THE IDENTIFICATION OF NATURALLY OCCURRING BRINE SEEPS RELATIVE TO THE BASE OF FRESH WATER WITH THE AID OF GEOGRAPHIC INFORMATION SYSTEMS

By

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INTRODUCTION

The Safe Drinking Water Act of 1974 was passed by Congress to address the growing concerns of the public about the integrity and protection of the nations drinking water. The Safe Drinking Water Act established primary and secondary standards for drinking water quality, set up a state/federal system to assure compliance, and developed the underground injection control (UIC) program to protect ground water supplies from the subsurface injection of fluids.

The Safe Drinking Water Act of 1974 established the Underground Injection Control Program by which the subsurface injection of fluids are regulated by the United States Environmental Protection Agency (USEPA). Under the UIC program, the states with USEPA approved programs enforce the program through a series of permits and required monitoring by well operators. Well operators are issued permits and are required to file quarterly reports on the physical and chemical properties of the injected fluids. Injection wells are tested regularly to insure the mechanical integrity of the injection system.

The Safe Drinking Water Act defined five classes of injection wells under the UIC program. These classes are defined as follows:

Class I - Wells used by generators of hazardous waste or owners of hazardous management facilities to inject hazardous waste beneath the lowermost formation containing, within one-quarter mile of the well bore, an underground source of drinking water.

Class II -	Wells which inject fluids which are brought to the surface in connection with natural gas storage operations, or conventional oil or natural gas production.
Class III -	Wells which are used in the solution mining of the following minerals: sulfur, uranium and other metals, and salts or potash.
Class IV -	Wells used by generators of hazardous waste or of radioactive wastes, by ownersor operators of hazardous management facilities or owners or operators of radioactive waste disposal facilities to dispose of radioactive or hazardous wastes above a formation which within one-quarter of a mile of the well contains an underground source of drinking water.
Class V -	Injection wells not included in Classes I, II, III, or IV.

In August of 1984, the USEPA published a final rule establishing the USEPA administered UIC program on Indian lands. Included was the Osage Mineral Reserve located in Osage County. The Osage Mineral Reserve, established by an act of Congress in 1906, allows the Osage Indian Nation to establish leasing policies and obtain royalties from oil and gas production within the reserve (Federal Register, Vol. 49, No. 222). The Osage Mineral Reserve encompasses all of Osage County, Oklahoma. The Region VI USEPA administers the UIC program for the Osage Mineral Reserve. The Region VI USEPA maintains a database of the Class II injection wells in Osage County. The database includes the legal description, elevation, date of completion, and the depth to the base of the Underground Source of Drinking Water (USDW) at each well location. The base of the USDW is defined by the USEPA as water having less than 10,000 mg/l total dissolved solids (TDS) (CFR, Chap. 1, Part 144.3)

The information contained in the USEPA UIC database is used to determine the depth of surface pipe necessary to protect the USDW at each proposed well location. Surface casing is required to prevent the movement of fluids into or between the USDW and surrounding formations. Surface casing is set in Class II wells to prevent the introduction of brines into the USDW. The entire USDW must be covered by surface casing. The minimum amount of surface casing required by the USEPA is 100 feet.

The origin of the brine laden oilfild water can be traced to many natural processes. Geologists believe that the water was originally meteoriuc water which reacted with weathered rock, soil and organic matter. This meteoric water eventually found its way to the oceans where evaporation concentrated the dissolved constituents. Some of the constituents precipitated to form evaporite deposits. As the sediments in the oceans were buried, this meteoric water was also buried where it reacted with the sediments. Oilfield brines differ from the original meteoric water deposited with the sediments due to ion exchange, infiltration of fresh water, sediment leaching, mineral formation, sulfate reduction, and ultrafiltration through clay-shale membranes (Collins, A.G., 1975).

In areas of extensive oil production, such as Osage County, Oklahoma, regulatory agencies must investigate complaints concerning water pollution. Many of these complaints in Osage County are directed at oil production companies and concern brine pollution. Traditionally, the method employed by geologists or regulatory investigators to locate brine seeps has required extensive field studies. Surface water samples within a study area or watershed are collected and analyzed for specific conductance and elevated readings are traced upgradient to the source.

If the source of elevated specific conductance readings cannot be located, several other methods are often employed in an attempt to determine the source of the brines. The use of Na/Cl ratios have been used in Western Oklahoma to distinguish oil field from salt spring brines (Leonard, Ward, 1962). If the ratio of Na/Cl is near or less than 50/100 then the source of the brines is probably from oil field activities. If the Na/Cl ratio is greater than 60/100, then the source is probably related to salt spring brines.

The concentration of specific chemical elements can also be used as indicators of the the source of brines. Elevated strontium concentrations, when compared to concentrations found in seawater, can indicate that oil field brine is the source of elevated TDS and conductivity reading (Rittenhouse, etal., 1968). Bromide can also be used as an indicator of the source of brines. Elevated bromide/ TDS ratios, when compared to seawater, can indicate that the source of the brines may bee related to oil field activities (Rittenhouse, etal., 1967).

The use of the above methods to determine the source of brines is not conclusive and the results can only be used as indicators of the source. In some instances, oil production companies are named as defendants in civil lawsuits involving brine pollution. In many instances, the ultimate source of the brines cannot be determined and the methods listed above are introduced in an attempt to convince the court that the oil production companies are responsible.

Computer applications in geography have been developed to manipulate large databases such as the USEPA UIC database. These computer applications are referred to as Geographic Information Systems (GIS). Geographic Information Systems have been developed as information storage, retrieval, and manipulation systems. GIS systems are currently being used in a wide variety of applications (J.L. Dweyer, J.T. Nash, 1988) to assimilate and manipulate data. Geographic Information Systems allow the user to input a wide variety of data and then overlay the different types of data to generate attributes of the existing data.

GIS applications are currently being used in geology and hydrogeology. These applications include the spatial analysis of geologic and geochemical data (Dweyer, J.L., J.T. Nash, 1988), mapping remote sensing geologic and thematic data (Purdy T.L., et al, 1985), the extraction of drainage networks from digital elevation models (O'Callaghan, J.F., 1984) and countless others.

