OKLAHOMA GEOLOGICAL SURVEY
Charles J. Mankin, *Director*

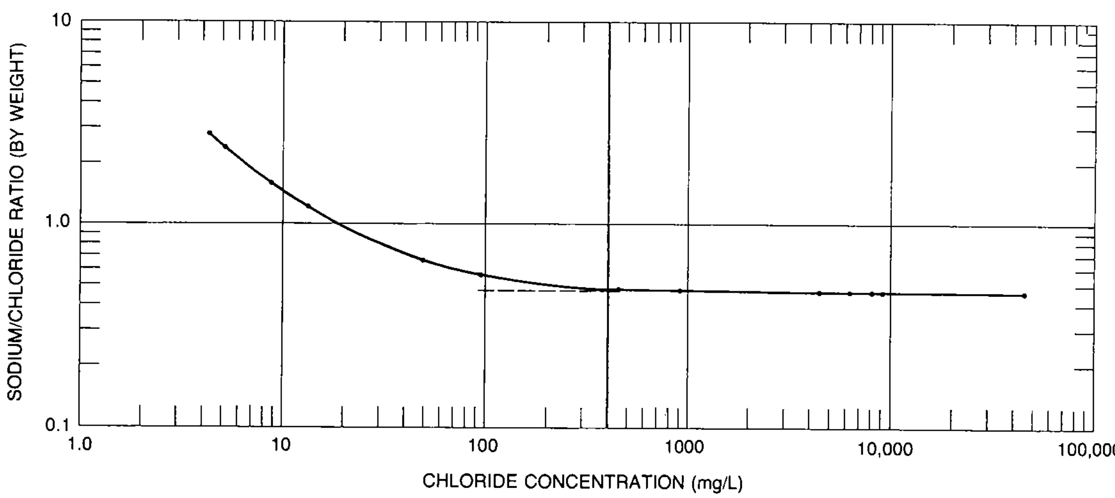
Circular 89

ISSN 0078-4397

EFFECTS OF BRINE ON THE CHEMICAL QUALITY OF WATER IN PARTS OF CREEK, LINCOLN, OKFUSKEE, PAYNE, POTTAWATOMIE, AND SEMINOLE COUNTIES, OKLAHOMA

ROBERT B. MORTON

Prepared by the United States Geological Survey in cooperation with the Oklahoma Geological Survey



The University of Oklahoma
Norman
1986

CONTENTS

ILLUSTRATIONS

Figures

Plate

TABLES

EFFECTS OF BRINE ON THE CHEMICAL QUALITY OF WATER IN PARTS OF CREEK, LINCOLN, OKFUSKEE, PAYNE, POTTAWATOMIE, AND SEMINOLE COUNTIES, OKLAHOMA

ROBERT B. MORTON[1]

Abstract.—A study of water-quality degradation due to brine contamination was made in an area of ~1,700 mi^2 in east-central Oklahoma. The study area coincides in part with the outcrop of the Vamoosa–Ada aquifer of Pennsylvanian age.

Water samples collected from 180 wells completed in the Vamoosa–Ada aquifer and at 167 sites from streams draining the Vamoosa–Ada aquifer show scattered occurrences of water-quality degradation by brine. Degradation of water quality by brine is indicated where (1) chloride concentration is ⩾400 mg/L, (2) bromide concentration is ⩾2 mg/L, (3) the ratio of sodium plus chloride to dissolved solids is ⩾0.64. Ratios of secondary importance that also indicate water-quality degradation by brine in the area are (1) a ratio of lithium to bromide ⩽0.01, when the chloride concentration is ⩾400 mg/L, (2) a sodium/chloride ratio of ~0.46, (3) a sodium/bromide ratio of ~92, and (4) a bromide/chloride ratio of ~0.0048.

Values for bromide, lithium, strontium, dissolved solids, calcium, magnesium, sodium, chloride, and sulfate concentrations were subjected to analysis of variance based on use of the index values in partition data sets. The analysis of variance showed the significance of the indexes for all constituents except sulfate.

The two most reliable brine indicators are chloride and bromide. Statistically, chloride is a slightly more reliable index than bromide. The developed indexes can be used to indicate water-quality degradation by brine. Accuracy is improved if both indexes are used.

When geophysical logs from 133 pairs of oil and gas wells were analyzed, data from 5 pairs of wells indicated a possible rise in the interface between fresh water and salt water in the Vamoosa–Ada aquifer. Therefore, any rise of the interface is local rather than regional.

The criteria developed in this study indicate that brine has degraded water quality at 63 sites on streams draining the Vamoosa–Ada aquifer, at 15 water wells completed in the Vamoosa–Ada aquifer, and at 5 oil and gas wells penetrating the Vamoosa–Ada aquifer.

INTRODUCTION

Background

An earlier study by D'Lugosz and McClaflin (1986) indicated that the water resources in the area of the Vamoosa–Ada aquifer may be affected by brines. On-site observations and analysis of water samples collected by D'Lugosz and McClaflin indicate that activities related to oil-and-gas operations may cause incursions of such brines. Their hydrologic work, recently published (1986), is the basis for the present study.

Purpose and Scope

This study, conducted in cooperation with the Oklahoma Geological Survey, was to determine areas where water quality has been degraded and the potential sources of the degradation. Chemical-graphical and geophysical methods were used to identify areas and sources of degraded water.

Parts of Creek, Lincoln, Okfuskee, Payne, Pottawatomie, and Seminole Counties are included in the study area (Fig. 1), which generally coincides with the areal extent of the Vamoosa–Ada aquifer (Pl. 1).

Location and General Description of the Study Area

The study area, slightly less than 1,700 mi^2, extends about 90 mi from the Cimarron River on the north to the Canadian River on the south, and about 30 mi from east to west. The area described includes T5–19N and R5–9E.

The study area is part of the Osage Plains section of the Central Lowlands physiographic prov-

[1]U.S. Geological Survey, Oklahoma City, Oklahoma.

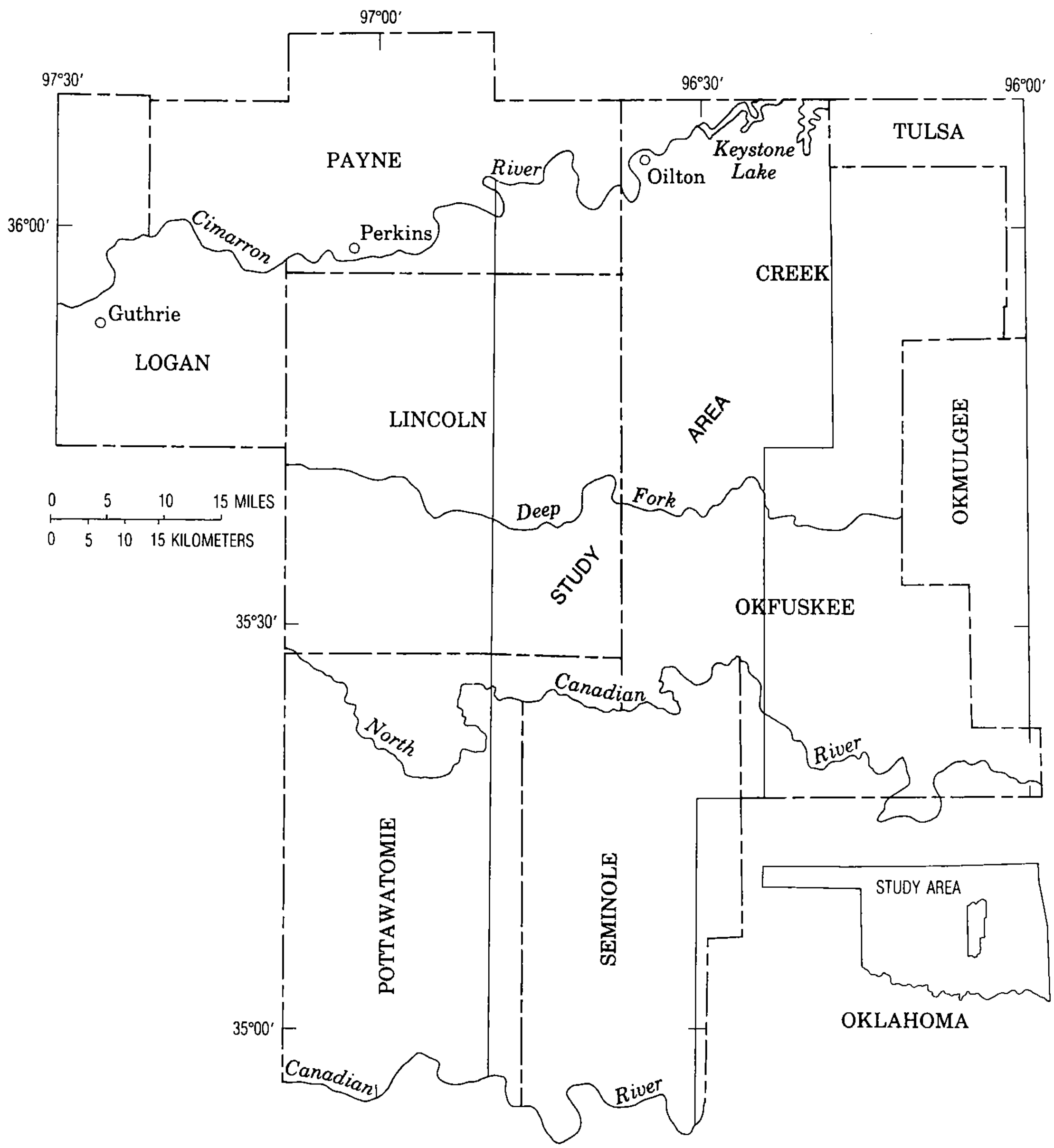


Figure 1. Location of study area.

ince (Fenneman and Johnson, 1946). The mean annual temperature is about 61°F (16°C), and the mean annual precipitation is about 37 in. The land surface slopes generally eastward and is gently rolling and well drained by the four principal streams—the Cimarron, North Canadian, and Canadian Rivers, and Deep Fork—and their numerous tributaries. Most of the major streams are perennial, whereas the smaller streams are dry during extended periods of little or no precipitation. Altitude of the land surface ranges from slightly less than 800 ft in the larger stream valleys to more than 1,100 ft in the uplands, but generally the higher altitudes range from 950 to 1,000 ft.

The petroleum industry, including many supportive enterprises, is the dominant industry in the study area. Oil and gas fields range in size from one or two wells to such huge fields as Cushing, Seminole, and Bowlegs, which had 1,605, 255, and 175 active wells, respectively, in 1976 (McCaslin, 1977). Few sizeable areas are without some evidence of oil and gas operations. The cattle and farm industries are next in importance.

Previous Studies

The chemistry of oil-field brines and degradation of water resources by brines have been widely studied in other areas. Except for the preliminary work of D'Lugosz and McClaflin (1986), a review of the literature indicates that this investigation is the first study of brine degradation of water resources in the project area.

Conventions

Land descriptions in this report are a modification of the U.S. Bureau of Land Management system of land subdivisions: township, range, section, and quarter-quarter-quarter section (Fig. 2). The number following the quarter-quarter-quarter section is the well sequence number.

A glossary of technical terms is presented in Appendix 1, and conversion factors for units of measurement are presented in Appendix 2.

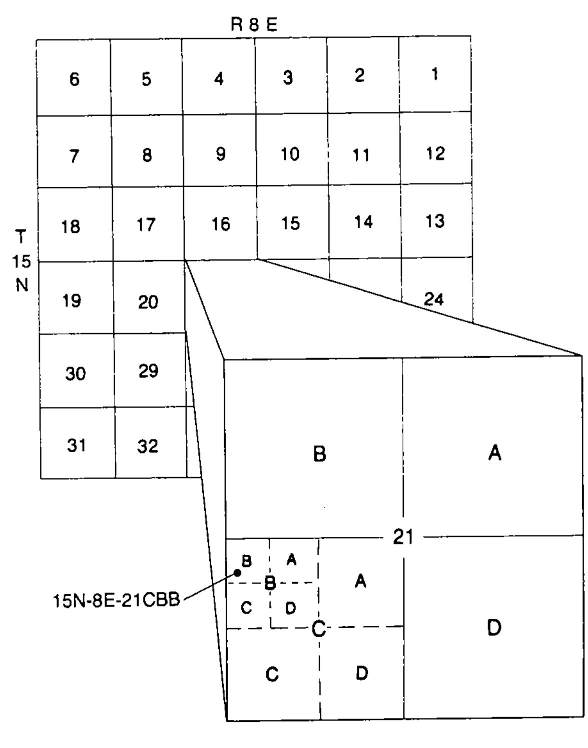


Figure 2. Site-numbering system.

Acknowledgments

Many farmers and ranchers interrupted their work to supply requested information on their water wells and in many instances to aid in the collection of water samples. Without their cooperation, this study would not have been possible.

GEOLOGY OF THE VAMOOSA–ADA AQUIFER

Most of the geologic descriptions and the following section on hydrology are condensed from D'Lugosz and McClaflin (1986). The outcrop area of the Vamoosa–Ada aquifer is shown on Plate 1. The bedrock is of Pennsylvanian age and is overlain locally by alluvial and terrace deposits of Quaternary age. The Vamoosa–Ada aquifer is part of the bedrock sequence and includes the Vamoosa Group and underlying and overlying Pennsylvanian formations that are lithologically similar and hydrologically connected. In the study area the Vamoosa–Ada aquifer comprises, in ascending order of units, the uppermost part of the Barnsdall Formation, the Tallant Formation, the Vamoosa Group, the Ada Group, and the lower part of the Vanoss Group.

Lithologically, the Vamoosa–Ada aquifer consists of a complex sequence of fine- to very fine-grained sandstone, siltstone, shale, and conglomerate, with very thin interbedded limestones. Individual sandstone units are 1–5 ft thick and are limited in areal extent.

Structurally, the Vamoosa–Ada aquifer is part of a homocline which dips westward at 30–90 ft/mi; thus, the aquifer is a source of ground water west of its outcrop area. A series of NW-trending en echelon normal faults extends from southern Seminole County across Okfuskee County into Creek County (and farther north). Few faults exceed 3 mi in length, and most average about 1 mi. Displacement commonly is about 50 ft and rarely is more than 100 ft.

HYDROLOGY OF THE VAMOOSA–ADA AQUIFER

In the outcrop area, water in the Vamoosa–Ada aquifer is under water-table conditions, whereas west of the western edge of the outcrop belt confined conditions prevail. The gradient of the water table in the outcrop area generally is to the east, but locally is toward gaining streams (Pl. 1, map A). In the confined part of the aquifer the potentiometric surface presumably follows the homoclinal dip to the west. Measurements made in a few wells that penetrate the confined part of the aquifer show that water levels in the confined part of the aquifer are 70–150 ft below water levels in the unconfined part of the aquifer. The occurrence and movement of water in the Vamoosa–Ada aquifer depend significantly on variations in thickness of the sandstone units. The base of fresh water is lower in altitude where the sandstone sequence is thick and is higher where sandstones grade into less-permeable shale and siltstone. The effect of the en echelon faults on the movement of ground water is not known; however, these faults are of limited extent and likely do not have regional effects on the hydrology of the aquifer. Movement of ground water across the fault zones depends on the degree of fracturing, brecciation, or cementation.

Based on recovery tests made in seven wells in 1978, transmissivity values for the aquifer were 70–490 ft^2/day (average 200 ft^2/day). Hydraulic conductivity was 2–4 ft/day (average slightly less than 3 ft/day). Storage coefficients determined from four unpublished tests made in the confined part of the aquifer in 1944 by the U.S. Geological Survey were 0.0001–0.0003, whereas storage, or specific yield, in the unconfined part was estimated at 0.12. Water-level measurements in wells were compared with base-flow measurements in the Hilliby and Polecat Creek basins, which are geologically and topographically typical of the aquifer outcrop area; the comparison shows that a rise in water level is accompanied by an increase in base flow, whereas a decline in water level results in a decrease in base flow. Thus, recharge and discharge are in approximate equilibrium. The volume of water in storage is near capacity most of the time.

BRINE-DETECTION METHODS

Chemical-Graphical Method

Water samples were collected for chemical analysis from 347 sites; 167 were surface-water sites and 180 were ground-water sites (Pl. 1, map B). Most of the samples were collected in 1979 and 1980; however, 15 samples were collected for less-complete chemical analysis in 1978. Selection of sample sites was based on a 2- to 3-mi grid; therefore, throughout the study area sample sites generally were evenly distributed. Time and budget constraints precluded a closer grid spacing. Because of the large grid spacing, many sites where water possibly is degraded by brine were not sampled; therefore, this study does not represent a complete inventory of all sites with degraded water in the area.

Three hundred forty-two samples were analyzed for the common ions plus bromide and lithium. One hundred eighteen surface-water samples and 127 ground-water samples were analyzed for dissolved organic carbon (DOC). As noted later in this report, chloride is the best brine index. Plotting of DOC concentration against chloride concentration showed no relationship for either the surface-water or ground-water samples; therefore, DOC analysis was terminated.

Figures 3 through 10 show a few data points at some distance from the general trend. Such points may represent valid data, but many probably are the result of errors. Included in the possible sources of error are laboratory analytical errors, errors in rounding of the laboratory values, laboratory tabulation errors, key-punch errors, contamination of the sample container, or contamination of the sample during collection. Most of the fresh water in the study area is either a sodium bicarbonate type or a sodium calcium bicarbonate type, and most brines are a sodium chloride type. The presence of other water types in the area may explain some of the variability of data seen in Figures 3 through 10. Data points with question marks may be the result of one or more types of errors. These outlying points were not used in determining the position of the median lines or in the delineation of the ranges of each ratio.

Laboratory analyses of water samples collected at the 347 sites are listed alphabetically by county in Appendix 3, which presents the data used in the chemical-graphical method for determining the presence of brine. In Appendix 3, surface-water analyses are indicated by a value for "Streamflow, instantaneous," whereas ground-water analyses are indicated by a value for "Depth of well, total."

Basis for Use of Brine-Effect Indexes

Brine in the subsurface may originate in two ways. One possible origin is by re-solution of halite, and in such cases the halite commonly occurs as bedded salt in the rock column. However, studies by many investigators have failed to identify salt or other evaporites in the Pennsylvanian rocks of Oklahoma. The ratio of sodium to chloride by weight in the re-solution of halite is 0.65. The average sodium concentration of all water samples collected in the study area is 679.4 mg/L, and the average chloride concentration is 1,383.5 mg/L, yielding a ratio of 0.49. This ratio indicates that the origin of the brine in the study area is not by re-solution of halite.

The second possible origin of brine (the one most acceptable in the study area) is from sea water. As indicated by Carpenter (1978), the chemical evolution of subsurface brines derived from sea water includes an evaporative process in which the least-soluble chemical elements progressively precipitate out of solution, whereas the more-soluble chemical elements remain in solution in increasing concentrations. Carpenter (1978) explained further that the sodium/chloride ratio should be between 0.55 and 0.58 for any concentration of sea water up to halite saturation. However, any modification of sea water by evaporative concentration beyond halite saturation, or by diagenetic reactions, should lower the sodium content relative to chloride, so that the sodium/chloride ratio should be less than 0.5. Since the sodium/chloride ratio in the subsurface brines of the study area is 0.49, those brines evidently originated from sea water.

On all the graphs, the value for the respective elemental ratios for sea water is shown. The position of the sea water value relative to the more briny (right) side of the graphs further indicates a sea water origin for the brines. Where available data permitted, plots from brine analyses are shown on some of the graphs. The analyses were made by various oil companies and later compiled by the University of Oklahoma, Energy Resources Institute, Office of Information Systems Programs, from whom the analyses were purchased for this study.

Sodium, chloride, bromide, and lithium—four of the more-soluble ions in the brines of the study area—were used in determining the brine-effect indexes as log-log plots (in some cases, plots of a ratio versus a component of the ratio). A semilog plot was used for Figure 10. Because there is a significant disparity in the concentrations of sodium, chloride, bromide, and lithium, the logarithmic approach was considered useful in most instances. Other workers (e.g., Whittemore and Pollack, 1979) have used a log-log plot of a ratio versus a component of the ratio. The combinations of elements used in the plots were decided empirically.

Brine-Effect Indexes and Their Limitations

The solubility of the alkali metals and halides and their usefulness to brine indexes has been discussed by Chebotarev (1955), White and others (1963), and Whittemore and Pollock (1979). The importance of chloride as an indicator of oil-field brine pollution has been discussed by Revelle (1941) and Collins (1974). Bromide as an indicator of oil-field waters has been discussed by Rittenhouse (1967). Collins (1976) reported on lithium and bromide in oil-field brine.

Sodium, chloride, bromide, and lithium occur in much greater concentrations in oil-field brines than in fresh ground water and surface water. For example, a representative analysis of freshwater in the study area shows 22 mg/L of sodium, 23 mg/L of chloride, 0.2 mg/L of bromide, and 20 μg/L of lithium (Appendix 3, analysis 325). By contrast, a representative analysis of oil-field brine in the area shows concentrations of 42,000 mg/L of sodium, 91,000 mg/L of chloride, 280 mg/L of bromide, and 1,900 μg/L of lithium (Appendix 3, analysis 290).

As shown in Table 1, these four constituents are concentrated during sea-water evaporation. Because of the greater solubility of sodium, chloride, bromide, and lithium, and because of their use as brine indicators by earlier researchers, these four constituents were used in a series of graphs (Figs. 3–10) to determine the indexes described in this study.

