AN ABSTRACT OF THE THESIS OF

Thomas E. Peterson for the Master of Science Degree in Earth Science, presented on December 3, 1992.

Title: Water Quality in Lake Kahola and Adjacent Domestic Water Wells

Abstract appproved: James S. Aber

Lake Kahola, in Chase and Morris Counties, Kansas, is a small detention dam and reservoir built by the Work Projects Administration in the 1930´s as an alternate water supply for Emporia, Kansas. Today the lake has the additional role of recreation for many residents of the region and is extensively developed for seasonal and year-round residency. Extensive development increases the prospect of septic-waste contamination in the lake. In order to investigate this possibility, a ten-month study of the lake´s water quality was conducted to identify elevated levels of chloride and phosphate in the lake and nearby wells. Samples from undeveloped regional springs, streams, and Chase County State Lake were a background against which Lake Kahola and the wells were compared.

Contamination of the numerous domestic water wells surrounding Lake Kahola is a possibility. Geologic structure at the lake presents the likelihood that at least some of the wells are being recharged by water from Lake Kahola.

The results of the study indicate that, when compared to undeveloped areas, Lake Kahola has high-quality water. Test results from sampled wells at the lake reveal that the possibility of contamination cannot be ruled out. One of the background sample sites had consistently higher chloride concentrations than any of the other sites which may indicate contamination by human intervention.

WATER QUALITY IN LAKE KAHOLA AND ADJACENT DOMESTIC WATER WELLS

A Thesis

Presented to

the Division of Physical Sciences

EMPORIA STATE UNIVERSITY

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

Thomas E. Peterson

December 1992

James S Aber
Approved for the Major Division

Faye N. Vowell
Approved for the Graduate Council

ACKNOWLEDGMENTS

I would like to thank Drs. Aber, Schroeder, and Finck, of my graduate committee, for their assistance and invaluable comments regarding my thesis.

I would like to thank Paul Johnston for his teaching skills which got me excited about Earth Science before I even thought about working towards a Master's degree. I owe a debt of gratitude to the others of the Physical Science Department of Emporia State University from whom I took classes. Without their dedication to teaching and students, learning wouldn't have been nearly as much fun.

I would like to thank Anne Sheve, of the Lyon County Health Department, for giving me the idea for this project.

Of all the people behind completion of this thesis, I owe the most to my wife, Naomi. Without her patience, understanding, and support I would never have been able to accomplish this achievement (thanks, honey).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

PURPOSE AND SCOPE

Lake Kahola provides recreation for many residents of east-central Kansas. In addition to this role the lake is an alternative water source for the City of Emporia, Kansas. Extensive development around the lake's perimeter has raised the question of water-quality conditions in the lake due to human intervention, such as by septic-waste contamination.

Each cabin on the lake's perimeter has its own septic holding tank which must be pumped out periodically. Numerous cabins are supplied by groundwater obtained from wells situated in close proximity to holding tanks. Geologic structure at Lake Kahola presents the possibility that wells around the lake are being recharged by lake water.

It is the purpose of this project to examine the chemical water quality of Lake Kahola, and selected wells at the lake, in an attempt to uncover the possibility of lake and/or well contamination. Specifically, chloride and dissolved phosphate concentrations are examined as possible indicators of contamination. If chloride and phosphate are entering Lake Kahola from faulty septic holding tanks it is possible that concentrations of these two ions are higher in the lake than in a series of background samples. Any leakage of waste into wells around the lake may also appear as higher-than-background concentrations.

Phosphate and chloride were chosen for analysis as indicators because these two ions are normally in low concentrations when occurring naturally. Concentrations above background levels in any of the samples could mean waste contamination, since phosphate and chloride are found in high concentrations in soaps and other cleaning agents which are a usual constituent of human effluent.

PREVIOUS STUDIES

The Kansas Department of Health and Environment (KDHE) has surveyed Lake Kahola in the past. Water analyses were conducted in 1986 and in 1990 by the KDHE. Results from these studies are presented in Table 1.1.

TABLE 1.1 Results of KDHE analyses of Lake Kahola. Conductance is in micromhos/cm. Phosphate is dissolved phosphate, concentrations of which are noted by the KDHE as being below detection limits for the analysis used (KDHE 1992).

	1986	1990
conductance	290-300	291-296
pH	8.4	8.2
phosphate (mg/L)	0.010	NA
chloride (mg/L)	2-3	3
calcium (mg/L)	49.5-51.0	46.8-52.8

In addition to Lake Kahola samplings, results of samplings done for similar lakes in eastern Kansas are available for which comparisons may be made.

Council Grove Reservoir, located 18.5 km to the north-northwest of Lake Kahola, serves a recreational function similar to Lake Kahola. Council Grove Reservoir, although more than six larger than Lake Kahola, is also extensively developed by residences and seasonal dwellings. KDHE water-sampling data for Council Grove Reservoir, for the years 1975, 1978, and 1981, are presented in Table 1.2.

TABLE 1.2 KDHE analyses of Council Grove Reservoir (KDHE 1975, 1978, 1981). Conductance is in micromohs/cm, phosphate is dissolved phosphate.

	1975	1978	1981
conductance	270-330	330-380	210-240
pH	7.3-8.7	8.0-8.4	7.9-8.3
phosphate (mg/L)	.034-.05	.002-.037	.06-.15
chloride (mg/L)	6-8	9-12	7-9
calcium (mg/L)	37-49	NA	40-45

Tables 1.1 and 1.2 show that in general Lake Kahola is comparable to Council Grove Reservoir in conductance and pH, lower in dissolved phosphate and chloride, and somewhat higher in calcium ion.

GENERAL DESCRIPTION OF THE STUDY AREA

Lake Kahola is located at the eastern edge of the Flint Hills on the border between Morris and Chase Counties, Kansas (Figure 1). The lake dam is located in the SE 1/4 of Section 33, T17S, R8E, Morris County, Kansas, and is oriented in a NW-SE direction (Figure 2). Completed in 1937, the dam is 567 m (1900 feet) long and up to 21 m (70 feet) high. The lake has a high-water elevation of 1269 feet at the lip of the spillway; it covers slightly more than 162 hectares (400 acres), and is about 15 m (50 feet) deep at the outlet tower.

Numerous springs feed Lake Kahola from its southern bluff due to the local dip of the bedrock toward the northwest. Groundwater recharge from these springs makes the lake relatively drought resistant, despite a fairly small drainage basin of about 41.5 km^2 (16 $miles^2$). Two streams feed the lake, Kahola Creek from the west, and a smaller, unnamed stream from the northwest. Both streams are intermittent in nature but Kahola Creek carries some water most of the year from springs in the southern bluffs. Lake Kahola stores a reserve water supply for the city of Emporia.

Surrounding Lake Kahola, Lake Kahola Park was developed early for summer cabins and sixty cabin sites were established by 1944. The lake became well known for sailboat and water-skiing competitions during the 1950s. The lake was a

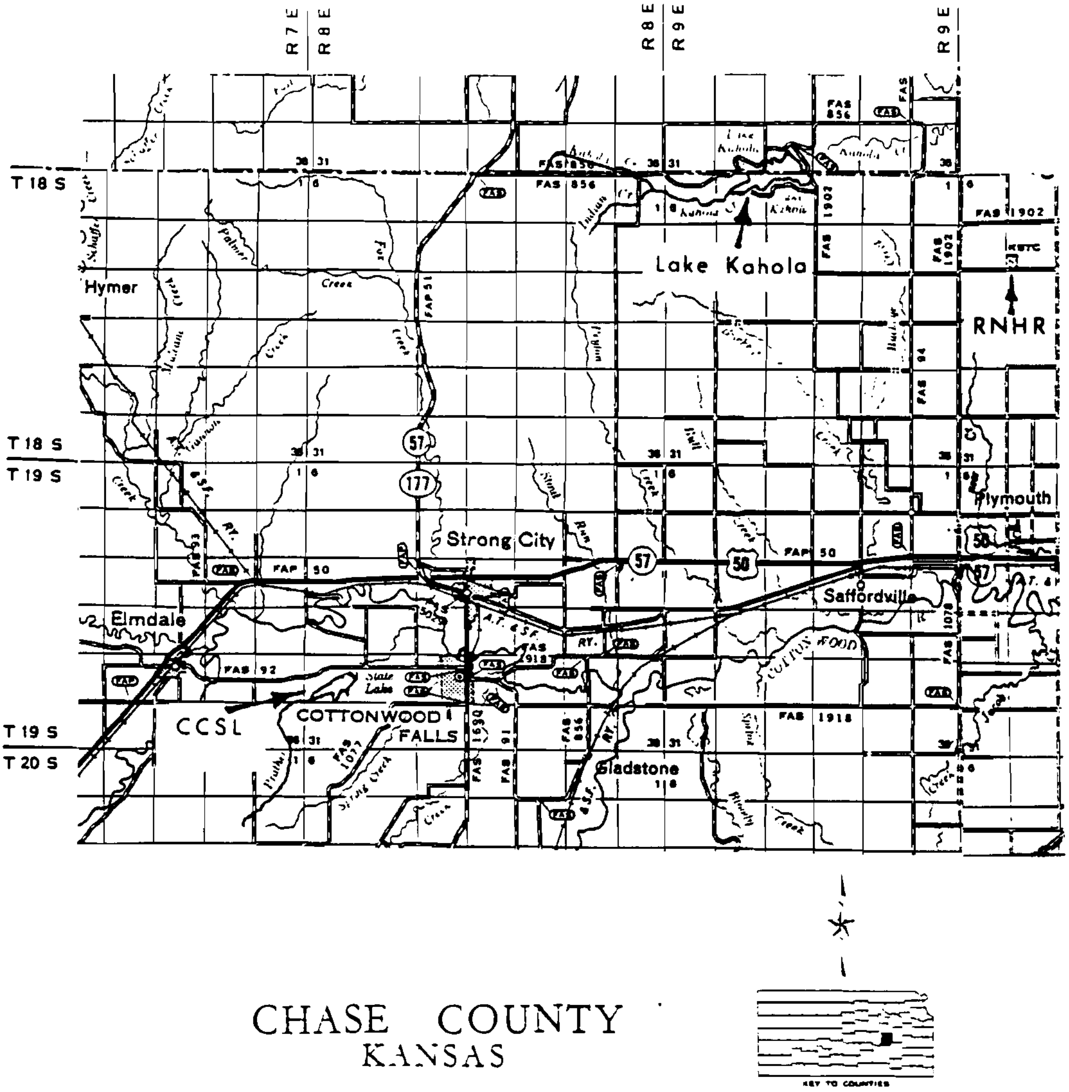


FIGURE 1

A map of the northeast quadrant of Chase County, Kansas, including, east of R9E, 2 miles of Lyon County and, north of T18S, 2 miles of Morris County. The locations of Lake Kahola, CCSL, and RNHR are pointed out (adapted from Chase County, Kansas, General Highway Map 1986). Scale: 1:253,440.

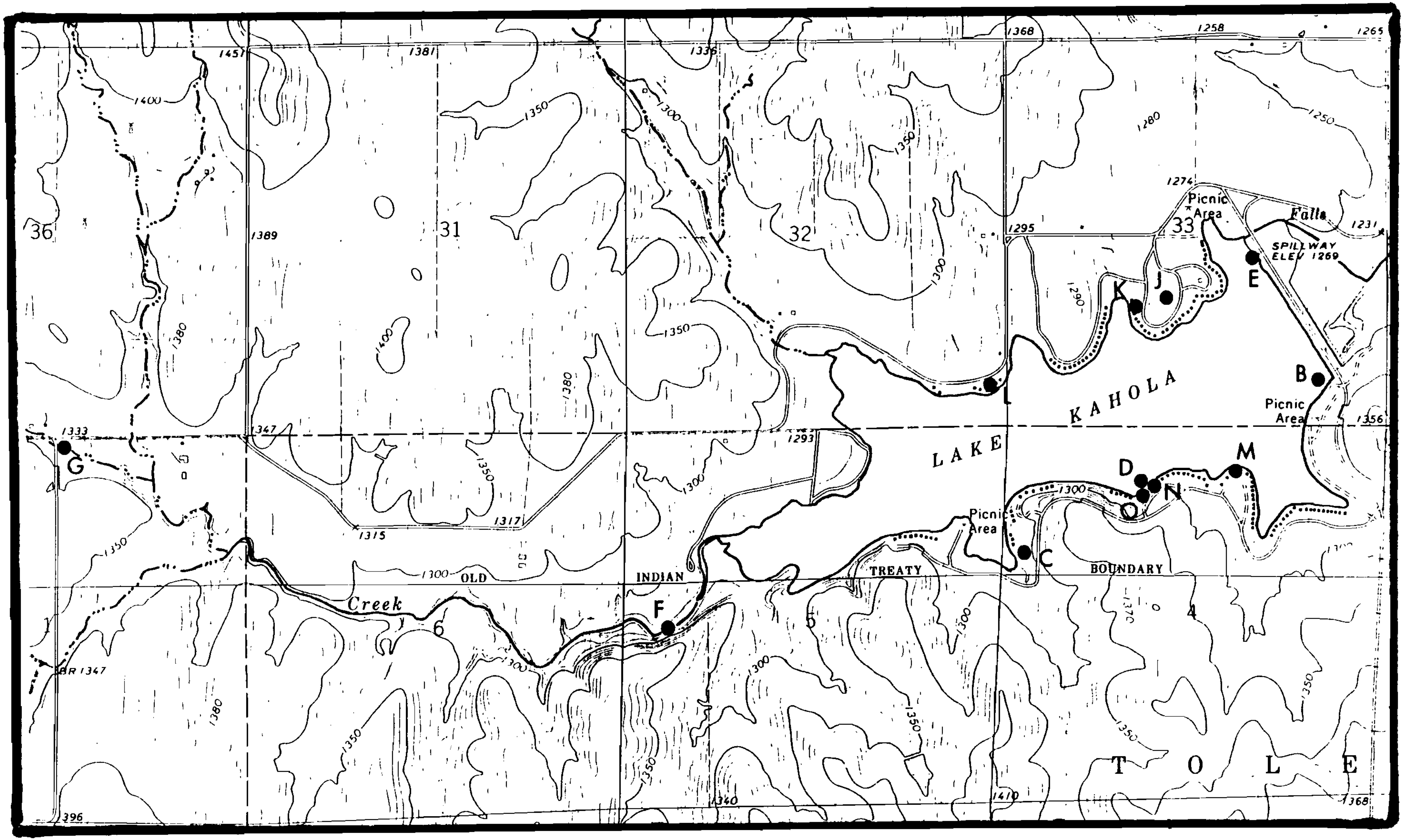

LAKE KAHOLA
Falls
SPILLWAY ELEV 1269
Picnic Area
Picnic Area
Picnic Area
OLD INDIAN TREATY BOUNDARY
Creek
TOLE
36
31
32
33
6
5
4
A
B
C
D
E
F
G
J
K
L
M
N
O
1451
1381
1336
1368
1258
1265
1400
1350
1300
1280
1250
1274
1295
1231
1389
1380
1333
1347
1293
1356
1317
1315
1300
1290
1370
BR 1347
396
1340
1410
1368

FIGURE 2 (previous page)

A map of the Lake Kahola and Kahola Creek region. Water sampling sites and sampled well locations are represented by dots with letters corresponding to Table 2.1 (adapted from Lake Kahola, Kansas, 7.5-minute topographic map quadrangle 1972). Scale: 1:24,000.