The objective of this study is to investigate the use of a GIS system to identify naturally occurring brine seeps in Osage County, Oklahoma. The USEPA UIC injection well database and USGS topographical data for a study area will be combined in a GIS system to locate areas with a high probability of naturally occurring brine seeps. Field studies will then be conducted to verify the GIS output.

In order to accomplish the objective of this study, the USDW elevation data will be placed on a USGS 7.5 minute map. The surface elevation data and USDW data will be digitized into separate databases. The surface elevation data and USDW elevation data will be gridded using the same grid size. The USDW elevation grid files will then be subtracted from the USDW elevation grid files to produce a database of the differences in elevation. This database will be mapped using the GIS program in order to locate areas within the study area with a difference in elevation of 100 feet or less. It is our belief that the areas with a difference in elevation of less than 100 feet will have the highest probability of naturally occurring brine seeps.

BASE OF FRESH WATER IN OSAGE COUNTY, OKLAHOMA

The USEPA has defined a Underground Source of Drinking Water (USDW) as a aquifer containing water having less than 10,000 mg/L Total Dissolved Solids (TDS). In this study, the 10,000 mg/L limit defined by the USEPA is also referred to as the base of fresh water. This TDS concentration is considered by many as the lower limit of brines. Water of this quality is not a source of drinking water for human consumption or livestock. The USEPA recommended limit for TDS in drinking water is 1,500 mg/L.

The region VI USEPA maintains a database of the injection wells in Osage County, Oklahoma. The database includes the legal description, elevation and the depth of the base of the USDW at each well location. The database includes all existing wells and those permitted after the effective date of the regulations. This information is used to determine the amount of surface pipe necessary to protect the entire USDW.

A map depicting the elevation of the base of freshwater in Osage County was generated using the USEPA data. The USEPA data was averaged for each quarter township within the county. The averaged data was gridded and mapped using the computer mapping program SURFER. This map is presented as Plate 2 and shows the trends in elevation of the base of fresh water throughout the county.

The method used to determine the depth of the base of the USDW at each site involves the calculation of the static spontaneous potential (SSP) reading at which 10,000 TDS occurs for the respective formation temperature and mud resistivity. The static spontaneous potential is a measurement of the direct current (DC) differences between the naturally occurring potential of a moveable electrode in the well bore and the potential of a fixed electrode located at the surface (Doll, 1948). The USEPA approach is a standard method accepted by the geophysical logging industry (G.B. Asquith, 1982) and has been in use since the early 1900's. A full description of the USEPA method is found in Appendix B. Tables have been developed by the USEPA to determine the SSP reading for formation water containing 10,000 mg/L TDS and are presented in Appendix B. These tables are adapted from the industry Schlumberger Log Interpretation Tables (Schlumberger Well Surveying Corp., 1958). The tables are useful for most formation waters encountered but there are several limitations. The tables are based on clean formations free of clay and silt which are 20 feet or more in thickness. If the bed is less than 20 feet thick, then SSP readings must be corrected using the Schlumberger Log Interpretation Chart A-8. The Schlumberger Log Interpretation Charts are found in Appendix A. The USEPA tables do not apply to gyp-based, oil- based, or calcium chloride based muds. The formation water is assumed to be essentially a NaCl solution (USEPA Internal Memo).

The use of borehole geophysical logging in geologic and hydrogeologic investigations is well documented. Borehole logging has been a tool of the petroleum exploration industry for many years. Borehole logging in hydrogeologic investigations has also become an important tool (Patten, E.P., G.D. Bennet, 1963). Borehole logging has been used in hydrogeologic investigations to determine the resistivity of formation waters (Kwader, Thomas, 1986) and to determine the location and characteristics of the interface between brine and freshwater (Keys, W.S., L.M. McCary, 1973) and is commonly used to delineate the succession of formations in wells.

WATERSHED SCREENING AND STUDY AREA SELECTION

A study area was chosen from one of the six major watershed basins within Osage County. The six major basins being the Arkansas River, Caney River, Salt Creek, Sand Creek, Bird Creek, and Hominy Creek. A screening process was developed to evaluate the basins based on the overlap of the maximum and minimum values for topographic surface and the base of the USDW, the number of USEPA data points within the basin, and geologic considerations. The overlap of the maximum and minimum valuses for topographic surface and the base of USDW were used as an indicator of the probability of brines seeps occurring within a basin. A map depicting the six major watersheds in Osage County is presented in Plate 1.

Three of the six major watershed basins did not meet the initial screening criteria and were eliminated due to the lack of overlap between the minimum and maximum topographic and base of USDW values. These basins were the Bird Creek, Sand Creek, and Caney River basins. The Arkansas River basin was eliminated due to the lack of data for the areas outside Osage County. The Arkansas River forms the southern boundary of Osage County and therefore data was not available for those portions outside Osage County. The results of the primary watershed screening evaluations are presented in Table I. The remaining two basins, Hominy Creek and Salt Creek, were divided into thirds and each sub-basin was evaluated individually using the same criteria.

The upper Salt Creek basin was eliminated due to a lack of USEPA data. The middle and lower Salt Creek sub-basins had sufficient USEPA data, 684 and 181 respectively, but after further investigation it was discovered that the oil companies operating in the area had filed for and received a aquifer exclusion from the USEPA UIC program for the Zee sands located approximately 800 - 900 feet. The aquifer exclusion granted by the USEPA raised the base of the USDW to 100 feet below land surface due to the lack of fresh ground water in the area. This elevation is listed in the USEPA database as the base of the USDW in the area. According to USEPA officials, the TDS of the Zee sands is below the 10,000 mg/L limit but is not used as a source of drinking water due to poor quality. The 100 foot USDW level is the minimum USEPA

Table I
Primary Watershed Screening Evaluations

Watershed	Surface Elevation		Base of USDW Elevation	
	Minimum	Maximum	Minimum	Maximum
Salt Creek	853	1246	500	975
Arkansas River	700	1246	550	1050
Hominy Creek	670	1139	450	750
Bird Creek	650	1312	500	500
Sand Creek	656	1313	500	500
Caney River	689	1148	600	650

requirement for the depth of surface casing (CFR, Chap. 1, Part 144). It was also discovered through a telephone conference with USEPA officials that a series of faults run north to south through the Salt Creek basin. Brine seeps from fractures along these faults were common in the basin. The middle and lower Salt Creek basins were eliminated for these reasons.