During preparation of this report, various combinations of the data in Appendix 3 were plotted. The purpose of the graphs was to determine quantitative relationships among constituents that would help to distinguish fresh water from various mixtures of fresh water and brine. The plotted data showing the most consistent relationships, from which numerical relationships could be derived, are shown in Figures 3 through 10. Because some of the indexes are derived from different approaches, the validity of such indexes is substantiated. The analyzed water samples grade from virtually fresh water, through different, increasingly briny mixtures of fresh water and brine, to samples that are essentially brine.

The use of numerical expressions for the indexes might be assumed to imply mathematical exactness. No assertion is made for such mathematical precision. The change from fresh water to brine—as indicated by plots of the analysis of the many water samples—is gradational. The indexes are considered the best means of identifying the point on this gradational series where the brine contamination begins.

Except for the iodide data, which have not been used, all values reported in Appendix 3 are rounded to one decimal place. This rounding helps explain the linear arrangement of some of the data points in Figures 3 through 10. Rounding also may affect the positions of points plotted on the graphs, and the scatter of points at the left (fresh water) ends of the graphs. In the case of bromide, a reported value of 0.1 mg/L may include values ranging from 0.05 to 0.15 mg/L; thus, the actual value may be 50% more or 50% less than the reported value. In Figure 3, the maximum sodium/bromide ratio is 3,500 and the minimum is 29 for a bromide concentration of 0.1 mg/L. Applying the maximum "correction" of 50% to the plotted ratio values results in a minimum maximum value of 1,750 and a maximum minimum value of 43. Thus, the scatter is slightly exaggerated by rounding of the reported data. However, the diffusion of points observed on the left of most of the graphs is real and is explained by the large range in constituent concentrations in mixtures of fresh water and brine. The lesser scatter observed on the right of the graphs might be incorrectly interpreted to indicate that pollution is widespread and that most water in the study area is not potable. However, most of the water in the study area is in fact potable, as shown by the proliferation and scatter of points on the left of the graphs.

As shown in Figure 3, sodium/bromide values are widely scattered until a critical bromide concentration of about 2 mg/L is reached. At bromide

TABLE 1.—FIVE RELATIVE CONCENTRATION CHANGES OF SOME DISSOLVED IONS DURING EVAPORATION OF SEA WATER AND BRINE*

	Approximate concentrations (mg/L) at various stages of evaporation**					
Constituents	Sea water	$CaSO_4$	NaCl	$MgSO_4$	KCl	$MgCl_2$
Lithium	0.2	2	11	12	27	34
Sodium	11,000	98,000	140,000	70,000	13,000	12,000
Potassium	350	3,600	23,000	37,000	26,000	1,200
Rubidium	0.1	1	6	8	14	10
Magnesium	1,300	13,000	74,000	80,000	130,000	153,000
Calcium	400	1,700	100	10	0	0
Strontium	7	60	10	1	0	0
Boron	5	40	300	310	750	850
Chloride	19,000	178,000	275,000	277,000	360,000	425,000
Bromide	65	600	4,000	4,300	8,600	10,000
Iodide	0.05	2	5	7	8	8

*Modified from Collins (1975); used with permission of the author and publisher.
**Beginning with normal sea water; progressive stages of evaporation are identified by substances which have last precipitated ($CaSO_4$, etc.).

concentrations ⩾2 mg/L, the range of sodium/bromide ratios narrows and reaches a median value of ~92. The median value range is 35 to 155. For the purpose of this report, a bromide concentration ⩾2 mg/L is proposed as one of the indexes of water-quality degradation by brine, because it represents a subtle break in the background bromide concentration in most waters of the study area.

The relationship of sodium/chloride ratios to bromide concentrations is shown in Figure 4. Here again, a bromide concentration ⩾2 mg/L apparently is a critical value for indexing possible water-quality degradation by brine; also, a median sodium/chloride ratio of ~0.46 is an index of brine if the bromide concentration is ⩾2 mg/L. The median value range is 0.28–0.72. The median sodium/chloride ratio of 0.46 generally agrees with a mean ratio of 0.52 derived from 45 random samples of oil-field brine in the Walnut River Basin of south- central Kansas (Leonard, 1972). The conclusions based on data used in this report also agree with Leonard's conclusions that the sodium/chloride ratio in fresh water commonly is >0.60, whereas the ratio in water containing brine usually is <0.60.

The relationship of bromide/chloride ratios to chloride concentrations is shown in Figure 5. As chloride concentrations increase, the range of the bromide/chloride ratio decreases until an approximately constant ratio is reached; this ratio is ~0.0048 beginning at a bromide concentration ⩾2 mg/L and a chloride concentration ⩾400 mg/L. The median value range is 0.0025 to 0.0090. The lines marking 400 mg/L of chloride and 2 mg/L of bromide and the median bromide/chloride ratio of 0.0048 have a common intersection. A bromide concentration ⩾2 mg/L again is indicated as a possible brine index, and a chloride concentration ⩾400 mg/L also appears to be significant as a brine index.

The relationship of sodium/chloride ratios to chloride concentrations is shown in Figure 6. The scatter of points at lower chloride concentrations is apparent. However, the range of sodium/chloride ratios converges and generally becomes linear at higher chloride concentrations; the rate of change of the median line progressively decreases and attains a constant value of ~0.46 beginning at a chloride concentration of ~400 mg/L. Therefore, a chloride concentration ⩾400 mg/L and a median sodium/chloride ratio of ~0.46 are further supported as brine indicators.

The curve shown in Figure 7 was constructed to test the hypothesis that the analyzed water samples are various mixtures of fresh water and brine. From the analyzed data, a sample analysis with the smallest constituent concentration (fresh water) and a sample analysis with the greatest constituent concentration (brine) were selected. The extremes in values for sodium and chloride are shown in Table 2. Different volumes of the two

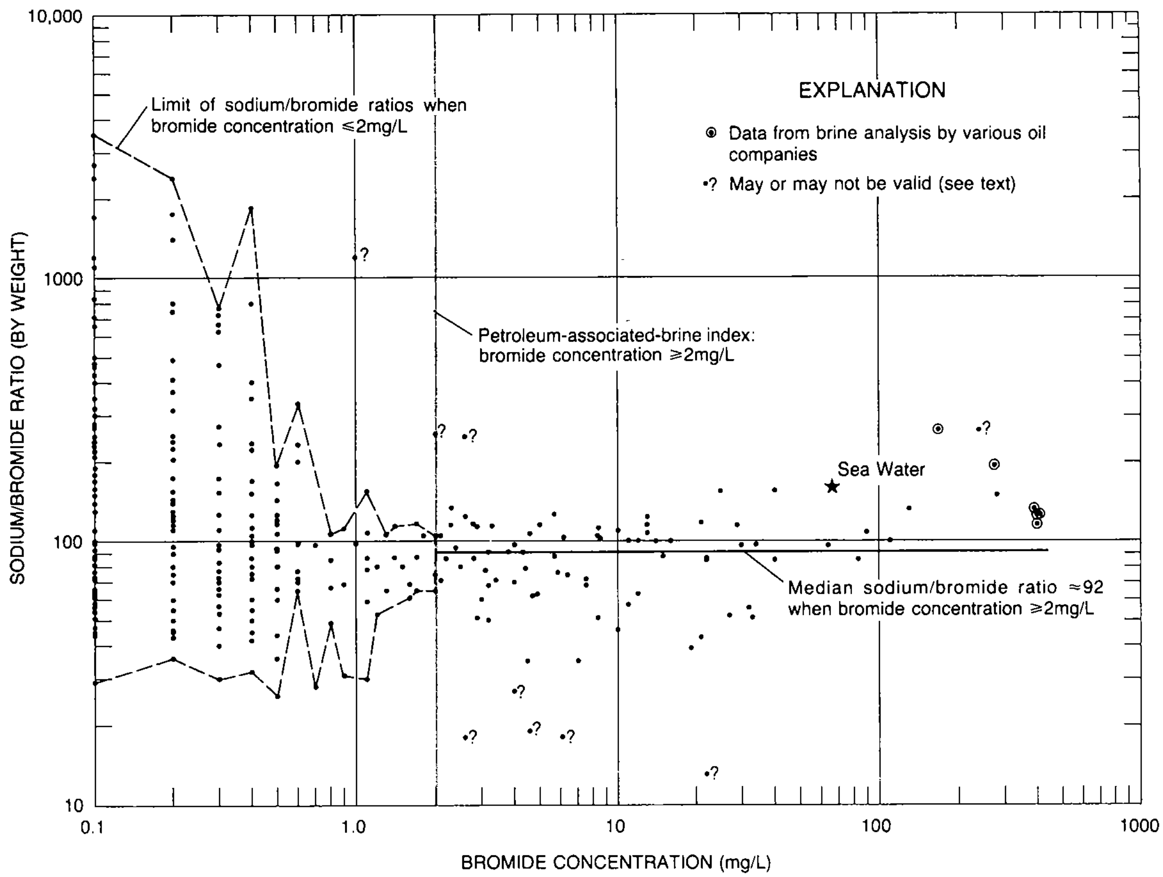


Figure 3. Relationship between sodium/bromide ratios and bromide concentrations.

solutions then were mixed, hypothetically, according to equation (1):

$$\frac{V_1C_1 + V_2C_2}{V_1 + V_2} = \text{concentration of constituent in mixture (mg/L)} \quad (1)$$

where V_1 = volume of solution 1,
V_2 = volume of solution 2,
C_1 = concentration of constituent in solution 1, and
C_2 = concentration of constituent in solution 2.

Because the hypothetical curve in Figure 7 approximates the shape of the curve in Figure 6, the sampled waters evidently are various mixtures of fresh water and brine. On both curves the sodium/chloride ratio stabilizes at the median value of ~0.46 at a chloride concentration ≥400 mg/L.

The relationship between lithium/bromide ratios and chloride concentrations is shown in Figure 8. The median line for the plotted values shows an inflection toward a greater rate of increase in chloride concentration beginning at a chloride concentration of ~400 mg/L. If the area of Figure 8 is divided into four quadrants by the 400 mg/L chloride line and the 0.01 lithium/bromide line, approximately 98% of the points plot in the upper left and lower right quadrants. The few values that plot in the upper right and lower left quadrants may result from one or more of the aforementioned errors. Because a chloride concentration ≥400 mg/L has been shown to be a brine index, Figure 8 indicates that values which plot both to the right of the 400 mg/L chloride line and on or below the 0.01 lithium/bromide ratio line represent brine contamination. Therefore, a lithium/bromide ratio ≤0.01 is considered a brine index if chloride concentration is ≥400 mg/L.

Figure 9 is a hypothetical-mixing curve constructed in the same way as Figure 7, except that

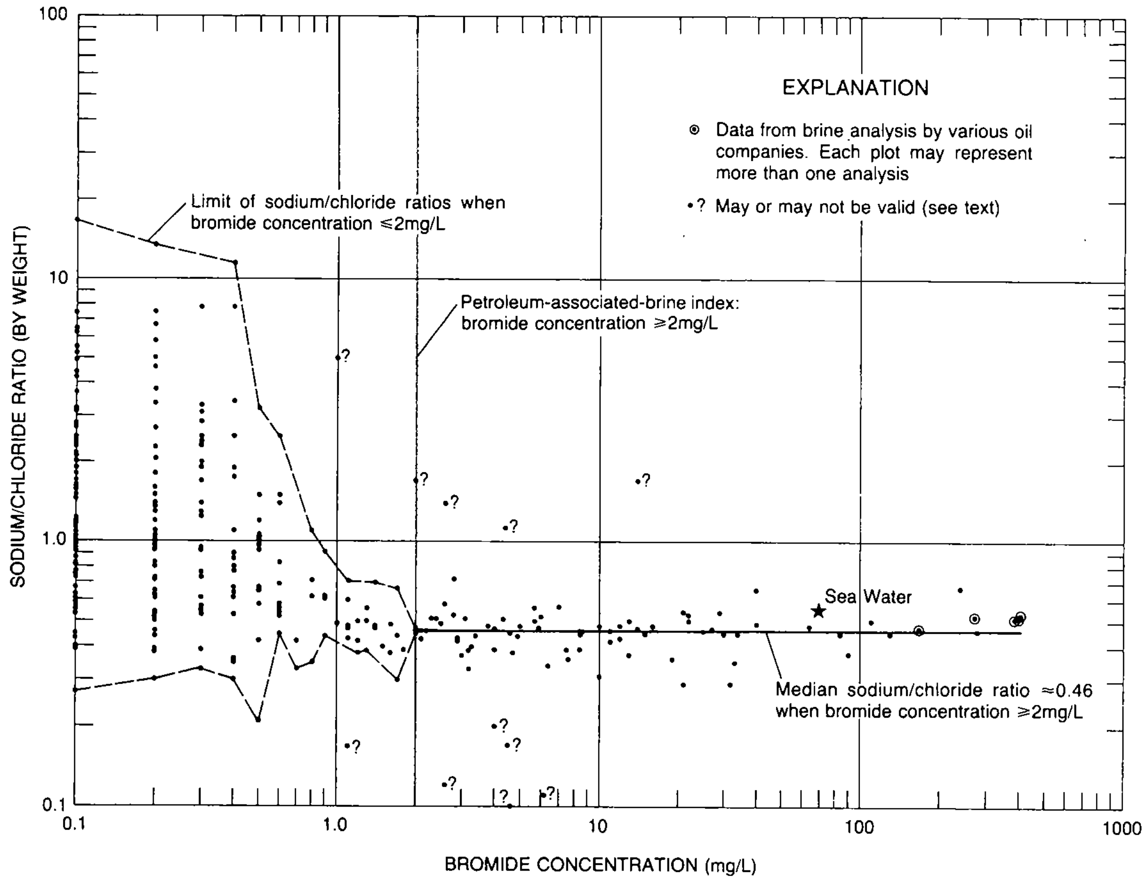


Figure 4. Relationship between sodium/chloride ratios and bromide concentrations.

concentrations of lithium, bromide, and chloride (Table 2) were used in equation (1). The two curves in Figures 8 and 9 show a close similarity; thus, the analyzed data apparently represent various combinations of fresh water and brine.

The relationship between the ratio of sodium plus chloride to dissolved solids (residue at 180°C) and chloride concentrations is shown in Figure 10. The median line through the plotted points shows an inflection toward a greater rate of increase in chloride concentration at ~400 mg/L. At this concentration of chloride, the ratio of sodium plus chloride to dissolved solids is about 0.64; therefore, when this ratio is ≥0.64, a brine effect is indicated. This interpretation of Figure 10 further substantiates that 400 mg/L of chloride apparently is a consistent brine index in the study area.

Although the indexes developed in this study are useful in defining and identifying water-quality degradation by brine, failure of the indexes usually is traceable to one or more of the several sources of error, or lack of conformity to water type, as described earlier in this report. The water-type problem is illustrated by the degradation of water from three wells in 8N-5E-6, 9N-5E-4, and 9N-5E-27, near the Seminole–Pottawatomie county line (Pl. 1, map B; Appendix 3, analyses 213, 216, and 294, respectively). According to the landowners, the three wells yielded potable water for domestic use; however, the water is now unfit to drink. In 1979, analyses of water samples from the three wells showed 3,840 mg/L, 2,530 mg/L, and 3,910 mg/L of dissolved solids, respectively.

The indexes used in this report are based on water of typical sodium chloride type (brine). The water from the three wells, and probably in the local area, is a sodium sulfate type, rather than a typical sodium chloride oil-field-brine type; the highest bromide concentration was 1.0 mg/L, and the highest chloride concentration was 220 mg/L. Therefore, the indexes do not apply in the unusual circumstances of these three wells. The failure of

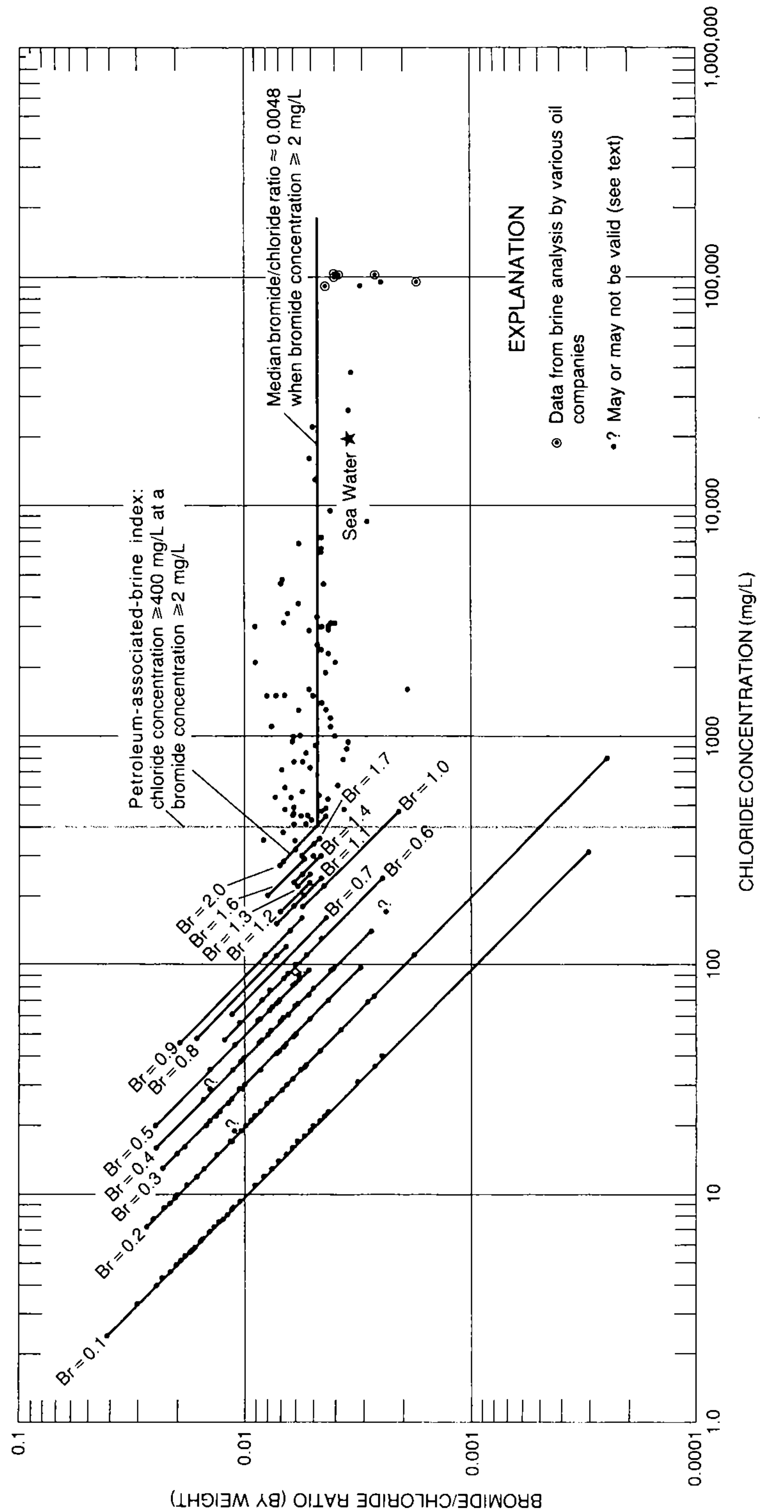


Figure 5. Relationship between bromide/chloride ratios and chloride concentrations.

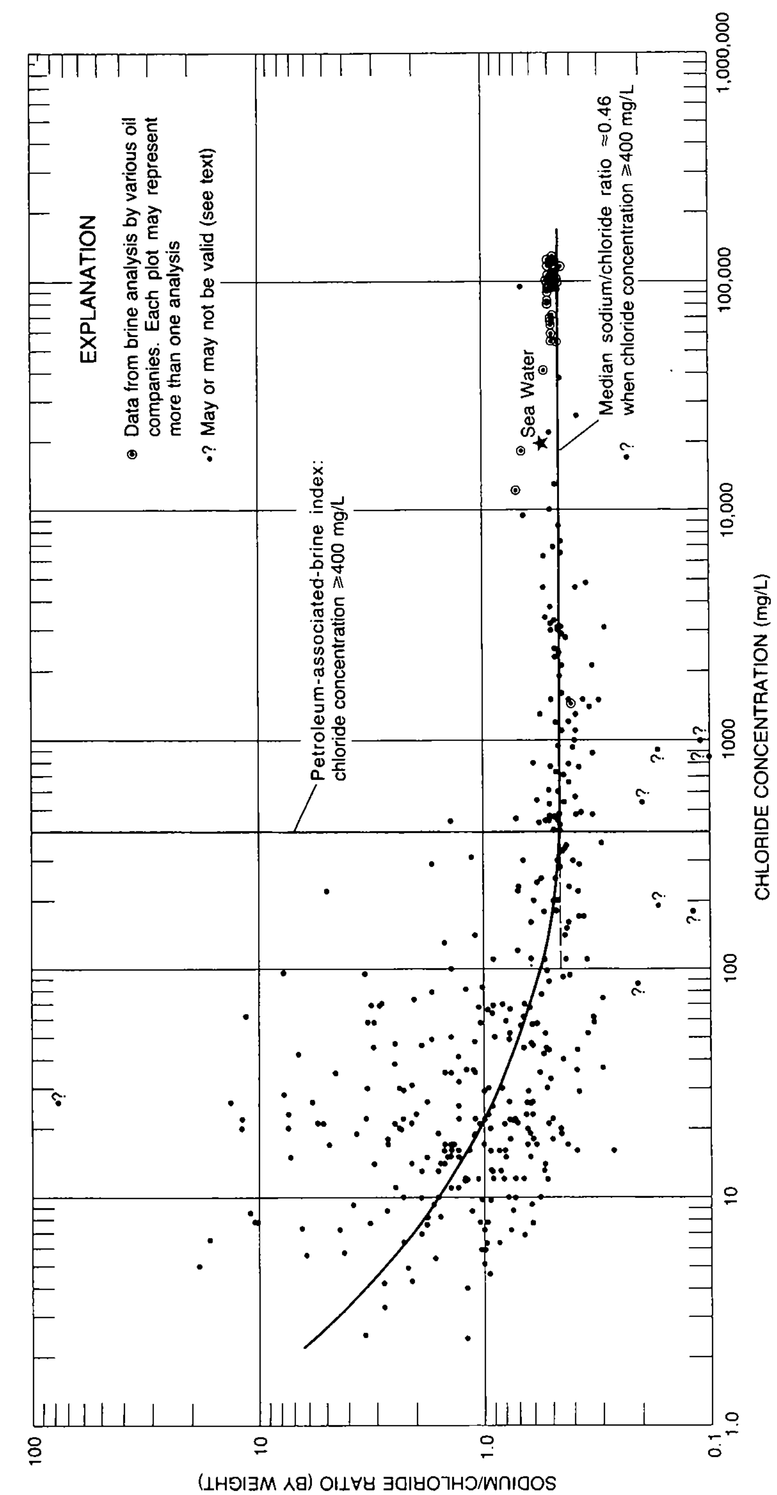


Figure 6. Relationship between sodium/chloride ratios and chloride concentrations.