---

popular swimming and fishing destination for people from nearby cities during the summer months. Lake Kahola Park now has nearly 200 cabins, some of which are occupied year around, and a year-round caretaker.

The water of Lake Kahola has naturally good quality, as it recharges from a relatively undeveloped grassland drainage basin which is nearly 90 percent range/pasture. The KDHE (Carney 1992) considers Lake Kahola to be one of Kansas´ highest quality water-supply lakes. The only real sources for pollution are the houses that are near the lake. Concern about lake and groundwater pollution has grown with the number of cabins. All cabins are required to use waterproof holding tanks for temporary storage of sanitary waste. No open septic systems or outhouses are allowed, and all water wells must meet approved standards. Maintaining safe water quality is a major goal of the Lake Kahola Cabin Owner´s Association (Aber 1990).

CHAPTER 2: METHODS OF INVESTIGATION AND PROCEDURE

The Lake Kahola water-quality project consists of six parts. In the first part, data pertaining to the history, geology, and previous water quality of Lake Kahola were collected as foundation for the project. Secondly, a register of sampling sites and wells at Lake Kahola (test samples), and background sampling sites (control samples), was developed. Thirdly, samples were taken and analyzed, with some analysis done at the collection site and some analysis done at the ESU chemistry laboratory. The fourth part of the project involved an investigation of the structural geology around and underlying Lake Kahola. This included investigation of groundwater sources for domestic wells surrounding the lake. The fifth part of the project consists of a compilation and interpretation of data collected. The sixth part is conclusions drawn based on data collected during the study.

INFORMATION SURVEY

Information includes previously mentioned KDHE data pertaining to chemical analyses of Lake Kahola done in 1986 and 1990. Historical information has been discussed and is included in the general description of the study area. The geology of the Lake Kahola region will be discussed in chapter 3.

SAMPLING-SITE REGISTER

In order to develop a background data base on which to compare water quality at Lake Kahola, sampling sites around the Lake Kahola region were chosen. Table 2.1 is a complete listing of Lake Kahola sample sites and background sample sites. Lake Kahola sampling sites represent up-lake and down-lake regions, and near bottom at the deepest place in the lake. Background sites were chosen on the basis of assumed uncontamination by development as it exists at Lake Kahola. Another criterion is that these sites are situated in geologic strata the same as, or similar to, those at Lake Kahola.

TABLE 2.1

A list of sample sites used in this study. Letter designations to each site are used for site location on maps and diagrams, and for listing results of chemical analyses. See Figures 1, 2, 3, and 4 for site locations.

LOCATION	LETTER DESIGNATION
RNHR	A
Lake Kahola outlet tower	B
South bluff spring	C
Lake Kahola at cabin # 93	D
Lake Kahola spillway	E
Kahola Creek 1	F

(continued on next page)

LOCATION	LETTER DESIGNATION
Kahola Creek 2	G
CCSL swim area	H
CCSL dam	I
Caretaker´s well	J
Cabin # 82 well	K
Cabin # 169A well	L
Cabin # 53 well	M
Cabin # 89 well	N
Cabin # 93 spring	O

Background sites chosen are: a perennial spring at Ross Natural History Reservation (RNHR, Figure 1), two sites on Kahola Creek upstream from Lake Kahola, a perennial spring on the south bluffs overlooking Lake Kahola, an intermittent spring near cabin #93 on the south bluff of Lake Kahola, and two sites at Chase County State Lake (CCSL), west of Cottonwood Falls (Figure 1).

The spring at RNHR, sampling site A (Figure 3), was chosen because it is in a region known to be free of farming practices and agricultural chemicals for at least 30 years. RNHR is situated on the Neva Limestone. Limited grazing and burning are still practiced at RNHR in order to maintain the native prairie. RNHR was donated to Emporia State University in 1961, and is dedicated to the following purposes:

1. To provide a living laboratory for research and field study.
2. To provide a site for teaching biology and other sciences.
3. To preserve a part of the Flint Hills prairie (Finck 1990).

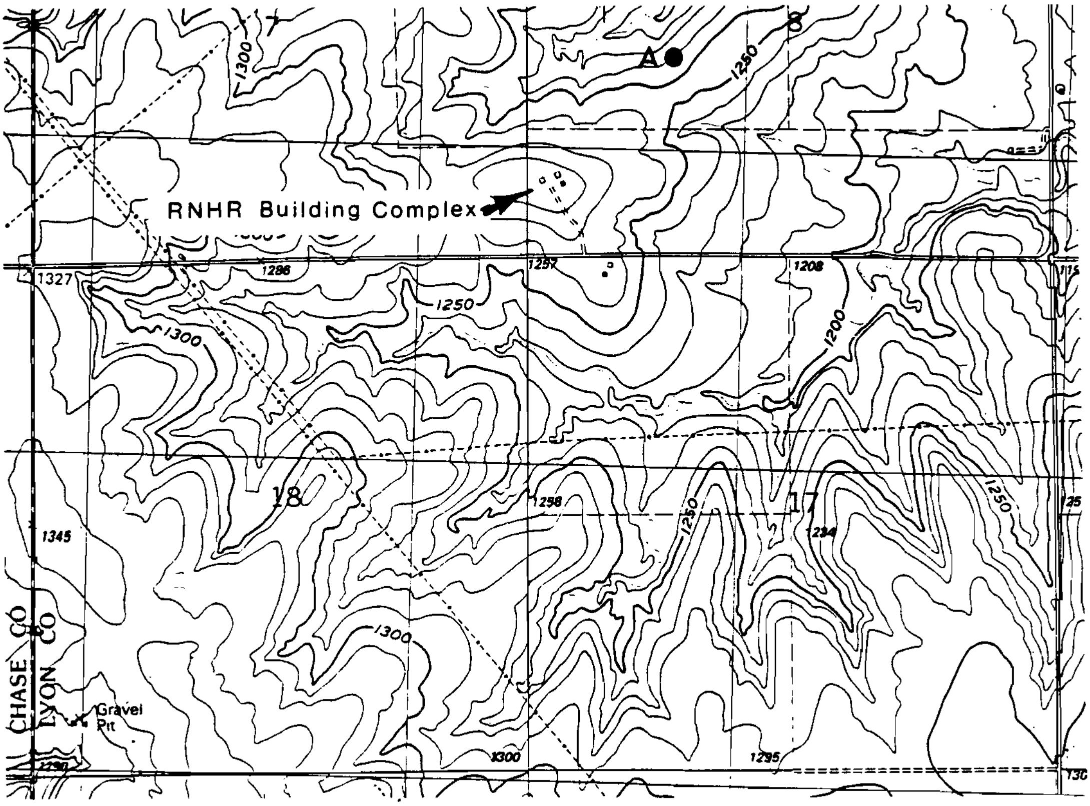


FIGURE 3

A map of the immediate vicinity of RNHR with the spring sampling site designated letter A (adapted from Plymouth, Kansas, 7.5-minute topographic quadrangle 1972). Scale 1:24,000.

The sites on Kahola Creek were chosen for comparison to water in the lake. Kahola Creek site F is just above the lake surface, and Kahola Creek site G is upstream about 2.4 km (1.5 miles) west of the lake (Figure 2).

The springs on Lake Kahola's south bluff were chosen because they emerge from strata overlain by native pasture, are elevated above human habitation, and are therefore assumed to be uncontaminated by human intervention. These springs, sites C and O, are two of many similar springs that contribute to Lake Kahola (Figure 2).

Chase County State Lake was chosen for background because of its size, relative nearness to Lake Kahola, and because it is situated in nearly the same geologic strata as Lake Kahola. In addition to these factors CCSL is undeveloped except for picnic and swimming areas, which include a public restroom facility over a septic holding tank. The two sampling sites at CCSL are site H, at the swim area, and site I, at the dam (Figure 4). These sites were selected for their accessibility.

CCSL was constructed in 1954, has a surface area of 44 hectares (109 acres), a volume of 2,410,269 m^3 (1,954 acre feet), and a drainage basin of 10.9 km^2 (3.75 square miles). Average depth for CCSL is 5.4 meters (17.9 feet) (Kansas Dept. of Wildlife and Parks records 1992).

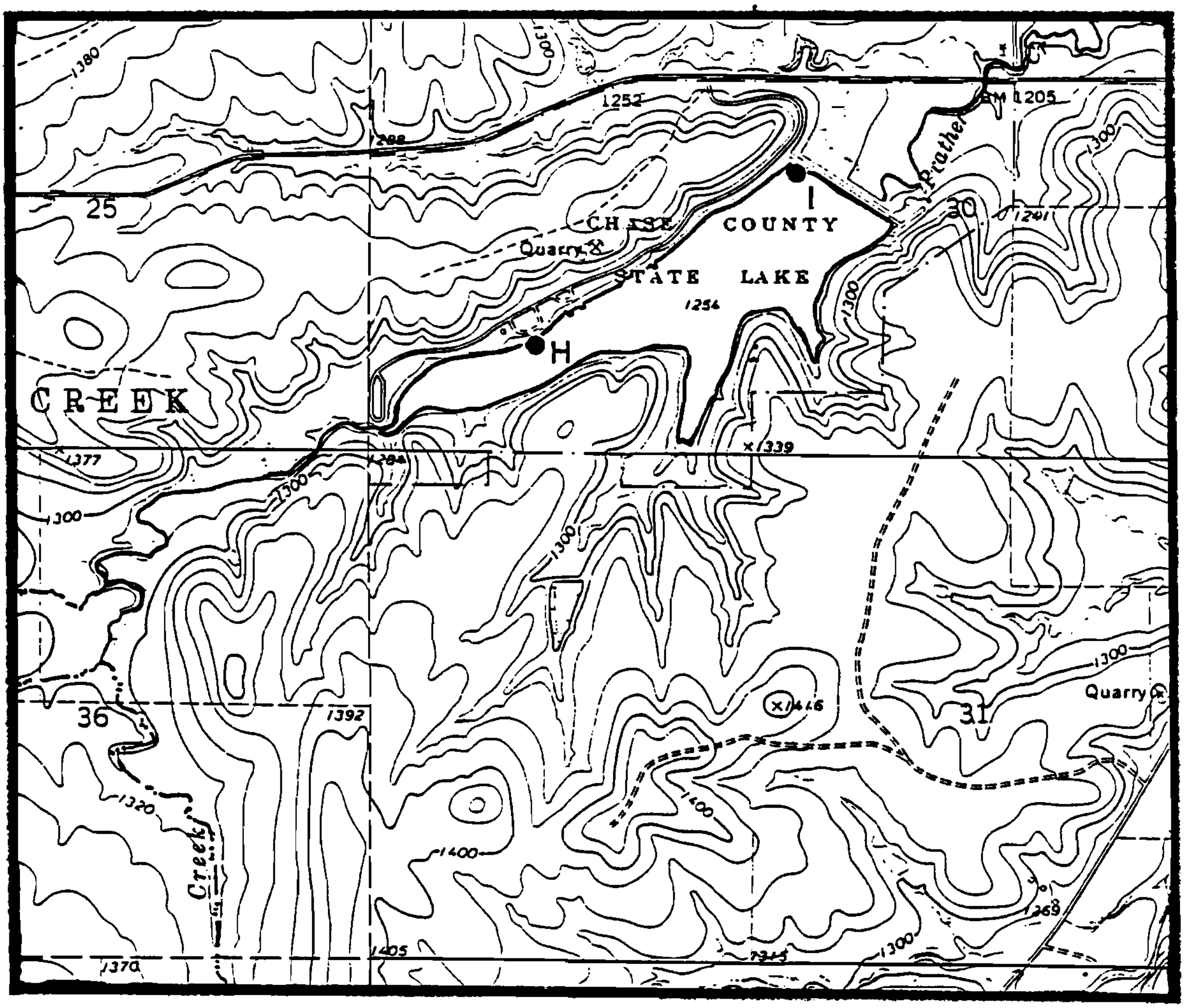


FIGURE 4

A map of Chase County State Lake and vicinity with locations of sampling sites H and I (adapted from Cottonwood Falls, Kansas, 7.5-minute topographic quadrangle 1973).

METHODS OF COLLECTION AND FIELD ANALYSIS

Samples were collected at each site in clean, 500 mL, plastic bottles. Prior to beginning the study the bottles were washed, rinsed, filled with dilute nitric acid solution and allowed to stand overnight. The bottles were then rinsed with distilled water and dried before use. Each bottle was designated to a sampling site for the duration of the study. Surface samples were collected straight from the surface by immersing the bottle in the water. Deeper samples, such as the Lake Kahola tower sample at 8.5 meters, were collected with the aid of a clean, rinsed, Kemmerer-type sampler from which the sample bottle was filled.

Analyses done at the site included pH and temperature measurements. These measurements were taken either in situ, where possible, or immediately post-collection from a fresh sample in a clean, rinsed, plastic bucket. Temperature measurements were done with a glass-mercury thermometer, which had been calibrated to 0 degrees in an ice/water bath. pH measurements were taken with a portable pH meter (Analytical Instruments, model 707S Redox pH Meter), which was calibrated prior to each measurement with pH 4.01 and pH 9.18 buffers. These buffers were prepared a day or two in advance of sampling to ensure viability. Sample preparation for further analysis was done in the chemistry laboratory at Emporia State University immediately upon return from collection. Sample preparation consisted of vacuum-aided filtration through a 0.45 micron filter, after which samples were refrigerated prior to phosphate analysis. Sample analyses were for specific conductance, phosphate (PO_4^{-3}), chloride (Cl^-), and calcium (Ca^{+2}).