The remaining basin, Hominy Creek, was also divided into thirds and each sub-basin was evaluated separately. The upper Hominy Creek sub-basin had over 300 USEPA data point and also had the most overlap between the maximum and minimum values for topographic surface and the base of the USDW. The middle and lower sub-basins each had less than 200 USEPA data points and approximately the same overlap for maximum and minimum topographic and base of USDW. A portion of the middle and all of the lower Hominy Creek sub-basins have now been inundated by the construction of Skiatook Lake. The upper Hominy Creek sub-basin was chosen as a study area based on these facts. The results of the secondary watershed screening evaluation are presented in Table II.

The study area defined in this report as the upper Hominy Creek sub-basin is that portion of the basin extending northwest from the dividing line of Range 8E and 9E of Township 22N. The study area is defined in Figure 1. The basin has an approximate surface area of 136 square miles. Surface elevation in the study area ranges from over 1100 feet above sea level in the northwest to as low as 750 feet in the southeast. Yearly precipitation averages 35 inches with 5 inches of annual runoff. Surface water quality averages over 1,000 mg/L total dissolved solids (TDS) (Bingham, 1980).

The rock sequences that crop out in Osage County range from Missourian to Wolfcampian in age. The surface rocks of the eastern two thirds of the county are characterized by sandstones, shales and thin marine limestones of the Missourian and Virgilian series. The strike is generally northeast to southwest with a gentle one percent

Table II
Secondary Watershed Screening Evaluation

Watershed	Surface Elevation		Base of USDW Elevation		USEPA Data
	Minimum	Maximum	Minimum	Maximum	
Upper Salt Creek	1090	1250	650	975	16
Middle Salt Creek	940	1140	600	925	620
Lower Salt Creek	830	1140	500	875	170
Upper Hominy Creek	740	1100	600	750	308
Middle Hominy Creek	640	1040	550	700	123
Lower Hominy Creek	600	960	450	650	187

shales, siltstones and limestones (Bellis, Rowland, 1976). The strike and dip of these dip to the west. The surface geologic topography is expressed as series of cuestas in the eastern two thirds of the county. The exposed rock of the western third of the county are formations is generally the same as in the eastern portion of the county.

The study area is underlain by two of the principle aquifers in Osage County. The eastern portion of the study area is underlain by the Vamoosa aquifer. The Vamoosa aquifer is composed of fine to coarse sandstone irregularly interbedded with shale and limestone (Bingham, 1980). The sandstone layers increase in thickness and become coarser to the south. The estimated thickness of the group is 437 feet (D'Lugosz, et al, 1977). Wells produce water of good quality and generally yield 25 to 50 gallons per minute.

The western portion of the study area is underlain by the Ada aquifer. The Ada aquifer is composed of shales and limestones that thin and pinch out southward where sand lenses become thicker and more numerous. This group can exist as a confined or unconfined aquifer (Bingham, 1980). Average thickness of the aquifer is approximately 162 feet (D'Lugosz, 1977). Wells produce water of good quality and generally yield 25 to 50 gallons per minute.

THE USE OF GIS FOR A SELECTED STUDY AREA

The GIS program chosen for this application was EARTHONE. EARTHONE was developed by the C.H. Guernsey Corporation of Oklahoma City, Oklahoma. EARTHONE is a vector based program and was designed as a automated mapping and facilities management system designed to maintain computer representations of large regions of land. With the EARTHONE system, geographical models can be created that combine graphical data, associate textural data to maps, create digital models and relate multi-key relational databases to any point (Guernsey Corp., 1988).

All data storage, management and manipulation was performed within the digital terrain model (DTM) of EARTHONE. Digital terrain models are information systems that store, manipulate and manage information about terrain (Puecker, 1979). DTMs are commonly used for contouring. EARTHONE's DTM takes irregularly spaced point data and develops regularly spaced rectangular grids. Each grid consists of a matrix of data points stored in rows and columns within the grid. This arrangement saves storage space because only the z coordinates are stored (Puecker, 1979).

Surface elevation data for the study area was obtained from USGS 7.5 minute maps. The watershed boundary for the study was first defined. The USDW data was placed on the USGS maps. The USDW data was averaged for each quarter section of the study area where data was available. The averaged data is found in Appendix C. The original USEPA data is presented in Appendix D. The 7.5 minute maps were then divided into sections in order to fit each section on a 11 x 17 inch digitizer board. Each map section was digitized individually. A Calcomp digitizer board was used to manually digitize the surface elevation, base of USDW and Township and Range boundaries. Fifty foot contour intervals were digitized.

After all the elevation information was digitized, the irregularly spaced data was gridded using a 528 foot rectangular grid size (Hutchinson, 1989). Each map section was gridded individually. After gridding each map section, the data for the adjoining map sections were left in memory while gridding the next section. No problems of matching contours in adjoining map sections were encountered. The original vector data digitized from the USGS maps was converted to rastor format in order to recreate the contour maps within the GIS program (Piwowat, et al, 1990). The individual map sections were then combined in EARTHONE to construct contour maps of the entire study area.

Two dimensional contour maps of the study area were generated upon completion of the gridding. Contour maps of the surface elevation and the base of the USDW were generated and are presented in Figures 2 and 3. The upper Hominy Creek drainage basin was well defined by the EARTHONE generated surface elevation map.

A FORTRAN program was developed to subtract the USDW elevation data from the topographic surface elevation data. The FORTRAN program was designed to subtract the grid values for the USDW elevation data from the grid values for the surface elevation data. The resulting database was a compilation of the differences in grid values for the two databases.

