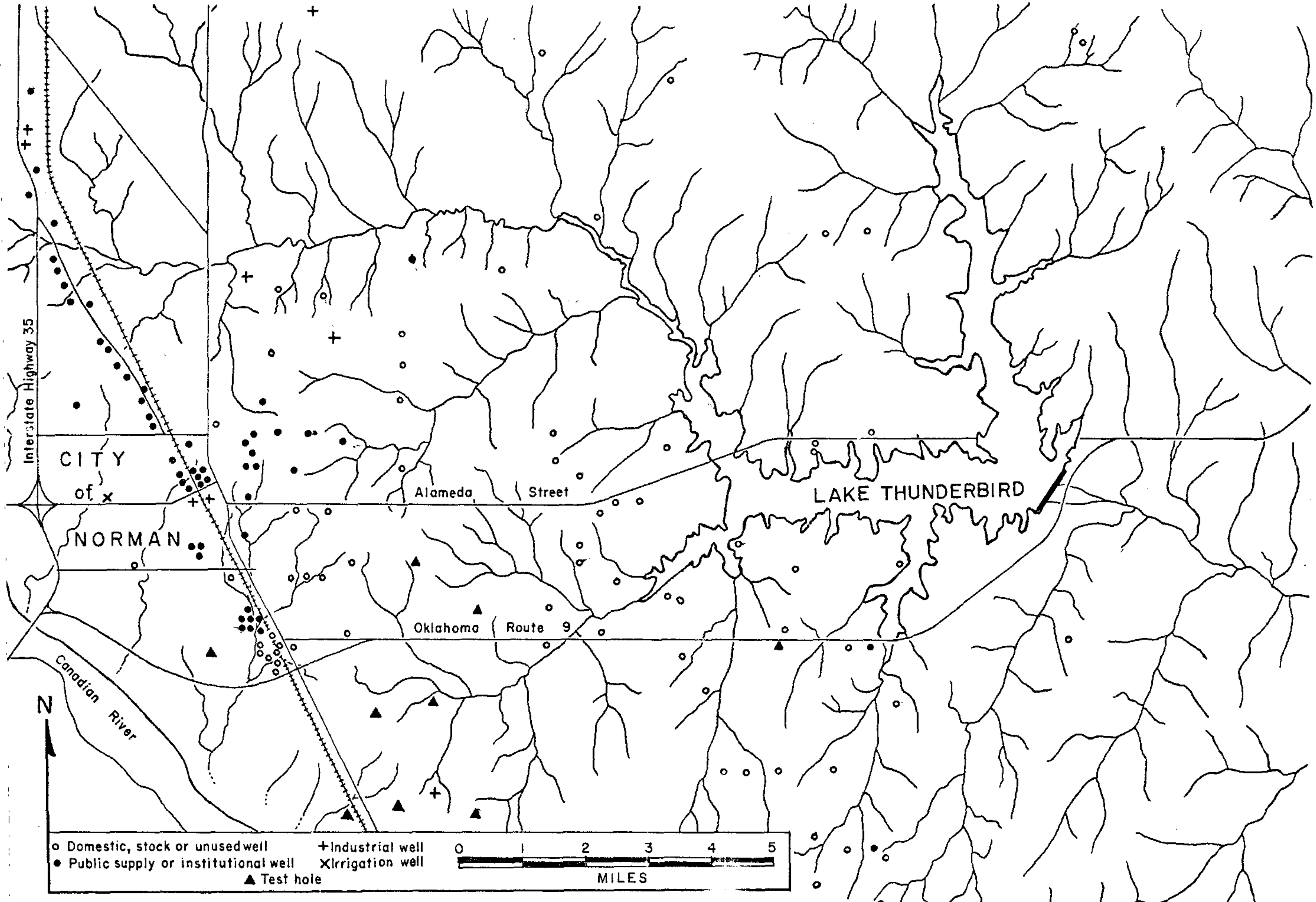

FIGURE 4. Location Map for City of Norman and Lake Thunderbird

CHAPTER 4

METHODOLOGY

The methodology is essentially one of analyzing, comparing, and correlating data and information relative to the quality of the two water supply sources. Inasmuch as it has become standard practice to measure quality in terms of such attributes as hardness, dissolved solids, turbidity, etc., and to identify the contributory parameters in terms of rainfall, antecedent moisture index, land use, land type, and aquifer properties in the case of surface water, a correlation can be established between a quality attribute and a set of contributory parameters or variables. This correlation is in the form:

$$X_n = B_o + B_1Y_1 + B_2Y_2 + B_3Y_3 + \ldots\ldots\ldots\ldots B_nY_n$$

Where:

X_n = a dependent water quality variable

B_n = a constant

B_n = partial regression coefficents

Y_n = independent variables

The constant B is determined by a separate equation of the form:

$$B_o = Y - B_1X_1 - B_2X_2 - \ldots\ldots\ldots\ldots B_nY_n$$

X_n = centroid values for the dependent variables

Y_n = centroid values for the independent variables

The partial regression coefficents B_1, B_2, B_3, ...B_n, are determined using the method of least squares which utilizes the following normal equations of the form:

$$Y = nB_o + B_1 X_1 + B_2 X_2$$

$$X_1Y = B_o X_1 + B_1 X_1^2 + B_2 X_1X_2$$

$$X_2Y = B_o X_2 + B_1 X_1X_2 + B_2 X_2^2$$

Where:

n = number of observations

Before any statistical analysis began all of the data was processed and monthly averages obtained. The data was then divided into seasons, Spring, Summer, Winter, and Fall. The information was then transferred to data cards and fed into an econometric software package for computer analysis. The title of the statistical subroutine used is BMDO2R. The exact methodology of computer operation may be obtained in the computer library of the University of Oklahoma.