Specific conductance of each sample was taken with a YSI Model 34 conductance-resistance meter, calibrated with a 0.00500 molar potassium chloride standard solution. Conductance measurements were corrected for temperature.

CHAPTER 3: LABORATORY CHEMICAL ANALYSES

PHOSPHATE

Phosphate analysis was done colorimetrically within 48 hours of sample collection. The principle of the analysis is that in acidic solution, phosphate forms a yellow complex with molybdate. Ascorbic acid, with antimony ions acting as a catalyst, reduces the complex, forming an intense blue color. The color intensity of each sample´s blue complex is measured in a cell with a 2.5-centimeter light path through the sample at a wavelength of 882 nm with a Hach DR 3000 Spectrophotometer.

Procedures for phosphate analysis were as follows:

Reagents:

1. Sulfuric acid, 5 N.
2. Ammonium molybdate solution: 20.0 g in 500 mL solution.
3. Antimony potassium tartrate solution: 1.10 g in 500 mL solution.
4. Ascorbic acid solution: 1.76 g in 100 mL solution

All solutions were made with deionized water. All glassware was cleaned with chromic acid to eliminate soap residue.

For the analysis a mixture of the above list of reagents was made thusly: in order, mixing well after each addition, 50 mL 5 N sulfuric acid, 5 mL antimony potassium tartrate solution, 15.0 mL ammonium molybdate solution, and 30 mL ascorbic acid solution (sufficient for 10 samples; must be used within 4 hours).

A 0.500 mg/L phosphorous standard solution was used for calibration.

The analysis is as follows:

1. Prepare one clean, dry 50 mL volumetric flask for each sample, blank, and standard, To each flask, add 8.0 mL of mixed reagent.
2. Dilute to the mark with the solution being analyzed (in this case, the sample). Stopper and mix well by inversion.
3. Measure the absorbance of each sample, blank, and standard against deionized water at between 10 minutes and one hour after mixing.

Sample phosphate concentration is given by formula 3.1:

Formula 3.1: $C_x = \frac{(A_x - A_b) \times C_s}{(A_s - A_b)}$

where A_b, A_s, and A_x refer to absorbances of blank, standard, and sample. C_x, and C_s refer to phosphate concentrations of sample and standard.

This method is standard phosphate analysis methodology. The detection limit for this analysis and particular light-path length used (2.5 cm) is about 0.005 mg/L (American Public Health Association 1985).

CHLORIDE

Chloride analysis was conducted on all the samples except for the well samples. Well owners routinely add chlorine bleach to their wells for antiseptic purposes. Analyzing wells for chloride would give misleading results at best.

The principle behind this chloride analysis in water is that of formation of a soluble metal-chloride precipitate, for which an endpoint can be determined when the reaction is complete. In this chloride determination silver is the metal to which chloride is bound into a complex according to formula 3.2:

Formula 3.2: $Cl^- + AgNO_3$ --- $AgCl(s)$

The endpoint is determined using a silver billet indicator electrode and a calomel reference electrode, by recording cell potential in mV and buret volume at several points near the equivalence point. The endpoint volume of $AgNO_3$ required, found graphically, is the point of maximum slope.

Apparatus/reagents:

1. silver billet electrode
2. calomel reference electrode (porous-plug with 1.0 M KCl)

3. Horizon model 5998-10 pH - mV meter
4. magnetic stirring apparatus
5. $AgNO_3$ titrant, 0.0070 N, standardized with 0.0100 N KCl

The analysis is as follows:

1. Measure 100.00 mL sample into a clean beaker.

   Record starting values of E (mV reading) and buret volume.
2. Titrate the sample with 0.0070 M $AgNO_3$ titrant, recording E and buret volumes at 20 mV intervals up to about 260 mV.
3. Construct a graph of E vs mL titrant. The end point is that part of the graph with the steepest slope. At the endpoint mL titrant is read from the graph.

   Chloride, in mg/L, is calculated with formula 3.3:

Formula 3.3: $Cl^- = \frac{8863\ V_{ta}}{V_a\ V_{ts}}$

where V_a = sample volume, V_{ta} = average titrant volume needed for sample, and V_{ts} = average $AgNO_3$ volume needed to titrate the KCl standard (adapted from American Public Health Association 1985).

CALCIUM

Analysis for Ca^{2+}, was done on flame atomic absorption equipment. The machine used was a Perkin-Elmer 603 Atomic Absorption Spectrophotometer. For Ca^{2+} analysis an airacetylene flame was used. A Ca^{2+} lamp was used at a wavelength setting of 423.7 nm.

Standards used for calibration-curve generation were 1.00 mg/L, 2.00 mg/L, 3.00 mg/L, and 4.00 mg/L. Samples were diluted to keep results within the absorbance range of the calibration curve and dilutions generally were 20:1. Exceptions (as samples from the cabin #169A well, site L) which exceeded the range of the calibration curve were diluted 50:1.

CHAPTER 4: GEOLOGY

GEOLOGY OF THE LAKE KAHOLA AREA

Lake Kahola is located at the eastern edge of the Flint Hills in rocks of Early Permian age. These rocks are characterized as light ash-gray to cream-colored limestone beds cyclicly interbedded with shale (Figure 5). Many of the limestone units are distinguished by an abundance of flinty chert, forming persistent benches or escarpments, among which the so-called Flint Hills are most prominent. The Flint Hills extend across Kansas from Nemaha County on the Nebraska border to western Chautauqua County adjoining the Oklahoma boundary. The escarpments are east-facing because the gentle regional dip of the Permian strata is westward. Between the limestone formations and members are gray, green, and red shale units, in part containing marine fossils and in part representing nonmarine sedimentation. Sandstone is virtually absent in this part of the Permian section (Moore et al. 1951a).

Description of Lower Permian rocks at Lake Kahola

The following description of the Lower Permian rocks at Lake Kahola is summarized from a State Geological Survey of Kansas publication (Moore et al. 1951b).

Crouse Limestone--The Crouse Limestone comprises an upper and lower limestone separated by shale. The combined thickness commonly is about 5 m (16 feet).

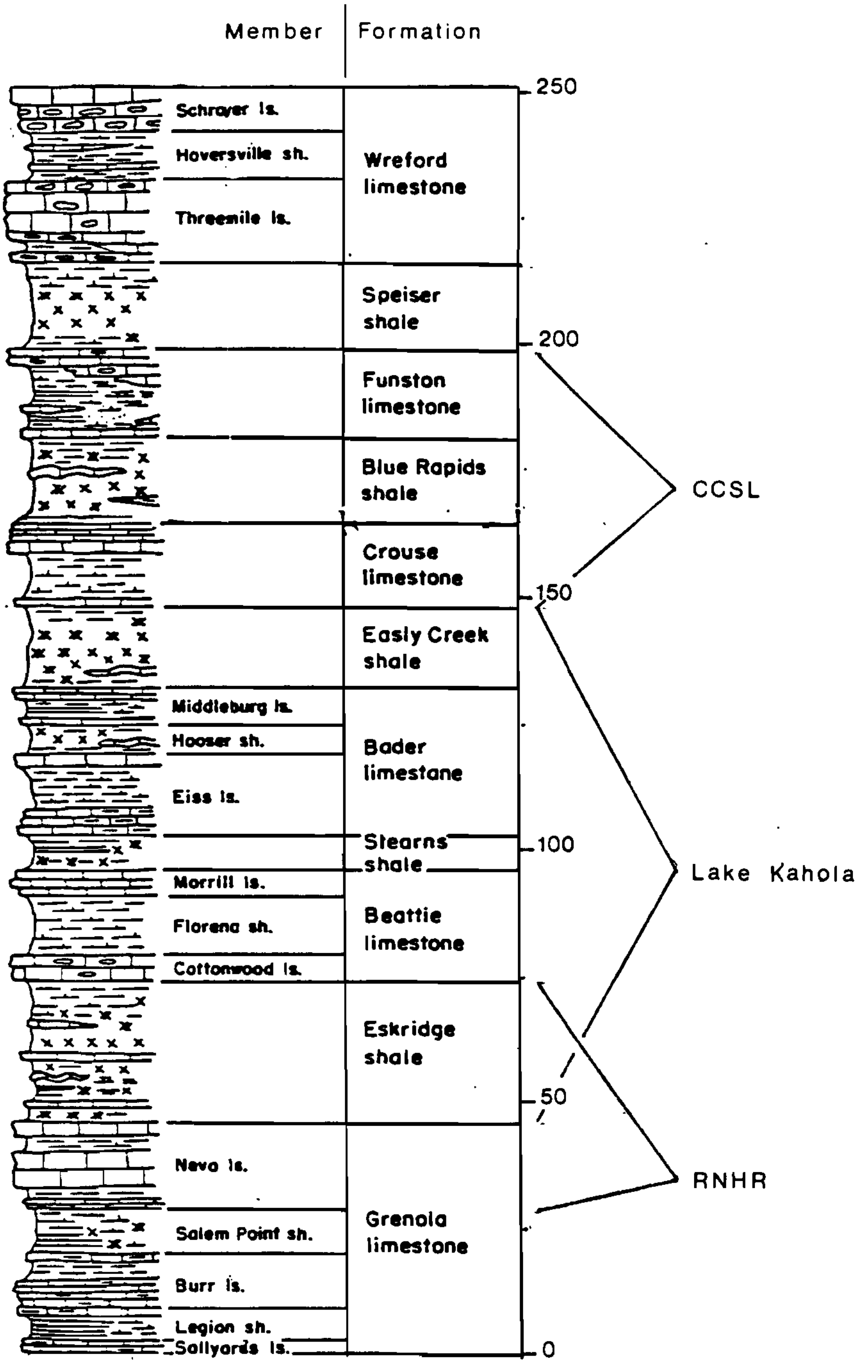


FIGURE 5

A general stratigraphic column of Lower Permian rocks in the Lake Kahola, Ross Natural History Reservation, and Chase County State Lake region. Thicknesses are in feet (Adapted from Moore et al. 1951b).

The upper Crouse Limestone is divisible into two lithologic units. The uppermost part, about 0.3 to 1 m thick (1 to 3 feet), is conspicuous because of its very platy structure. It is light to dark gray or buff, In some places this part has the appearance of platy calcareous shale. Gray or buff massive limestone, which forms a prominent topographic bench and furnishes large detached blocks of rock along its outcrop, comprises the lower part of the upper Crouse Limestone. This part ranges in thickness from about 0.5 to 1 m (1.5 to 3 feet). Locally it contains siliceous nodules or geodes and is characterized by rusty-weathering, small, high-spired gastropods, and small clams.

The middle shale of the Crouse Limestone is divisible into two distinct units. The upper part, 1.5 to 3 m (5 to 10 feet) thick, is gray or buff unfossiliferous clay shale. The lower part, ranging from about 0.3 to 1.5 m (1 to 5 feet) in thickness, is gray and abundantly fossiliferous, containing microfossils, bryozoans, echinoderm fragments, and brachiopods.

The lower part of the Crouse is a gray or buff mottled silty limestone which has a rather slabby structure. Commonly it is a molluscan limestone, but locally it contains a varied assemblage of mollusks, bryozoans, and brachiopods. The thickness range is between 0.25 and 0.75 meters (0.8 to 2.5 feet).

A few shallow wells obtain small supplies of ground water from the Crouse Limestone. Deeper wells penetrating this limestone generally obtain little or no water from this zone.

Easly Creek Shale--Measured sections of the Easly Creek Shale range from 3.65 to 5.5 m (12 to 18 feet) in thickness. Predominantly the formation comprises green clayey and calcareous shale, with two zones of bright red or purple material occurring near the middle or in the lower part. A zone of nodular limy material or "boxwork" occurs in some outcrops near the base. It supplies little or no ground water to wells in Chase County.

Bader Limestone--The average thickness of the Bader Limestone is about 8.5 m (28 feet). Locally this formation, principally the lower member, is a source of small supplies of ground water for domestic and stock wells.

Middleburg Limestone Member--This member is divisible into four lithologic units. The total thickness commonly is about 2.1 m (7 feet). At the top is 0.3 to 0.6 m (1 to 2 feet) of light-gray platy to slabby limestone commonly containing small high-spired gastropods. This uppermost limestone unit is underlain by 0.3 to 0.6 m (1 to 2 feet) of black or dark-gray platy shale. Below this is a zone of dark-gray slabby limestone or calcareous shale, about 0.15

to 0.6 m (0.5 to 2 feet) thick. The lowermost unit is light-gray massive to slabby, or nodular limestone, 0.3 to 0.9 meters (1 to 3 feet) thick. It commonly contains small snails and clams; locally, however, it bears crinoid fragments, bryozoans, and productid brachiopods.

Hooser Shale Member--Green and gray shales with a marly "boxwork" zone in the middle part comprise the Hooser Shale. In places, beds of red shale are obsrved in the middle and lower parts. The thickness typically is about 1.8 m (6 feet) but ranges from 0.9 to 2.1 m (3 to 7 feet).

Eiss Limestone Member-- The thickness of the Eiss Limestone is about 4.9 m (16 feet). It is divisible into three distinct units.

The upper part is a gray siliceous bench-making limestone, which becomes characteristically pitted when weathered. Coarse crystalline fossils stand out in relief on weathered surfaces. The thickness ranges from 0.3 to 0.75 m (1 to 2.5 feet). The middle part comprises about 1 to 1.5 m (several feet) of gray and olive shale commonly with abundant crinoid and echinoid fragments, bryozoans, and brachiopods occurring in the lower part.

The lower unit, ranging in thickness from 0.9 to 3.65 m (3 to 12 feet), is dark-gray to nearly black shaly limestone. The basal part is molluscan, but higher in the rock crinoid fragments, bryozoans, and the brachiopods *Meekella, Chonetes*, and *Composita* mingle with small snails and clams.

Stearns Shale--The average thickness of the Stearns Shale is about 2.1 m (7 feet). It is gray, black, and green in the upper part and gray-green or locally calcareous and cream-colored in the lower part. Red shale occurs near the middle in some places. It is of little importance as a source of ground water.