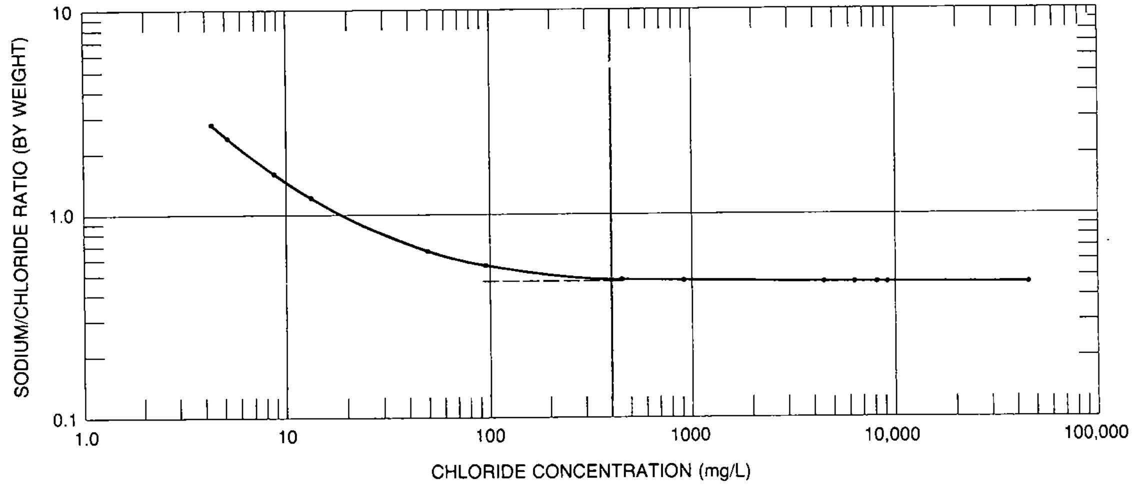


Figure 7. Relationship between sodium/chloride ratios and chloride concentrations resulting from the hypothetical mixing of two solutions with different volumes and concentrations. Concentrations range from 12 to 42,000 mg/L of sodium, and from 4.2 to 91,000 mg/L of chloride.

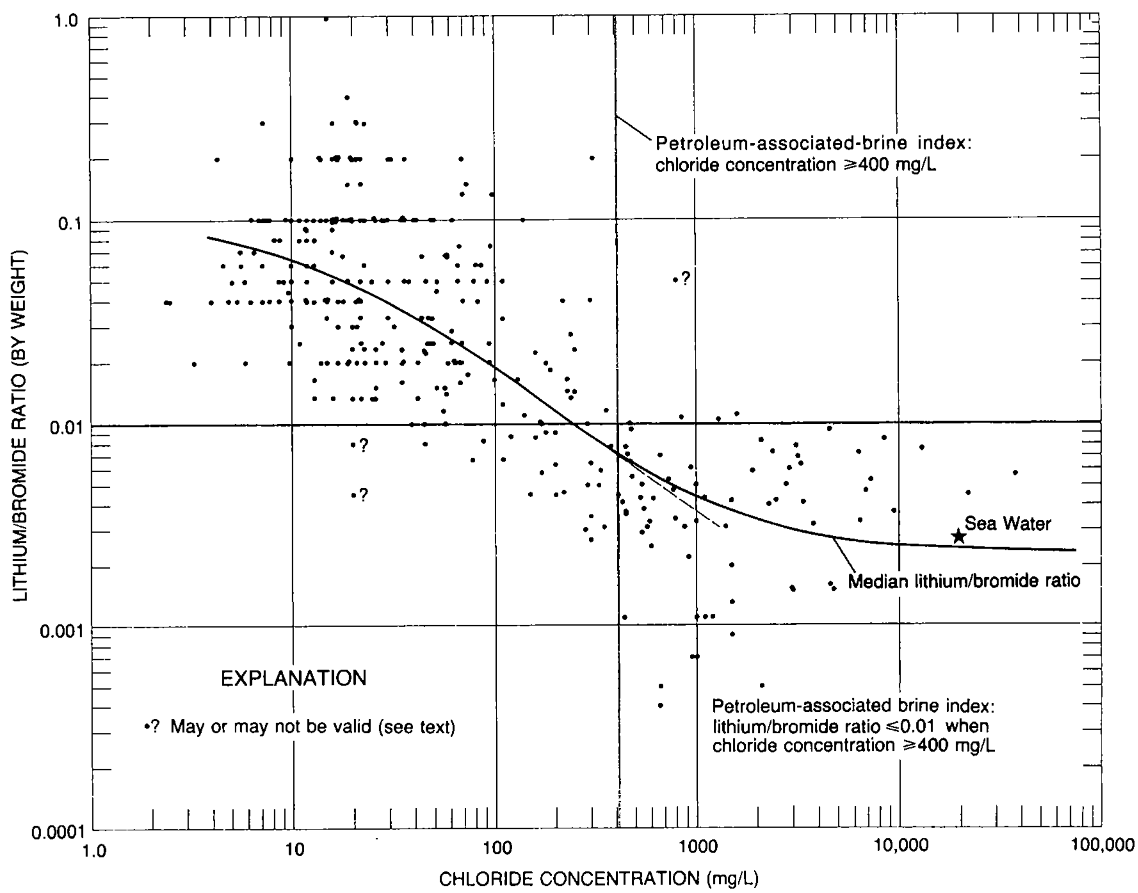


Figure 8. Relationship between lithium/bromide ratios and chloride concentrations.

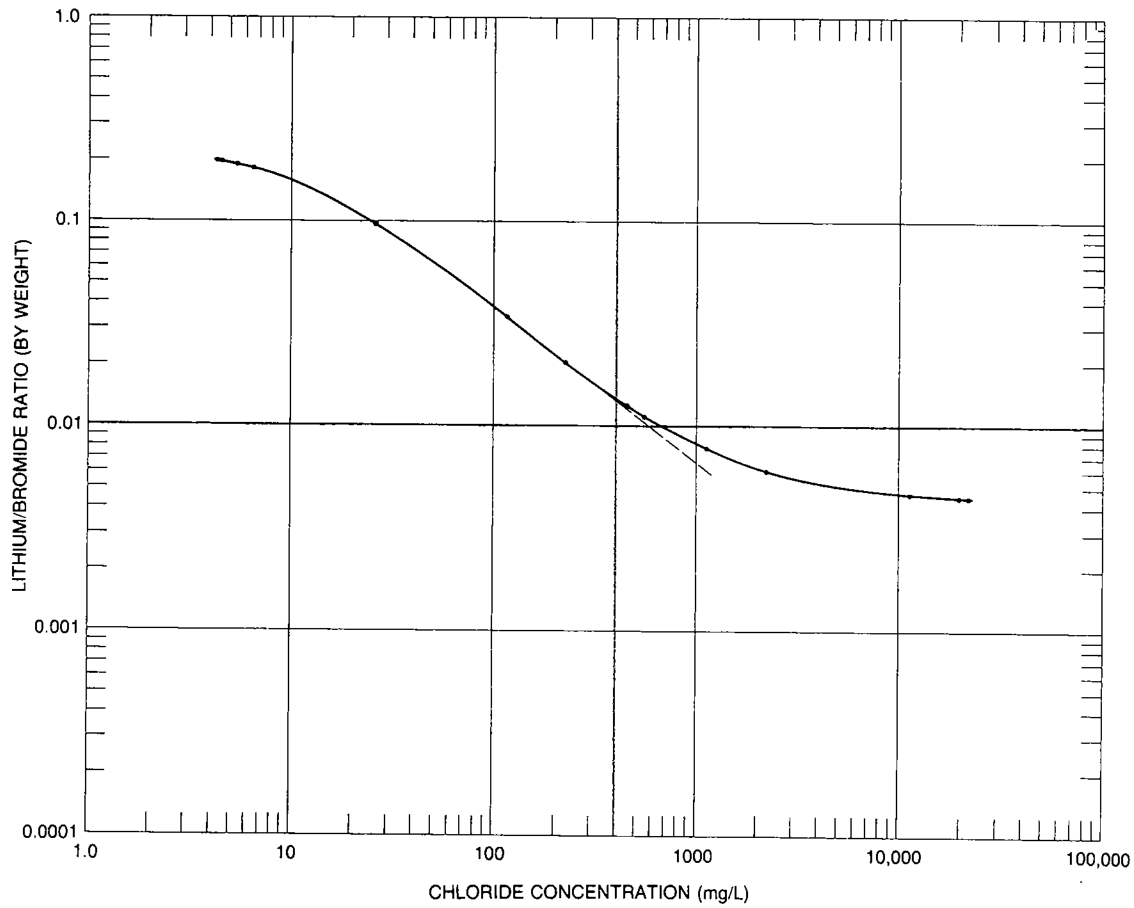


Figure 9. Relationship between lithium/bromide ratios and chloride concentrations resulting from the hypothetical mixing of two solutions with different volumes and concentrations. Concentrations range from 0.02 to 0.5 mg/L of lithium, 0.1 to 110 mg/L of bromide, and 4.3 to 22,000 mg/L of chloride.

the indexes in the case of sodium sulfate water is predictable from the statistical analysis (see following section), which shows no significant difference in sulfate concentration between group 1 (fresh water) and group 2 (degraded water).

The explanation of the anomalous water type in the three wells is not known; the water chemistry may reflect a difference in the local geology or hydrology. Other possible explanations are (1) atypical brine at the time of origin; (2) geochemical alteration of typical brine (gypsum is unknown in the rock column of the area, but the sulfate-type water may be caused by oxidation of the hydrogen sulfide commonly associated with some crude oil); (3) a combination of (1) and (2); or (4) addition of chemicals to the brine by the oil operator after the water leaves the rock, or reservoir, which originally contained it.

Statistical Analysis

A summary of the described indexes is presented in Table 3. Some indexes are more important than others. The three most important are called *primary* indexes; the other four, called *secondary* indexes, have supporting value and are to be used with the primary indexes.

Inspection of the water-sample analyses indicated that—for an index not significantly greater than the minimum (e.g., bromide concentration = 2 mg/L)—concentrations of lithium, strontium, magnesium, and sulfate did not necessarily correlate with changes in the value of the index. For example, a water sample with 3.0 mg/L of bromide may have a lower concentration of strontium than another water sample with a bromide concentration of 2.5 mg/L. Therefore, the primary indexes were statistically evaluated, using analysis of variance and Duncan's multiple-range test. Concentration values for the following constituents were used in the test: bromide, lithium, strontium, dissolved solids, calcium, magnesium, sodium, chloride, and sulfate.

Water samples whose constituent concentrations are too low to be included with the indexed water samples represent fresh water and are called *group 1*. Samples with constituent concentrations compatible with the index values represent degraded water and are called *group 2*. Except for sulfate, each constituent showed a significant statistical difference (at the 95% confidence level) between group 1 and group 2 data when classed according to the indexes. The concentration of sulfate in the water resources of the study area is not significantly different (at the 95% confidence level) between the two groups. The mean sulfate concentration in analyzed water samples from the 347 sites is ~63 mg/L. The two most reliable brine indicators are chloride and bromide. Computer comparison of the difference in standard deviation between waters in groups 1 and 2—segregated according to concentrations of chloride and bromide—shows that chloride is a slightly more reliable indicator than bromide. Chloride at a concentration ⩾400 mg/L is the best single indicator of water degradation by brine. Reliability of the indexes developed in this study usually is increased in a combination of indexes, particularly if one of the indicators is chloride.

The bromide and chloride indexes can be further tested by the R^2 statistic, which measures how much variation in the dependent variable can be accounted for by a linear regression model, according to the following general equation for simple regression:

$$\mu = \alpha + \beta (X - \bar{X}) \qquad (2)$$

where μ = mean of dependent variable (for example, magnesium),
α and β = regression coefficients,
X = sample value for independent variable (for example, chloride), and
$\bar{X}$ = sample mean for independent variable (for example, chloride).

The R^2 statistic multiplied by 100 is a measure, expressed as percent, of how well the dependent variables in groups 1 and 2 correlate with the independent variables, bromide and chloride. The correlation can range from 0 to 100% (the greater the percentage, the better the correlation). Correlations of the dependent variables with bromide and chloride in waters from groups 1 and 2 are shown in Table 4.

When bromide is the independent variable, the correlation with the other constituents in waters of group 1 (fresh water) is weak in most cases, in contrast to strong correlations between bromide and the other constituents in waters of group 2 (degraded water). Similarly, where chloride is the independent variable, correlations with most constituents in waters of group 1 is considerably less than correlations with those constituents in waters of group 2. Sulfate was ignored in the R^2 calculations because, as stated earlier, the sulfate concentration is not significantly different between the two groups.

TABLE 2.—WATER-SAMPLE ANALYSES USED IN CONSTRUCTING FIGURES 7 AND 9 (SEE TEXT)

Figure	Solution	Extreme values of constituent concentrations (mg/L)		
		Sodium		Chloride
7	1	12		4.2
	2	42,000		91,000
		Lithium	Bromide	Chloride
9	1	0.02	0.1	4.3
	2	0.5	110	22,000

Geophysical Method

The vertical change from fresh water to salt water can be seen on geophysical logs. The ideal means of detecting a rise in the interface by using geophysical logs is to compare a log made during well construction with a log from the same hole many years later. Such ideal conditions do not exist for this study; therefore, comparison was made between logs from any two wells no more than 0.5 mi apart, and generally with a difference of at least 20 yr in drilling date. Relative structural positions of the wells and stratigraphic correlations of the sandstone units were considered. A rise of 10 ft was considered significant. About 266 geophysical logs of oil or gas tests (133 pairs; Pl. 1, map C) met the constraints of distance, time, structural position, and stratigraphic correlation. Significant rises in the interface between fresh water and salt water may have occurred in five of the 133 pairs (Table 5) but a widespread rise in the interface apparently has not taken place.

Because porosity logs were not available for most of the older wells and for some of the younger wells, accurate data on dissolved-solids concentrations of the formation waters could not be obtained from standard log analysis; therefore, a qualitative inspection was made of the suite of curves on each log to determine a possible rise in the interface. It was assumed that the change in dissolved solids across the interface occurs in the range of 1,000–1,500 mg/L. In some wells the change from fresh water to salt water is abrupt, whereas in other wells a transition zone of 200 ft or more may exist. In wells with transition zones, the interface depth was drawn at the depth of greatest contrast in the suite of curves.

A rise in the interface may have resulted from disposal of large quantities of brine in wells. The

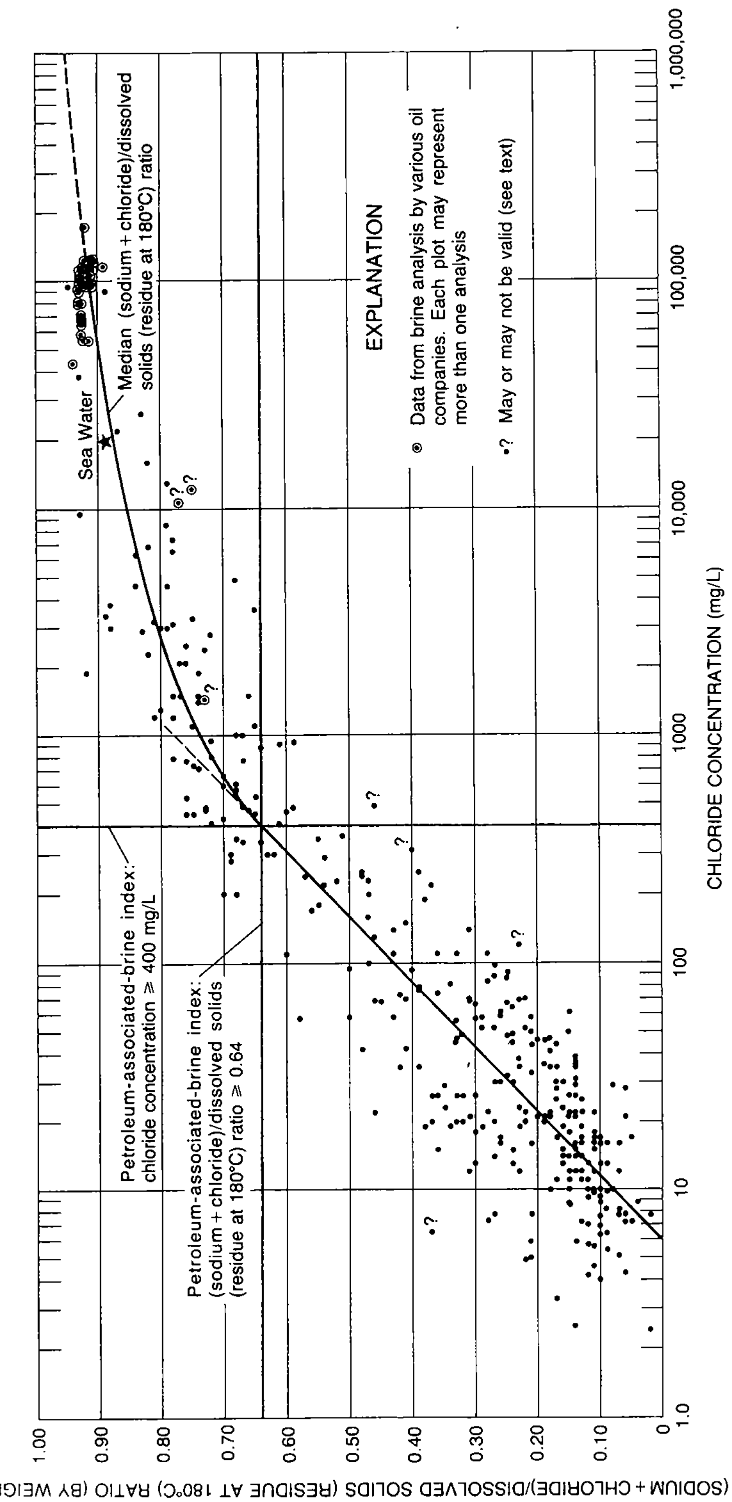


Figure 10. Relationship between ratios of sodium plus chloride to dissolved solids (residue at 180°C) and chloride concentrations.

TABLE 3.—SUMMARY OF BRINE INDEXES

Index type	Description of index (values approximate)
Primary	Chloride concentration ≥ 400 mg/L
Primary	Bromide concentration ≥ 2 mg/L
Primary	Ratio of sodium plus chloride to dissolved solids (residue at 180°C) ≥ 0.64
Secondary	Ratio of lithium to bromide ≤ 0.01 when chloride concentration is ≥ 400 mg/L
Secondary	Median sodium/chloride ratio ≈ 0.46 (range 0.28–0.72) when bromide concentration ≥ 2 mg/L or chloride concentration ≥ 400 mg/L
Secondary	Median sodium/bromide ratio ≈ 92 (range 35–155) when bromide concentration ≥ 2 mg/L
Secondary	Median bromide/chloride ratio ≈ 0.0048 (range 0.0025–0.0090) when bromide concentration ≥ 2 mg/L or chloride concentration ≥ 400 mg/L

TABLE 4.—VALUES OF THE R^2 STATISTIC (%)

Dependent variables	Bromide		Chloride	
	Group 1	Group 2	Group 1	Group 2
Bromide	—	—	81.58	95.98
Lithium	1.39	89.36	2.45	87.53
Strontium	0.68	93.76	2.05	96.61
Dissolved solids	12.38	96.29	22.82	99.07
Calcium	6.90	97.45	10.40	96.86
Magnesium	7.94	94.66	7.22	93.32
Sodium	7.56	96.10	16.24	98.96
Chloride	53.76	96.03	—	—

TABLE 5.—POSSIBLE RISE OF INTERFACE BETWEEN FRESH WATER AND SALT WATER

Location of compared well pairs	Possible rise of interface (ft)
5N-7E-19	230
9N-5E-13	120
11N-6E-35	250
15N-7E-33	90
16N-5E-28	100

disposal wells either are drilled specifically for that purpose or are converted noncommercial oil or gas wells. Brine commonly is introduced into the disposal well from a holding tank. Usually the hydrostatic head of the water column forces brine to enter the disposal zone at depth, but in some areas the brine must be forced into the disposal zone by pumping.