Two additional methods of analysis were tried but were unfruitful and not presented. The description of the methods and reasons for their exclusion are as follows. The first method did not divide the data into seasons, and the R^2 values obtained were unacceptable. The second method was a variation of the method which was used. In it, all of the data was weighed equally, and the computer was not allowed to delete information in order to determine which independent variables actually had the most effect on water quality.

CHAPTER 5

DISCUSSION OF RESULTS

The values obtained by using the multiple linear regression technique on data obtained in this study are shown in Table 1. Raw data for Table 1 may be found in Appendix 1.

The best fit for the data was selected on the basis of the highest coefficient of multiple correlation or R^2 value. It should be noted that not all of the independent variables are included in each equation. As stated previously, the computer program selectively eliminated independent variables and re-ran each equation over and over until a maximum R^2 value was obtained. This technique not only selects the relationship which gives the highest correlation coefficients, but effectively demonstrates which of the independent variables has the greatest effect on water quality under given circumstances.

Results and correlation coefficients regarding pH values were found to be somewhat different than expected. pH was found to be at its lowest in the summer with a value of 7.58 and highest in the winter with a value of 7.82. The correlation coefficient R^2, for summer was 0.7531 and the R^2 for winter was 0.7462. R^2 values can generally be expected to be lower during the fall and spring.

Correlation coefficients for alkalinity were stable and within expected limits, R^2 was 0.6317 during winter, 0.6097 during spring, and

0.7141 during dall. However, the R^2 value for alkalinity fall off sharply during the summer with a value of only 0.4515. This drop is due to carbon dioxide, alkalinity, and pH interrelationships. This can be better explained by the following equations:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 + H^+$$

$$M(HCO_3)_2 \rightleftharpoons M^{++} + 2HCO_3^-$$

$$HCO_3 \rightleftharpoons CO_3^{--} + H^+$$

$$CO_3^{--} + H_2O \rightleftharpoons HCO_3^- + OH^-$$

It is obvious that carbon dioxide and the three forms of alkalinity are all part of one system that exists in equilibrium, since all of the equations involve HCO_3^- . A change in concentration of any one member of the system will, of course, cause a shift in equilibrium and alter the concentration of the other ions. This ion shift can, and does account for noted changes in both pH, and alkalinity (11).

Values obtained for hardness are typical for this area, and were well within the scope of the anticipated results.

Turbidity values were generally constant, and showed a noteworthy fluctuation only during the spring and fall. The R^2 value for spring was 0.5595, and the R^2 value for fall 0.3420. This increase of turbidity may be attributed to a number of factors, but the main ones are probably higher surface wind speeds during the spring, which accounts for more mixing and less settling of suspended solids, and more rainfall which means more siltation in the stream or lake. Normally, turbidity is affected by at least such factors as carbon dioxide content, nutrient availability, and solar radiation.

Iron, while its concentrations are low the year around, does appear in larger concentrations during the spring, summer, and fall months. This suggests that anaerobic conditions may exist in some parts of Lake Thunderbird during the warmer months. This would account for the reduction of iron from its Fe^{+++} state to its Fe^{++} state. Since only the reduced form of iron is soluble, this would possibly explain the higher concentrations.

Table 1. Seasonal Variations of Water Quality Parameters

Dependent Variable	Constant Partial Regression Coefficients X Independent Variables	R^2	Std. Error
Winter			
pH	$= 8.48693 + 0.00597Y_2 - 0.00651Y_4 - 0.00726Y_5$	0.7462	0.1995
Alkalinity	$= 1427.33154 + 0.38541Y_2 - 1.24378Y_3 + 0.32239Y_4 + 0.06686Y_5$	0.6317	12.9906
Hardness	$= 1676.80420 - 0.26049Y_2 - 1.45767Y_3 + 0.18885Y_4 - 0.15746Y_5$	0.8564	10.3185
Turbidity	$= 262.53979 - 0.24349Y_3 - 0.05018Y_4 + 0.05115Y_5$	0.5897	3.2138
Iron	$= -0.21597 - 0.00641Y_2 + 0.00032Y_3 - 0.00098Y_4 + 0.00057Y_5$	0.4134	0.0515
Spring			
pH	$= 23.66663 - 0.00801Y_2 - 0.01559Y_3 + 0.00113Y_4$	0.5253	0.2448
Alkalinity	$= 943.74927 + 0.92789Y_2 - 0.74012Y_3 - 0.04339Y_4 - 0.17313Y_5$	0.6097	13.8041
Hardness	$= 1091.51440 + 0.29639Y_2 - 0.86604Y_3 - 0.05727Y_4 - 0.33286Y_5$	0.8203	9.7041
Turbidity	$= 600.07275 + 1.10423Y_2 - 0.58266Y_3 + 0.09879Y_4 + 0.17738Y_5$	0.5595	0.6397
Iron	$= 12.68387 - 0.01742Y_2 - 0.01256Y_3 + 0.00352Y_4 - 0.00447Y_5$	0.7548	0.0890
Summer			
pH	$= -8.96371 + 0.05066Y_2 + 0.01630Y_3 - 0.00630Y_4 + 0.00816Y_5$	0.7531	0.1970
Alkalinity	$= 1085.27295 - 0.18451Y_2 - 0.90206Y_3 + 0.08307Y + 0.06876Y_5$	0.4515	12.2892