A contour map of the differences in elevation between the USDW and surface elevation data was gridded using the same 528 foot grid size used for the previous maps. This map is presented as Figure 4. The purpose of this map was to locate areas where the difference in elevation between the base of USDW and surface elevation was less than 100 feet. It was our belief that areas with a difference in elevation of less than 100 feet would have a high probability of naturally occurring brine seeps. A review of the elevation difference database revealed that there were no areas located where the difference in elevation was less than 50 feet.

Field studies were initiated upon the completion of the contour maps. Surface water samples were collected in those areas defined by the GIS generated difference map. Surface water samples were collected in that portion of the upper Hominy Creek sub-basin including all associated tributaries. Samples were analyzed in the field for specific conductance as an indicator of brine seeps. Elevated specific conductance readings were further investigated to locate the source of the elevated readings.

RESULTS OF GIS ANALYSIS AND FIELD STUDIES

Several areas were isolated within the upper Hominy Creek sub-basin by the GIS generated difference map where the difference in surface elevation and the base of USDW elevation was less than 100 feet. These areas were chosen as the areas where naturally occurring brine seeps were most likely to occur. The highest concentration of probable seeps was located in the southwestern quarter of Township 23N, Range 8E. The field studies were concentrated in the following sections: 19, 20, 28, 29, 30, 31, 32 and 33.

Field studies to verify the GIS output began during the month of May, 1993. A portable conductivity meter with a variable scale was used to analyze surface water samples taken within the study area for specific conductance. Elevated specific conductance readings would indicate the presence of brine seeps. Sampling sites were established during the first field study. Samples were taken and analyzed at the same sites on the following studies. These sites are presented in Figure 1. Conductivity readings for the field studies are listed in Table III.

Conductivity readings taken durring the field syudies ranged from 200 to 1350 umhos/cm. Abnormally high rainfall during the months of May and June hampered the collection of samples and resulted in the dilution of ground water discharges. The final field study was performed approximately 2 weeks after a significant rainfall during baseflow conditions.

Table III
Field Study Conductivity Analyses

Site No.	Site	Specific Conductance umhos/cm May 1,2	Specific Conductance umhos/cm May 15,16	Specific Conductance umhos/cm June 5,6	Specific Conductance umhos/cm Aug. 14,15
#1	Hominy Creek	740	600	720	950
#2	Hominy Creek	640	590	810	1020
#3	Hominy Creek	710	300	620	850
#4	Hominy Creek	790	340	670	900
#5	Turkey Creek	610	240	520	920
#6	Hominy Creek	850	780	880	970
#7	Hominy Creek	840	660	780	1140
#8	Unnamed	570	410	510	1020
#9	Hominy Creek	880	840	920	1200
#10	Hominy Creek	770	690	860	1350
#11	Unnamed	520	200	410	840
#12	Unnamed	530	360	490	930

Sampling sites #7, #8, #9, and #10 displayed elevated conductivity readings. Conductivity readings at these sites were higher than all other sampling sites during all four field studies. A search of the immediate areas surrounding each sampling site did not reveal the visible presence of a brine seep.

CONCLUSIONS

The purpose of this study was to investigate the effectiveness of the use of a GIS system in locating naturally occurring brine seeps in Osage County, Oklahoma. This goal was to be accomplished by combining the USEPA UIC injection well database and USGS surface topography data for a study area in a GIS system to locate areas with a high probability of brine seeps. Field studies were then conducted to verify the GIS output.

Several areas were isolated within the upper Hominy Creek sub-basin by the GIS generated difference map where the difference in surface elevation and the base of USDW elevation was less than 100 feet. These areas were chosen as the areas where naturally occurring brine seeps were most likely to occur. The highest concentration of probable seeps were located in the southwestern quarter of Township 23N, Range 8E. The field studies were concentrated in the following sections: 19, 20, 28, 29, 30, 31, 32 and 33.

The field studies in the areas isolated by the GIS output revealed that brine seeps or highly mineralized water was discharging into the study area. Evidence of this discharge is seen in the elevated conductivity readings at sampling sites #7, #8, #9 and #10. Field studies were hampered by abnormally high rainfall during the months of May and June. The conductivity readings taken during the first two field studies were well below the historical TDS values for Hominy Creek (Bingham, Bergman, 1980). The final field study was performed in mid-August approximately two weeks after a significant rainfall event during baseflow conditions. The conductivity readings taken during this field study were higher than those of previous studies but below historical values.

A library search for historical water quality data within the study area resulted in only two references to the Hominy Creek watershed. Roy Bingham and Deroy Bergman indicated in the USGS Hydrologic Atlas HA-7 that there was a water quality sampling station located on Hominy Creek near the city of Hominy. Data was available for seven years during the 1950 - 1966 period. The average TDS concentration for the upper Hominy Creek basin during this period is greater than 1,000 mg/L. The estimated conductivity for this period, by back calculation, is over 1,500 umhos/cm. The Oklahoma Water Resources Board (OWRB) also cited water quality data for the Hominy Creek watershed during this same time period. The OWRB states that the specific conductance for the upper Hominy Creek watershed during the 1950 - 1966 time period to range from 534 - 4,460 umhos/cm. The data taken during the field studies corresponds with the lower ranges of the OWRB conductivity data.

Conductivity readings were taken from two other watersheds within the area to compare with the readings taken in the study area. Surface water samples were taken from the Sand Creek and Bird Creek watersheds on August 16, 1993. Conductivity readings for the basins were 350 and 720 umhos/cm respectively. These values are considerably lower than the values obtained in the study area. This could indicate the presence of brine seeps or highly mineralized water discharging in the study area.

Several explanations are possible for the results obtained during the field studies.

One possible explanation is that the discharge of any brine seep in the study area is masked or diluted by the discharge of the abnormally high spring rainfall. The discharge of any brine seep in the area is not likely to be influenced by infiltration and should remain constant. If the discharge of the brine seeps is of low volume, their presence could be hidden by the dilution resulting from the discharge of the recent rains.