Beattie Limestone--The Beattie Limestone comprises two massive limestones, each averaging about 1.5 m (5 feet) in thickness, separated by about 3.65 m (12 feet) of shale. It is one of the principal aquifers of the Council Grove Group and supplies many stock and domestic wells with ground water.

Morrill Limestone Member--This member ranges in thickness from about 1 to 1.8 m (3.5 to 6 feet). It exhibits various lithologic characters in different beds, which commonly are separated by thin shale partings. The upper portion may be either soft or dense limestone, gray to yellowish brown, fossiliferous, with calcite vugs and geodes. The middle and lower parts are mostly molluscan or algal.

Florena Shale Member--Measured sections of the Florena Shale range from 2.4 to 4.6 m (8 to 15 feet) in thickness. The upper 0.3 to 1.5 m (1 to 5 feet) is unfossiliferous or only very sparsely fossiliferous. This part, which is gray, yellow, or black, commonly contains calcitic and siliceous vein fillings and geodes. In places, gypsum is associated with the geodes. The lower 1.8 to 2.75 m (6 to 9 feet) is dark gray to black or gray and is abundantly fossiliferous. The brachiopod *Chonetes* is the most common fossil, but *Derbyia*, productids, and *Composita* are common. Echinoid and crinoid fragments and bryozoans are found locally. Small trilobites are sparsely present.

Cottonwood Limestone Member--This unit ranges in thickness from about 0.9 to 2 m (3 to 6.5 feet). Commonly it is a massive gray to creamy buff limestone that weathers light gray. There are one or more very thin shale partings. Abundant slender fusulinids are characteristic. The fusulinids are abundant only in the upper half or less of the Cottonwood member, and they are absent in the lower part except for very sparse specimens locally near the top of the lower division. The lower part generally carries echinoderm fragments, bryozoans, and brachiopods and more or less commonly irregularly platy algal material. This lower part may be massive or slabby.

Eskridge Shale--Measured sections of the Eskridge Shale show a thickness range from 7 to 11.6 m (23 to 38 feet) and furnish a record of marked changes in lithology from north to south across Chase County. The Eskridge shale is not an important source of ground water; however, a few wells do obtain small supplies of water from it at shallow depths.

Grenola Limestone--The thickness of the Grenola Limestone is about 13.75 m (45 feet). It is the chief aquifer for many wells in Chase County. The Neva Limestone Member is the most important aquifer.

Neva limestone member--The upper unit of the Neva Limestone is an algal and molluscan limestone bed, 0.3 to 1.8 m (1 to 6 feet) thick. Locally it is a coquina of small shells, fossil fragments and algal material. It is separated from the "main ledge" by gray fossiliferous shale, which ranges in thickness from a featheredge to as much as 2.75 m (9 feet). Echinoid spines and brachiopods are abundant in this part. The middle or main ledge is a gray massive limestone containing echinoderm fragments, brachiopods, and locally fusulinids in the upper part and fusulinids in the lower part. It appears brecciated and pitted in weathered exposures. It ranges in thickness from about 1 to 2.45 m (3.5 to 8 feet). Below this is a thin bed of gray to nearly black fusulinid-bearing shale overlying about 0.3 m (1 foot) of brownish-gray fusulinid limestone that commonly has an upper crust composed principally of the brachiopod *Crurithyris*. A few centimeters of shale, locally containg algal material, lies above a pitted algal limestone, about 0.15 to 0.3 m (0.5 to 1 foot) thick, which comprises the lower unit of the Neva member.

Salem Point shale member--The average thickness of the Salem Point Shale is about 2.75 meters (9 feet). Buff limy nodular shale occurs in the upper part as a zone from 0.15 to 0.9 m (0.5 to 3 feet) thick. The lower 1.5 to 2.1 m (5 to 7 feet) is gray to gray-green or black thin-bedded to fissile shale.

Burr Limestone Member--The Burr Limestone comprises several limestone beds separated by shales. As seen in most exposures there is a limestone bed 0.1 to 0.4 m (0.3 to 1.5 feet) thick at the top; this is underlain by 0.3 to 1.5 m (1 to 5 feet) of gray-green or gray shale that seemingly is without fossils. The middle part is characterized by extremely platy limestone. This part is light gray or bluish and weathers light tan or yellow. At some outcrops there are shale partings in this zone and locally a thin layer rich in ostacodes in included. The lower part of the Burr Limestone is gray and mottled shaly to slabby limestone, 0.75 to 2.1 m (2.5 to 7 feet) thick, and containing an abundance of clams. Locally, several shale partings occur in this lower part. The average thickness of the member is about 3.65 m (12 feet).

Legion shale member--Commonly the upper few centimeters of the Legion Shale are black, platy, and carbonaceous. Locally a thin limestone is exposed; it contains crinoid fragments, bryozoans, brachiopods, and pelecypods in the upper part. Mostly, however, this member of the Grenola Limestone comprises gray seemingly unfossiliferous shale. In places gray-green or buff colors are seen in the lower part. The overall thickness range is between 0.9 and 2.45 m (3 to 8 feet).

Sallyards Limestone Member--Gray platy to shaly limestone and gray shale characterize the Sallyards limestone, The thickness ranges from 0.3 to 1.5 meters (1 to 5 feet). Where thin the member commonly contains only pelecypods, but where thicker crinoid fragments, bryozoans, gastropods, and pelecypods are common (Moore et al. 1951b).

STRUCTURAL GEOLOGY AT LAKE KAHOLA

Lake Kahola is located in the Council Grove Group of the Lower Permian System. Specifically, the extreme western end of the lake nearly reaches the lower part of the Crouse Limestone Member. Eastward the lake is situated in the Easly Creek Shale, Bader Limestone, Stearns Shale, Beattie Limestone, Eskridge Shale and Grenola Limestone Members (Figure 6). At the surface the southeastern-most reach of Lake Kahola is situated just under the Cottonwood Limestone of the Beattie Limestone, in the Eskridge Shale Member. The deepest regions of Lake Kahola, near the outlet tower in the submerged Kahola Creek channel, extend into the Grenola Limestone.

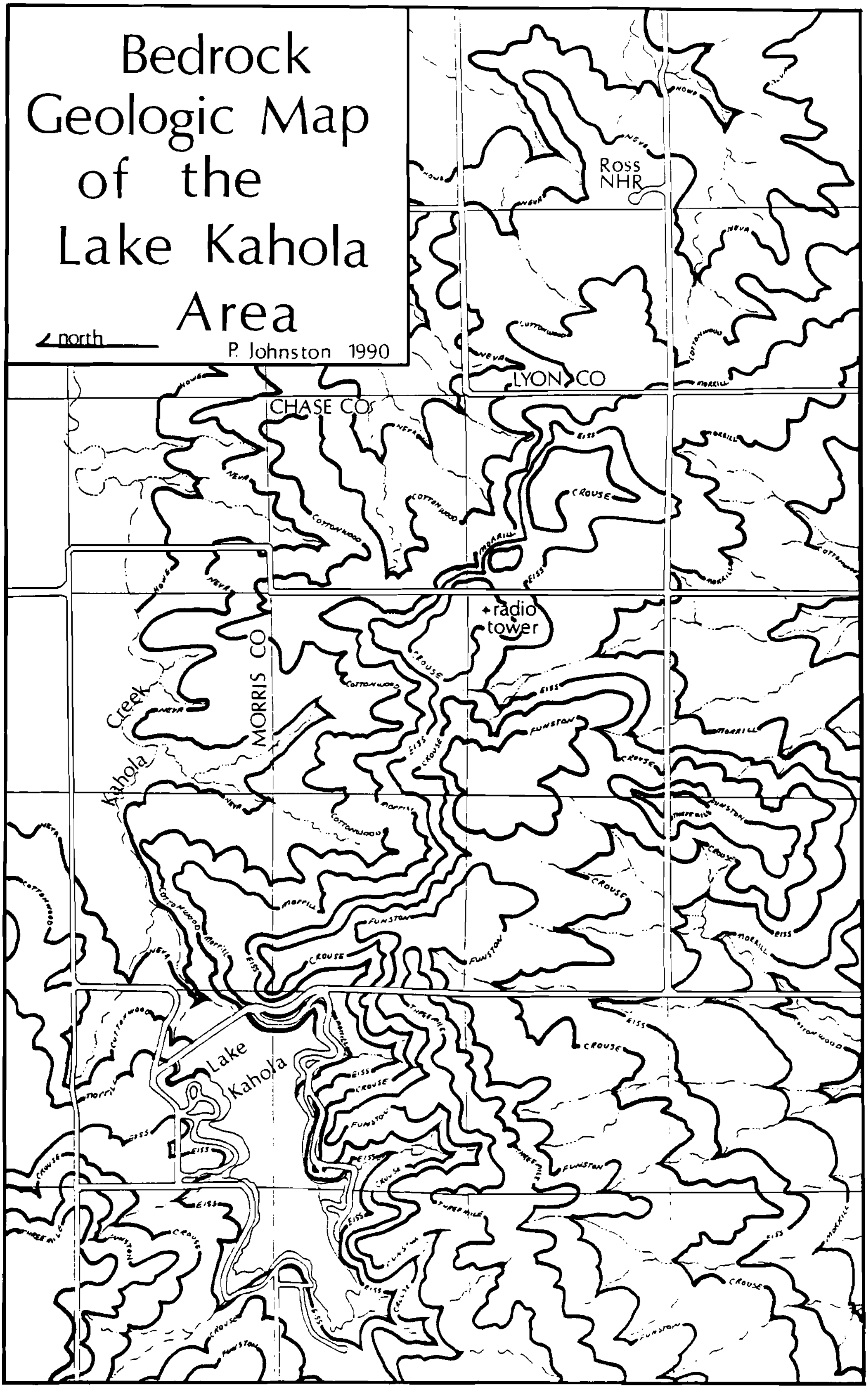
Figure 6 illustrates that in the Lake Kahola region the bedrock layers dip gently to the northwest. For example, the Cottonwood Limestone is visible on the southeastern edge of the lake but not on the northeastern. The Cottonwood limestone reappears from under the lake at about the spillway location.

FIGURE 6 (Next page)

Surface outcrops of major limestone strata in the Lake Kahola vicinity (Johnston 1990).

Bedrock Geologic Map of the Lake Kahola Area

P. Johnston 1990



Structure at Lake Kahola was found by measuring the elevations of two exposed strata. One stratum, the Cottonwood Limestone, is exposed at the lake's edge. Elevations of three of these exposures were extrapolated by locating them on the Lake Kahola Quadrangle topographic map. Once the elevations were known it was a simple trigonometric exercise to calculate the dip direction, dip angle, and dip magnitude of the stratum. These calculations show that the Cottonwood Limestone dips towards the northwest (317 degrees) at an angle of 0.28 degrees, which is equivalent to a dip of 4.9 m per kilometer (26 feet per mile).

The other stratum for which structure was established is the Crouse Limestone, which has a wider ranging exposure around Lake Kahola than does the Cottonwood Limestone. Elevation measurements of the Crouse Limestone were made using an American Paulin System Model M-1-6 MICRO Surveying Altimeter. This altimeter has an accuracy of + 0.3 m (1 foot). As in calculations for the Cottonwood Limestone, locations of three Crouse Limestone exposures were identified on the Lake Kahola Quadrangle topographic map and their elevations were found by use of the altimeter. Calculations show that in the Lake Kahola region the Crouse Limestone dips towards the west (270 degrees) at an angle of 0.35 degrees. This is equivalent to 6.1 m per kilometer (32 feet per mile).

The differences in dip directions and angles between the Cottonwood and Crouse Limestones are probably due to variations in thickness of one or the other, or of the intervening, strata in the Lake Kahola region. Regardless of the local difference in these two limestones the west to northwest regional dip of strata at Lake Kahola affects groundwater movement in this area. Since the Cottonwood Limestone is in the submerged basin of the lake it is probably more representative of geologic structure in the basin than is the Crouse Limestone.

GROUNDWATER SOURCES FOR WELLS SURROUNDING LAKE KAHOLA

The Neva Limestone Member of the Grenola Limestone is the most important aquifer in northeastern Chase County (O´Connor 1949; Moore et al. 1951b). The Beattie Limestone is also an aquifer. The Neva Limestone lies at the bottom of the Lake Kahola basin and the Beattie Limestone is at lake surface level in the eastern portion of the lake (Figure 6). These two water-bearing strata are the aquifers into which water wells around Lake Kahola are drilled for supply.

KDHE water-well records, for the four sections in which Lake Kahola lies, contain drillers´ data including well location by 1/64th-section quadrants (Figure 7), depth below ground-level at which water was first encountered, static water level in the well, and a description of types and depths below ground-surface of rocks encountered while drilling.

FIGURE 7 (Next page)

This illustration is an outline of Lake Kahola with township sections numbered. The lettered quadrants outline regions for which drillers´ well data are available. Table 4.1 contains driller´s data for each quadrant: the left figure is static water level in feet below ground surface, the right figure is depth water was first encountered.