Hardness	$= 1279.04419 - 0.87572Y_2 - 1.07110Y_3 + 0.07715Y_4 - 0.07525Y_5$	0.5850	11.8652
Turbidity	$= 50.42255 + 0.78381Y_2 - 0.02645Y_3 - 0.12063Y_4 + 0.02466Y_5$	0.5890	5.5094
Iron	$= -8.91810 - 0.00454Y_2 + 0.00891Y_3 - 0.00231Y_4 + 0.00176Y_5$	0.6221	0.0770
Fall			
pH	$= 13.22942 - 0.04368Y_2 - 0.00540Y_3 + 0.00106Y_4 + 0.00169Y_5$	0.4858	0.2446
Alkalinity	$= 1474.51587 - 0.21071Y_2 - 1.27430Y_3 + 0.09982Y_4 + 0.05377Y_5$	0.7141	11.0497
Hardness	$= 1299.53979 - 1.08665Y_3 + 0.02136Y_4 - 0.09057Y_5$	0.7665	10.6243
Turbidity	$= 107.70085 + 0.34158Y_2 - 0.08597Y_3 - 0.05427Y_4 - 0.01347Y_5$	0.3420	4.6990
Iron	$= 3.67254 - 0.00157Y_2 - 0.00346Y_3 + 0.00035Y_5$	0.3258	0.0796

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

1. Water quality in Lake Thunderbird definitely varies with seasonal changes as evidenced by the changing values of the water quality parameters selected for this study. For instance, pH varies seasonally with its lowest values in Summer and its greatest values apparent in the Winter. Alkalinity reaches its highest values during the Spring, and its lowest values during the Summer months. Hardness, as explained in Chapter 5, was generally constant for all seasons. Fluctuations in turbidity were probably due to surface mixing due to wind action, and to land erosion due to surface run-off. Turbidity was lowest in the Winter when wind-speeds and rainfall amounts were at their lowest. Iron concentrations were found to be generally constant during all seasons except Winter when it is lowest. This is believed to be due to possible anaerobic conditions which undoubtedly exist in at least some parts of Lake Thunderbird.

2. Water withdrawals from Lake Thunderbird are not confined to sole use by the City of Norman. Midwest City, Oklahoma, and Del City, Oklahoma, also use Lake Thunderbird as a supplemental water supply. With this in mind, it should be noted that municipal water quality genrally decreases to some degree during the summer due to increased demands from the lake by these cities. These decreases in water quality are due, in part, to

evaporation and concentration of suspended solids and salts. Evaporation rates tend to increase as lake levels are lowered. The sum total of these demands on the lake's resources would seem to necessarily be limited to some degree in order to maintain desirable water quality levels within the lake.

In addition, constraints exist which prevent unrestricted use of subsurface water. As stated in Chapter 1, the reason for using Lake Thunderbird as a supplemental source of water supply was to prevent further lowering of the water table in the Norman area. Therefore, since a finite quantity of well water does exist, and since a finite quantity of lake water is available, these water supplies may be visualized as discreet amounts of water available to the City of Norman for use. Logic dictates the use of well water when the Lake's quality is at its lowest, and lake water when the lake's quality is at its highest. However, since lake water, even at its best requires extensive treatment, well and lake water are used as a mixture. The higher the quality of the lake, the greater the amount used in the mixture. In this manner full advantage is taken of the changes in water quality which occur in Lake Thunderbird.

Quality as the sole criteria for municipal, or other use, cannot always be the element defining the source of supply. The constraint which sometimes exists is actual availability of either the subsurface surface quantities. Demand may well effect water quality parameters as much, if not greater, than seasonal variations.

The Central Oklahoma Water Conservency District has the responsibility of insuring that Lake Thunderbird does retain desirable water quality levels as shown in Appendix 2 and that the lake is not overtaxed by demands for water from municipalities.