The resolution of this method could be improved by increasing the number of USEPA data points used in the study. Over 22,000 data points were input for the surface elevation within the study area. The surface topography map generated by the GIS program offers good resolution of surface features when compared to the USGS 7.5 minute map of the study area. The USEPA base of USDW data was averaged for each quarter section within the study area. Only 164 averaged data points were available. All other data points within the study were interpolated by the GIS program. The resolution of these interpolations could be improved by using a greater number of data points.
In this study, averaged quarter section USEPA base of USDW data was used as an approach to locate areas with a high probability of naturally occurring brine seeps. The location of each data point in the USEPA database is described by section, township, range and legal description. The conversion of this system to latitude and longitude or universal mercator system would easily allow the use of all data in the database and would greatly increase the resolution of the output.

In areas of extensive oil production, such as Osage County, Oklahoma, regulatory agencies must investigate complaints concerning water pollution. Many of these complaints in Osage County are directed at oil production companies and involve brine pollution. Traditionally, the method employed by geologists to locate brine seeps has required extensive field studies. Surface water samples within a study area or watershed are analyzed for specific conductance and elevated readings are traced upgradient to the source. This method could be used by regulatory agencies to isolate areas where the probability of naturally occurring brine seeps is high. This method could also be used in civil lawsuits concerning brine pollution to show that the probability of naturally occurring brines seeps is either high or low in specific areas.

In this application, the results obtained from the GIS program isolated areas with a high probability of naturally occurring brine seeps. This was based on the assumption that areas in which the difference in elevation of the base of fresh water and surface elevation of less than 100 feet have a higher probability of brine seeps. Although difficulty was experienced in verifying the results in the field, the effective use of Geographic Information Systems as a screening tool to locate areas with a high probability of brine seeps can be effectively accomplished.