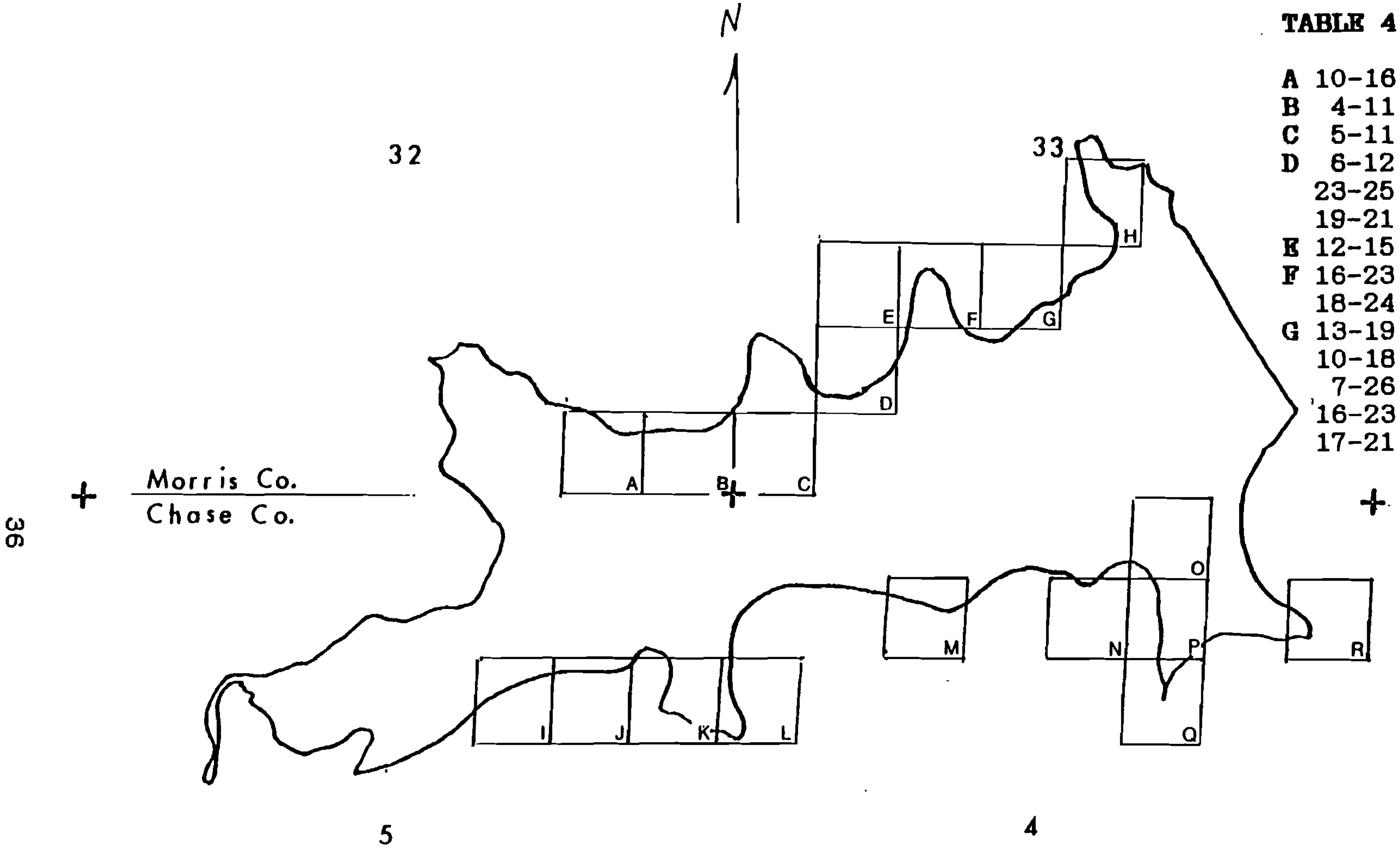


TABLE 4.1

A	10-16
B	4-11
C	5-11
D	6-12
	23-25
	19-21
E	12-15
F	16-23
	18-24
G	13-19
	10-18
	7-26
	16-23
	17-21
H	13-52
	6-13
	18-22
	10-11
I	11-NA
	18-NA
J	15-18
	15-NA
K	21-27
L	13-20
	40-NA
M	20-33
	9-19
	11-20
	31-NA
N	7-23
	11-29
	10-24
	8-11
	20-NA
O	16-18
P	9-10
	9-13
	9-20
	10-11
	10-11
Q	3-15
R	8-11
	6-21
	21-22
	12-NA
	7-NA

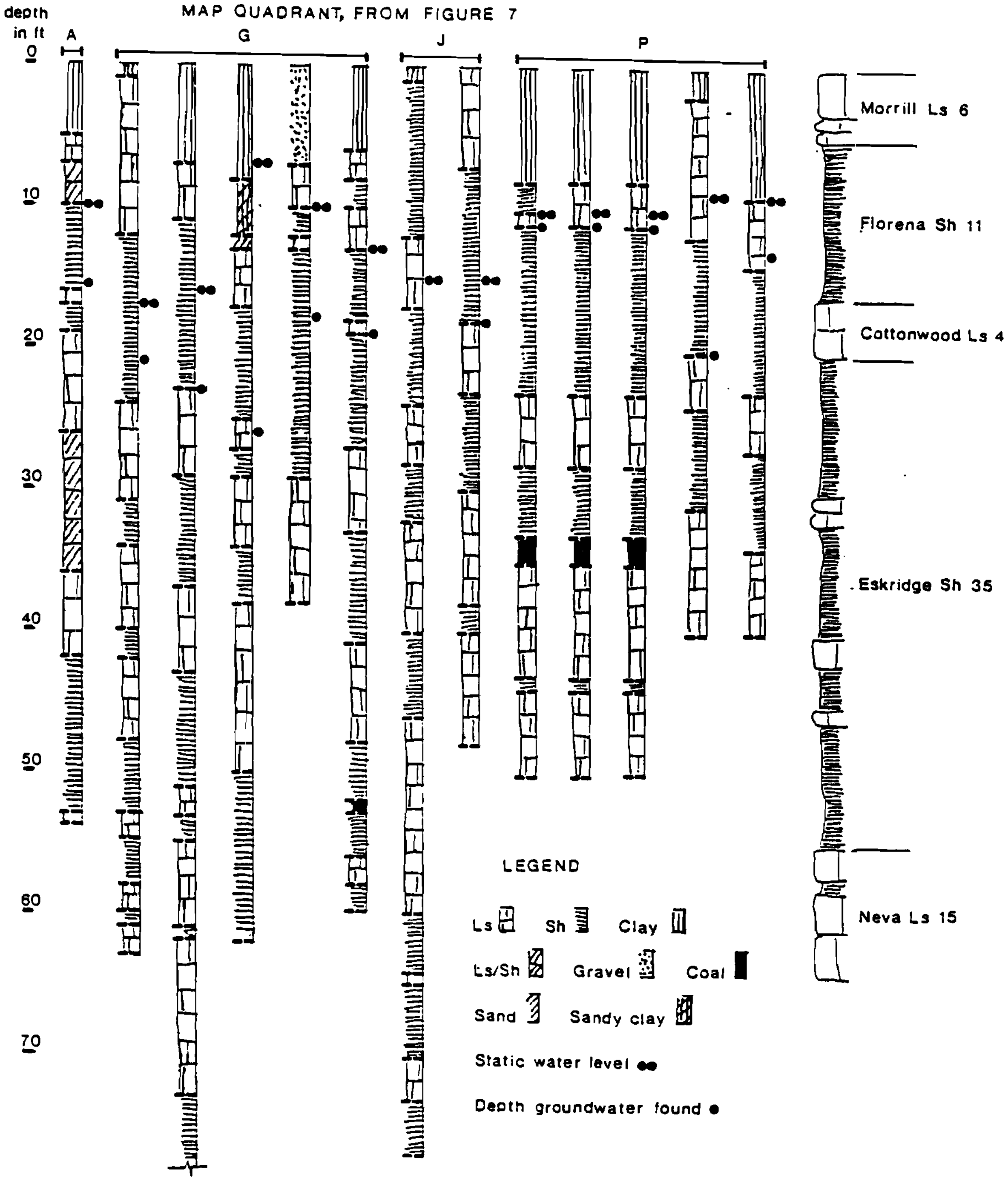
The right-hand column of Figure 8 is a measured stratigraphic section taken from the SE 1/4, SE 1/4, Sec 34, T17S, R9E, Morris County, which is one mile east of Lake Kahola (Moore et al. 1951a). In the same figure are stratigraphic columns drawn from driller´s data for selected quadrants around Lake Kahola. The stratigraphic section and water-well drillers´ data have been drawn to the same scale. Comparing the measured stratigraphic section to the alternating limestone/shale rock units in well drillers´ data should give a general impression of which rock units are penetrated and which rock units supply groundwater to wells. For example, the first limestone encountered in quadrant P should be the Cottonwood limestone, with the Eskridge shale directly below and the Neva limestone the first major limestone encountered below that.

If the Beattie and Neva Limestones were the aquifers at Lake Kahola, the northwest dip of the regional stratigraphy should be evident in well drillers´ data from east to west as progressively deeper depths of water encountered in wells drilled around Lake Kahola. From well drillers´ data for

---

FIGURE 8 (Next page)

A reconstruction of drillers´ data for selected quadrants at Lake Kahola, depths are from ground level. The right-hand column is a measured stratigraphic section near Lake Kahola, thicknesses are in feet.


depth in ft
0
10
20
30
40
50
60
70
MAP QUADRANT, FROM FIGURE 7
A
G
J
P
Morrill Ls 6
Florena Sh 11
Cottonwood Ls 4
Eskridge Sh 35
Neva Ls 15
LEGEND
Ls
Sh
Clay
Ls/Sh
Gravel
Coal
Sand
Sandy clay
Static water level
Depth groundwater found

selected quadrants around Lake Kahola (Figures 7 and 8) it is evident that water is encountered in strata other than the Neva and Beattie limestones. Table 4.1 of Figure 8 supports this. Depths of well water encountered around Lake Kahola seem to be random rather than show a trend of deepening from east to west as might be expected.

It appears that water is encountered at depths substantially above the Neva limestone but nearly always in a limestone and at fairly shallow depths below ground surface. Around the eastern end of the lake, the Beattie limestone aquifer may be providing groundwater to wells on the south side. On the north side of Lake Kahola the Beattie limestone aquifer, at least locally, is probably being recharged from the lake as water flows down-dip from exposures of the Beattie limestone below lake surface level in the Lake Kahola basin.

Generally, static water levels are at shallow depth pointing to the fact that, in wells for which data are available, the static water level is near lake surface level. Apparently, on the north side of Lake Kahola, but probably on the south side also, wells are being recharged with water from Lake Kahola itself. For wells around Lake Kahola, any limestone that is able to transport water is acting as a conduit from the lake to any well in the immediate vicinity of the lake. There is the possibility that joints and fractures in shale strata also conduct water from the lake to wells that chance to penetrate such a joint or fracture.

CHAPTER 5: RESULTS AND INTERPRETATION OF WATER ANALYSES

The complete water analysis data are found in the appendix. Data is lacking for several sites and dates due to lack of flow in springs, lack of sufficient water in wells after the flushing-out interval or, in the case of two wells, seasonal well shutdown. Lake Kahola surface conditions made sample collection impossible at the outlet tower (site E) for collection date 1/22/92.

Results are presented graphically. Dates on the graphs correspond to the dates on which the samples were collected, as presented in Table 5.1. Temperature data for sample sites at Lake Kahola, and lake levels, as measured from the lip of the spillway, are also presented in Table 5.1.

TABLE 5.1.

Sample dates, with lake levels (in meters below the spillway lip), and water temperatures at Lake Kahola sample sites B, D, and E.

Date	Level	Temperatures (°C)		
		B	E	D
9/20/91	0.46	23	23	22
10/16/91	0.61	16	16	16
2/4/91	0.76	4	5	4

Table 5.1 continued next page

Table 5.1 continued...

1/22/92	0.76	NA	3	2
2/27/92	0.61	6	7	7
4/2/92	0.0	10	10	10
5/14/92	0.0	18	21	21
6/13/92	0.0	19	24	23

RESULTS OF BACKGROUND AND WELL SAMPLES ANALYSES

Background samples (control samples) include the spring at RNHR, two springs on the south bluff of Lake Kahola, two sites at Chase County State Lake, and two sites on Kahola Creek. Wells include sites J, K, L, M, and N at Lake Kahola.

CHLORIDE

Springs at RNHR, the south bluff spring, and the cabin #93 spring at Lake Kahola--Figure 9.

Chloride concentrations at RNHR ranged from a low of 5.1 mg/L on 6/15/92 to a high of 9.4 mg/L on 12/4/91. The highest chloride levels were found during the driest months of December and January when flow in the RNHR spring was at its lowest. The lowest levels of chloride at RNHR were found during April, May, and June after significant rainfall had occurred and the spring had increased discharge.

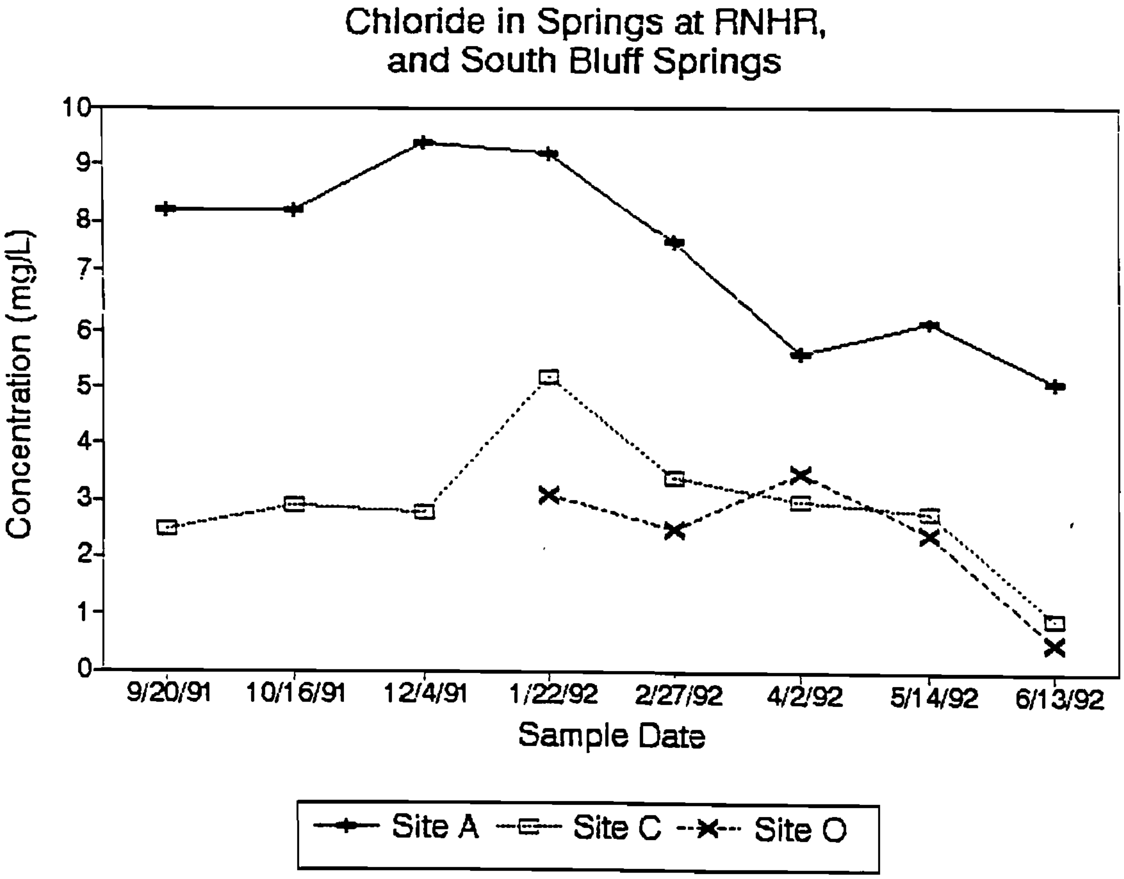


FIGURE 9

Chloride levels at RNHR, site A, and in the two springs on the south bluff of Lake Kahola, sites C and O.