The terms *disposal well* and *injection well* commonly are used interchangeably. An injection well is an opening or hole used to transfer material, usually a fluid, from the surface into the subsurface. A disposal well is used to discard unwanted material, usually a fluid, from the surface to the subsurface. Thus, a disposal well is a special kind of injection well distinguished by its use.

Injection wells, if properly constructed and maintained, usually present no contamination problems. However, mechanical failures in the well, inadequate cementing, pipe corrosion, or otherwise inadequate construction or use may allow the injected brines to travel upward outside the casing, where they can invade shallower permeable formations which may be sources of fresh water. If this situation persists, especially in a pressurized system, the interface between fresh water and salt water rises and fresh water is degraded.

POSSIBLE SOURCES OF BRINES

Possible sources of brines identified in the streams and ground water of the study area are evaluated below:

1) *Solution of salt beds within the Vamoosa–Ada aquifer and underlying formations.* Bedrock in the study area is of Pennsylvanian age and consists mostly of sandstone, shale, siltstone, and limestone. Studies by many investigators have failed to disclose salt or other evaporites in the Pennsylvanian rocks of Oklahoma.

2) *Addition of minerals from agriculture.* Chloride is present only in trace quantities in commercial fertilizers, at most. Consequently, fertilizers are not a source of brines.

3) *Solution of salt from formations of Permian age west of the study area.* About 80 mi west of the study area, formations of Permian age contain salt deposits. The Cimarron River crosses the area of salt deposits (Fig. 1) and carries some salts from solution of these deposits. The average chloride concentration in the Cimarron for the 1976–79 water years, inclusive, was about 3,000 mg/L at Perkins.

During this time, the mean of the mean daily discharges was about 670 ft^3/sec at Perkins. The average chloride concentration for the same period near Guthrie was about 3,300 mg/L. No discharge data are available for the Cimarron River near Guthrie, but flow should be less than at Perkins, because Guthrie is a considerable distance upstream from Perkins. Thus, the average chloride concentration in the Cimarron River decreased about 300 mg/L from Guthrie to Perkins. Geologic and hydrologic data indicate that increased discharge causes a continued decrease in chloride concentration to less than 3,000 mg/L for the remaining distance downstream to the study area. For example, Plate 1 (map A) shows almost 200 ft of hydraulic head toward the Cimarron River along the northern border of the study area. Thus, the Cimarron is for the most part a gaining stream; this is shown by an average flow of 1,244 ft^3/sec at Oilton during 1934–45, a rate almost double the flow of 670 ft^3/sec at Perkins. Lesser streams originating in or a short distance west of the study area are not affected by natural brine contamination because they lack a connection to salt-bearing formations. This hydrologic evidence supports the geochemical evidence (Carpenter, 1978) which discredits re-solution of salt as a source of brine in the study area.

4) *Natural surface discharge of connate brines.* The interface between salt water and fresh water in most places is several hundred feet below land surface, and no known natural hydraulic-head relationship would cause a significant rise in the interface.

5) *Pumpage of ground water.* There is very little use of ground water for irrigation in the study area. Most large- capacity wells are municipal, and degradation of ground-water supplies is not associated with towns or surrounding areas. Most wells in the study area are less than 200 ft deep and yield less than 10 gal/min. The total annual pumpage of ground water is less than 5,000 acre-ft (D'Lugosz and McClaflin, 1986), which is insufficient to induce significant upward movement of the interface.

6) *Natural fluctuations caused by changes in recharge from precipitation.* Natural fluctuations in the interface between salt water and fresh water may result from changes in hydraulic head caused by changes in recharge lasting more than an estimated 20 yr. Available precipitation data indicate no significant changes in precipitation during the last 20 yr; therefore, significant changes in recharge during this time probably have not occurred.

7) *Atmospheric source.* The insignificance of airborne chloride in inland areas is clearly indicated in the literature. Junge and Gustafson (1957) obtained average concentrations of chloride in precipitation at many sampling points in the United States during 1955 and 1956. Their data show that only a small area near the coasts has as much as 0.5 mg/L of chloride in precipitation, and that over most of the country the average is less than 0.3 mg/L. Riffenburg (1925) reported that the average chloride concentration in rainwater for several parts of the world is 3.0 mg/L.

8) *Industrial source.* No known industries in the study area—other than oil or gas—produce a brine effluent; the distribution of observed brine occurrences in the water resources of the project area is related to the distribution of brine effluent from oil and gas operations.

Plate 1 (map B) shows water-sample sites, active and abandoned oil and gas fields, and oil and gas well sites where a significant rise in the interface between salt water and fresh water has occurred. Analyses of 63 surface-water samples and 15 ground-water samples show brine effects by indexes developed in this study. These 78 sampling sites and the five locations showing a rise of the interface are in or near oil or gas fields.

A single oil-field source of brine in a drainage basin may account for more than one degraded surface-water sample downstream. Thus, the 63 surface-water samples showing brine effects do not necessarily represent 63 separate brine sources.

D'Lugosz and McClaflin (1986) determined that the specific conductance of water in Wewoka Creek and its tributaries was 255–44,000 μmho. They determined the entrance points of such mineralized water into the creek by making a series of measurements during a base-flow period in August 1975. The measurements show that specific conductance increased from 5,800 μmho near the mouth of the creek to 19,000 μmho about 8 mi upstream. From the upstream point, specific conductance increased to 44,000 μmho near the headwaters of the creek; the discharge of the creek did not change significantly upstream. These measurements show that mineralized water was entering the upstream reach of Wewoka Creek during August 1975.

Not all sites with degraded water necessarily show visual effects of oil and gas operations, whereas evidence of the incursion of oil and gas activity is apparent at other sites. Most of the circumstances in the following list do not represent isolated instances, but can be observed at several locations; all of these circumstances were identified near present or past oil or gas operations.

1) Salt encrustation is visible on the alluvium surface and along the banks of small tributary streams.

2) Water in a small tributary is briny; dark-brown oil sludge floats on the water and covers the stream banks; flow in the tributary originates near an oil well on the stream bank.

3) Sizeable areas of dead vegetation, including large trees, can be seen near producing wells and associated installations, such as storage tanks for oil and for salt water.

4) Pipe from a salt-water storage tank near a producing well leads to a stream bank; brine is flowing from the pipe, and water downstream from the pipe is degraded.

5) Unlined pits contain brine or brine and crude oil.

6) Analysis of a water sample collected from an unused water well (Appendix 3, analysis 175) in 13N-7E-9, Okfuskee County, (Pl. 1, map B) showed 4,800 mg/L chloride, 1,700 mg/L sodium, 9,530 mg/L dissolved solids (residue at 180°C), and 33 mg/L bromide. Reportedly, water from the well initially was potable, but as the hydraulic head in the Vamoosa–Ada aquifer was lowered by continued use, chemical quality deteriorated. Analysis of water from a nearby stream (Appendix 3, analysis 176) showed 22,000 mg/L chloride, 11,000 mg/L sodium, 38,000 mg/L dissolved solids (residue at 180°C), and 110 mg/L bromide. This area had at one time been the site of an oil well, as evidenced by a concrete base which once supported an oil-well pumping unit; the concrete base is obscured in vegetation several hundred yards east of the unused water well.

7) A domestic well that reportedly once was a source of potable water is now unusable because of degradation of the chemical quality of the water. A salt-water-injection well is located several hundred feet from the unusable domestic well. This relationship can be observed at a number of places in the study area and therefore may be significant.

8) On-site examination of a small tributary disclosed that the water is briny; streamflow originates opposite a salt-water-injection well on the stream bank several hundred feet from the stream.

Collins (1971) gave a detailed discussion of oil and gas operations that may be potential sources of contamination from overflow of brine or emulsions of petroleum and brine from disposal ponds, or from leakage of such liquids from faulty or inadequately constructed ponds. The leaking brines may pass through the soil, reappear at the surface, and produce scar areas. Some brine may remain in the soil, and subsequent leaching will pollute surface streams or shallow subsurface aquifers.

Other potential sources of pollution Collins (1971) discussed are crude oil (or brine) escaping from leaky pipe connections, unplugged or improperly plugged wells, improperly cased and cemented wells, holes in pipelines or storage tanks, and accidents.

Collins (1971) cited casing leaks in disposal wells as a means by which brine may enter fresh-water aquifers. He stated that injected brines must be chemically compatible with the brine in the disposal zone; if they are not, precipitates may form on the face of the injection zone, thus decreasing fluid conductivity. Commonly the injected brines are chemically treated to inhibit precipitation reactions. However, if pressure is used to force brines into a disposal zone, bottomhole pressure must not exceed 1 (lb/ft^2)/ft of overburden, or the hydraulic pressure may induce fracturing and in time the brine may migrate upward to a fresh-water zone. Collins stated that most accidental fractures will be horizontal if the disposal zone beneath the overlying impermeable rocks is no deeper than 1,000 ft. However, if the disposal zone is deeper than 1,500 ft, the fracture orientation may be vertical, resulting in an increased potential for contamination of upper fresh-water zones.

CONCLUSIONS

The presence of brine is most apparent in small streams where dilution is at a minimum and salt crusts and brown oil sludge are fairly common. Degradation of water quality by brine is indicated at 63 of the 167 surface-water sites and 20 of the 180 ground-water sites.

Two methods, chemical-graphical and geophysical, were used for detecting the presence of brine in the water resources. The two more reliable chemical-graphical indexes are: chloride $\geq$400 mg/L, and bromide $\geq$2 mg/L. The chloride index probably is the most reliable of the proposed indexes. All indexes are based on concentrations of chloride, bromide, sodium, lithium, and dissolved solids, or ratios of the concentrations of these constituents and dissolved-solids concentrations. The use of geophysical logs for detecting brine contamination by rise of the interface between fresh water and salt water is reliable in most instances.

The indexes are supported in many places by visual evidence of brine degradation in the streams from which the samples were collected. The same indexes also are applicable to ground waters; however, the presence of brine in ground water is not obvious, because visual evidence is absent. Results of this study indicate that the effect of brine on the water quality of the study area is local rather than extensive.

SELECTED REFERENCES

Bingham, R. H.; and Moore, R. L., 1975, Reconnaissance of the water resources of the Oklahoma City quadrangle, central Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 4, scale 1:250,000, 4 sheets.

Bingham, R. H.; and Bergman, D. L., 1980, Reconnaissance of the water resources of the Enid quadrangle, north-central Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 7, scale 1:250,000, 4 sheets.

Carpenter, A. B., 1978, Origin and chemical evolution of brines in sedimentary basins, *in* Johnson, K. S.; and Russell, J. A. (eds.), Thirteenth annual forum on the geology of industrial minerals: Oklahoma Geological Survey Circular 79, p. 60–77.

Case, L. C., 1977, Water problems in oil production: an operator's manual [2nd ed.]: Petroleum Publishing Co., Tulsa, 163 p.

Chebotarev, I. I., 1955, Metamorphism of natural waters in the crust of weathering, parts 1–3: Geochimica et Cosmochimica Acta, v. 8, p. 22–48, 137–170, 198–212.

Collins, A. G., 1971, Oil and gas wells—potential polluters of the environment: Journal Water Pollution Control Federation, v. 43, no. 12, p. 2382–2393.

—— 1974, Saline groundwaters produced with oil and gas: U.S. Bureau of Mines Project Report 16060 EOO for the U.S. Environmental Protection Agency, 68 p.

—— 1975, Geochemistry of oilfield waters: Elsevier Scientific Publishing Co., Amsterdam, 496 p.

—— 1976, Lithium abundances in oilfield waters, *in* Lithium resources and requirements by the year 2000: U.S. Geological Survey Professional Paper 1005, p. 116–123.

Collins, W. D.; and Williams, K. T., 1933, Chloride and sulfate in rain water: Industrial and Engineering Chemistry, v. 25, p. 944–945.

Dixon, W. J.; and Massey, F. J., 1969, Introduction to statistical analysis: McGraw-Hill, New York, 638 p.

D'Lugosz, J. J.; McClaflin, R. G.; and Marcher, M. V., 1986, Geohydrology of the Vamoosa–Ada aquifer, east-central Oklahoma: Oklahoma Geological Survey Circular 87, 41 p.

Fenneman, N. M.; and Johnson, D. W., 1946, Physical divisions of the United States: U.S. Geological Survey map, scale 1:7,000,000.

Gary, Margaret; McAfee, Robert, Jr.; and Wolf, C. L., 1972, Glossary of geology: American Geological Institute, Falls Church, Va., 805 p.

Hart, D. L., Jr., 1974, Reconnaissance of the water resources of the Ardmore and Sherman quadrangles, southern Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 3, scale 1:250,000, 4 sheets.

Hawley, G. G. (ed.), 1971, The condensed chemical dictionary [8th ed.]: Van Nostrand Reinhold, New York, 971 p.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water [1st ed.]: U.S. Geological Survey Water-Supply Paper 1473, 269 p.

—— 1970, Study and interpretation of the chemical characteristics of natural water [2nd ed.]: U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Junge, C. E.; and Gustafson, P. E., 1957, On the distribution of sea salt over the United States and its removal by precipitation: Tellus, v. 9, p. 164–173.

Keys, W. S.; and MacCary, L. M., 1973, Location and characteristics of the interface between brine and fresh water from geophysical logs of boreholes in the Upper Brazos River basin, Texas: U.S. Geological Survey Professional Paper 809-B, p. B1–B23.

Langbein, W. B.; and Iseri, K. T., 1960, General introduction and hydrologic definitions: U.S. Geological Survey Water-Supply Paper 1541-A, p. 1–29.

Leonard, R. B., 1964, A method for evaluating oil-field-brine pollution of the Walnut River in Kansas, *in* Geological Survey Research 1984: U.S. Geological Survey Professional Paper 501-B, p. B173–B176.

—— 1972, Chemical quality of water in the Walnut River basin, south-central Kansas: U.S. Geological Survey Water-Supply Paper 1982, 113 p.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Lohman, S. W.; and others, 1972, Definitions of selected ground-water terms—revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.

McCaslin, J. C., 1977, Here are the big U.S. reserves: Oil and Gas Journal, v. 75, no. 5, p. 129–132.

Miller, D. W. (ed.), 1980, Waste disposal effects on ground water, *in* The report to Congress, waste disposal practices and their effects on ground water: U.S. Environmental Protection Agency, 512 p.

Miodrag, Sarkovic, 1975, Should we consider geochemistry as important exploratory technique?: Oil and Gas Journal, v. 73, no. 31, p. 106–110.

National Oceanic and Atmospheric Administration, 1978, Tulsa, Okla., International Airport: Airport Climatological Summary, 18 p.

Revelle, Roger, 1941, Criteria for recognition of sea water in ground-waters: American Geophysical Union Transactions, v. 22, p. 593–597.

Riffenburg, H. B., 1925, Chemical character of ground waters of the northern Great Plains: U.S. Geological Survey Water-Supply Paper 560, p. 31–52.

Rittenhouse, Gordon, 1967, Bromine in oil-field waters and its use in determining possibilities of origin of these waters: American Association of Petroluem Geologists Bulletin, v. 51, p. 2430–2440.

Skougstad, M. W.; and others (eds.), 1979, Methods for determination of inorganic substances in water and fluvial sediments: Techniques of Water Resources Investigations of the United States Geological Survey, Book 5, Chap. A-1, 626 p.

White, D. E., 1965, Saline waters of sedimentary rocks, *in* Fluids in subsurface environments—a symposium: American Association of Petroleum Geologists Memoir 4, p. 342–366.

White, D. E.; Hem, J. D.; and Waring, G. A., 1963, Chemical composition of subsurface waters, *in* Data of geochemistry [6th ed.]: U.S. Geological Survey Professional Paper 440-F, p. F1–F67.

Whittemore, D. O.; and Pollack, L. M., 1979, Determination of salinity sources in water resources of Kansas by minor alkali metal and halide chemistry: Kansas Water Resources Research Institute Contribution No. 208, 28 p.

Woolf, H. B. (ed.), 1979, Webster's new collegiate dictionary: G. and C. Merriam Co., Springfield, Mass., 1532 p.

Wright, Jack; Pearson, Cynthia; Kurt, E. T.; and Watkins, J. W., 1957, Analyses of brines from oil-productive formations in Oklahoma: U.S. Bureau of Mines Report of Investigations 5326, 71 p.

Appendixes

Appendix 1: Glossary of Technical Terms

The following definitions are in part from Dixon and Massey (1969), Hawley (1971), Lohman (1972), Lohman and others (1972), Gary and others (1972), Hem (1970), Skougstad and others (1979), and Woolf (1979). Some definitions have been modified.

Acre-foot—The volume of water required to cover 1 acre to a depth of 1 ft; equivalent to 43,560 ft^3 or 325,851 U.S. gal.

Alkali metal—A metal in group 1A of the periodic system: lithium, sodium, potassium, rubidium, cesium, and francium.

Aquifer—A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Base flow—Sustained or fair-weather streamflow, usually composed mostly of ground-water effluent.

Breccia—A coarse-grained clastic rock composed of large (>2 mm diameter), angular rock fragments cemented by a fine-grained matrix.

Brine—A solution of sodium chloride and water, usually containing other salts also; concentrations are 3–20% or more.

Cation—An ion with a positive charge. An ion is an atom or radical that has lost or gained one or more electrons and thus has acquired an electric charge.

Confidence level—A percentage indicating how sure one is of the inference being made. In statistics the value for the confidence level is $1-\alpha$, where α is the area in the critical region at either end of a normal distribution curve.

Confined ground water—Ground water under pressure significantly greater than atmospheric; its upper limit is the bottom of a bed of distinctly lesser hydraulic conductivity than that of the material in which the confined water occurs.

Conglomerate—A coarse-grained, clastic sedimentary rock composed of rounded (to subangular) fragments >2 mm in diameter in a fine-grained matrix of sand, silt, or any of the common natural cementing materials.

Connate water—Water that is contained in a rock and that has not been in contact with the atmosphere essentially since the rock was formed.

Diagenesis (mineral)—All the chemical, physical, and biological changes undergone by a sediment after its deposition, and during and after its lithification, exclusive of surficial alteration (weathering) and metamorphism.

Evaporite—A nonclastic sedimentary rock composed primarily of minerals produced from a saline solution that became concentrated by evaporation.

Fault—A surface or zone of rock fracture along which there has been displacement.

Geophysical log—A log obtained by lowering an instrument into a borehole or well and recording continuously on a meter at the surface some physical property of the rock material being logged.

Gypsum—A widely distributed mineral consisting of hydrous calcium sulfate: $CaSO_4 \cdot 2H_2O$.

Halides—Binary compounds of the halogens: fluorine, chlorine, bromine, iodine, and astatine.

Head, static—The height (above a standard datum) of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point.

Homocline—A sequence of strata inclined from the horizontal at a uniform angle over a wide area.

Hydraulic conductivity—In a porous, isotropic medium, the volume of homogeneous water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Ion—An atom or radical that has lost or gained one or more electrons and has thus acquired an electric charge.

Mean—A central value, or average, of a distribution, defined as the sum of all observations divided by the number of observations.

Median—A central value defined as the middle observation if there is an odd number of observations, or (by convention) the mean of the two central observations if there is an even number of observations.

National Geodetic Vertical Datum of 1929 (NGVD of 1929)—A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada; formerly called *mean sea level.*

Normal fault—A fault in which rocks above the fault appear to have moved downward relative to rocks below the fault.

Pennsylvanian—A period of the Paleozoic Era, and its corresponding system of rocks, thought to represent the span of time between 320 and 280 million years ago.

Permian—The last period of the Paleozoic Era, and its corresponding system of rocks, thought to represent the span of time between 280 and 225 million years ago.

Potentiometric surface—A surface which represents the static head; as related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. The water table is a particular potentiometric surface.

Recharge—The absorption and addition of water to the zone of saturation; also, the volume of water added.

Residue at 180°C—The weight of material remaining from an aliquot of a water sample dried at 180°C for 2 hr and immediately weighed.

Specific conductance—The reciprocal of the resistance, in ohms, measured between opposite faces of a centimeter cube of an aqueous solution at a specific temperature.

Specific yield—The ratio of (1) the volume of water which a saturated rock or soil will yield by gravity to (2) the volume of the rock or soil. The definition implies that gravity drainage is complete.

Standard deviation—The positive square root of the variance of a distribution.

Storage coefficient—The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Stratigraphy—The branch of geology that deals with the definition and description of major and minor natural divisions of rocks available for study in outcrops or in the subsurface, and with the interpretation of their significance.

Transmissivity—The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Unconfined ground water—Ground water in an aquifer that has a water table.

Variance—The sum of squares of the deviations of the observations from the arithmetic mean of the observations, divided by one less than the total number of observations; a measure of the spread of a distribution about the mean.

Viscosity—Internal resistance to flow of a substance; its internal friction.

Water table—That surface in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water. In wells which penetrate to greater depths, the water level will stand above or below the water table if an upward or downward component of ground-water flow exists.