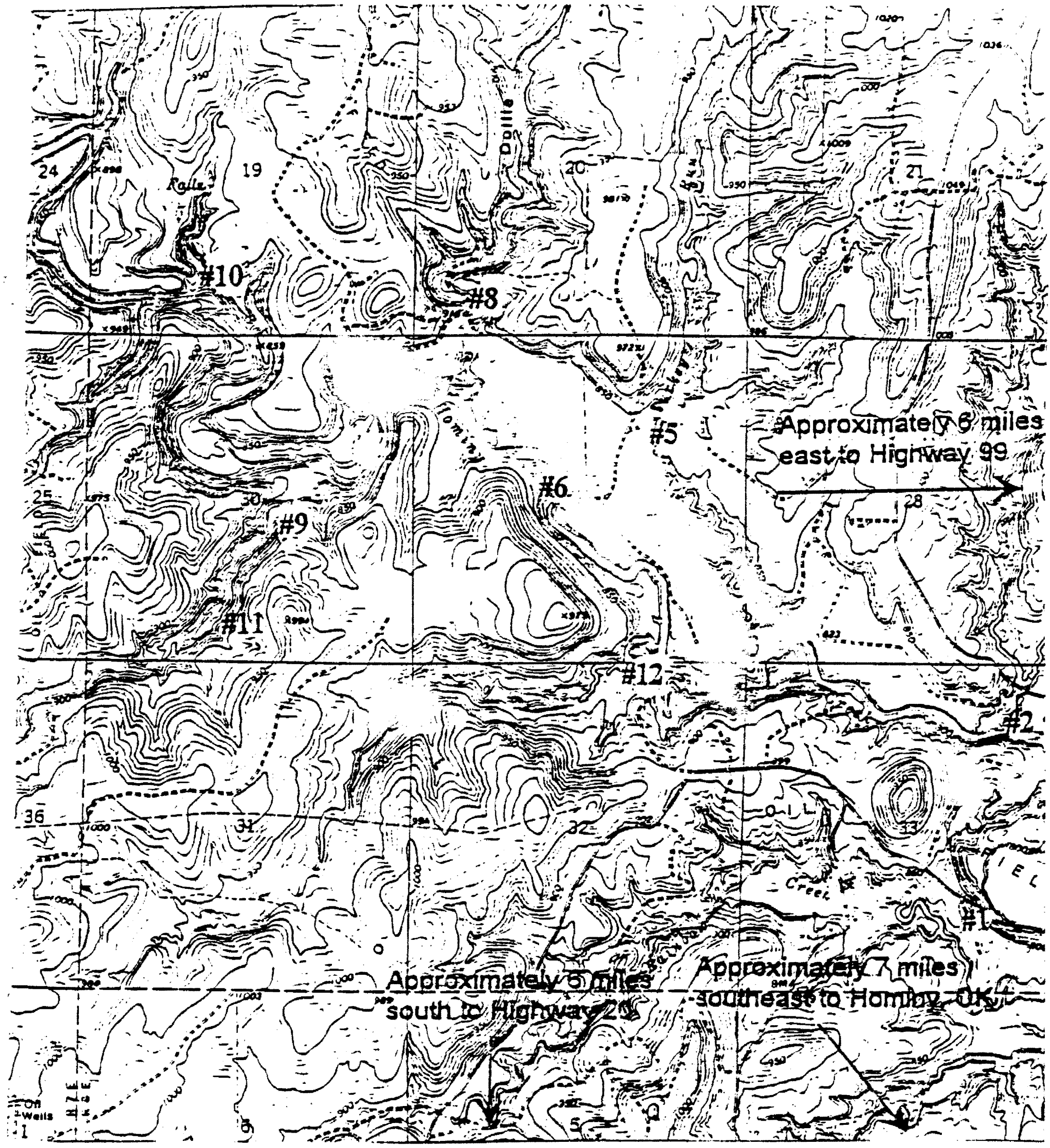

Figure 1

Study area and Sampling Locations

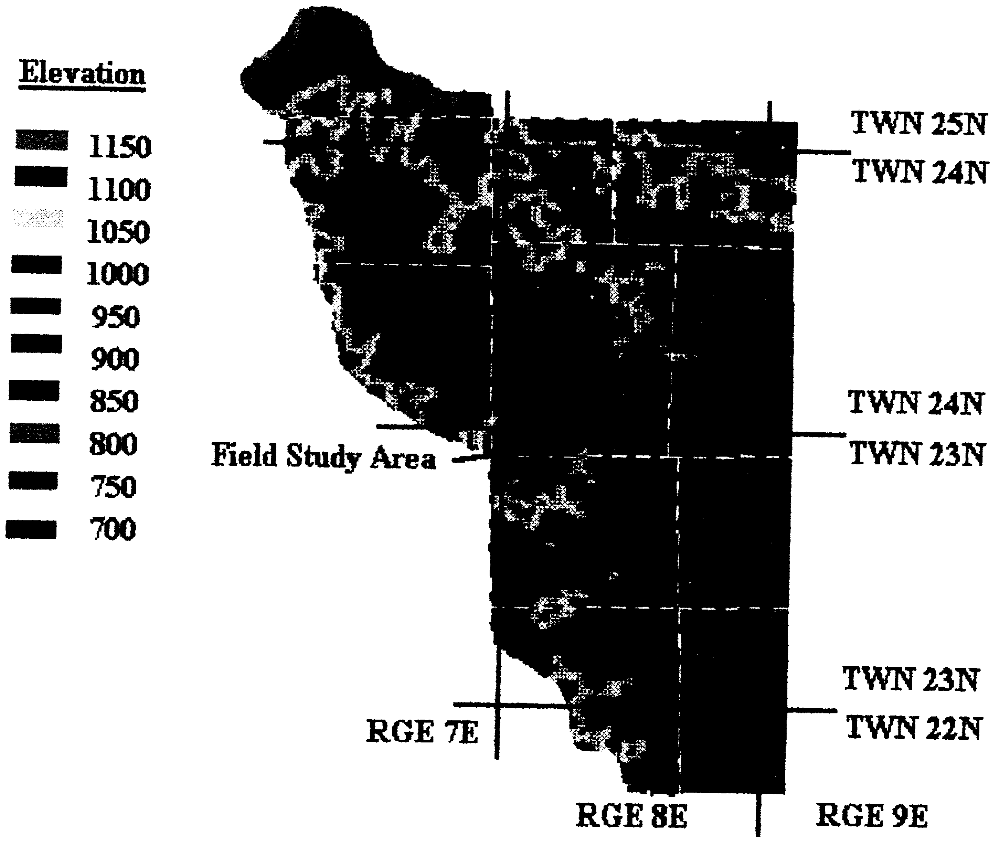

Figure 2

Surface elevation map of study area generated by GIS program EARTHONE by manually digitizing USGS surface elevation data

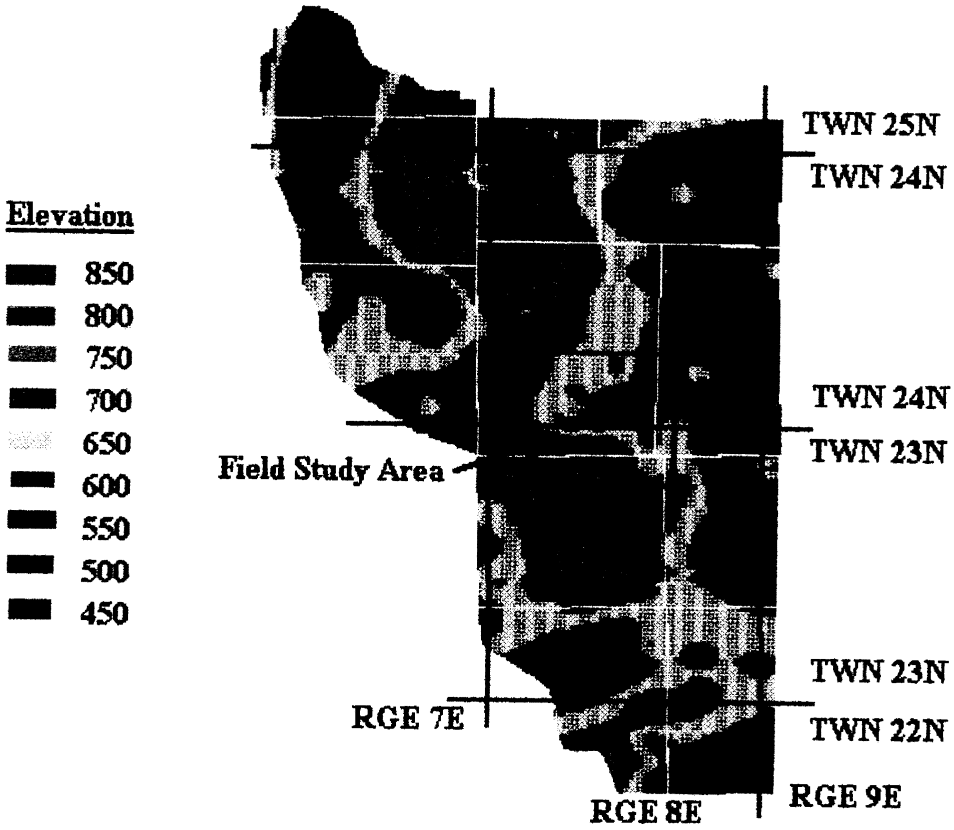

Figure 3

Elevation of base of Underground Source of Drinking Water (USDW) generated by GIS Program EARTHONE by manually digitizing USEPA UIC data averaged per quarter township