Samples taken from the south bluff Spring at Lake Kahola reflect trends seen in the RNHR data but at significantly lower levels; chloride ranged from a low of 0.9 mg/L on 6/15/92, to a high of 5.2 mg/L during the lowest spring-flow month of January. Chloride in the intermittent spring at cabin #93 ranged from a low of 0.5 mg/L on 6/15/92, to a high of 3.5 mg/L on 4/2/92, and this variability is probably a factor of rainfall infiltration, and recharge of the aquifer supplying this spring. As in the other background samples, chloride concentrations in this spring appear to follow a trend inversely related to rainfall amounts, for example, more rain results in lower chloride concentrations as water in the sample sites is diluted.

Kahola Creek and CCSL--Figure 10.

Chloride concentrations at the Kahola Creek site F follow a trend of slight increase during the traditionally dry months of January and February, and then slight decrease during the spring months of April, May, and June, typically months of rainfall and subsequent runoff in Kansas. Higher concentrations of chloride could be expected to occur during dry periods when Kahola Creek is being fed solely by groundwater sources. Groundwater, in close contact with subsurface, naturally occurring sources of chloride, may carry higher chloride concentrations than rainfall-generated runoff.

Kahola Creek site G exhibits a large increase in chloride concentration on 10/16/91 and then returns to values more typical of downstream at Kahola Creek site F. The high value of 10/16/91 may have been a case of temporary, upstream point-source contamination of Kahola Creek.

Chloride at the two CCSL sites varied little throughout the study period up to the last sample. During the study

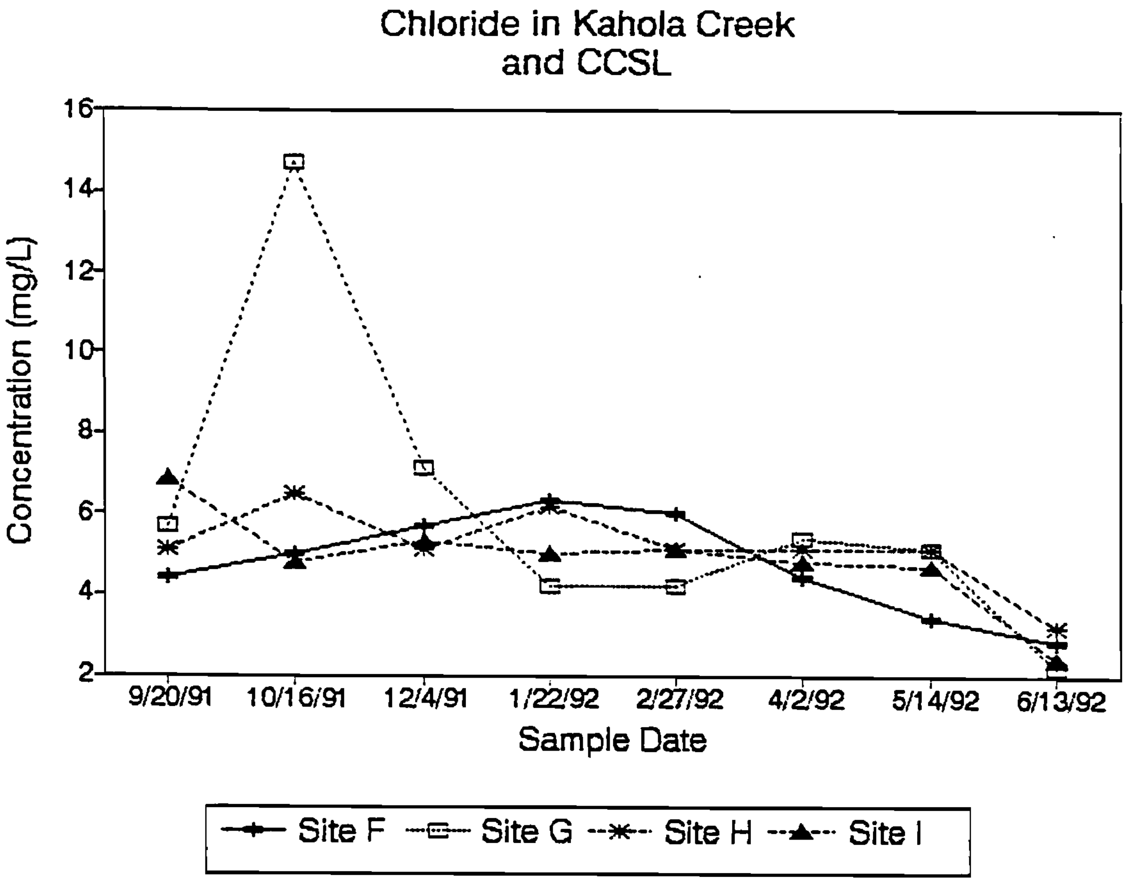


FIGURE 10

Chloride levels at the two Kahola Creek sites, F and G, and the two CCSL sites, H and I.

---

chloride concentrations in the lake varied from a low of 2.4 mg/L at the dam to a high of 6.9 mg/L, also at the dam. CCSL was, up to the last sample, below normal lake level. Prior to the last sample heavy rains and subsequent runoff filled the lake, diluting chloride concentrations contained therein.

PHOSPHATE

Springs at RNHR and the south bluff of Lake Kahola--Figure 11.

Few of these samples tested above the detection limit of 0.005 mg/L phosphate, an indication that phosphate is not introduced into these waters or that any phosphate introduced is removed before sample collection occurs. One site, RNHR, tested positively three out of the eight samples, each of these very low, ranging from 0.005 to 0.007 mg/L.

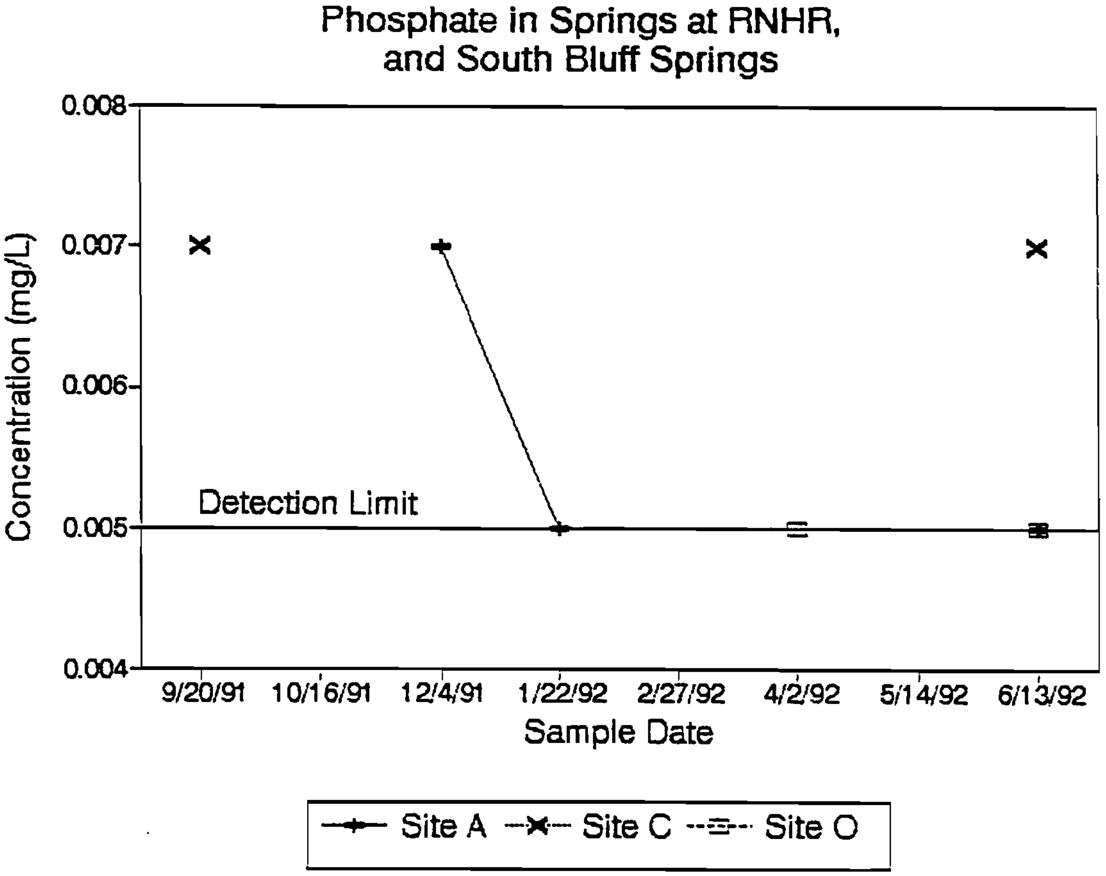


FIGURE 11 (previous page)

Phosphate levels in the spring at RNHR, site A, and the south bluff springs of Lake Kahola, sites C and O. The detection limit is 0.005 mg/L phosphate.

Phosphate in Kahola Creek and CCSL--Figure 12.

The CCSL swim area site tested at, or above, the detection limit only once during the study and this result was at the detection limit.

The CCSL dam site tested at, or above, the detection limit three times during the study but each of these results were at very low concentrations ranging from 0.006 to 0.007 mg/L.

The Kahola Creek site F tested at, or above, the detection limit for all but two of the sample dates, ranging from a low of 0.005 to 0.12 mg/L. The periods of phosphate presence would seem to indicate phosphate introduction from agricultural sources, as agricultural fields are fertilized in the fall and spring. It perhaps should be noted that there are agricultural fields bordering on Kahola Creek within two kilometers upstream of the site. However, the fall of 1991 was a dry period with little to no precipitation and certainly little to no runoff. Without more evidence it would be impossible to explain the presence of higher than normal phosphate in Kahola Creek site F.

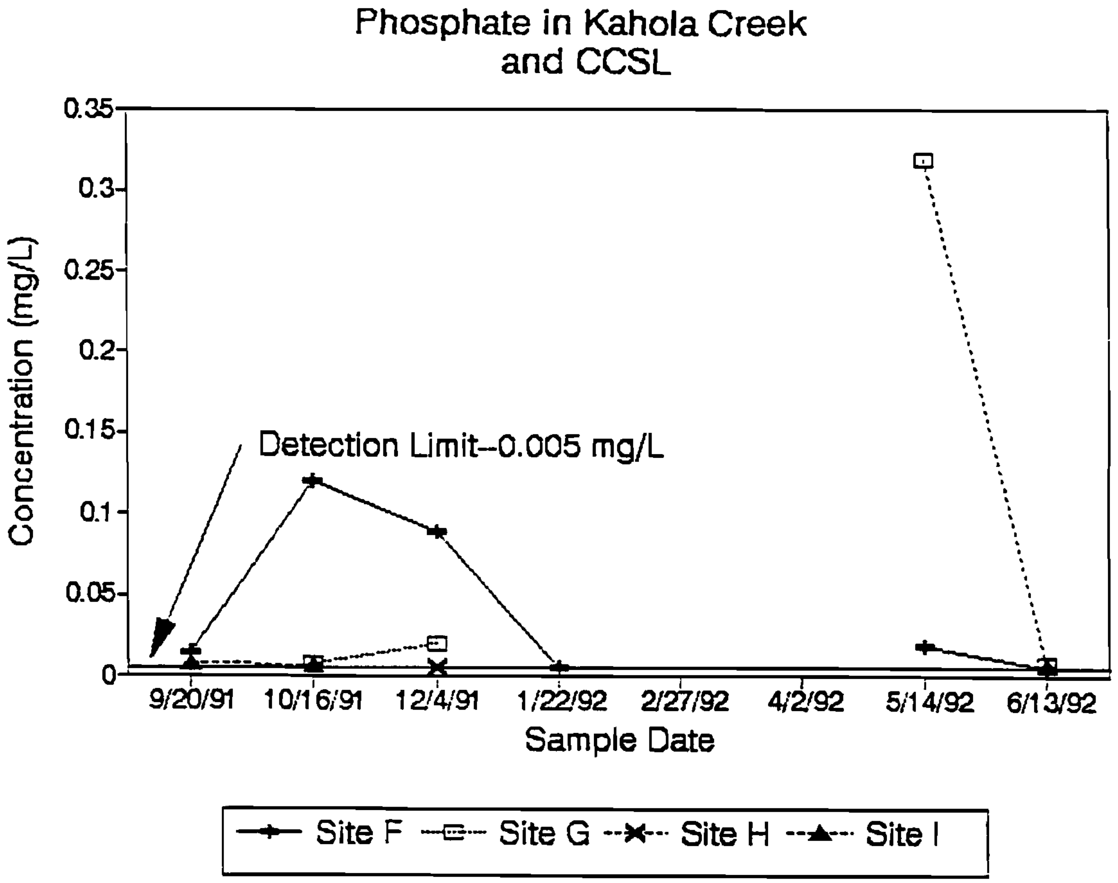


FIGURE 12

Phosphate levels at the two Kahola Creek sites, F and G, and the two CCSL sites, H and I. The detection limit is 0.005 mg/L phosphate.

Another, more probable, factor to consider is phosphate from the dropping of foliage into Kahola Creek which, at least during the dry fall of 1991, held only pools fed by extremely limited base flow at best. These pools were, at times, choked with leaves that had fallen into them.

The Kahola Creek site G tested at, or above, the detection limit four of the sample periods and followed the fall-spring trend of the Kahola Creek site F. The values ranged from a low of 0.007 to 0.319 mg/L, the highest test of any of the samples. The 0.319 mg/L test was in the 5/14/92 sample, a sample collected after significant rainfall and runoff, so a naturally occurring source of phosphate is probably not implicated. It seems more likely, especially as this test was so much higher than any of the other samples, that some point-source contamination took place at or near the collection site. Perhaps it should be taken into consideration that there is a house, appearing to be occupied, very closely situated upstream of Kahola Creek site G.