3. As stated previously land use, land type, recreational function, hydrologic conditions, and geologic conditions were necessarily considered to be constant for purposes of this study. These factors were inherent constants since only the one reservoir was studied. This assumption was unavoidable in order to use the available mathematical modeling techniques. These techniques worked well for this study, but it must be stated that a need exists for similar studies to be conducted on other bodies of water and for different land use parameters and hydrologic values. Just as various geologic formations are unique, so is each set of land use, land type, hydrologic, and geologic parameters. These parameters vary from lake to lake and from watershed to watershed, but studies of a large number of these areas could produce useful patterns and models for future study. Therefore, it is recommended that further studies of this type be undertaken.

4. All of the water quality parameters were judgementally rated on a scale from 0 to 2. A rating of poor, 0, indicates that said parameter is at its worst level as indicated by data gathered for this study. A rating of good, 2, indicates that said parameter is at its best level as indicated by data gathered for this study. It must be realized that this scale is subjective and is only meant to compare data within this study. As can easily be determined from the values listed on the following table, overall, or conjunctive water quality in Lake Thunderbird reaches its peak during the Summer and Winter months. Therefore, considering this data and the fact that greater demands are made upon the lake in the Summer months, it is recommended that maximum withdrawals of water from the lake be made during the Winter. Further it is recommended as determined in this study and based on water quality considerations, that insofar as possible, well water be used during the Spring and Fall.

TABLE 2

SPRING	SUMMER	FALL	WINTER	
2	1	1	0	pH
0	2	1	1	ALKALINITY
0	2	1	1	HARDNESS
0	1	1	2	TURBIDITY
1	1	0	2	IRON
3	7	4	6	TOTALS

5. According to the U.S. Geological Survey, the City of Norman's water wells are located in geological formations known as terrace deposits. These deposits generally exist along alluvial rivers and are composed of gravel, sand, silt, and clay. These particular deposits are located in and along the Canadian River and North Canadian River valleys. These deposits are moderately permeable and yield small to moderate quantities of water to wells. This water is suitable for most uses, but may require some softening. It is for this reason, and because the water quality from all the wells was very similar, that well water quality was determined from all available records to be constant for purposes of this study. These parameters are nearly constant from year to year, and from season to season because of the homogenous nature of the aquifer from which the water is taken. It is noteworthy to mention that small variations occur in well water quality, but these have been determined to be of small magnitude. The following is a typical listing of City of Norman well water quality parameters.

TABLE 3

PARAMETER	VALUE
pH	8.8
ALKALINITY	267.7 mg/1
HARDNESS	34.7 mg/1
TURBIDITY	0.0 JTU
IRON	0.026 mg/1

These values reflect a data base of only ten years. The reason that longer periods of time were not considered is that records of this type are taken out of the State of Oklahoma Archives and destroyed after a period of ten years.

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YEAR= 1986

Mixtures of Lake and Well Water

PREC= RAINFALL FOR MONTH IN INCHES
PH= HYDROGEN ION CONCENTRATION
ALK= ALKALINITY IN MG/L
HARD= TOTAL HARDNESS IN MG/L
TURB= TURBIDITY IN JACKSON TURBIDITY UNITS
IRON= IRON IN MG/L
LL= LAKE LEVEL IN FEET ABOVE SEA LEVEL
SW= SURFACE WATER USED IN MILLION GAL/MONTH
WW= WELL WATER USED IN MILLION GAL/MONTH
TW= TOTAL WATER USED IN MILLION GAL/MONTH
0.0 INDICATES DATA NOT AVAILABLE

MONTH	PREC	PH	ALK	HARD	TURB	IRON	LL	SW	WW	TW
1	0.68	0.0	0.0	0.0	0.00	0.000	0.00	0.000	81.412	81.412
2	1.88	8.5	209.0	121.0	0.00	0.000	0.00	0.000	0.000	0.000
3	0.65	0.0	0.0	0.0	0.00	0.000	0.00	0.000	0.000	0.000
4	5.16	8.1	191.5	194.5	29.30	0.000	1011.75	23.803	65.069	88.872
5	0.90	7.8	180.7	186.0	21.50	0.500	1014.11	32.951	65.156	98.107
6	1.91	8.0	182.9	194.1	15.40	0.077	1013.84	45.021	64.578	109.599
7	4.51	0.0	0.0	0.0	0.00	0.000	0.00	0.000	0.000	0.000
8	9.01	7.4	192.0	206.0	18.00	0.000	1013.45	85.071	0.000	85.071
9	1.71	0.0	0.0	0.0	0.00	0.000	0.00	0.000	0.000	0.000
10	0.34	7.8	180.6	190.7	18.40	0.118	1014.22	83.369	0.000	83.369
11	0.61	7.8	184.0	198.8	17.40	0.000	1013.62	73.249	6.710	79.959
12	0.22	8.2	184.0	211.0	15.00	0.108	1013.33	74.249	0.000	74.249

YEAR= 1967

PREC= RAINFALL FOR MONTH IN INCHES
PH= HYDROGEN ION CONCENTRATION
ALK= ALKALINITY IN MG/L
HARD= TOTAL HARDNESS IN MG/L
TURB= TURBIDITY IN JACKSON TURBIDITY UNITS
IRON= IRON IN MG/L
LL= LAKE LEVEL IN FEET ABOVE SEA LEVEL
SW= SURFACE WATER USED IN MILLION GAL/MONTH
WW= WELL WATER USED IN MILLION GAL/MONTH
TW= TOTAL WATER USED IN MILLION GAL/MONTH
0.0 INDICATES DATA NOT AVAILABLE