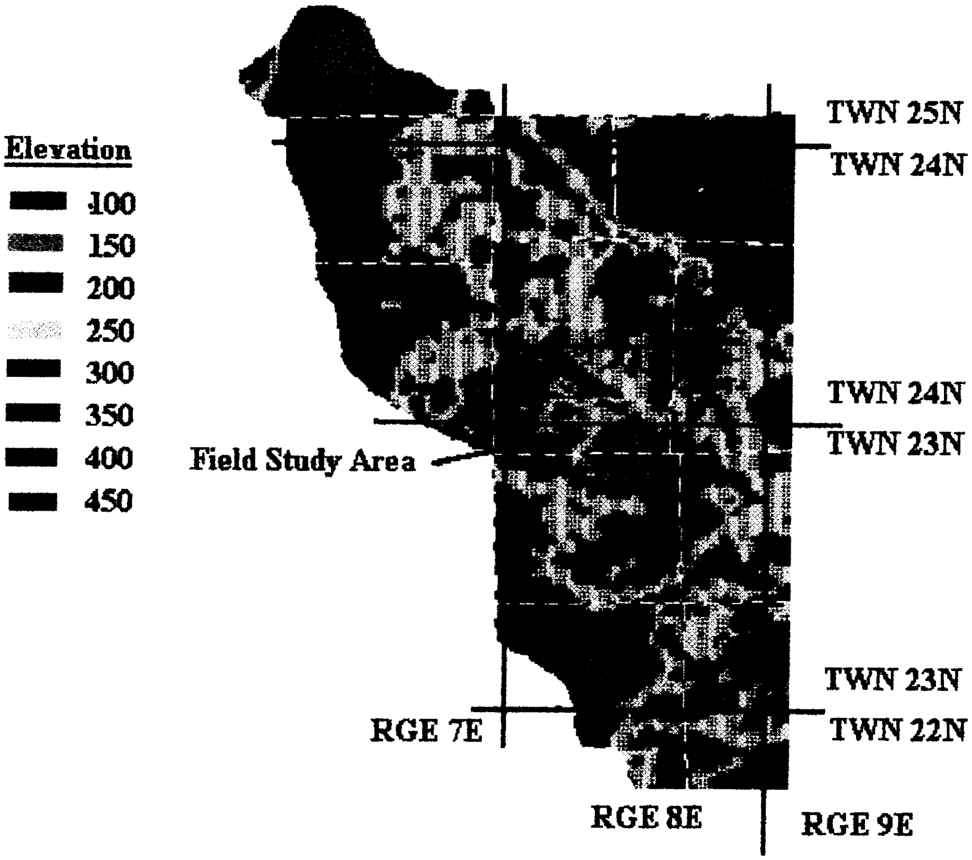

Figure 4

Difference in elevation map generated by GIS program EARTHONE by subtracting grid values for surface elevation from grid values for base of USDW, areas with a difference in elevation of less than 100 feet were considered to have a high probability of naturally occurring brine seeps.

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APPENDIX A

Formation Water Resistivity Calculations and Schlumberger Log Interpretation Charts

The method used to calculate the depth of the base of fresh water involves the calculation of the resistivity of the formation water from the spontaneous potential curve on the electric logs required for all oil wells in Osage County, Oklahoma. The spontaneous potential curve is a record of the direct current voltage differences between the naturally occurring potential of a moveable electrode in the borehole and the potential of a fixed electrode at the surface measured in millivolts. Electrochemical factors arising from the differences in the salinities between the mud filtrate (Rmf) and the formation water resistivity (Rw) within permeable beds generate the potential.

Several steps are involved in the calculation of formation water resistivity from spontaneous potential. These steps include the determination of the formation temperature at the zone of interest, the correction of the resistivities of the mud filtrate and the drilling mud to the formation temperature, determination of the R_{mf}/R_{we} ratio, determination of the equivalent resistivity (Rwe), and the correction of the equivalent resistivity to the resistivity of the formation water (R_w). These steps will be explained in detail in the following paragraphs.

To Calculate formation water resistivity (R_w) from spontaneous potential, the formation temperature (T_f)at the zone of interest must first be determined. Formation temperature can be determined by using the Schlumberger Chart in Figure 5. Formation temperature is determined by first calculating the temperature gradient using the following formula:

$$m = \frac{y - c}{x}$$

m = temperature gradient

x = total depth

c = surface temperature

y = bottom hole temperature

After the temperature gradient has been established, the formation temperature at the zone of interest can be calculated using the following equation:

$$y = mx + c$$

The resistivities of the mud filtrate (R_{mf}) and the drilling mud (R_m) can then be corrected to the formation temperature using the following formula or the Schlumberger Chart in Figure 6.

$$R_{tf} = R_{temp} \text{ x } (\text{temp} = 6.77) / (T_f + 6.77)$$

R_{tf} = resistivity at formation temp.

R_{temp} = resistivity at a temp. other than formation temp.

temp = temperature at which resistivity was measured

T_f = formation temperature

The spontaneous potential (SP) must then be corrected to the static spontaneous potential (SSP). Static spontaneous potential represents the maximum SP that a thick, shale free, porous and permeable formation can produce. The correction factor necessary is obtained using the Schlumberger chart in Figure 7.

The SSP value obtained can then be used to determine the ratio of the mud filtrate (R_{mf}) and the equivalent resistivity (R_{we}). The R_{mf}/R_{we} ratio is determined by using the chart located in Figure 8. The equivalent resistivity (R_{we}) can then be determined by dividing the resistivity of the mud filtrate (R_{mf}) by the R_{mf}/R_{we} ratio.