Phosphate in wells at Lake Kahola--Figure 13.

Except for the last sample period, only two wells tested above the detection limit of 0.005 mg/L phosphate: site J, and site K. Both these wells are on the north side of Lake Kahola and, coincidently, located within 100 meters of each other. The site J well consistently tested highest of the wells for every sample period but the last, and phosphate in this well fell below detection limit during just one of the sample periods. It may or may not be significant that all wells revealed detectable levels of phosphate on the last sample period after significant amounts of rain had fallen. The very highest level of phosphate for

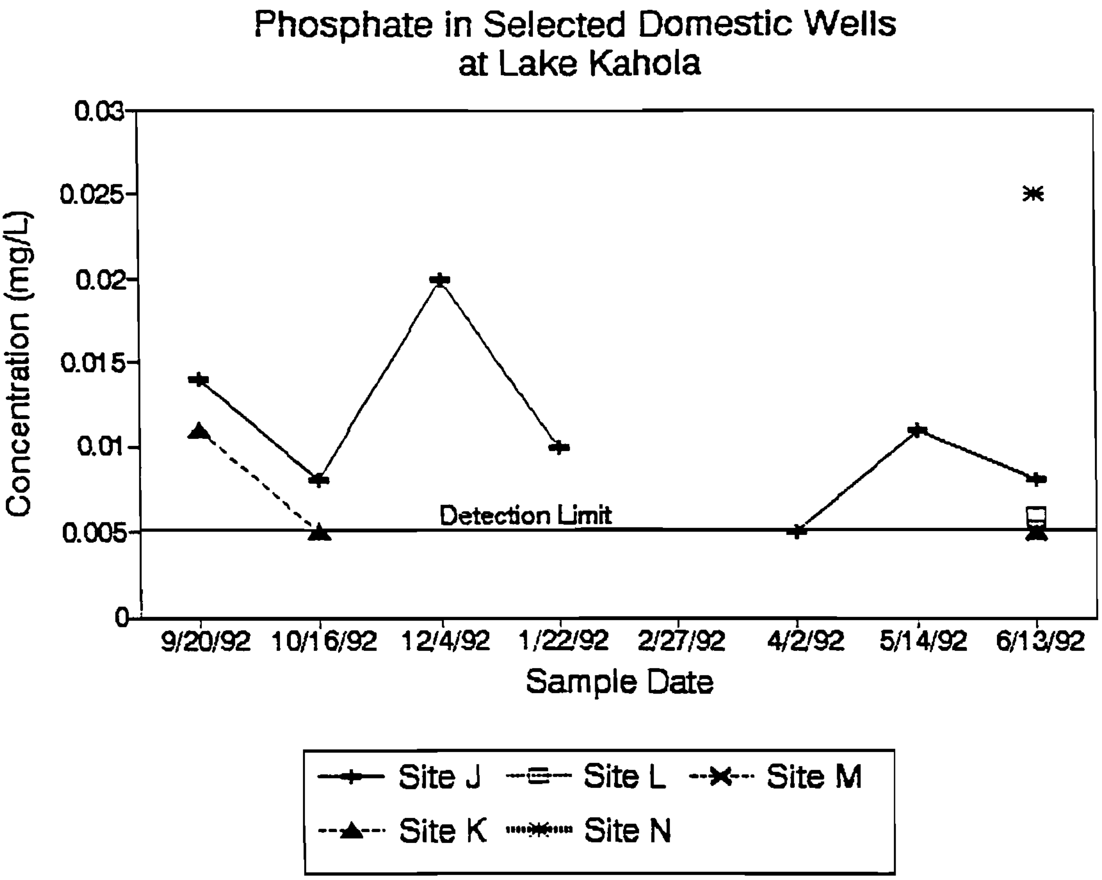


FIGURE 13

Phosphate levels in wells tested at Lake Kahola. The detection limit is 0.005 mg/L phosphate.

----

this last sample occurred in a well, site N, that had just been turned on for the summer season.

With any amount of certainty it is not possible to account for the higher phosphate results in the last samples. One possibility is more active transport of phosphate from the source to the wells following heavy rainfall and aquifer recharge. In the case of wells with consistently higher phosphate (above detection level in this case) the wells may be closer to the source. Sources of phosphate may be natural, as in a geologic source, or artificial, as in a septic holding tank which includes waste water with phosphate-containing detergents.

LAKE KAHOLA SAMPLE RESULTS

Test samples at Lake Kahola include surface samples up-lake at site D, and down-lake at site B. Site E, at the outlet tower, is from 8.5 m depth.

Chloride in Lake Kahola--Figure 14.

Chloride in Lake Kahola was at low levels ranging from a low of 1.8 mg/L at the spillway on sample period 6/15/92, to a high of 5.2 mg/L on 4/2/92 at cabin #93. All Lake Kahola sites follow a general trend of steady to slightly increasing concentration through sample date 2/27/92 after which a decline in concentration occurs. The slight upward trend may be a result of lake levels falling due to evaporation and decreased influx of water during the extremely dry fall and winter of 1991-1992. Evaporation would tend to increase concentrations of suspended ions. The decline in concentration is probably due to the diluting effect of runoff from spring rains which returned the lake level to maximum height, overflowed the spillway, and essentially flushed the lake with new water.

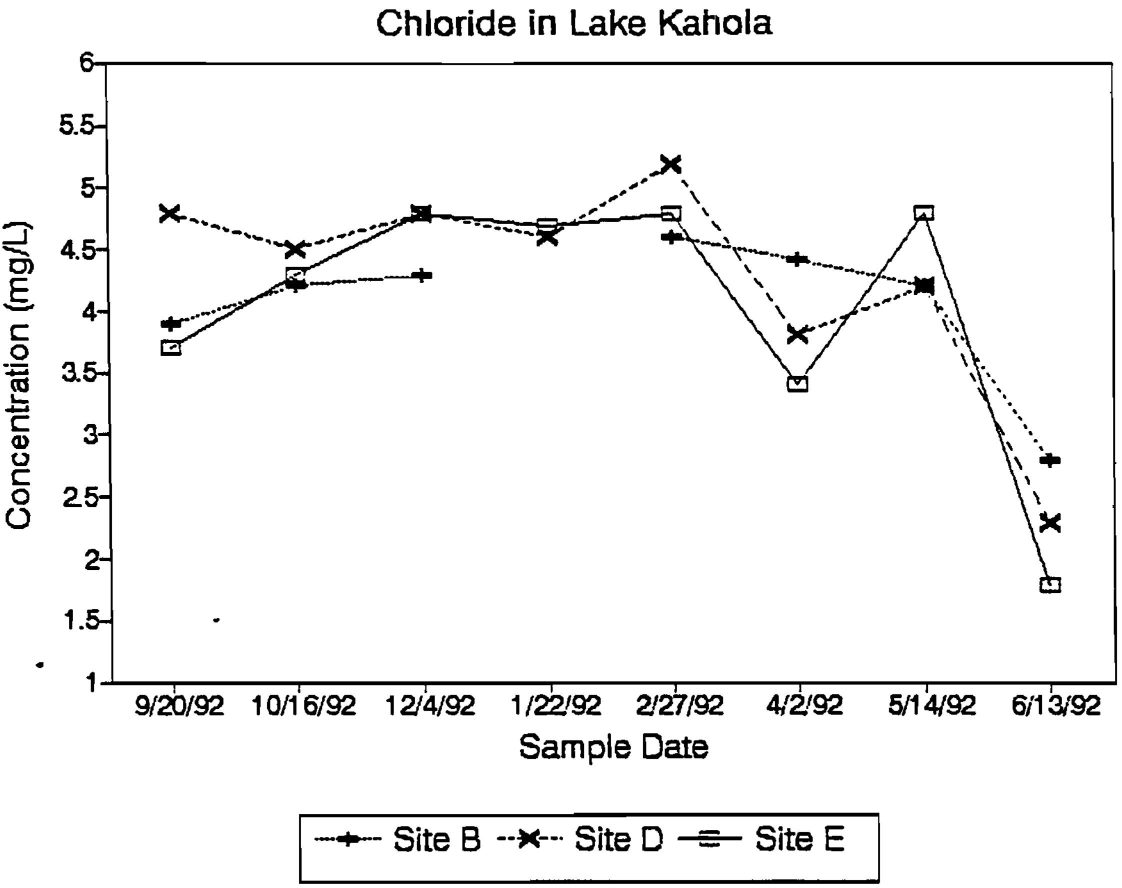


FIGURE 14

Chloride levels at the three Lake Kahola sites, B,D, and E.

The close correlation of chloride concentrations, not varying by more than 1.1 mg/L between the three Lake Kahola sites, would indicate that Lake Kahola is a well-mixed, homogeneous body of water. Temperature data (Figure 15) also indicate a well-mixed body of water. Water temperatures at the three Lake Kahola sample sites vary not more than one degree throughout all of the sample periods except for the last two. At these sample periods it is noted that the tower sample, taken from 8.5 meters depth, departed from the previous trend and a wider spread of temperatures developed. This is probably attributable to the seasonal effects of lengthening days. Higher air temperatures, and longer sunlight exposure in the spring warms the surface of the lake at sample sites D and E.

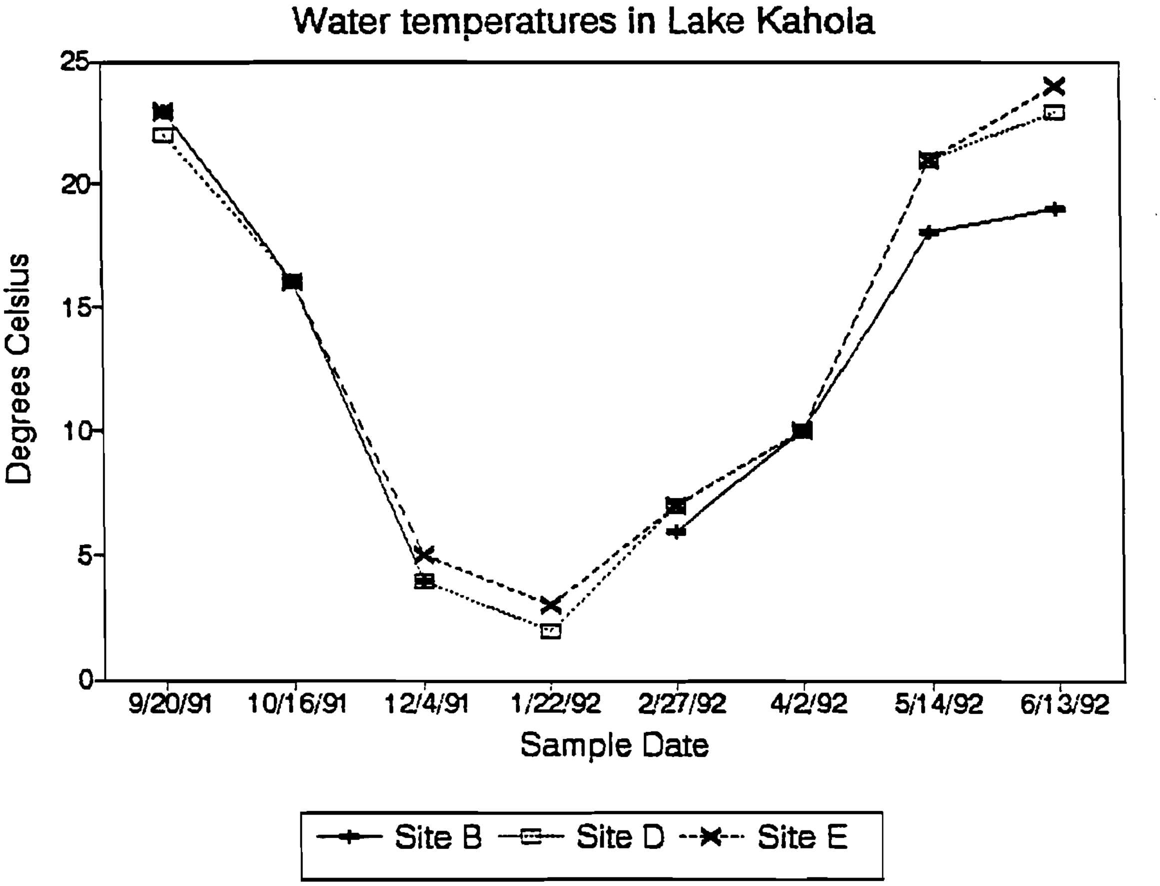


FIGURE 15

Water temperatures at the three Lake Kahola sites, B, D, and E.

Phosphate in Lake Kahola--Figure 16.

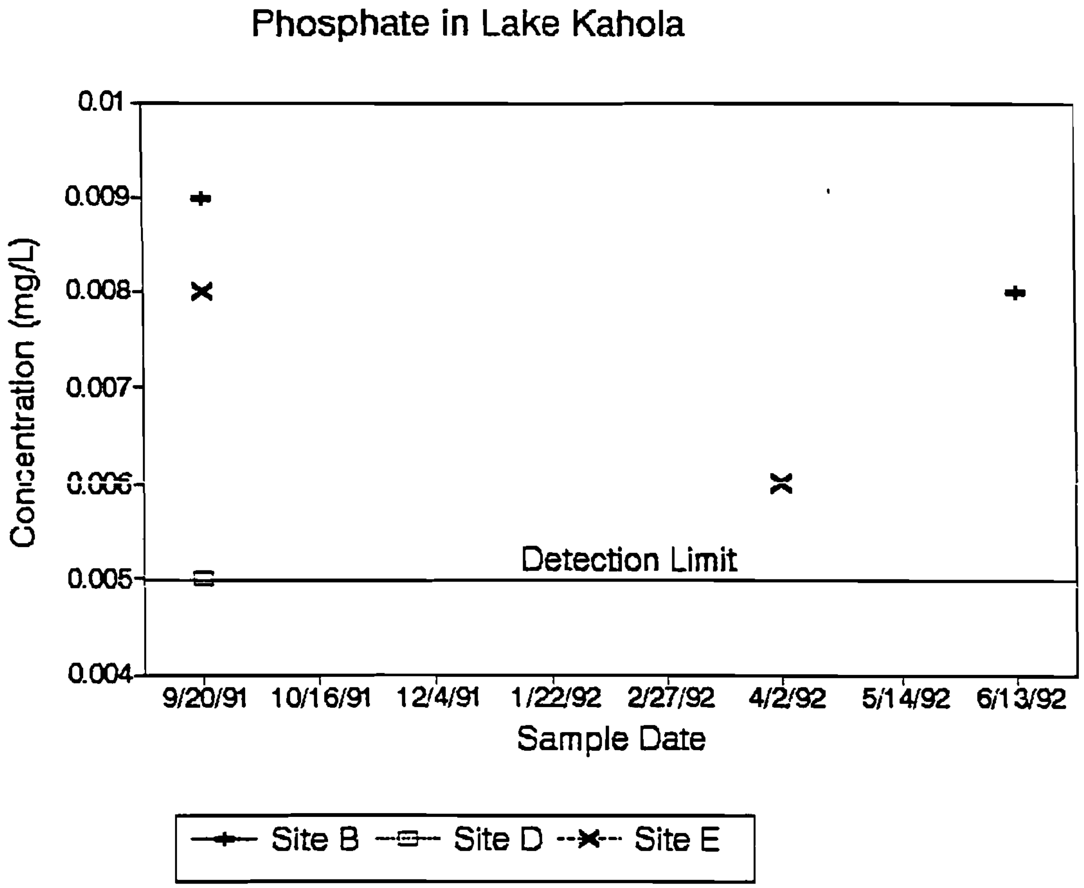


FIGURE 16

Phosphate levels at the three Lake Kahola sites, B, D, and E. The detection limit is 0.005 mg/L phosphate.