MONTH	PREC	PH	ALK	HARD	TURB	IRON	LL	SW	WW	TW
1	0.23	7.9	190.0	218.9	10.10	0.022	1013.06	58.919	19.731	78.650
2	0.19	0.0	0.0	0.0	0.00	0.000	0.00	0.000	0.000	0.000
3	2.11	8.3	199.0	216.0	16.50	0.108	1012.66	63.998	19.693	83.691
4	6.23	8.0	199.0	217.0	20.00	0.066	1015.01	71.850	6.204	78.054
5	4.69	7.6	155.6	176.0	55.40	0.000	1017.06	73.284	23.125	96.409
6	3.19	7.6	154.0	168.0	17.00	0.000	1017.10	83.278	13.842	97.120
7	1.34	0.0	0.0	0.0	0.00	0.000	0.00	0.000	0.000	0.000
8	2.99	0.0	0.0	0.0	0.00	0.000	0.00	0.000	0.000	0.000
9	4.73	7.7	187.8	189.3	16.80	0.000	1015.94	67.898	14.219	82.117
10	0.96	7.8	188.0	193.8	20.80	0.252	1015.84	76.436	15.470	91.906
11	0.40	8.0	188.0	199.5	17.20	0.244	1015.68	68.820	13.399	82.279
12	1.05	7.9	188.0	201.0	15.00	0.000	1015.43	68.038	13.330	81.368

[illegible]

PREC= RAINFALL FOR MONTH IN INCHES
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HARD= TOTAL HARDNESS IN MG/L
TURB= TURBIDITY IN JACKSON TURBIDITY UNITS
IRON= IRON IN MG/L
LL= LAKE LEVEL IN FEET ABOVE SEA LEVEL
SW= SURFACE WATER USED IN MILLION GAL/MONTH
WW= WELL WATER USED IN MILLION GAL/MONTH
TW= TOTAL WATER USED IN MILLION GAL/MONTH
0.0 INDICATES DATA NOT AVAILABLE

MONTH	PREC	PH	ALK	HARD	TURB	IRON	LL	SW	WW	TW
1	2.79	8.1	182.4	198.2	11.30	0.050	1015.52	59.149	26.293	85.442
2	0.82	8.2	171.5	192.5	15.80	0.000	1016.15	55.682	26.336	82.018
3	3.12	8.2	174.0	199.0	10.50	0.000	1016.60	63.369	22.527	85.896
4	3.87	0.0	0.0	0.0	0.00	0.000	0.00	0.000	0.000	0.000
5	5.79	7.5	182.0	189.0	25.50	0.000	1020.11	80.943	13.517	94.460
6	4.09	7.2	153.0	168.7	33.00	0.000	1024.40	86.477	14.083	100.560
7	2.04	7.3	159.0	175.0	18.00	0.000	1024.89	101.368	19.409	120.777
8	3.71	7.3	171.8	161.7	15.40	0.000	1024.29	112.512	21.468	133.980
9	5.08	7.4	174.8	183.0	15.60	0.000	1024.41	92.623	15.039	107.662
10	2.31	7.6	175.3	180.0	16.30	0.000	1024.80	83.811	13.660	97.471
11	4.65	7.7	173.5	180.8	12.50	0.000	1025.13	77.858	13.505	91.363
12	1.76	7.7	169.9	181.0	12.00	0.050	1025.97	74.658	15.429	90.087

YEAR= 1969

PREC= RAINFALL FOR MONTH IN INCHES
PH= HYDROGEN ION CONCENTRATION
ALK= ALKALINITY IN MG/L
HARD= TOTAL HARDNESS IN MG/L
TURB= TURBIDITY IN JACKSON TURBIDITY UNITS
IRON= IRON IN MG/L
LL= LAKE LEVEL IN FEET ABOVE SEA LEVEL
SW= SURFACE WATER USED IN MILLION GAL/MONTH
WW= WELL WATER USED IN MILLION GAL/MONTH
TW= TOTAL WATER USED IN MILLION GAL/MONTH
0.0 INDICATES DATA NOT AVAILABLE