Appendix 2: Conversion Factors

Multiply inch-pound unit	By	To obtain SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot per second (ft^3/sec)	0.02832	cubic meter per second (m^3/sec)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.59	square kilometer (km^2)
gallon per minute (gal/min)	0.06309	liter per second (L/sec)
acre	4,047.856	square meter (m^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
foot per day (ft/day)	0.3048	meter per day (m/day)
square foot per day (ft^2/day)	0.0929	square meter per day (m^2/day)
gallon (gal)	3.785	liter (L)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
pound per square inch per foot (lb/in.^{2}/ft)	0.23	kilogram per square centimeter per meter (kg/cm^2/m)
micromhos per centimeter [at 25°C] (μmho/cm)	1	microsiemens per centimeter [at 25°C] (μS/cm)

APPENDIX 3: Chemical analyses of water from selected streams and wells

Site	Sample Location	Sample Date	Sample Time	Well depth, total (ft)	Streamflow, instantaneous (cfs)	Specific conductance (μmho)	Field pH	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
					CREEK COUNTY						
1	14N-06E-12 AAA	80-02-27	1500	260	--	690	7.5	230	0	47.0	28.0
2	14N-07E-09 BCB	80-03-03	1630	236	--	720	7.6	200	0	39.0	24.0
3	14N-07E-12 CCB	80-03-04	1145	--	<0.10	159	7.3	67	13	15.0	7.1
4	14N-07E-14 BBB	80-03-04	1045	117	--	284	6.9	120	18	27.0	12.0
5	14N-07E-18 ACA	80-03-04	0830	--	0.20	3710	7.9	900	690	200.0	96.0
6	14N-07E-20 DCD	80-03-05	1330	--	<0.10	136	7.1	40	16	8.5	4.6
7	14N-07E-23 DDA	80-03-05	1100	63	--	226	6.6	98	9	21.0	11.0
8	14N-07E-27 AAA	80-03-05	1200	--	0.10	194	6.7	45	13	11.0	4.3
9	14N-07E-29 DAD	80-03-05	1530	38	--	194	5.8	38	4	9.4	3.4
10	14N-08E-06 BBA	80-03-04	1530	--	0.10**	4820	3.7	740	740	160.0	81.0
11	14N-08E-06 BCC	80-03-04	1430	35	--	4310	6.5	930	860	230.0	85.0
12	14N-08E-09 BAB	80-03-06	1400	--	3.50	2440	7.7	500	370	130.0	42.0
13	14N-08E-12 BBB	80-03-06	1730	--	<0.10	281	9.1	59	35	14.0	5.8
14	14N-08E-15 BDA	80-03-06	1230	114	--	138	5.5	32	30	8.5	2.7
15	14N-08E-21 CBB	80-03-06	1000	--	<0.10	134	6.7	36	18	7.0	4.6
16	14N-08E-30 CCB	80-03-05	0930	--	<0.10	4180	6.8	640	610	150.0	64.0
17	15N-07E-02 BCC	80-04-03	0915	118	--	1000	7.3	390	60	80.0	45.0
18	15N-07E-15 CBB	80-04-08	1500	--	<0.10	670	8.2	270	9	63.0	27.0
19	15N-07E-15 CCD	80-08-03	1630	147	--	390	7.6	170	0	40.0	17.0
20	15N-07E-19 DDD	80-04-03	1800	140	--	615	7.3	260	50	46.0	35.0
21	15N-07E-24 AAA	80-04-03	1500	111	--	422	7.6	190	0	43.0	21.0
22	15N-07E-26 CCB	80-03-04	1800	59	--	520	7.1	240	1	57.0	24.0
23	15N-07E-26 CDC	80-03-04	1630	--	0.25	232	7.8	91	5	21.0	9.3
24	15N-07E-29 CDD	80-02-28	1630	--	<0.10	3213	8.2	1400	1000	260.0	170.0
25	15N-08E-04 DCD	80-03-13	0830	41	--	150	7.6	45	0	13.0	3.1
26	15N-08E-07 BBB	80-04-03	1245	159	--	2110	6.7	490	410	110.0	52.0
27	15N-08E-08 BAA	80-03-12	1745	--	<0.10	2580	7.5	390	330	91.0	40.0
28	15N-08E-10 AAA	80-03-12	1500	--	<0.10	649	7.4	290	44	68.0	30.0
29	15N-08E-11 AAA	80-03-12	1630	119	--	561	7.4	230	0	48.0	26.0
30	15N-08E-15 CDC	80-03-12	1200	134	--	471	6.8	130	30	28.0	14.0
31	15N-08E-16 CCC	80-03-11	1800	--	<0.10	7300	8.1	1000	920	250.0	91.0
32	15N-08E-17 CDD	80-03-12	0930	85	--	700	7.2	350	16	71.0	41.0
33	15N-08E-26 BBA	80-03-12	1300	--	<0.10	1530	7.5	290	180	71.0	28.0
34	15N-08E-28 DCC	80-03-11	1415	--	<0.10	1290	7.6	260	110	63.0	24.0
35	15N-08E-33 CBB	80-03-11	1645	51	--	154	6.0	60	12	15.0	5.5
36	15N-08E-34 DDD	80-03-06	1630	114	--	760	7.2	300	140	69.0	30.0
37	15N-09E-31 CCC	80-03-11	1200	99	--	3500	12.7	800	51	320.0	0.3
38	15N-09E-32 BCC	80-03-11	0945	--	0.30	1120	7.7	200	120	49.0	18.0
39	16N-07E-10 DDC	80-04-02	1400	59	--	285	6.4	93	24	26.0	6.7
40	16N-07E-16 BBB	80-04-01	1600	--	<0.10	1700	8.6	250	180	62.0	23.0
41	16N-07E-17 DCD	80-04-01	1800	178	--	459	7.5	190	13	47.0	18.0
42	16N-07E-23 ABA	80-04-02	1200	--	7.00	1400	7.9	270	160	66.0	26.0
43	16N-07E-26 BCA	80-04-02	1100	109	--	560	7.4	240	0	57.0	24.0
44	16N-07E-28 ADD	80-04-02	0900	--	0.75	568	8.0	170	48	39.0	17.0
45	16N-08E-02 CAD	80-03-18	1715	--	<0.10	158	7.4	54	17	12.0	5.8
46	16N-08E-04 BAC	80-03-19	1015	34	--	320	7.0	110	2	31.0	8.4
47	16N-08E-07 CAD	80-05-07	1445	210	--	202	6.4	82	13	19.0	8.4
48	16N-08E-13 DCD	80-03-18	1615	158	--	545	7.4	240	0	52.0	26.0
49	16N-08E-16 ABB	80-03-18	1145	--	<0.10	2630	8.3	490	310	110.0	52.0
50	16N-08E-16 DDA	80-03-18	0945	99	--	261	6.3	89	30	21.0	8.8

Sodium, dissolved (mg/L as Na)	Sodium-adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Iodide, dissolved (mg/L as I)	Silica, dissolved (mg/L as SiO_2)	Total dissolved solids* (mg/L)	Lithium, dissolved (µg/L as Li)	Strontium, dissolved (µg/L as Sr)	Organic carbon, dissolved (mg/L as C)
					CREEK COUNTY								
45.0	1.3	2.7	280	13.0	36.0	0.2	0.2	--	17.0	356	20	410	8.5
71.0	2.2	6.9	310	27.0	19.0	0.4	0.1	--	18.0	398	40	850	--
7.3	0.4	1.2	54	17.0	10.0	0.2	0.2	--	14.0	112	6	50	4.7
9.1	0.4	0.8	99	14.0	9.7	0.2	0.2	0.01	16.0	169	9	60	1.5
390.0	5.7	5.2	210	50.0	1000.0	0.2	4.0	0.04	12.0	2060	20	1900	4.3
7.8	0.5	1.6	24	18.0	10.0	0.1	0.1	--	9.7	100	<4	40	3.8
5.1	0.2	1.3	89	11.0	5.1	0.2	0.1	--	18.0	140	5	70	2.3
13.0	0.8	1.6	32	19.0	20.0	0.1	0.5	--	15.0	121	<4	60	3.3
21.0	1.5	0.6	34	19.0	15.0	0.1	0.3	0.00	26.0	136	10	60	3.1
630.0	10.0	9.2	0	7.6	1500.0	0.2	11.0	0.01	20.0	2740	10	4200	2.4
480.0	6.9	5.2	63	11.0	1400.0	0.1	6.4	0.00	24.0	2540	20	1300	6.4
280.0	5.5	4.0	130	9.9	660.0	0.3	22.0	--	11.0	1350	10	1800	--
23.0	1.3	2.3	24	27.0	42.0	0.1	0.3	--	5.9	160	<4	90	5.9
9.3	0.7	1.0	2	12.0	20.0	0.0	0.2	--	13.0	91	6	50	1.0
16.0	1.2	1.7	18	15.0	26.0	0.1	0.3	0.00	17.0	126	7	60	--
510.0	8.8	7.3	28	20.0	1200.0	0.1	19.0	0.01	12.0	2190	20	2000	2.9
52.0	1.2	7.1	330	47.0	98.0	0.2	0.3	0.00	18.0	550	40	4700	--
30.0	0.8	5.4	260	25.0	35.0	0.3	0.4	--	8.4	366	8	380	--
13.0	0.4	1.5	180	5.0	6.9	0.2	0.1	--	16.0	204	10	200	--
29.0	0.8	2.0	210	54.0	30.0	0.1	0.3	--	18.0	343	10	920	--
9.3	0.3	1.5	210	1.3	4.3	0.1	0.1	--	15.0	220	20	180	--
12.0	0.3	1.4	240	3.5	13.0	0.2	0.2	--	18.0	277	20	170	4.9
8.1	0.4	2.1	86	12.0	12.0	0.2	0.1	--	13.0	138	6	80	3.9
160.0	1.9	3.4	310	25.0	910.0	0.3	4.5	0.02	19.0	1760	10	2500	3.8
6.1	0.4	3.3	45	11.0	5.9	0.1	0.1	--	17.0	87	5	60	17.0
220.0	4.3	4.8	80	30.0	570.0	0.1	3.2	0.03	18.0	1160	10	470	--
350.0	7.7	5.0	67	30.0	730.0	0.2	3.8	0.02	7.2	1440	20	1600	9.0
23.0	0.6	1.9	250	41.0	29.0	0.3	0.3	--	13.0	365	6	340	6.1
32.0	0.9	2.5	280	4.3	7.2	0.3	0.1	--	15.0	304	30	250	8.0
46.0	1.8	1.6	98	30.0	68.0	0.1	0.5	--	12.0	253	10	130	3.4
1100.0	15.0	10.0	85	21.0	2300.0	0.1	10.0	0.04	4.6	4160	40	5600	6.9
13.0	0.3	1.2	330	13.0	16.0	0.2	0.4	0.01	19.0	385	20	130	--
200.0	5.1	5.8	110	14.0	430.0	0.2	2.2	--	3.3	897	9	1100	12.0
140.0	3.8	3.0	150	12.0	300.0	0.2	1.4	--	12.0	692	9	820	7.0
6.4	0.4	1.0	48	8.1	12.0	0.1	0.1	--	21.0	81	5	80	2.6
18.0	0.5	3.7	160	68.0	86.0	0.1	0.5	--	11.0	409	30	350	--
26.0	0.4	21.0	--	55.0	17.0	0.3	0.2	0.00	3.8	847	20	1700	14.0
130.0	4.0	2.3	78	16.0	280.0	0.1	2.0	--	6.3	593	6	680	2.8
14.0	0.6	0.8	69	18.0	23.0	0.1	0.1	--	17.0	157	6	70	--
240.0	6.6	3.9	71	49.0	450.0	0.1	2.8	0.01	5.5	915	10	1100	--
14.0	0.4	1.8	180	29.0	7.6	0.1	0.1	--	17.0	219	10	930	--
150.0	4.0	4.2	110	12.0	330.0	0.2	2.0	--	3.7	745	10	880	--
22.0	0.6	2.6	250	4.7	19.0	0.2	0.2	--	19.0	302	30	290	--
43.0	1.4	3.4	120	20.0	77.0	0.2	0.6	--	3.4	307	<4	370	--
9.4	0.6	1.7	37	12.0	15.0	0.2	0.1	--	12.0	102	<4	60	3.4
2.9	0.1	20.0	110	11.0	2.4	0.2	0.1	--	14.0	218	<4	180	8.7
5.4	0.3	1.2	69	9.8	6.3	0.2	0.1	--	17.0	112	<4	40	--
15.0	0.4	3.4	240	10.0	16.0	0.2	0.1	--	16.0	278	30	410	2.8
330.0	6.5	1.3	180	9.8	790.0	0.4	2.9	--	5.5	1430	10	1600	6.7
8.8	0.4	5.6	59	24.0	12.0	0.1	0.1	--	13.0	141	<4	90	27.0

APPENDIX 3. – *Continued*

Site	Sample Location	Date	Time	Well depth, total (ft)	Streamflow, instantaneous (cfs)	Specific conductance (µmho)	Field pH	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
					CREEK COUNTY *Continued*						
51	16N-08E-19 BDC	80-04-02	1730	101	--	141	6.0	51	16	12.0	5.2
52	16N-08E-26 BAB	80-03-13	1330	--	0.30	1340	8.0	240	150	61.0	22.0
53	16N-08E-27 DDA	80-03-13	1230	140	--	440	8.4	180	15	41.0	20.0
54	16N-08E-31 BBB	80-04-02	1515	--	<0.10	219	7.5	80	13	19.0	8.0
55	16N-09E-06 DDD	80-03-20	1015	120	--	136	5.6	38	22	9.0	3.8
56	16N-09E-08 CCC	80-03-18	1400	--	<0.10	9100	8.0	1200	1100	350.0	72.0
57	17N-07E-02 BAB	80-07-09	1400	121	--	860	7.0	300	0	50.0	42.0
58	17N-07E-03 BBC	78-03-29	1000	--	0.10**	15000	5.7	33000	33000	10000.0	1900.0
59	17N-07E-03 CCD	80-05-09	0830	--	0.04	8500	7.2	1300	1200	320.0	110.0
60	17N-07E-08 BAA	80-05-08	1230	--	<0.10	22360	8.0	3800	3700	1000.0	320.0
61	17N-07E-12 CCB	80-05-08	1330	256	--	460	8.0	200	0	40.0	25.0
62	17N-07E-16 CBB	80-05-08	1830	110	--	2750	6.7	1100	970	220.0	130.0
63	17N-07E-18 BAA	80-07-11	0900	58	--	340	--	130	51	31.0	12.0
64	17N-07E-19 DCD	80-07-10	1800	190	--	460	--	260	59	49.0	33.0
65	17N-07E-23 CAC	80-05-08	1530	--	<0.10	850	8.4	100	49	26.0	9.3
66	17N-07E-25 ADD	80-05-08	1000	153	--	218	5.8	54	26	12.0	5.8
67	17N-07E-28 AAA	80-05-09	1045	108	--	610	6.2	190	130	43.0	19.0
68	17N-07E-31 DAD	80-05-07	1100	--	0.10	845	7.9	400	55	86.0	46.0
69	17N-07E-33 DDC	80-05-07	1015	--	0.75	2800	8.0	380	310	98.0	33.0
70	17N-07E-35 CAA	80-05-07	1800	146	--	419	6.7	180	32	40.0	20.0
71	17N-08E-07 ABB	80-05-08	1115	--	<0.10	2225	7.9	410	260	93.0	43.0
72	17N-08E-09 BBB	80-07-09	1530	67	--	184	5.5	50	16	12.0	4.9
73	17N-08E-10 AAA	80-07-10	1230	43	--	700	--	170	15	65.0	2.9
74	17N-08E-12 CDD	80-04-08	1700	--	<0.10	1120	7.2	240	170	51.0	27.0
75	17N-08E-14 CDD	80-07-10	1030	--	<0.10	1462	--	340	240	74.0	37.0
76	17N-08E-15 CCD	80-03-19	1630	--	<0.10	4700	7.1	890	860	190.0	100.0
77	17N-08E-17 DCC	80-03-19	1530	--	<0.10	800	8.3	220	110	45.0	25.0
78	17N-08E-21 BCB	80-03-19	1430	79	--	232	6.6	79	0	17.0	8.8
79	17N-08E-26 CBD	80-03-19	1800	144	--	350	7.6	150	0	37.0	14.0
80	17N-08E-32 CCA	80-03-19	1200	--	<0.10	522	7.9	100	43	25.0	9.1
81	17N-08E-36 DDC	80-03-20	1300	117	--	244	6.3	60	14	13.0	6.6
82	17N-09E-30 BDC	80-03-20	1100	--	1.00	940	8.0	190	97	47.0	18.0
83	18N-07E-01 DCD	80-04-23	1645	115	--	1300	7.2	460	81	97.0	52.0
84	18N-07E-05 ABA	80-04-23	1030	160	--	710	6.7	230	34	54.0	24.0
85	18N-07E-08 DAA	80-04-18	1400	--	0.01	36000	7.5	6400	6300	1800.0	450.0
86	18N-07E-10 AAD	80-05-06	1430	181	--	740	7.3	270	0	63.0	25.0
87	18N-07E-16 ACD	80-04-18	1200	95	--	1581	7.1	670	420	180.0	53.0
88	18N-07E-19 CAA	80-04-18	0900	--	2.30	6510	8.0	1000	790	260.0	93.0
89	18N-07E-23 ABA	80-05-06	1600	--	0.01	1004	8.3	470	150	74.0	70.0
90	18N-07E-29 CBB	80-04-17	1745	45	--	998	7.3	380	130	87.0	40.0
91	18N-08E-01 CAC	80-07-17	1700	138	--	375	6.0	150	110	34.0	16.0
92	18N-08E-04 DDA	80-07-18	1000	168	--	349	7.3	260	90	64.0	24.0
93	18N-08E-18 ABA	80-04-23	1800	--	0.35	376	8.2	150	17	34.0	15.0
94	18N-08E-21 CBC	80-07-11	1045	51	--	138	--	48	15	12.0	4.4
95	18N-08E-22 BAB	80-07-11	1200	--	0.01	370	--	170	37	37.0	18.0
96	18N-08E-24 ABB	80-07-16	1430	120	--	192	6.6	88	6	21.0	8.4
97	18N-08E-31 BAA	80-05-06	1800	28	--	920	7.1	310	35	63.0	38.0
98	18N-08E-32 ADA	80-07-09	1600	--	<0.10	460	7.9	190	25	41.0	20.0
99	18N-08E-34 AAB	80-07-10	1430	171	--	330	--	170	0	35.0	20.0
100	18N-09E-08 BCB	80-07-16	1600	--	<0.10	900	7.7	260	24	66.0	24.0
101	18N-09E-30 AAA	80-07-16	1200	300	--	440	7.2	300	34	77.0	27.0
102	18N-09E-31 CCC	80-07-10	1600	103	--	371	--	190	0	34.0	26.0
103	19N-07E-26 CDD	80-04-23	1230	--	2.00	1880	8.0	540	340	130.0	52.0
104	19N-07E-36 AAA	80-04-23	1330	--	1.10	440	7.9	150	28	36.0	14.0
105	19N-08E-15 ABA	80-07-24	1500	126	--	3290	7.4	840	670	240.0	56.0