Phosphate in Lake Kahola is very low ranging from below the detection limit to a high of 0.009 mg/L at the outlet tower site on 9/18/91. Of the five phosphate results at or above the detection limit, two of the three highest occurred at the outlet tower. These samples are taken from 8.5 meters depth. Depth perhaps accounts for the higher phosphate readings, as generally cooler water temperatures and reduced light at depth combine to reduce algal activity--often a factor in phosphate uptake from natural waters.

Phosphate is found in low levels in nearly all the background and Lake Kahola samples. Factors contributing to this include the effects of the 6.3 to 8.9 pH range found in the study area. Phosphate generally precipitates out of solution at these pH levels. It is likely that algae also plays a role in reducing phosphate levels as phosphate is a nutrient requirement for plant life. Another factor reflecting phosphate concentrations entering Lake Kahola, and other surface water systems in the study area, is that runoff from the native bluestem grass rangeland predominant in the drainage basin is very low in phosphate. One of the characteristics of bluestem grass is its low-phosphate nutritional requirements. Bluestem grass requires soils low in phosphate for growth.

CHAPTER 6: CONCLUSIONS

Data collected during this study show that Lake Kahola does not have a water-quality problem caused by phosphate or chloride contamination. No cyclical levels of either of these essentially human-originated chemical ions were revealed by this ten month study. From this data, I have drawn the conclusion that septic-waste contamination at Lake Kahola is either non-existent or at levels below detection by this study.

Domestic water wells at Lake Kahola appear to be recharged directly from the lake. Since the chemical water properties of Lake Kahola seem to be of high quality, lake recharge of wells should merit no concern by domestic well users at the lake.

Domestic water wells at Lake Kahola which were sampled and analyzed for phosphate show a range of results. While most wells rarely exceeded the detection limit for the analytical method used, one well, site J, contained detectable amounts of phosphate throughout most of the study. Site J may be acquiring phosphate from a source nearby or somewhere in the groundwater stream up-current. Whether or not the source is of human or natural origin is inconclusive.

There appear to be chloride concentrations at sample site A (RNHR) higher than those at any of the other background sites. Without a naturally occurring source for chloride nearby, which is undoubtedly the case considering the composition of Lower Permian rocks in the area, the chloride contamination must be from a local human source. One possibility is the cattle-raising operation in the pasture to the east of RNHR. Another possibility is runoff of or groundwater infiltration by the septic waste treatment system at Emporia State University's study center and living quarters located uphill to the southwest of sample site A.

BIBLIOGRAPHY

Aber, J.S. 1990. History of Lake Kahola. *Kansas Academy of Science, Multidisciplinary Guidebook 3.* Emporia State Press, Emporia, Kansas, 1990, p. 5-6.

American Public Health Association, American Water Works Association, Water Pollution Control Federation 1985. *Standard Methods for the Examination of Water and Wastewater, 16th Edition.* American Public Health Association, Washington DC.

Carney, E. 1992. Personal correspondence with Bureau of Environmental Quality, KDHE, 1992.

Cottonwood Falls, Kansas, 7.5-minute topographic quadrangle. United States Geological Survey, 1973.

Finck, Elmer J. 1990. History of Ross Natural History Reservation. *Kansas Academy of Science, Multidisciplinary Guidebook 3*. Emporia State Press, Emporia, Kansas 1990, p. 3.

Johnston 1990. Bedrock Geologic Map of the Lake Kahola Area. *Kansas Academy of Science, Multidisciplinary*

Guidebook 3. Emporia State Press, Emporia, Kansas, 1990, p. 10.

KDHE 1992. Kansas Department of Health and Environment, Lake Kahola water quality studies, STORET computer retrieval date, [92/03/09.) ?
m/d/y

KDHE 1975, 1978, 1981. Kansas Department of Health and Environment, Council Grove Reservoir water quality analyses, chemical data 1975, 1978, and 1981.

KDOT 1986. *General Highway Map of Chase County, Kansas*. Kansas Department of Transportation Bureau of Transportation Planning, 1986.

X —

Kansas Department of Wildlife and Parks Records. Kansas Department of Wildlife and Parks Region 4 Office, 8420 North Broadway, PO Box 317, Valley Center, Kansas.

Moore, R.C., Frye, J.C., Jewett, J.M., Lee, W., and O'Connor, H.G. 1951a. The Kansas Rock Column. *Kansas Geological Survey, Bulletin 89*, vol. 1.

Moore, R.C., O'Connor, H.G., Jewett, J.M., and Smith, K.R. 1951b. Geology, Mineral Resources, and Ground-Water Resources of Chase County, Kansas. *State Geological Survey of Kansas, Volume 11*. University of Kansas Publication, Lawrence,Kansas, 1951.

O´Connor, H.G. 1949. Ground-Water Resources of Chase County, Kansas, Plate 3 of Geology, Mineral Resources, and Ground-Water Resources of Chase County, Kansas. *State Geological Survey of Kansas, Volume 11*. University of Kansas Publication, Lawrence, Kansas, 1951.

Lake Kahola, Kansas, 7.5-minute topographic quadrangle. United States Geological Survey, 1972.

Plymouth, Kansas, 7.5-minute topographic quadrangle. United State Geological Survey, 1972.

APPENDIX OF DATA

TEMPERATURE RECORDS Degrees Celsius

SITE	9/18/91	10/16/91	12/4/91	1/23/92	2/27/92	4/2/92	5/14/92	6/13/92
A	18	16	11	8	10	10	14	14
B	23	16	4	NA	6	10	18	19
C	20	18	8	12	12	12	14	15
D	22	16	4	2	7	10	21	23
E	23	16	5	3	7	10	21	24
F	19	16	2	5	10	11	21	23
G	17	19	5	5	11	12	21	24
H	20	20	3	6	8	10	24	27
I	22	18	5	3	8	12	24	28
J	15	16	14	14	7	15	15	16
K	15	16	NA	NA	NA	NA	NA	15
L	NA	17	NA	15	15	14	15	15
M	15	15	13	14	14	14	16	15
N	15	15	NA	NA	NA	NA	NA	16
O	NA	NA	NA	3	7	9	18	18

pH RESULTS

SITE	9/18/91	10/16/91	12/4/91	1/23/92	2/27/92	4/2/92	5/14/92	6/13/92
A	6.8	6.9	6.3	6.8	7.0	6.9	6.6	8.2
B	7.8	7.4	7.8	NA	8.0	8.0	7.2	7.4
C	7.6	7.5	7.6	7.1	8.0	6.8	6.4	8.0
D	8.1	7.5	7.4	7.7	7.6	7.4	7.3	8.0
E	8.3	7.6	7.4	8.0	8.0	7.8	7.3	7.9
F	7.6	6.7	6.5	7.5	7.3	8.1	7.1	7.5
G	8.1	7.6	7.4	7.8	8.0	8.1	7.2	7.5
H	8.4	8.2	7.5	8.1	7.5	8.2	7.0	7.9
I	8.3	7.6	7.6	7.5	7.4	8.1	7.4	8.0
J	7.3	6.5	6.8	7.5	7.2	6.9	7.0	7.8
K	7.1	6.9	NA	NA	NA	NA	NA	7.1
L	NA	6.9	NA	7.3	7.2	6.9	7.2	7.6
M	6.8	6.8	6.7	7.0	7.0	7.2	6.8	8.1
N	6.9	6.8	NA	NA	NA	NA	NA	8.9
O	NA	NA	NA	7.4	7.1	7.0	6.8	8.7

CONDUCTANCE RESULTS--mmohs/cm

SITE	9/18/91	10/16/91	12/4/91	1/23/92	2/27/92	4/2/92	5/14/92	6/13/92
A	647	666	622	609	672	612	616	628
B	258	275	273	NA	281	272	302	291
C	402	373	399	433	470	476	490	510
D	257	278	270	271	282	282	284	290
E	279	276	256	268	280	276	285	289
F	344	366	421	479	436	1511	270	420
G	351	585	361	316	438	372	279	430
H	265	250	260	251	273	282	281	246
I	271	262	268	265	274	257	283	269
J	932	889	898	798	896	895	695	830
K	779	952	NA	NA	NA	NA	NA	674
L	NA	1320	NA	1298	1515	1525	1692	1365
M	843	782	782	763	786	781	933	916
N	650	657	NA	NA	NA	NA	NA	648
O	NA	NA	NA	441	451	468	519	520

CHLORIDE RESULTS--mg/L

SITE	9/18/91	10/16/91	12/4/91	1/23/92	2/27/92	4/2/92	5/14/92	6/15/92
A	8.2	8.2	9.4	9.2	7.6	5.6	6.2	5.1
B	3.9	4.2	4.3	NA	4.6	4.4	4.2	2.8
C	2.5	2.9	2.8	5.2	3.4	3.0	2.8	0.9
D	4.8	4.5	4.8	4.6	5.2	3.8	4.2	2.3
E	3.7	4.3	4.8	4.7	4.8	3.4	4.8	1.8
F	4.4	5.0	5.7	6.3	6.0	4.4	3.4	2.8
G	5.7	14.7	7.1	4.2	4.2	5.4	5.1	2.2
H	5.1	6.5	5.1	6.2	5.1	5.1	5.1	3.2
I	6.9	4.8	5.3	5.0	5.1	4.8	4.7	2.4
O	NA	NA	NA	3.1	2.5	3.5	2.4	0.5

PHOSPHATE RESULTS--mg/L

SITE	9/18/91	10/16/91	12/4/91	1/23/92	2/27/92	4/2/92	5/14/92	6/13/92
A	BDL	BDL	0.007	0.005	BDL	BDL	BDL	0.005
B	0.009	BDL	BDL	NA	BDL	BDL	BDL	0.008
C	0.007	BDL	BDL	BDL	BDL	BDL	BDL	0.007
D	0.005	BDL	BDL	BDL	BDL	BDL	BDL	BDL
E	0.008	BDL	BDL	BDL	BDL	0.006	BDL	0.002
F	0.014	0.120	0.090	0.005	BDL	BDL	0.018	0.005
G	BDL	0.007	0.020	BDL	BDL	BDL	0.319	0.008
H	BDL	BDL	0.005	BDL	BDL	BDL	BDL	BDL
I	0.007	0.006	0.001	BDL	BDL	BDL	BDL	0.006
J	0.014	0.008	0.020	0.010	BDL	0.005	0.011	0.008
K	0.011	0.005	NA	NA	NA	NA	NA	0.005
L	-----	BDL	NA	BDL	BDL	BDL	BDL	0.006
M	BLD	BDL	BDL	BDL	BDL	BDL	BDL	0.005
N	BDL	BDL	NA	NA	NA	NA	NA	0.025
O	-----	-----	-----	0.020	BDL	0.005	BDL	0.005

BDL = Below Detection Limit

NA = Not Available--either conditions disallowed sample collection
or wells were seasonally shut down

CALCIUM ANALYSES RESULTS--mg/L

Site	9/18/91	10/16/91	12/4/91	1/23/92	2/27/92	4/2/92	5/17/92	6/13/92
A	84.4	75.0	90.4	84.0	78.8	80.4	83.0	59.0
B	39.2	38.2	52.6	NA	39.0	39.8	44.0	40.0
C	49.4	46.4	60.0	63.2	62.2	64.6	56.0	46.6
D	37.2	40.0	50.0	41.2	39.0	38.4	42.0	41.6
E	36.6	36.8	52.6	40.0	38.5	38.4	42.0	42.0
F	45.4	50.0	75.6	77.0	66.6	67.0	40.0	47.2
G	43.0	65.0	60.4	49.6	70.4	55.6	39.2	61.4
H	33.2	34.2	49.2	40.6	37.4	41.6	41.2	39.6
I	35.0	36.8	53.6	41.2	38.0	35.0	42.0	40.8
J	73.6	75.0	95.6	77.8	80.8	77.4	58.8	47.2
K	53.2	73.2	NA	NA	NA	NA	NA	54.4
L	NA	NA	NA	152.0	157.0	164.0	161.5	130.0
M	83.2	77.6	95.6	85.0	84.6	82.0	83.0	77.0
N	NA	63.0	NA	NA	NA	NA	NA	69.6
O	NA	NA	NA	83.4	69.8	70.4	72.2	62.0

I, Thomas E. Peterson, hereby submit this thesis to Emporia State University as partial fulfillment of the requirements for and advanced degree. I agree that the Library of the University may make it available for use in accordance with its regulations governing materials of this type. I further agree that quoting, photocopying, or other reproduction of this document is allowed for private study, scholarship (including teaching), and research purposes of a nonprofit nature. No copying which involves potential gain will be allowed without written permission of the author.

Thomas E. Peterson
Signature of Author

December 3, 1992

WATER QUALITY IN LAKE KAHOLA
AND ADJACENT DOMESTIC WATER WELLS

Douglas K. Cooper
Signature of Graduate Office
Staff Member

December 12, 1992
Date Received