MONTH	PREC	PH	ALK	HARD	TURB	IRON	LL	SW	WW	TW
1	1.40	7.8	169.9	185.5	10.00	0.050	1026.21	65.323	28.863	94.186
2	2.91	7.7	177.7	188.0	13.30	0.000	1026.99	61.616	25.383	86.999
3	2.92	7.7	187.3	191.2	14.50	0.100	1028.27	70.289	28.321	98.610
4	2.62	7.7	190.5	195.6	13.70	0.028	1029.22	77.758	19.877	97.635
5	4.22	7.6	184.7	190.8	17.10	0.100	1031.80	88.347	17.875	106.222
6	2.73	7.4	179.4	187.0	12.20	0.000	1032.39	93.183	26.446	119.629
7	2.10	7.6	184.9	194.9	9.00	0.017	1031.96	129.569	37.341	166.910
8	2.83	0.0	0.0	0.0	0.00	0.000	0.00	0.000	0.000	0.000
9	4.82	7.5	186.0	198.6	13.20	0.025	1031.19	92.263	14.743	107.006
10	2.56	7.6	188.1	199.4	14.10	0.063	1030.79	92.862	7.399	100.261
11	0.39	7.8	193.9	201.9	9.20	0.066	1030.44	83.096	12.323	95.419
12	2.12	7.9	194.8	203.6	5.03	0.028	1030.33	77.531	12.096	89.627

YEAR= 1970

PREC= RAINFALL FOR MONTH IN INCHES
PH= HYDROGEN ION CONCENTRATION
ALK= ALKALINITY IN MG/L
HARD= TOTAL HARDNESS IN MG/L
TURB= TURBIDITY IN JACKSON TURBIDITY UNITS
IRON= IRON IN MG/L
LL= LAKE LEVEL IN FEET ABOVE SEA LEVEL
SW= SURFACE WATER USED IN MILLION GAL/MONTH
WW= WELL WATER USED IN MILLION GAL/MONTH
TW= TOTAL WATER USED IN MILLION GAL/MONTH
0.0 INDICATES DATA NOT AVAILABLE

MONTH	PREC	PH	ALK	HARD	TURB	IRON	LL	SW	WW	TW
1	0.11	7.9	196.2	204.6	4.50	0.022	1030.27	77.892	18.794	96.686
2	0.60	7.8	196.9	204.4	6.30	0.013	1030.12	71.401	14.810	86.211
3	2.92	7.9	197.5	203.9	11.90	0.060	1030.07	74.982	14.811	89.793
4	3.43	7.8	196.5	202.3	8.80	0.044	1030.41	79.965	14.967	94.932
5	6.17	7.6	194.4	201.0	10.90	0.038	1031.14	104.506	14.673	119.179
6	1.83	7.6	180.9	194.9	12.00	0.206	1032.29	98.641	22.235	120.876
7	2.77	7.5	178.3	190.4	6.40	0.072	1031.67	126.397	27.104	153.501
8	2.66	7.5	182.1	192.8	7.00	0.066	1030.88	132.678	27.271	159.949
9	10.41	7.3	170.8	186.7	17.60	0.072	1031.21	106.014	16.631	122.645
10	5.19	7.7	141.5	157.5	25.50	0.141	1036.01	93.342	6.501	99.843
11	1.58	7.7	141.7	157.8	19.60	0.152	1036.91	79.015	13.789	92.804
12	0.25	7.7	143.5	161.2	13.20	0.108	1036.83	83.321	12.677	95.998

PREC= RAINFALL FCR MONTH IN INCHES
PH= HYDROGEN ION CONCENTRATION
ALK= ALKALINITY IN MG/L
HARD= TOTAL HARDNESS IN MG/L
TURB= TURBIDITY IN JACKSON TURBIDITY UNITS
IRON= IRON IN MG/L
LL= LAKE LEVEL IN FEET ABOVE SEA LEVEL
SW= SURFACE WATER USED IN MILLION GAL/MONTH
WW= WELL WATER USED IN MILLION GAL/MONTH
TW= TOTAL WATER USED IN MILLION GAL/MONTH
0.0 INDICATES DATA NOT AVAILABLE

MONTH	PREC	PH	ALK	HARD	TURB	IRON	LL	SW	WW	TW
1	1.06	7.8	146.3	156.7	7.60	0.072	1036.87	80.382	15.350	95.732
2	1.71	7.8	149.4	166.6	6.10	0.038	1037.25	69.341	19.703	89.044
3	0.03	7.7	151.1	175.7	10.60	0.072	1037.43	76.747	26.874	103.621
4	1.60	7.5	155.4	171.6	15.60	0.072	1037.10	97.462	16.375	113.837
5	3.59	7.6	155.9	174.1	8.90	0.066	1036.91	107.380	10.788	118.168
6	5.54	7.6	156.0	173.0	9.00	0.066	1037.18	107.925	14.355	122.280
7	3.18	7.5	156.0	173.0	7.00	0.056	1036.86	128.215	26.359	154.574
8	2.09	7.5	163.2	175.5	6.90	0.050	1036.24	118.950	17.976	136.926
9	4.74	7.5	168.1	176.9	9.20	0.038	1035.81	122.062	23.015	145.077
10	4.42	7.5	168.0	176.0	8.00	0.033	1036.20	106.818	2.755	109.573
11	0.93	7.5	168.0	176.0	12.00	0.033	1036.00	80.017	28.098	108.115
12	3.29	7.6	168.0	176.0	12.50	0.038	1036.19	79.331	31.989	111.320