Sodium, dissolved (mg/L as Na)	Sodium-adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Iodide, dissolved (mg/L as I)	Silica, dissolved (mg/L as SiO_2)	Total dissolved solids* (mg/L)	Lithium, dissolved (µg/L as Li)	Strontium, dissolved (µg/L as Sr)	Organic carbon, dissolved (mg/L as C)
					CREEK COUNTY *Continued*								
4.7	0.3	1.4	35	21.0	4.0	0.1	0.1	0.03	13.0	83	<4	70	--
150.0	4.2	3.3	90	11.0	340.0	0.2	1.7	--	7.2	731	10	1100	8.8
14.0	0.4	1.5	170	21.0	12.0	0.1	0.1	0.01	14.0	237	10	100	1.7
8.6	0.4	2.1	67	17.0	10.0	0.1	0.1	--	14.0	126	<4	70	--
7.2	0.5	1.0	16	14.0	13.0	0.2	0.1	0.01	14.0	83	<4	40	4.1
1400.0	18.0	11.0	63	18.0	3000.0	0.2	14.0	0.09	6.0	5020	510	15000	5.6
25.0	0.6	1.7	320	28.0	7.7	0.4	0.0	0.00	14.0	437	10	520	--
64000.0	154.0	820.0	66	--	95000.0	--	240.0	9.80	--	168000	--	--	--
1300.0	16.0	15.0	61	23.0	2900.0	0.2	15.0	0.15	9.3	5040	90	6900	--
3900.0	27.0	38.0	120	16.0	17000.0	0.1	--	--	9.3	15600	210	--	--
24.0	0.7	2.8	220	17.0	5.7	0.2	0.1	--	18.0	253	6	1100	--
82.0	1.1	4.4	120	0.5	830.0	0.2	4.6	0.01	20.0	1820	50	560	--
22.0	0.9	0.8	76	13.0	74.0	0.2	0.4	0.01	15.0	263	7	150	--
17.0	0.5	1.4	200	68.0	22.0	0.3	0.1	0.01	13.0	335	20	520	--
120.0	5.1	4.8	55	25.0	200.0	0.3	1.1	--	6.7	473	10	670	--
17.0	1.0	1.1	28	21.0	26.0	0.2	0.4	--	15.0	115	6	60	--
39.0	1.2	3.4	58	59.0	110.0	0.1	0.8	--	20.0	349	10	120	--
32.0	0.7	5.1	350	52.0	39.0	0.3	0.4	--	9.8	503	<4	620	--
390.0	8.7	7.4	70	10.0	770.0	0.2	4.1	0.05	3.1	1530	20	2000	--
11.0	0.4	1.5	150	16.0	22.0	0.2	0.2	0.00	19.0	221	10	70	--
280.0	6.0	5.5	150	27.0	600.0	0.2	4.0	0.01	13.0	1260	10	2100	--
11.0	0.7	0.8	34	7.6	29.0	0.2	0.2	0.00	13.0	115	<4	90	--
13.0	0.4	7.2	160	5.4	8.2	0.1	0.1	0.01	12.0	246	8	410	--
110.0	3.1	2.5	69	19.0	290.0	0.1	1.6	0.00	9.5	627	8	630	--
190.0	4.5	2.3	94	7.5	480.0	0.3	1.8	0.05	16.0	993	10	1300	--
540.0	7.9	5.9	30	26.0	1500.0	0.2	7.6	0.01	3.2	2630	10	2900	4.4
61.0	1.8	2.3	110	7.1	170.0	0.3	0.4	--	10.0	410	4	450	11.0
12.0	0.6	1.3	96	0.2	4.2	0.4	0.0	--	22.0	130	10	90	7.3
13.0	0.5	1.3	150	2.8	11.0	0.3	0.1	--	14.0	182	10	140	3.9
59.0	2.6	1.9	57	18.0	110.0	0.2	0.6	--	14.0	280	4	270	3.4
22.0	1.2	2.1	46	21.0	19.0	0.2	0.2	--	18.0	143	<4	60	10.0
86.0	2.7	2.2	95	13.0	180.0	0.2	1.1	--	5.3	479	10	570	3.3
66.0	1.3	4.3	380	170.0	31.0	0.3	0.1	0.01	15.0	665	20	3900	--
51.0	1.5	1.5	200	46.0	66.0	0.2	0.4	--	18.0	390	20	470	--
7200.0	39.0	96.0	140	43.0	16000.0	0.3	84.0	0.69	9.5	28200	930	62000	--
50.0	1.3	3.9	290	70.0	11.0	0.3	0.1	--	17.0	417	10	9200	--
47.0	0.8	1.9	250	13.0	380.0	0.4	2.6	--	15.0	1040	20	800	--
950.0	13.0	12.0	250	14.0	2100.0	0.3	8.4	0.09	14.0	3960	70	6700	--
45.0	0.9	3.5	320	170.0	50.0	0.4	0.4	--	3.5	646	10	310	--
62.0	1.4	2.4	250	67.0	140.0	0.2	0.9	--	19.0	648	10	2200	--
18.0	0.6	2.0	39	40.0	40.0	0.3	0.1	0.01	16.0	295	10	240	--
40.0	1.1	2.4	170	57.0	36.0	0.3	0.1	0.00	17.0	399	20	1000	--
19.0	0.7	2.3	130	21.0	20.0	0.2	0.3	0.01	2.1	203	<4	170	--
7.6	0.5	0.6	33	16.0	7.8	0.2	0.1	0.00	14.0	94	<4	70	--
26.0	0.9	5.5	130	26.0	69.0	0.3	0.2	0.01	14.0	306	5	230	--
6.2	0.3	0.7	82	7.7	6.3	0.2	0.1	0.00	16.0	121	10	730	--
28.0	0.7	1.8	280	16.0	46.0	0.2	0.9	--	17.0	375	20	680	--
28.0	0.9	3.5	160	22.0	52.0	0.3	0.2	0.01	8.0	279	9	300	--
16.0	0.5	1.6	180	7.6	7.0	0.3	0.0	0.01	14.0	196	9	320	--
140.0	3.8	3.3	240	7.8	240.0	0.3	0.6	0.06	14.0	671	8	530	--
14.0	0.4	1.2	270	9.2	36.0	0.3	0.2	0.00	11.0	349	10	140	--
21.0	0.7	1.7	210	15.0	14.0	0.3	0.1	0.01	16.0	246	10	270	--
160.0	3.0	3.5	200	13.0	480.0	0.2	3.2	0.02	6.6	1080	20	1400	--
30.0	1.1	2.6	120	19.0	45.0	0.2	0.5	--	3.6	230	<4	230	--
380.0	5.7	6.4	170	200.0	940.0	0.3	3.3	0.10	8.2	2230	20	5800	--

APPENDIX 3. – *Continued*

Sample: Site	Sample: Location	Sample: Date	Sample: Time	Well depth, total (ft)	Streamflow, instantaneous (cfs)	Specific conductance (μmho)	Field pH	Hardness (mg L as $CaCO_3$)	Hardness, noncarbonate (mg L as $CaCO_3$)	Calcium, dissolved (mg L as Ca)	Magnesium, dissolved (mg L as Mg)
				CREEK COUNTY *Continued*							
106	19N-08E-20 DAA	80-07-24	1715	218	--	470	6.2	130	92	32.0	11.0
107	19N-08E-24 BBB	80-07-17	1230	163	--	610	7.4	490	200	160.0	22.0
108	19N-08E-26 DCD	80-07-17	1430	63	--	380	7.6	220	0	53.0	21.0
109	19N-08E-28 DCC	80-07-18	1130	112	--	114	5.7	31	7	7.7	2.7
110	19N-09E-06 DCC	80-07-24	1215	--	0.02	3080	8.4	420	210	110.0	34.0
111	19N-09E-18 DDD	80-07-17	1000	106	--	390	7.6	210	0	44.0	25.0
112	19N-09E-31 AAA	80-07-16	1730	81	--	441	7.6	290	0	63.0	32.0
				LINCOLN COUNTY							
113	12N-05E-36 DDA	79-07-17	1000	96	--	670	7.5	200	0	41.0	23.0
114	12N-06E-10 ADD	79-07-24	1530	189	--	688	8.2	100	0	20.0	12.0
115	12N-06E-15 BAA	79-07-24	0830	--	<0.10	719	--	330	0	52.0	49.0
116	12N-06E-17 DAA	79-07-23	1700	230	--	385	6.8	140	0	31.0	16.0
117	12N-06E-19 BBB	79-07-23	1500	--	<0.10	8427	7.9	1300	1000	290.0	130.0
118	12N-06E-28 DAD	79-07-11	1200	412	--	675	6.8	180	21	56.0	9.7
119	13N-05E-36 DDD	80-02-28	0930	--	<0.10	1102	8.3	500	0	81.0	73.0
120	13N-06E-06 AAD	79-07-25	1200	--	0.10	774	8.4	230	62	43.0	30.0
121	13N-06E-07 BAA	79-07-25	1430	161	--	1321	7.6	52	0	11.0	5.9
122	13N-06E-15 BCC	79-07-25	1000	170	--	773	7.1	140	0	30.0	16.0
123	13N-06E-19 CDC	79-07-26	0845	127	--	721	7.8	35	0	7.3	4.1
124	13N-06E-21 ABA	79-07-25	0830	--	<0.10	880	7.5	370	0	69.0	49.0
125	13N-06E-26 CBC	79-07-24	1700	109	--	1060	7.1	170	0	33.0	20.0
126	13N-06E-32 DDC	79-09-14	0900	109	--	460	7.1	280	16	56.0	33.0
127	13N-06E-34 CCD	80-02-28	1100	--	<0.10	550	8.0	210	0	48.0	23.0
128	14N-06E-11 BAA	80-02-28	1230	68	--	982	7.2	350	55	67.0	43.0
129	14N-06E-15 CBB	79-09-14	1100	--	500.00**	900	8.1	230	51	51.0	25.0
130	14N-06E-27 CCB	79-07-26	1030	125	--	520	6.9	190	0	41.0	20.0
131	14N-06E-27 DCD	80-02-27	1700	--	<0.10	6200	7.5	1600	1300	330.0	180.0
132	14N-06E-35 DDC	79-07-26	1200	118	--	644	7.5	240	0	51.0	27.0
133	15N-05E-01 DAD	80-03-20	1800	92	--	562	7.7	210	25	43.0	26.0
134	15N-06E-02 AAA	80-03-10	1800	153	--	625	7.5	260	1	56.0	29.0
135	15N-06E-10 CCD	80-03-07	0930	79	--	920	8.0	100	0	23.0	11.0
136	15N-06E-12 ADC	80-04-04	0930	24	--	411	7.3	170	0	40.0	17.0
137	15N-06E-18 DCC	80-03-21	0830	42	--	565	8.3	66	0	15.0	6.8
138	15N-06E-22 BBB	80-03-07	0800	--	<0.01	750	7.6	260	12	62.0	26.0
139	15N-06E-26 DDC	80-02-27	1330	55	--	442	7.3	170	0	39.0	18.0
140	15N-06E-33 BBA	80-02-28	1430	231	--	710	7.6	230	0	49.0	27.0
141	15N-06E-34 CCD	80-02-27	1130	--	<0.10	760	8.1	250	50	57.0	26.0
142	16N-05E-04 AAA	80-04-15	1700	--	<0.10	1170	8.3	330	78	70.0	37.0
143	16N-05E-11 BCB	80-04-22	1830	15	--	413	7.5	160	19	39.0	15.0
144	16N-05E-12 DCD	80-03-21	1200	--	<0.10	680	8.2	270	4	55.0	33.0
145	16N-05E-24 CBB	80-03-17	1700	30	--	1590	7.3	620	200	130.0	72.0
146	16N-06E-01 BCB	80-04-09	1030	80	--	134	6.2	44	15	10.0	4.5
147	16N-06E-03 CCD	80-08-09	0845	--	<0.10	680	8.0	290	43	61.0	34.0
148	16N-06E-18 AAA	80-03-21	1345	31	--	1093	7.6	410	96	75.0	53.0
149	16N-06E-23 BBA	80-04-01	1430	87	--	5210	7.2	1300	1200	370.0	100.0
150	16N-06E-29 ADA	80-03-21	1030	120	--	441	7.7	190	18	39.0	22.0
151	16N-06E-33 DAD	80-03-20	1700	134	--	690	7.5	270	0	45.0	38.0
152	16N-06E-35 BCB	80-03-10	1630	--	<0.10	444	8.5	200	6	37.0	25.0
153	17N-05E-26 DAA	80-04-09	1640	--	0.50	560	8.3	190	33	41.0	22.0
154	17N-05E-28 ABA	80-04-15	1830	104	--	850	7.5	370	0	46.0	61.0
155	17N-05E-35 AAD	80-04-09	1500	105	--	1220	7.9	98	0	28.0	6.6
156	17N-06E-27 DCD	80-04-09	1130	--	<0.10	495	7.8	250	9	60.0	24.0
157	17N-06E-31 CDC	80-04-09	1400	--	<0.10	330	7.9	140	9	34.0	13.0
158	17N-06E-32 DDD	80-04-09	1245	177	--	604	7.5	250	0	51.0	30.0

Sodium, dissolved (mg/L as Na)	Sodium-adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Iodide, dissolved (mg/L as I)	Silica, dissolved (mg/L as SiO_2)	Total dissolved solids* (mg/L)	Lithium, dissolved (µg/L as Li)	Strontium, dissolved (µg/L as Sr)	Organic carbon, dissolved (mg/L as C)
					CREEK COUNTY *Continued*								
40.0	1.6	1.2	33	34.0	94.0	0.2	0.5	0.01	8.8	333	10	240	--
29.0	0.6	2.1	290	240.0	29.0	0.4	0.2	0.00	14.0	711	20	2000	--
21.0	0.6	2.0	230	25.0	13.0	0.2	0.1	0.00	16.0	280	8	740	--
11.0	0.9	0.4	24	13.0	13.0	0.2	0.1	0.00	16.0	80	6	130	--
480.0	10.0	11.0	210	160.0	800.0	0.4	0.2	0.10	7.9	1770	10	1800	--
27.0	0.8	1.8	240	12.0	15.0	1.0	0.1	0.00	16.0	262	20	380	--
25.0	0.6	1.8	290	31.0	22.0	0.2	0.2	0.00	15.0	353	10	300	--
					LINCOLN COUNTY								
83.0	2.6	2.1	280	16.0	49.0	0.4	0.3	--	20.0	412	30	310	3.4
150.0	6.6	3.1	380	17.0	20.0	1.1	0.2	--	12.0	459	20	660	1.2
52.0	1.2	3.7	380	30.0	21.0	0.5	0.3	--	11.0	478	9	300	4.0
22.0	0.8	1.2	150	14.0	21.0	0.2	0.2	--	25.0	231	8	140	0.9
1500.0	18.0	4.3	250	28.0	3000.0	0.4	13.0	0.03	11.0	5610	20	3400	3.8
93.0	3.0	2.8	160	210.0	5.0	0.7	0.0	0.01	13.0	475	10	1100	--
74.0	1.4	4.3	560	56.0	22.0	0.3	0.2	0.01	10.0	647	8	430	6.2
65.0	1.9	6.6	170	61.0	150.0	0.4	1.1	--	2.7	517	5	520	10.0
350.0	21.0	3.0	420	360.0	26.0	4.6	0.2	0.01	7.6	1040	20	450	0.8
140.0	5.1	2.9	240	45.0	100.0	1.6	0.6	--	12.0	510	10	640	0.5
190.0	14.0	3.4	330	20.0	58.0	0.5	0.3	--	10.0	497	20	190	0.8
60.0	1.4	4.2	390	28.0	58.0	0.4	0.5	--	13.0	568	7	440	6.0
200.0	6.8	6.0	300	110.0	130.0	1.1	0.6	--	9.2	718	10	280	5.5
23.0	0.6	0.9	260	42.0	25.0	0.4	0.2	--	19.0	357	10	140	1.3
19.0	0.6	3.7	220	22.0	16.0	0.2	0.1	--	5.8	275	9	210	10.0
63.0	1.5	3.3	290	110.0	69.0	0.4	0.2	0.00	12.0	561	40	490	0.6
100.0	2.9	7.4	180	69.0	160.0	0.5	0.9	0.07	5.3	549	20	850	7.0
39.0	1.2	1.3	190	26.0	35.0	0.4	0.4	--	15.0	326	8	170	2.6
750.0	8.3	5.3	300	18.0	2100.0	0.2	19.0	0.03	13.0	3750	10	3400	11.0
54.0	1.5	3.1	280	24.0	48.0	0.5	0.8	--	17.0	400	20	520	1.2
31.0	0.9	0.7	190	47.0	19.0	0.4	0.2	--	14.0	310	20	100	5.6
28.0	0.8	2.6	260	28.0	11.0	0.2	0.1	--	16.0	327	10	1400	11.0
150.0	6.4	3.9	340	69.0	26.0	0.6	0.2	--	9.8	540	20	310	6.7
18.0	0.6	1.0	170	23.0	10.0	0.2	0.1	--	9.3	229	10	150	--
110.0	5.9	3.2	190	74.0	15.0	0.5	0.1	--	11.0	342	10	750	3.4
47.0	1.3	3.5	250	29.0	59.0	0.3	0.4	--	4.5	405	8	500	8.9
22.0	0.7	1.0	190	15.0	14.0	0.3	0.1	--	13.0	236	20	180	0.2
45.0	1.3	2.7	270	37.0	21.0	0.7	1.0	--	13.0	356	30	490	3.0
41.0	1.1	4.6	200	62.0	61.0	0.2	0.4	--	3.0	398	10	410	12.0
46.0	1.1	3.7	250	62.0	88.0	0.4	0.6	0.00	8.1	486	5	350	--
22.0	0.8	6.6	140	31.0	16.0	0.2	0.3	--	12.0	265	<4	230	--
33.0	0.9	2.1	270	32.0	25.0	0.5	0.3	--	5.9	348	<4	240	12.0
98.0	1.7	1.6	420	110.0	180.0	1.0	1.0	0.01	11.0	928	20	750	20.0
4.4	0.3	0.5	29	14.0	4.6	0.1	0.1	0.01	11.0	79	6	130	--
24.0	0.6	3.2	250	72.0	17.0	0.3	0.2	--	9.0	400	8	190	--
89.0	1.9	1.4	310	190.0	46.0	0.9	0.4	0.01	11.0	692	20	580	4.1
460.0	5.5	2.7	110	15.0	1500.0	0.0	10.0	0.01	17.0	2970	20	1100	--
15.0	0.5	1.0	170	33.0	6.4	0.8	0.1	--	8.4	238	10	180	4.5
46.0	1.2	3.4	320	10.0	17.0	0.5	0.1	--	15.0	363	20	1300	8.6
15.0	0.5	3.4	190	24.0	11.0	0.2	0.2	--	1.2	223	5	280	8.5
40.0	1.3	4.2	160	35.0	52.0	0.3	0.4	--	7.3	335	6	340	--
25.0	0.6	1.2	390	18.0	16.0	1.1	0.1	0.00	13.0	430	20	430	--
240.0	11.0	3.1	280	290.0	20.0	0.6	0.1	0.01	13.0	807	20	690	--
7.2	0.2	1.4	240	9.7	7.2	0.4	0.2	--	11.0	275	8	140	--
10.0	0.4	3.6	130	16.0	8.7	0.3	0.1	--	6.9	192	4	170	--
30.0	0.8	2.5	270	24.0	14.0	0.3	0.1	2.40	14.0	334	10	1200	--

APPENDIX 3. – *Continued*

Site	Sample Location	Date	Time	Well depth, total (ft)	Streamflow, instantaneous (cfs)	Specific conductance (μmho)	Field pH	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
				OKFUSKEE COUNTY							
159	11N-07E-08 DDD	79-07-31	1600	--	1.00	425	8.0	180	33	42.0	19.0
160	11N-07E-19 CCC	79-08-01	0800	--	1.50	1112	7.7	340	260	86.0	31.0
161	11N-07E-20 BBB	79-08-01	1000	105	--	1280	6.2	440	5	100.0	45.0
162	12N-07E-02 CDC	79-08-07	1430	83	--	340	6.5	160	5	34.0	17.0
163	12N-07E-03 DAA	79-08-06	1630	--	<0.10	1545	8.2	410	200	80.0	50.0
164	12N-07E-17 DCC	79-07-27	0900	150**	--	516	6.4	270	0	60.0	29.0
165	12N-07E-24 ADA	79-11-02	0930	39	--	129	4.6	26	14	6.4	2.5
166	12N-07E-26 CDC	80-02-22	1000	--	<0.10	261	--	89	16	20.0	9.4
167	12N-07E-27 DDA	79-08-01	1330	130	--	420	5.6	210	0	45.0	23.0
168	12N-07E-32 BAA	79-07-31	1200	--	<0.10	351	7.3	180	1	41.0	19.0
169	12N-07E-32 BCB	79-07-31	1430	87	--	610	6.8	310	35	66.0	34.0
170	12N-08E-08 AAC	79-08-07	1630	109	--	116	6.0	25	1	6.4	2.1
171	12N-08E-31 DAA	79-08-01	1600	57	--	200	5.2	110	23	32.0	8.3
172	12N-08E-32 CCB	79-08-01	1430	--	<0.10	343	7.3	160	3	39.0	16.0
173	12N-08E-34 BBB	79-08-02	0830	--	<0.10	705	7.2	230	83	60.0	20.0
174	13N-07E-09 DAA	79-08-16	1115	105	--	356	6.6	140	17	30.0	15.0
175	13N-07E-09 DAA	79-08-16	1300	149	--	12760	6.2	3400	3200	840.0	320.0
176	13N-07E-10 CBC	79-08-16	1000	--	<0.10	42140	7.0	6000	5900	1600.0	450.0
177	13N-07E-11 CCC	79-07-26	1630	--	<0.10	470	7.6	220	3	53.0	22.0
178	13N-07E-12 AAA	79-08-07	1300	120	--	470	6.9	230	0	48.0	26.0
179	13N-07E-17 ABB	79-07-26	1500	--	<0.10	400	8.0	180	0	43.0	18.0
180	13N-07E-18 BAA	79-07-26	1400	89	--	548	7.2	290	0	63.0	33.0
181	13N-07E-22 DCC	79-08-07	0930	149	--	387	6.5	200	0	43.0	22.0
182	13N-07E-24 DDD	79-08-07	1100	--	<0.10	501	7.9	270	0	53.0	33.0
183	13N-07E-27 CCB	79-08-06	1500	--	<0.10	500	7.1	260	14	56.0	30.0
184	13N-07E-30 BAB	79-08-06	1300	--	<0.10	297	7.5	140	0	31.0	15.0
185	13N-07E-33 CCC	79-08-07	0830	133	--	813	7.0	280	0	57.0	34.0
186	13N-08E-27 BBC	79-11-02	1400	115	--	380	6.5	160	3	37.0	17.0
187	13N-08E-30 DDC	79-11-02	1230	40	--	320	5.9	67	0	14.0	7.7
188	13N-08E-33 DCD	79-11-02	1100	--	<0.10	136	5.8	33	17	7.7	3.3
				PAYNE COUNTY							
189	17N-05E-11 DDC	80-04-10	1420	--	0.40	900	8.7	260	73	62.0	26.0
190	17N-06E-02 AAD	80-04-17	1400	--	0.07	291	7.4	96	16	23.0	9.3
191	17N-06E-05 AAA	80-04-11	0845	--	10.00	507	7.8	150	27	34.0	15.0
192	17N-06E-05 BBA	80-04-10	1700	--	<0.10	700	8.7	360	0	63.0	49.0
193	17N-06E-07 DDC	80-04-10	1800	203	--	539	8.3	24	0	7.4	1.4
194	17N-06E-10 BAA	80-04-11	1045	145	--	391	7.2	160	9	42.0	13.0
195	17N-06E-14 CCC	80-04-10	0930	120	--	405	6.3	130	91	31.0	13.0
196	17N-06E-16 CBB	80-04-10	1100	--	0.04	400	7.9	150	18	36.0	14.0
197	17N-06E-20 CDC	80-04-10	1200	83	--	880	7.4	320	0	60.0	40.0
198	18N-05E-11 AAB	80-04-16	1500	140	--	12932	6.9	2500	2300	690.0	190.0
199	18N-05E-12 BCB	80-04-16	1330	81	--	2100	7.0	780	590	220.0	56.0
200	18N-05E-22 BBA	80-04-22	1530	88	--	1080	7.4	370	37	61.0	52.0
201	18N-05E-24 DDA	80-04-16	1700	--	<0.10	850	8.0	550	17	90.0	78.0
202	18N-05E-34 BBB	80-04-16	1100	--	1.00	2420	8.6	330	180	79.0	33.0
203	18N-05E-35 AAD	80-04-10	1600	179	--	990	7.3	270	0	63.0	26.0
204	18N-06E-07 CBB	80-04-16	1600	--	0.05	1165	8.2	360	92	110.0	21.0
205	18N-06E-23 CCC	80-04-17	1200	93	--	283	6.4	99	8	23.0	10.0
206	18N-06E-28 BCC	80-04-17	0930	238	--	630	7.3	240	2	61.0	21.0
207	18N-07E-28 ADD	80-04-18	1015	--	0.10	2460	8.0	850	560	160.0	110.0