YEAR= 1972

PREC= RAINFALL FOR MONTH IN INCHES
PH= HYDROGEN ION CONCENTRATION
ALK= ALKALINITY IN MG/L
HARD= TOTAL HARDNESS IN MG/L
TURB= TURBIDITY IN JACKSON TURBIDITY UNITS
IRON= IRON IN MG/L
LL= LAKE LEVEL IN FEET ABOVE SEA LEVEL
SW= SURFACE WATER USED IN MILLION GAL/MONTH
WW= WELL WATER USED IN MILLION GAL/MONTH
TW= TOTAL WATER USED IN MILLION GAL/MONTH
0.0 INDICATES DATA NOT AVAILABLE

MONTH	PREC	PH	ALK	HARD	TURB	IRON	LL	SW	WW	TW
1	0.33	7.8	167.8	175.6	6.20	0.033	1036.38	77.076	32.160	109.236
2	0.67	7.8	169.4	179.2	4.90	0.038	1036.27	81.645	29.177	110.822
3	0.59	7.7	172.6	179.7	11.30	0.038	1036.08	95.911	29.406	125.317
4	4.55	7.6	177.0	181.1	11.80	0.210	1035.94	108.749	17.292	126.041
5	2.89	7.6	171.0	180.1	13.10	0.017	1036.88	110.237	22.351	132.588
6	1.23	7.6	170.3	177.7	8.80	0.017	1036.62	138.025	42.402	180.427
7	2.51	7.5	167.4	173.9	5.70	0.013	1036.39	140.219	59.358	199.577
8	1.24	7.6	166.0	176.0	5.00	0.017	1035.69	133.652	70.980	204.632
9	0.43	7.5	171.3	176.6	7.90	0.013	1035.07	119.064	59.106	178.170
10	6.47	7.6	174.0	178.0	12.00	0.013	1034.51	62.604	99.242	161.846
11	5.87	7.7	170.4	173.2	12.30	0.013	1036.27	9.807	113.760	123.567
12	1.03	7.7	172.0	176.0	12.00	0.013	1036.55	62.826	61.500	124.326

YEAR= 1973

PREC= RAINFALL FOR MONTH IN INCHES
PH= HYDROGEN ION CONCENTRATION
ALK= ALKALINITY IN MG/L
HARD= TOTAL HARDNESS IN MG/L
TURB= TURBIDITY IN JACKSON TURBIDITY UNITS
IRON= IRON IN MG/L
LL= LAKE LEVEL IN FEET ABOVE SEA LEVEL
SW= SURFACE WATER USED IN MILLION GAL/MONTH
WW= WELL WATER USED IN MILLION GAL/MONTH
TW= TOTAL WATER USED IN MILLION GAL/MONTH
0.0 INDICATES DATA NOT AVAILABLE

MONTH	PREC	PH	ALK	HARD	TURB	IRON	LL	SW	WW	TW
1	3.66	7.9	165.5	175.0	5.90	0.013	1037.16	81.704	43.676	125.380
2	1.23	7.9	166.0	175.0	6.00	0.013	1037.88	81.142	36.471	117.613
3	7.31	7.9	162.0	174.3	20.00	0.013	1039.34	82.130	43.139	125.269
4	3.19	7.7	155.3	162.0	22.50	0.006	1040.91	82.013	43.035	125.048
5	5.92	7.6	158.1	162.1	14.40	0.006	1039.95	87.106	67.131	154.237
6	6.18	7.7	152.1	157.6	16.30	0.010	1040.79	122.916	16.972	139.888
7	2.41	7.4	150.7	157.4	11.30	0.010	1039.23	135.548	41.144	176.692
8	0.99	7.3	150.1	163.5	9.50	0.116	1038.70	146.881	55.352	202.243
9	9.31	7.1	156.8	163.1	17.80	0.181	1038.87	85.442	56.842	142.284
10	3.51	7.2	149.5	154.5	20.90	0.167	1039.50	59.394	98.292	157.686
11	3.10	7.7	151.2	151.1	17.80	0.163	1039.50	32.993	116.476	149.469
12	0.47	7.3	155.7	153.0	15.30	0.163	1039.46	62.939	81.588	144.527

YEAR= 1974

PREC= RAINFALL FOR MONTH IN INCHES
PH= HYDROGEN ION CONCENTRATION
ALK= ALKALINITY IN MG/L
HARD= TOTAL HARDNESS IN MG/L
TURB= TURBIDITY IN JACKSON TURBIDITY UNITS
IRON= IRON IN MG/L
LL= LAKE LEVEL IN FEET ABOVE SEA LEVEL
SW= SURFACE WATER USED IN MILLION GAL/MONTH
WW= WELL WATER USED IN MILLION GAL/MONTH
TW= TOTAL WATER USED IN MILLION GAL/MONTH
0.0 INDICATES DATA NOT AVAILABLE

MONTH	PREC	PH	ALK	HARD	TURB	IRON	LL	SW	WW	TW
1	0.14	7.4	158.8	157.7	8.80	0.018	1039.47	68.552	77.739	146.291
2	1.64	7.2	161.4	162.5	8.90	0.154	1039.36	62.586	76.192	138.778
3	1.77	7.0	165.7	167.3	16.00	0.150	1039.32	75.370	73.933	149.303
4	2.78	7.6	168.5	171.1	22.30	0.188	1039.05	97.663	65.705	163.368
5	4.19	8.1	168.0	172.0	20.00	0.344	1039.73	122.274	56.609	178.883
6	2.23	8.1	167.8	171.2	17.40	0.213	1039.49	124.964	55.509	180.473
7	0.36	8.1	168.1	166.0	12.20	0.288	1038.83	149.337	137.796	287.133
8	5.22	8.1	162.5	161.7	12.40	0.183	1038.26	134.508	51.905	166.413
9	4.57	8.1	164.0	160.0	12.00	0.180	1037.99	122.578	46.642	169.220
10	5.04	8.1	162.0	165.0	23.00	0.169	1037.89	91.151	77.608	168.759
11	1.83	8.1	162.0	165.0	13.00	0.154	1039.64	79.376	60.649	140.025
12	1.36	8.1	162.0	168.0	8.00	0.161	1039.23	64.801	66.745	131.546

APPENDIX 2. GENERAL WATER QUALITY STANDARDS FOR THE STATE OF OKLAHOMA

Minerals: For chlorides, sulfates, and total dissolved solids the arithmetic mean of the concentrations of the samples taken for a year at any point shall not exceed one standard deviation greater than the arithmetic mean of the historical data. Not more than one in twenty samples randomly collected shall exceed two standard deviations greater than the arithmetic mean of the historical data generated for that point.

Bacteria: In areas designated as recreational, primary body contact, or a public or private water supply, bacteria of the fecal coliform group shall not exceed a monthly geometric mean of 200/100ml, as determined by multiple tube fermentation or membrane filter procedures and based on a minimum of not less than five samples for any 30-day period, nor shall more than ten percent (10%) of the total samples during any thirty day period exceed 400/100ml.

In areas designated secondary body contact bacteria of the fecal coliform group shall not exceed a monthly geometric mean of 1000/100ml, nor shall more than ten percent(10%) of the total samples during any 30-day period exceed 2000/100ml.

Oil and Grease: Essentially free of floating or emulsified oil and grease.

Solids: Free of floating devris, bottom deposits, scum, foam and other materials of a persistent nature from other than natural sources.

Turbidity: Turbidity of other than natural origin shall be restricted to the following in-stream numerical values:

Warm Water Lakes	25 Jackson Units
Warm Water Streams	50 Jackson Units
Cold Water Streams (those designated as small-mouth bass or trout fisheries)	10 Jackson Units

Color: Color producing substances of a persistent nature from other than natural sources shall be limited to concentrations which will not be detremental to beneficial uses.

Temperature:

During any month of the year, heat shall not be added to any stream in excess of the amount that will raise the temperature of the water more than 5°F. In lakes the temperature of the epilimnion shall not be raised more than 3°F above that which existed before the addition of artificial heat. Normal daily and seasonal fluctuations shall be maintained. The maximum temperature due to man-made causes shall not exceed 68°F in trout streams, 84°F in small mouth bass streams, or 90°F in all other streams and lakes except for the following:

Arkansas River from Kaw Reservoir Dam to the Headwaters of Keystone Reservoir 94°F.
Arkansan River from Keystone Reservoir Dam to Coody Creek near Muskogee, Okla 93°F.
Salt Fork Arkansas River 93°F.
Red River excluding Lake Texoma 93°F.
North Fork Red River 91°F.

Taste and Odor: Taste and odor producing substances from other than natural origin shall be limited to concentrations that will not interfere with the production of potable water by modern treatment methods or impart off-color or unpalatable flavor to flesh of fish, or result in offensive odors in the vicinity of the water, or otherwise interfere with beneficial uses.

Dissolved Oxygen: The dissolved oxygen concentration shall not be less than 5mg/l for all warm waters, and 6mg/l for those waters designated as small-mouth bass or trout fisheries. Diurnal variations may cause the dissolved oxygen to decrease 1mg/l below the above values for short periods (not to exceed 8 hours) during any 24 hours provided that the water quality is favorable in all other respects.

Nutrients: The total phosphorous concentration and nitrogen/phosphorous ratio shall be limited to prevent eutrophication problems.

Toxic Substances: Toxic substances shall not be present in such quantities as to cause the waters to be toxic to human, animal, plant, or aquatic life, nor detremental to any beneficial use including continued ingestion by livestock or continued use for irrigation. For aquatic life, using bioassay techniques, the toxic limit shall not exceed one-tenth of the 96-hour median tolerance limit for the most sensitive species common to the stream. In the absence of information on the most sensitive species the concentration shall not exceed the one-tenth of the 96-hour median tolerance limit to *Pimephales promelas* (Fathead Minnow) and/or *Lepomis macrochirus* (Bluegill).

Species Diversity Index: A diversity value for benthic (bottom dwelling) macroinvertebrate organisms shall be maintained at a minimum of three (3) unless natural conditions op phenomena cause the value to be less.

pH: The pH shall be between 6.5 and 8.5. pH values below 6.5 and above 8.5 must not be due to waste discharge.