Sodium, dissolved (mg/L as Na)	Sodium-adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Iodide, dissolved (mg/L as I)	Silica, dissolved (mg/L as SiO_2)	Total dissolved solids* (mg/L)	Lithium, dissolved (µg/L as Li)	Strontium, dissolved (µg/L as Sr)	Organic carbon, dissolved (mg/L as C)
OKFUSKEE COUNTY													
24.0	0.8	2.4	150	20.0	45.0	0.3	0.4	--	14.0	281	4	190	6.3
110.0	2.6	3.5	84	15.0	360.0	0.1	1.7	0.02	28.0	925	20	600	19.0
100.0	2.1	1.8	430	56.0	110.0	0.2	0.9	0.03	23.0	758	30	280	14.0
13.0	0.5	1.1	150	14.0	12.0	0.2	0.1	--	21.0	187	9	120	2.9
190.0	4.1	4.6	210	16.0	410.0	0.4	2.2	0.03	11.0	978	10	280	3.7
15.0	0.4	1.6	310	4.1	8.2	0.3	0.0	--	15.0	319	10	190	0.5
11.0	0.9	0.7	12	13.0	12.0	0.1	0.1	0.01	14.0	73	8	40	0.6
12.0	0.6	2.2	73	25.0	13.0	0.2	0.3	--	18.0	154	<4	110	3.6
16.0	0.5	0.9	220	14.0	10.0	0.2	0.2	--	19.0	257	10	200	6.5
10.0	0.3	2.0	180	14.0	9.8	0.3	0.2	--	15.0	210	<4	130	2.7
23.0	0.6	0.8	270	29.0	44.0	0.2	--	--	21.0	402	10	190	1.1
11.0	1.0	0.9	24	16.0	4.9	0.1	0.1	--	15.0	73	<4	40	0.2
5.7	0.2	1.2	91	14.0	10.0	0.2	0.1	--	14.0	148	6	50	2.9
12.0	0.4	1.2	160	12.0	15.0	0.3	0.2	--	11.0	194	8	100	1.2
68.0	1.9	3.6	150	24.0	160.0	0.3	0.7	--	23.0	482	6	360	5.5
18.0	0.7	1.1	120	20.0	17.0	0.1	0.2	0.02	19.0	204	6	200	2.9
1700.0	13.0	7.2	200	47.0	4800.0	0.1	33.0	0.02	14.0	9530	50	8000	4.7
11000.0	63.0	31.0	89	130.0	22000.0	0.3	110.0	0.80	11.0	38000	500	93000	4.2
16.0	0.5	4.2	220	11.0	26.0	0.4	0.3	--	13.0	293	4	320	6.1
18.0	0.5	2.3	230	6.7	28.0	0.2	0.4	--	19.0	274	10	240	0.9
8.1	0.3	4.2	200	10.0	7.8	0.3	0.1	--	8.9	241	<4	220	5.2
9.8	0.3	2.2	300	8.9	12.0	0.2	0.1	--	15.0	323	9	140	1.2
5.6	0.2	1.1	200	8.5	7.2	0.0	0.1	0.00	20.0	222	6	80	0.9
19.0	0.5	2.9	280	12.0	15.0	0.7	0.2	--	12.0	303	<4	270	9.0
11.0	0.3	2.2	250	15.0	17.0	0.5	0.2	--	16.0	264	<4	220	3.4
8.9	0.3	4.0	150	7.2	5.4	0.3	0.1	--	6.0	161	<4	200	7.1
98.0	2.5	2.0	310	53.0	81.0	0.7	0.5	--	17.0	523	30	350	1.3
14.0	0.5	2.0	160	8.8	18.0	0.2	0.3	--	15.0	210	20	160	21.0
28.0	1.5	0.7	84	12.0	22.0	0.7	0.3	--	22.0	176	10	60	0.8
8.7	0.7	2.1	16	12.0	19.0	0.1	0.2	--	14.0	81	10	50	4.3
PAYNE COUNTY													
68.0	1.8	5.0	190	70.0	110.0	0.3	0.8	--	4.5	491	10	530	--
16.0	0.7	1.5	80	20.0	22.0	0.2	0.3	--	10.0	172	<4	80	--
39.0	1.4	5.0	120	32.0	56.0	0.3	0.6	--	7.5	285	7	300	--
25.0	0.6	2.7	360	14.0	13.0	0.5	0.3	0.06	12.0	389	5	350	--
110.0	9.7	1.5	230	18.0	6.5	0.5	0.1	--	12.0	311	7	170	--
15.0	0.5	0.7	150	16.0	11.0	0.3	0.1	--	10.0	211	8	180	--
17.0	0.6	1.2	40	40.0	33.0	0.1	--	--	11.0	238	--	--	--
15.0	0.5	4.7	130	19.0	23.0	0.2	0.2	0.00	2.5	229	<4	210	--
51.0	1.3	3.6	370	17.0	35.0	0.4	0.2	--	19.0	467	20	900	--
1800.0	16.0	3.6	200	16.0	4600.0	0.2	32.0	0.01	19.0	8090	50	4400	--
110.0	1.7	1.5	190	0.0	540.0	0.2	4.0	--	22.0	1290	20	700	--
84.0	1.9	1.9	330	92.0	83.0	0.4	0.5	0.00	19.0	587	20	500	--
54.0	1.0	3.0	530	63.0	35.0	0.5	0.5	--	13.0	646	8	850	--
330.0	7.9	14.0	150	220.0	460.0	9.1	2.8	--	9.3	1310	20	1100	--
95.0	2.5	1.9	280	140.0	38.0	0.4	0.4	0.01	14.0	569	20	490	--
98.0	2.2	1.7	270	26.0	200.0	0.3	1.6	--	15.0	638	10	430	--
15.0	0.7	0.6	91	16.0	12.0	0.3	0.2	--	15.0	154	8	30	--
35.0	1.0	2.5	240	71.0	5.6	0.3	0.1	0.01	19.0	365	7	3000	--
180.0	2.7	3.8	290	280.0	490.0	0.4	3.0	0.03	5.1	1460	10	2000	--

APPENDIX 3. – *Continued*

Sample				Well depth, total (ft)	Streamflow, instantaneous (cfs)	Specific conductance (μmho)	Field pH	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
Site	Location	Date	Time								
			POTTAWATOMIE COUNTY								
208	06N-05E-04 BCC	79-11-15	1400	176	--	484	7.2	120	0	25.0	14.0
209	06N-05E-06 AAA	79-11-15	1500	--	0.10	6600	6.7	1100	800	240.0	120.0
210	06N-05E-32 BAB	79-12-05	1330	--	<0.10	782	7.3	340	0	65.0	44.0
211	07N-05E-21 DCD	79-11-15	0930	--	0.30	9244	7.3	1100	840	160.0	170.0
212	07N-05E-28 BBA	79-11-15	1200	208	--	1018	6.7	400	17	88.0	43.0
213	08N-05E-06 CDD	79-11-01	1700	220	--	5010	7.8	310	66	71.0	31.0
214	08N-05E-20 DDA	79-11-13	1600	216	--	1387	8.6	20	0	4.5	2.2
215	09N-04E-25 DDD	79-10-01	1730	--	1.50	1503	8.2	270	31	39.0	42.0
216	09N-05E-04 DCC	79-09-19	1100	248	--	3400	9.4	220	110	55.0	19.0
217	09N-05E-08 ABA	79-09-13	1530	87	--	400	7.1	180	0	47.0	15.0
218	09N-05E-16 ADD	78-09-28	1145	--	<0.10	150000	6.8	--	--	--	--
		79-09-13	1630	--	0.10	17500	6.7	2200	1800	600.0	170.0
219	09N-05E-18 CCB	79-11-01	1500	--	0.10	714	7.9	320	7	69.0	35.0
220	09N-05E-29 ABA	79-10-01	1630	41	--	1264	7.1	390	130	83.0	45.0
221	11N-05E-09 ADA	79-09-11	1300	--	0.10	491	7.1	200	0	51.0	18.0
222	11N-05E-13 ABB	79-07-17	1100	--	<0.10	512	8.1	200	19	40.0	24.0
223	11N-05E-21 AAA	79-09-11	1430	54	--	350	5.6	110	73	28.0	8.7
224	11N-06E-04 CDC	79-07-16	1700	--	<0.10	810	8.6	120	0	30.0	12.0
225	11N-06E-11 BAA	79-07-11	1500	211	--	510	7.3	170	0	38.0	17.0
226	11N-06E-16 DAD	79-07-17	1500	196	--	315	7.5	72	0	17.0	7.1
227	11N-06E-28 ADB	79-08-15	1730	--	600.00**	1440	8.4	370	160	93.0	34.0
			SEMINOLE COUNTY								
228	05N-05E-01 AAA	79-12-06	1700	197	--	694	7.0	140	0	27.0	18.0
229	05N-05E-11 BCC	79-12-06	1030	199	--	827	7.2	190	0	38.0	22.0
230	05N-05E-12 BCB	79-12-06	1500	--	0.75	1320	7.8	390	120	91.0	40.0
231	05N-05E-15 BAB	79-12-05	1630	--	<0.10	432	7.2	180	0	52.0	12.0
232	05N-06E-01 CBA	80-02-20	1400	179	--	713	--	180	0	52.0	12.0
233	05N-06E-18 CCC	79-12-06	1200	64	--	999	7.4	71	0	12.0	10.0
234	05N-06E-19 ABD	79-12-06	1400	--	0.15	632	7.6	250	0	66.0	20.0
235	06N-05E-01 DDC	79-10-04	1030	86	--	868	7.0	410	140	82.0	49.0
236	06N-05E-02 BCC	79-11-15	1630	--	0.10	4680	7.8	1100	740	200.0	140.0
237	06N-05E-22 BBB	79-12-05	1100	154	--	466	7.0	170	7	42.0	15.0
238	06N-05E-24 ABB	80-01-30	1230	78	--	703	7.2	150	0	22.0	24.0
239	06N-05E-26 BCB	80-02-20	1000	--	<0.10	651	8.0	320	0	66.0	37.0
240	06N-05E-34 BBC	79-12-05	1530	187	--	832	6.9	250	0	39.0	36.0
241	06N-06E-04 CDC	80-01-30	1000	--	<0.10	2250	7.3	630	320	140.0	69.0
242	06N-06E-15 CCB	80-01-31	1000	236	--	965	7.3	400	88	75.0	51.0
243	06N-06E-17 DDD	80-02-20	1100	--	<0.10	1471	--	620	49	150.0	59.0
244	06N-06E-27 DAA	80-01-31	1500	242	--	480	6.9	220	11	52.0	22.0
245	06N-06E-33 BCC	80-01-30	1500	--	0.20	1562	7.4	530	240	110.0	61.0
246	06N-06E-36 CCB	80-01-31	1600	--	<0.10	1520	6.0	53	21	16.0	3.2
247	07N-05E-02 DCC	79-11-14	1800	122	--	905	6.8	160	0	25.0	24.0
248	07N-05E-15 AAD	79-11-14	1600	--	2.50	4928	8.0	890	700	200.0	93.0
249	07N-05E-25 CBC	79-10-04	1700	246	--	1763	8.5	25	0	6.7	2.0
250	07N-06E-01 BBD	79-10-02	1000	--	<0.10	1962	8.0	440	190	82.0	58.0
251	07N-06E-04 CCC	79-10-02	1300	240	--	609	6.9	340	9	73.0	38.0
252	07N-06E-12 CCD	79-09-27	1330	240	--	565	7.3	270	0	53.0	34.0
253	07N-06E-17 AAA	80-02-21	1530	--	<0.10	760	--	370	37	89.0	35.0
254	07N-06E-17 DDD	79-10-03	1530	117	--	1066	8.5	12	0	2.0	1.6
255	07N-06E-18 BCB	79-10-02	1515	114	--	980	7.0	390	0	70.0	51.0
256	07N-06E-19 BCC	79-10-03	1330	--	0.40	1936	8.1	300	180	62.0	34.0
257	07N-06E-23 BCB	79-09-27	1545	--	<0.10	14541	7.6	1500	1200	380.0	140.0

Sodium, dissolved (mg/L as Na)	Sodium-adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Iodide, dissolved (mg/L as I)	Silica, dissolved (mg/L as SiO_2)	Total dissolved solids* (mg/L)	Lithium, dissolved (µg/L as Li)	Strontium, dissolved (µg/L as Sr)	Organic carbon, dissolved (mg/L as C)
POTTAWATOMIE COUNTY													
82.0	3.3	2.4	260	21.0	7.8	0.3	0.2	--	16.0	326	20	310	29.0
880.0	12.0	9.9	300	24.0	1900.0	0.3	8.4	--	11.0	3750	50	3600	34.0
46.0	1.1	2.1	400	18.0	23.0	0.5	0.3	--	13.0	432	7	420	22.0
1600.0	21.0	13.0	270	32.0	3200.0	0.2	13.0	0.06	9.2	5920	90	5700	9.9
58.0	1.3	3.0	380	30.0	70.0	0.6	0.6	--	14.0	585	40	490	33.0
1200.0	30.0	6.6	240	1300.0	230.0	1.8	1.0	0.05	9.5	3840	40	1100	34.0
320.0	31.0	1.9	390	170.0	95.0	1.0	0.4	--	9.4	836	10	120	29.0
200.0	5.3	4.6	240	74.0	300.0	0.4	1.7	--	2.0	810	6	520	6.3
750.0	22.0	7.8	110	1600.0	96.0	1.0	0.4	0.01	3.0	2530	30	1100	12.0
16.0	0.5	2.9	190	25.0	9.3	0.4	0.1	0.01	11.0	244	10	830	0.6
49000.0	--	--	--	--	100000.0	--	220.0	--	--	205000	--	--	--
3400.0	32.0	27.0	420	78.0	6900.0	0.5	40.0	0.30	12.0	12500	190	17000	5.4
29.0	0.7	3.4	310	17.0	47.0	0.3	0.4	--	13.0	412	10	310	35.0
96.0	2.1	1.8	260	44.0	230.0	0.5	1.2	0.32	19.0	699	20	350	1.5
35.0	1.1	2.5	260	12.0	9.2	0.4	0.2	--	19.0	313	10	250	3.5
33.0	1.0	3.6	180	17.0	57.0	0.4	0.5	--	6.9	303	5	230	4.4
19.0	0.8	1.6	33	26.0	58.0	0.1	0.3	--	34.0	264	20	220	1.8
140.0	5.5	9.3	290	76.0	45.0	0.5	0.3	0.04	6.8	560	7	260	5.1
47.0	1.6	3.4	260	9.8	20.0	0.3	0.1	0.02	18.0	305	10	890	0.3
47.0	2.4	2.4	150	12.0	7.3	0.3	0.1	--	16.0	192	10	330	0.0
170.0	3.8	10.0	210	180.0	240.0	0.7	1.1	0.04	3.7	847	30	1200	9.3
SEMINOLE COUNTY													
170.0	6.2	2.2	440	32.0	23.0	0.5	0.1	0.01	13.0	543	30	250	6.1
120.0	3.8	2.1	380	33.0	47.0	0.5	0.6	--	14.0	504	20	440	8.6
120.0	2.6	3.2	270	43.0	250.0	0.3	1.4	--	19.0	763	20	590	3.6
17.0	0.6	1.0	180	15.0	21.0	0.3	0.1	--	36.0	272	20	200	2.7
94.0	3.1	2.6	330	37.0	8.5	0.2	0.0	--	15.0	410	10	290	--
220.0	11.0	3.1	520	12.0	28.0	0.7	0.3	0.02	10.0	614	30	160	15.0
38.0	1.1	1.8	250	22.0	49.0	0.3	0.3	0.02	31.0	366	10	210	16.0
20.0	0.4	2.7	270	86.0	61.0	0.3	0.7	--	15.0	520	20	230	6.0
890.0	12.0	8.9	340	21.0	1900.0	0.3	8.6	--	11.0	3020	--	--	30.0
41.0	1.4	0.7	160	39.0	32.0	0.3	0.2	--	20.0	295	6	160	0.7
110.0	3.9	2.3	330	42.0	21.0	0.2	0.1	--	16.0	425	30	310	--
21.0	0.5	1.6	330	12.0	16.0	0.3	0.3	--	11.0	352	<4	230	9.7
98.0	2.7	3.5	400	20.0	30.0	0.6	--	0.02	20.0	480	40	590	16.0
240.0	4.2	2.1	310	19.0	540.0	0.2	3.4	--	9.8	1190	10	1000	5.5
42.0	0.9	3.5	310	34.0	92.0	0.2	0.6	0.02	8.6	540	30	550	19.0
85.0	1.5	0.7	570	73.0	120.0	0.3	0.8	0.02	7.5	874	7	1100	11.0
9.1	0.3	1.4	210	19.0	18.0	0.2	0.2	--	8.8	249	20	140	1.5
140.0	2.7	4.1	290	170.0	250.0	0.5	1.3	--	11.0	997	30	710	18.0
4.4	0.3	1.5	32	16.0	16.0	0.1	0.1	0.00	9.2	98	10	70	6.2
150.0	5.1	5.9	380	16.0	73.0	0.3	0.2	0.01	15.0	534	30	660	16.0
750.0	11.0	10.0	190	51.0	1500.0	0.3	12.0	--	4.4	3020	50	3800	19.0
650.0	57.0	2.2	750	100.0	450.0	5.2	2.6	0.05	10.0	1690	20	60	12.0
310.0	6.4	6.7	250	62.0	610.0	0.4	2.3	0.10	3.2	1360	10	1100	7.6
6.6	0.2	1.1	330	15.0	8.8	0.4	0.1	0.00	15.0	337	8	310	2.6
25.0	0.7	3.9	290	15.0	30.0	0.2	0.2	--	8.7	337	20	670	0.7
23.0	0.5	1.5	330	33.0	22.0	0.2	0.2	--	11.0	404	5	270	4.1
270.0	35.0	1.0	550	23.0	22.0	0.6	0.1	--	8.4	632	<4	30	1.4
71.0	1.6	1.8	390	31.0	50.0	0.5	0.3	--	2.0	571	30	300	4.5
270.0	6.8	4.6	120	11.0	530.0	0.3	2.3	0.07	3.0	1050	10	1100	6.5
3400.0	38.0	46.0	380	50.0	6300.0	0.3	29.0	0.50	2.0	11600	210	12000	8.6

APPENDIX 3. – *Continued*

Sample: Site	Sample: Location	Sample: Date	Sample: Time	Well depth, total (ft)	Streamflow, instantaneous (cfs)	Specific conductance (μmho)	Field pH	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
				SEMINOLE COUNTY *Continued*							
258	07N-06E-26 CBB	79-09-27	1745	110	--	3773	6.4	1300	1200	350.0	94.0
259	07N-06E-28 BAD	79-10-03	1600	--	0.56	1654	8.0	280	150	66.0	28.0
260	07N-06E-30 DCC	79-10-04	1500	--	<0.10	1528	8.0	460	140	110.0	44.0
261	07N-06E-33 CDC	79-10-04	1300	235	--	1071	8.9	4	0	0.9	0.4
262	07N-07E-05 ACD	79-09-27	1030	375	--	946	7.1	430	200	100.0	43.0
263	07N-07E-10 BBB	79-09-26	1600	59	--	900	6.8	510	120	100.0	63.0
264	07N-07E-20 BBA	79-09-26	1700	--	5.00	1891	8.2	360	140	78.0	41.0
265	08N-05E-13 ABB	80-02-21	1230	--	<0.10	10192	--	1500	1300	350.0	150.0
266	08N-05E-14 BAB	79-11-14	1400	82	--	612	7.0	250	0	52.0	30.0
267	08N-05E-15 ACC	78-10-03	1550	--	<0.10	50000	7.6	--	--	--	--
268	08N-05E-23 BBD	79-11-13	1730	--	2.50	1343	8.1	340	48	66.0	42.0
269	08N-05E-36 BBB	79-11-14	1030	156	--	1108	7.7	140	0	20.0	21.0
270	08N-06E-07 CBA	80-02-19	1515	53	--	3150	--	850	660	180.0	97.0
271	08N-06E-09 ADA	78-08-10	0930	178	--	1650	8.5	--	--	--	--
		80-02-01	0900	178	--	726	7.8	35	0	8.4	3.4
272	08N-06E-10 DBC	79-12-04	1630	--	<0.10	2553	10.8	46	0	14.0	2.7
273	08N-06E-13 DAD	79-09-20	1330	--	<0.10	3442	7.6	650	460	140.0	72.0
274	08N-06E-23 AAD	78-08-09	1630	--	<0.10	9400	8.1	--	--	--	--
		80-02-01	1030	--	<0.10	6688	6.7	1500	1200	360.0	150.0
275	08N-06E-26 DDA	78-08-10	1700	--	<0.10	15000	8.0	--	--	--	--
		80-02-21	1100	--	0.10	9400	--	1400	1200	350.0	130.0
276	08N-06E-28 DDD	80-02-19	1700	--	<0.10	766	--	360	0	81.0	37.0
277	08N-07E-02 ABB	79-09-25	1330	--	<0.10	707	6.9	150	78	36.0	14.0
278	08N-07E-03 ADC	79-09-25	1530	102	--	143	5.0	32	21	7.7	3.2
279	08N-07E-05 ABA	79-09-20	1030	104	--	320	6.4	140	14	33.0	15.0
280	08N-07E-06 DDB	79-09-20	1200	--	<0.10	329	6.7	130	24	32.0	13.0
281	08N-07E-16 BBB	79-09-25	1700	--	0.16	2186	9.1	330	140	80.0	32.0
282	08N-07E-18 BAA	78-11-30	1300	--	<0.10	4000	8.1	--	--	--	--
283	08N-07E-18 CBB	79-09-20	1430	170	--	26200	6.6	1400	1200	280.0	180.0
284	08N-07E-20 AAA	79-09-26	1200	67	--	151	5.3	32	16	6.2	4.0
285	08N-07E-22 ABA	79-09-26	1000	--	<0.10	6820	7.3	240	86	53.0	25.0
286	08N-07E-29 ABB	80-02-20	1730	--	0.10	1100	--	190	160	46.0	19.0
287	08N-07E-32 AAA	79-09-20	1700	94	--	269	5.3	42	31	9.8	4.3
288	08N-07E-34 DDD	80-02-20	1600	--	<0.10	800	--	410	100	110.0	34.0
289	09N-05E-03 DAD	79-09-13	1400	--	0.10	16500	7.9	2600	2400	650.0	230.0
290	09N-05E-03 DDD	79-09-18	1730	--	<0.10	161000	6.9	20000	20000	5500.0	1400.0
291	09N-05E-13 CDA	79-11-16	1130	98	--	675	7.0	270	0	40.0	40.0
292	09N-05E-15 BBB	79-09-19	0930	114	--	656	6.4	210	67	53.0	18.0
293	09N-05E-24 BCB	79-09-28	0900	--	<0.10	23217	7.5	1300	1200	--	310.0
294	09N-05E-27 AAA	79-11-01	1130	272	--	4446	7.1	1000	910	290.0	68.0
295	09N-05E-34 ABA	79-11-01	1400	--	<0.10	813	7.5	370	0	74.0	46.0
296	09N-06E-03 AAB	78-08-02	1500	--	<).10	12000	7.7	--	--	--	--
		79-07-20	0800	--	<0.10	7210	7.8	1100	790	260.0	99.0
297	09N-06E-04 BCA	78-08-02	1030	--	<0.10	35500	7.3	--	--	--	--
		79-09-12	1630	--	<0.10	22500	6.9	2400	2100	590.0	220.0
298	09N-06E-06 BBB	79-09-13	1730	265	--	700	7.1	310	0	61.0	38.0
299	09N-06E-08 CDD	79-09-12	1230	120	--	641	7.2	160	0	44.0	13.0
300	09N-06E-09 CDC	78-08-01	1600	--	0.10	5200	8.6	--	--	--	--
		79-07-20	1100	--	0.10	1675	7.5	260	140	68.0	22.0
301	09N-06E-10 BBA	79-07-20	0930	--	<0.10	4337	8.1	400	230	100.0	35.0
302	09N-06E-10 DAA	78-08-07	1800	--	<0.10	15200	6.8	--	--	--	--
		79-09-12	1100	--	0.10	1550	7.3	230	140	59.0	21.0

Sodium, dissolved (mg/L as Na)	Sodium-adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Iodide, dissolved (mg/L as I)	Silica, dissolved (mg/L as SiO_2)	Total dissolved solids* (mg/L)	Lithium, dissolved (µg/L as Li)	Strontium, dissolved (µg/L as Sr)	Organic carbon, dissolved (mg/L as C)
					SEMINOLE COUNTY *Continued*								
250.0	3.1	7.5	69	1200.0	440.0	0.1	7.0	0.01	9.6	2200	8	1000	1.9
230.0	6.0	4.5	130	13.0	450.0	0.4	2.4	--	3.1	899	9	970	4.5
150.0	3.1	2.6	320	11.0	350.0	0.5	2.9	--	18.0	906	9	330	5.2
280.0	62.0	0.9	510	37.0	42.0	1.0	0.2	--	10.0	666	<4	10	11.0
33.0	0.7	4.6	230	26.0	190.0	0.2	1.1	--	11.0	580	20	790	2.6
11.0	0.2	2.6	390	140.0	21.0	0.2	0.2	--	9.6	571	20	310	0.5
230.0	5.3	6.2	220	32.0	470.0	0.3	1.0	--	4.8	1050	10	1100	5.1
1900.0	21.0	15.0	210	44.0	3800.0	0.2	22.0	0.09	2.5	6500	70	8200	8.9
43.0	1.2	1.3	310	25.0	14.0	0.1	0.1	--	16.0	360	20	160	3.5
9800.0	--	--	--	--	26000.0	--	90.0	--	--	43300	--	--	--
160.0	3.8	4.4	290	52.0	230.0	0.4	1.4	--	13.0	743	20	590	37.0
230.0	8.6	1.8	500	43.0	58.0	1.3	0.3	0.01	12.0	676	20	180	37.0
290.0	4.3	2.1	190	28.0	880.0	0.2	3.2	0.02	31.0	1820	10	370	5.0
280.0	--	--	--	--	22.0	--	0.3	--	--	830	--	--	--
160.0	12.0	2.4	290	68.0	35.0	1.3	0.2	--	9.6	464	20	130	6.6
510.0	33.0	2.7	590	250.0	290.0	1.4	2.0	0.03	20.0	1480	20	180	23.0
500.0	8.6	4.6	190	18.0	1000.0	0.3	5.7	--	6.4	2190	4	1700	3.3
1500.0	--	--	--	--	2800.0	--	8.2	--	--	5310	--	--	--
1400.0	16.0	2.1	300	53.0	3100.0	0.2	13.0	0.12	12.0	5730	110	7000	5.6
2400.0	--	--	--	--	4700.0	--	21.0	--	--	8530	--	--	--
1400.0	16.0	7.2	200	26.0	3000.0	0.2	27.0	0.14	23.0	5560	40	6400	4.9
48.0	1.1	4.6	370	53.0	26.0	0.3	0.2	--	7.4	488	<4	280	14.0
95.0	3.4	3.6	70	12.0	200.0	0.2	1.1	--	2.9	423	5	560	5.6
12.0	0.9	1.2	11	16.0	19.0	0.1	0.2	--	14.0	81	<4	20	0.6
7.3	0.3	1.1	130	13.0	17.0	0.3	0.1	--	13.0	184	20	40	1.8
16.0	0.6	1.1	110	14.0	30.0	0.4	0.2	0.02	16.0	194	10	90	2.9
320.0	7.6	11.0	190	56.0	550.0	0.5	2.6	--	3.8	1270	10	1100	11.0
580.0	--	--	--	--	1200.0	--	5.0	--	--	2200	--	--	--
110.0	1.3	16.0	230	8.3	1000.0	0.2	6.1	0.06	9.2	2360	20	4100	3.9
11.0	0.8	1.0	16	8.8	18.0	0.2	0.2	--	19.0	97	8	30	0.8
64.0	1.8	0.9	150	8.1	170.0	0.2	1.2	--	19.0	414	7	310	2.0
120.0	3.8	3.6	30	24.0	300.0	0.1	1.5	--	14.0	611	<4	630	3.8
35.0	2.3	1.1	11	24.0	57.0	0.1	0.4	--	14.0	157	6	50	0.4
4.7	0.1	0.7	310	110.0	7.7	0.2	0.0	--	6.6	484	<4	160	5.4
2900.0	25.0	23.0	190	54.0	6500.0	0.3	30.0	0.32	6.3	12000	100	13000	3.8
42000.0	131.0	620.0	1	570.0	91000.0	0.4	280.0	10.00	13.0	150000	1900	280000	--
50.0	1.3	2.5	330	15.0	22.0	0.3	0.2	--	14.0	391	30	330	9.0
72.0	2.2	0.8	140	150.0	68.0	0.2	0.5	--	20.0	451	8	150	2.1
6300.0	--	25.0	100	130.0	9500.0	0.3	40.0	0.30	16.0	17000	150	6500	4.9
720.0	9.9	9.6	100	2300.0	62.0	0.8	0.4	--	12.0	3910	40	3000	1.8
52.0	1.2	2.9	440	18.0	41.0	0.3	0.3	0.01	16.0	521	30	320	52.0
1700.0	--	--	--	--	3900.0	--	18.0	--	--	7260	--	9400	--
1200.0	16.0	12.0	270	26.0	2500.0	0.2	12.0	--	11.0	4880	50	4200	3.7
6100.0	--	--	--	--	9300.0	--	20.0	--	--	23900	--	40000	--
3300.0	29.0	32.0	340	49.0	7300.0	0.4	34.0	0.68	11.0	13500	180	18000	4.2
42.0	1.0	1.8	310	19.0	67.0	0.4	0.4	--	19.0	430	30	310	0.0
83.0	2.8	3.7	290	51.0	17.0	0.3	0.1	--	17.0	377	10	1100	0.0
780.0	--	--	--	--	1700.0	--	8.0	--	--	3110	--	2900	--
220.0	5.9	4.0	120	8.8	480.0	0.2	2.1	--	7.7	953	20	1100	4.1
730.0	16.0	9.4	170	44.0	1300.0	0.4	5.7	--	6.0	2520	60	2300	6.4
2300.0	--	--	--	--	4800.0	--	21.0	--	--	9340	--	--	--
240.0	6.8	4.4	91	16.0	470.0	0.2	3.1	--	5.6	976	20	880	4.1

APPENDIX 3. – *Continued*

Site	Sample Location	Date	Time	Well depth, total (ft)	Streamflow, instantaneous (cfs)	Specific conductance (µmho)	Field pH	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
				SEMINOLE COUNTY *Continued*							
303	09N-06E-10 DDC	79-09-12	1430	100	--	434	7.1	240	3	54.0	26.0
304	09N-06E-13 DDA	78-08-03	1000	--	<0.10	35000	7.6	--	--	--	--
		79-08-14	1545	--	<0.10	29412	7.5	4300	4100	1100.0	360.0
305	09N-06E-17 BBA	78-08-01	1430	--	<0.10	13300	8.2	--	--	--	--
		79-09-12	1430	--	0.10	9500	8.0	940	670	250.0	74.0
306	09N-06E-23 DCC	78-11-30	0945	--	<0.01	3800	7.3	--	--	--	--
307	09N-06E-25 CCB	80-01-29	1600	235	--	457	7.0	240	6	58.0	22.0
308	09N-06E-26 CCB	79-11-16	0900	--	0.40	942	7.1	170	0	51.0	11.0
309	09N-06E-29 CCD	79-12-04	1500	--	0.30	3670	7.5	560	420	140.0	51.0
310	09N-06E-31 BCB	79-09-28	1000	150	--	1231	7.3	250	0	43.0	35.0
311	09N-07E-03 CDC	79-08-13	1600	150	--	271	6.8	110	2	25.0	12.0
312	09N-07E-17 DDD	79-09-25	0845	--	<0.10	2657	6.9	550	340	140.0	47.0
313	09N-07E-18 CBB	79-08-14	1700	119	--	593	7.3	290	17	57.0	35.0
314	09N-07E-19 DCD	78-11-29	1530	--	<0.10	2650	8.1	--	--	--	--
315	09N-07E-22 DBA	79-09-25	1200	117	--	143	5.6	52	22	11.0	5.9
316	09N-07E-30 ADD	80-02-21	0930	--	<0.10	475	--	200	0	42.0	23.0
317	10N-05E-12 ADA	79-07-18	1030	215	--	920	8.0	49	0	12.0	4.5
318	10N-05E-27 AAD	79-09-13	1230	44	--	657	6.6	190	0	44.0	20.0
319	10N-06E-08 DDC	79-07-18	1200	--	1.70	9900	7.7	1500	1300	380.0	140.0
320	10N-06E-14 BAA	79-07-19	0930	--	<0.10	13140	7.5	1200	1100	310.0	110.0
321	10N-06E-15 ADD	79-07-19	1300	157	--	839	7.6	320	160	60.0	41.0
322	10N-06E-20 BBC	79-07-19	1400	90	--	562	7.3	220	0	43.0	28.0
323	10N-06E-30 CCC	79-07-18	1500	--	1.70	8600	7.9	1400	1200	340.0	140.0
324	10N-06E-31 CDD	79-07-18	1630	--	<0.10	61250	7.3	9100	8900	2500.0	660.0
325	10N-06E-35 CCC	80-08-22	0945	129	--	656	7.1	300	11	64.0	34.0
326	10N-07E-02 ABA	79-08-03	0930	--	0.12	823	7.4	260	120	64.0	24.0
327	10N-07E-02 BBB	79-08-03	0830	212	--	500	6.6	230	55	51.0	26.0
328	10N-07E-05 CCB	79-08-14	1030	119	--	441	6.7	260	28	62.0	25.0
329	10N-07E-15 CDC	79-09-19	1600	38	--	489	7.0	220	47	49.0	23.0
330	10N-07E-17 CDD	79-08-08	0930	--	<0.10	3617	7.2	870	730	240.0	65.0
331	10N-07E-20 BBB	79-08-14	1200	83	--	664	7.0	400	16	48.0	67.0
332	10N-07E-24 DDC	79-08-14	1330	182	--	451	5.2	110	88	23.0	12.0
333	10N-07E-27 BBB	79-08-13	1230	--	<0.10	155	6.3	53	19	12.0	5.5
334	10N-07E-29 DDD	79-09-19	1430	41	--	236	5.4	63	28	16.0	5.6
335	10N-07E-30 CDC	79-08-13	1700	--	<0.10	428	7.8	240	34	53.0	27.0
336	10N-08E-05 BBB	79-09-21	0900	84	--	205	6.0	43	0	11.0	3.8
337	11N-06E-19 CCC	79-08-15	0845	--	<0.10	302	7.2	120	3	31.0	11.0
338	11N-06E-29 CCC	79-07-17	1600	180	--	1145	6.6	310	0	46.0	48.0
339	11N-06E-35 BCB	79-07-18	0900	120	--	710	7.6	140	0	41.0	8.1
340	11N-06E-35 CDC	79-07-18	1330	--	3.70	7500	7.2	1100	940	280.0	100.0
341	11N-07E-10 DDA	79-08-15	1400	62	--	82	5.3	12	0	3.0	1.0
342	11N-07E-14 CDD	79-08-15	1230	--	<0.10	26	7.5	59	8	14.0	5.8
343	11N-07E-25 BBA	79-08-15	1100	122	--	95	5.7	29	11	7.6	2.4
344	11N-08E-09 AAA	79-08-02	1030	26	--	152	5.7	43	0	12.0	3.1
345	11N-08E-21 DDD	79-08-02	1400	58	--	715	5.7	240	37	60.0	21.0
346	11N-08E-22 ABB	79-08-02	1200	--	<0.10	330	6.3	110	0	26.0	10.0
347	11N-08E-33 DCD	79-08-02	1530	--	<0.10	3177	7.5	540	410	140.0	46.0

*Residue at 180°C.

**Estimated.

Sodium, dissolved (mg/L as Na)	Sodium-adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Iodide, dissolved (mg/L as I)	Silica, dissolved (mg/L as SiO_2)	Total dissolved solids* (mg/L)	Lithium, dissolved (µg/L as Li)	Strontium, dissolved (µg/L as Sr)	Organic carbon, dissolved (mg/L as C)
					SEMINOLE COUNTY *Continued*								
23.0	0.6	2.3	240	46.0	17.0	0.4	0.2	--	18.0	316	20	520	3.5
6800.0	--	--	--	--	13000.0	--	13.0	--	--	24100	--	1000	--
6200.0	42.0	57.0	150	150.0	13000.0	0.2	64.0	0.27	8.7	24400	480	26000	6.3
2100.0	--	--	--	--	4000.0	--	16.0	--	--	6950	--	6100	--
1800.0	26.0	17.0	270	51.0	3400.0	0.5	22.0	0.17	15.0	5830	90	5500	2.7
510.0	--	--	--	--	1300.0	--	7.5	--	--	2250	--	--	--
10.0	0.3	3.6	230	23.0	17.0	0.2	0.1	0.01	8.9	264	20	890	3.5
140.0	4.6	16.0	280	86.0	79.0	0.6	0.4	--	19.0	556	20	600	39.0
500.0	9.2	6.0	140	16.0	1100.0	0.2	4.6	0.12	4.9	2130	20	2300	3.9
160.0	4.4	5.7	330	120.0	140.0	0.4	0.4	--	15.0	690	40	740	1.0
5.8	0.2	1.0	110	4.1	9.3	0.2	0.1	--	12.0	143	0	140	0.0
350.0	6.5	3.6	210	780.0	310.0	0.2	0.1	--	11.0	1640	20	1800	1.9
11.0	0.3	1.9	270	8.6	37.0	0.3	0.2	--	8.3	349	0	420	2.5
290.0	--	--	--	--	770.0	--	4.7	--	--	1530	--	--	--
6.3	0.4	1.1	30	10.0	16.0	0.1	0.1	0.00	15.0	87	7	40	0.4
22.0	0.7	8.0	220	16.0	15.0	0.3	0.1	--	3.6	269	<4	230	11.0
220.0	14.0	2.1	240	180.0	69.0	1.1	0.5	--	7.6	625	10	130	--
64.0	2.0	1.2	230	13.0	66.0	0.2	0.5	--	25.0	429	30	240	3.1
1600.0	18.0	20.0	230	45.0	3300.0	0.3	16.0	0.31	8.3	6540	100	8900	8.3
2500.0	31.0	15.0	140	60.0	4600.0	0.2	21.0	0.29	7.1	8460	200	8300	3.7
48.0	1.2	8.9	160	120.0	110.0	0.3	0.2	--	17.0	480	10	1500	0.0
48.0	1.4	3.1	310	11.0	20.0	0.3	0.1	--	22.0	354	20	480	0.0
1200.0	14.0	13.0	230	43.0	2800.0	0.2	12.0	--	9.8	5580	60	--	7.3
17000.0	78.0	170.0	120	230.0	38000.0	0.1	130.0	--	9.3	54400	730	80000	3.6
22.0	0.6	2.3	290	35.0	23.0	0.4	0.2	0.16	16.0	365	20	730	--
84.0	2.3	3.8	140	13.0	220.0	0.2	1.3	--	14.0	561	6	430	4.3
18.0	0.5	2.2	180	22.0	52.0	0.2	0.4	--	13.0	322	20	180	1.9
14.0	0.4	2.8	230	26.0	16.0	0.2	0.1	--	12.0	278	9	480	33.0
17.0	0.5	1.5	170	14.0	44.0	0.1	0.3	--	11.0	296	20	100	1.0
430.0	6.4	3.4	140	23.0	1100.0	0.2	8.4	0.11	20.0	2360	9	1700	3.7
23.0	0.5	1.7	380	24.0	10.0	0.2	0.1	--	10.0	395	20	250	1.4
47.0	2.0	3.2	19	54.0	70.0	0.1	0.5	--	20.0	287	20	220	1.6
7.6	0.5	1.6	34	3.7	14.0	0.3	0.1	--	6.7	79	2	180	2.7
20.0	1.1	0.5	35	16.0	35.0	0.1	0.3	0.02	25.0	142	7	70	0.8
16.0	0.4	1.5	210	20.0	22.0	0.5	0.2	--	16.0	266	0	220	6.4
25.0	1.7	0.6	44	20.0	20.0	0.2	0.3	--	26.0	137	7	140	1.1
15.0	0.6	5.9	120	3.8	21.0	0.2	0.2	--	3.3	178	0	280	18.0
200.0	4.9	3.9	380	270.0	70.0	0.6	0.3	--	13.0	880	40	720	1.4
120.0	4.5	3.8	190	190.0	22.0	0.5	0.1	--	13.0	507	10	900	0.7
1100.0	14.0	17.0	170	40.0	2400.0	0.2	11.0	--	7.0	4820	80	2100	17.0
9.3	1.2	1.7	12	3.9	3.3	0.1	0.1	--	29.0	73	2	140	1.4
20.0	1.1	1.3	51	9.1	26.0	0.2	0.4	--	31.0	155	0	250	1.8
6.1	0.5	0.8	18	6.1	5.9	0.3	0.1	0.02	11.0	57	2	140	3.3
8.6	0.6	2.3	59	5.9	2.5	0.1	0.1	--	9.9	78	<4	90	0.9
59.0	1.7	21.0	200	70.0	64.0	0.3	0.5	--	6.9	501	10	290	4.8
24.0	1.0	4.4	140	18.0	8.7	0.4	0.2	--	39.0	217	10	180	3.1
450.0	8.4	4.6	130	30.0	950.0	0.2	5.9	0.09	15.0	1950	4	2100	4.2

Index

Type faces: Text in 9-pt. Century Schoolbook, with 1-pt. leading
Heads in 10-pt. Century Schoolbook bold
Text-figure captions in 8-pt. Helvetica, with 1-pt. leading
Table heads in 10-pt. Century Schoolbook, caps and small caps
Running heads in 8-pt. Century Schoolbook bold

Presswork: Miehle TP-29 Perfector

Binding: Saddle-stitched, softbound covered
Smythe sewn, hardbound covered

Paper: Text on 70-lb. Mountie Matte (hardbound), 100-lb. Mountie Matte (softbound)
Cover (hardbound) on Gane 8117LV red cloth on 160-pt. binder's board
Cover (softbound) on 65-lb. Hammermill gray, antique finish