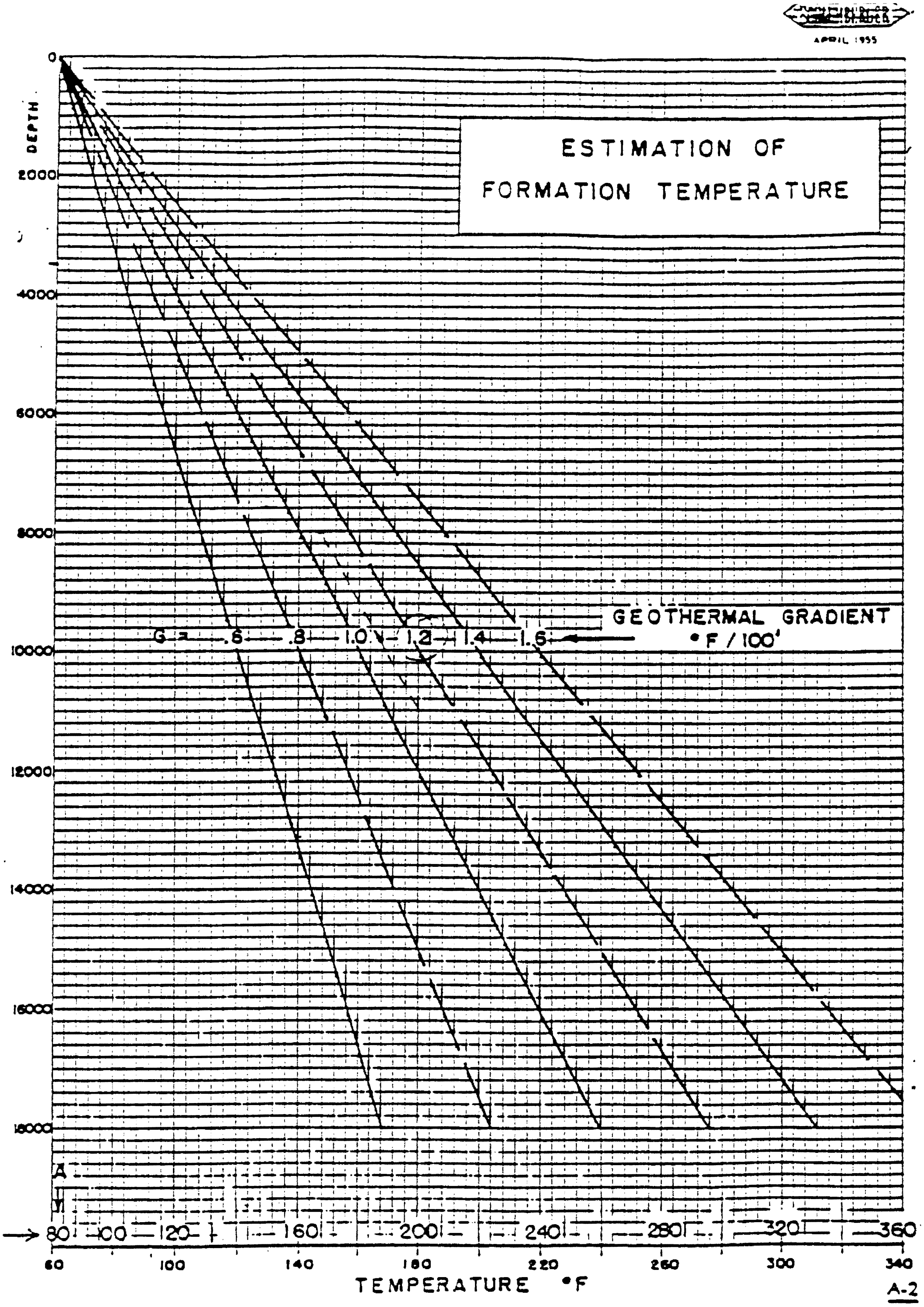
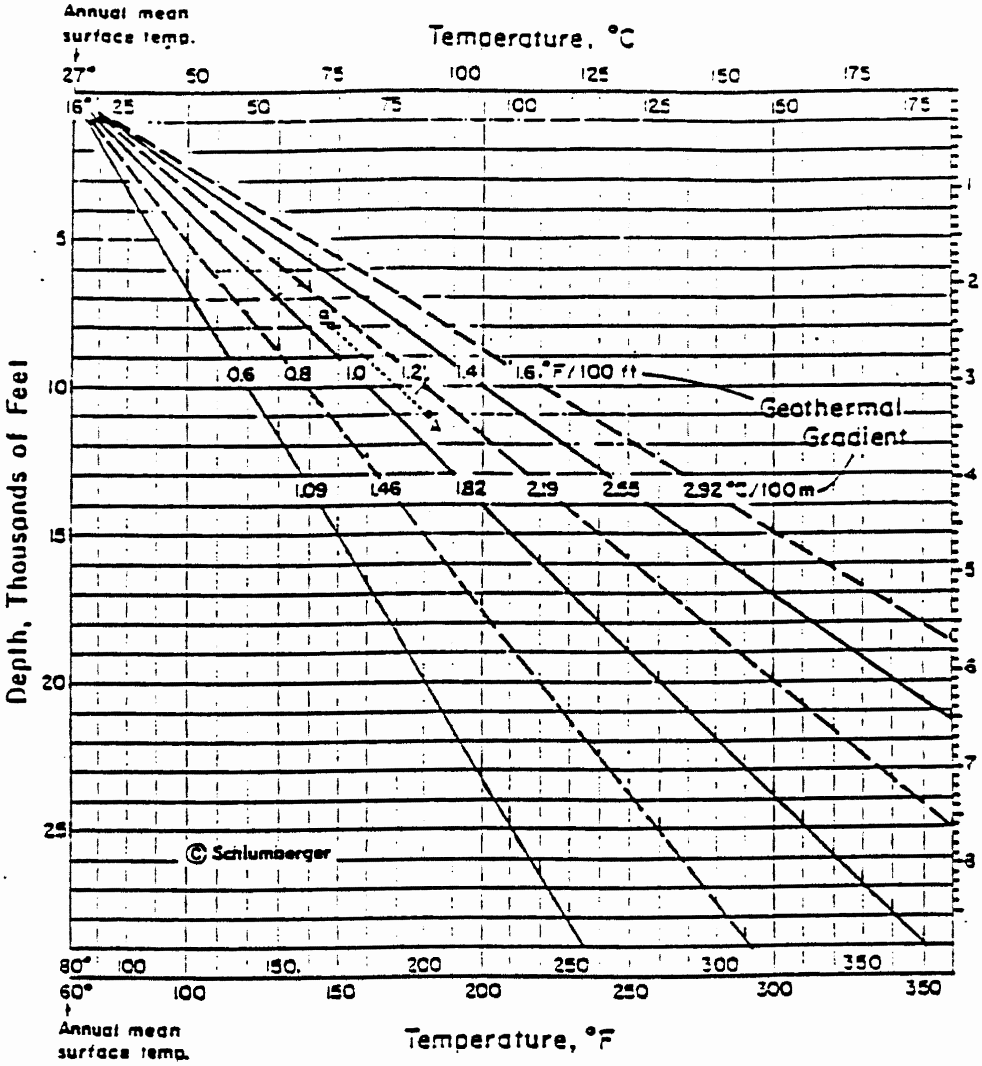


FIGURE 5

Schlumberger Formation Temperature Chart

ESTIMATION OF FORMATION TEMPERATURE

(Linear Gradient Assumed)



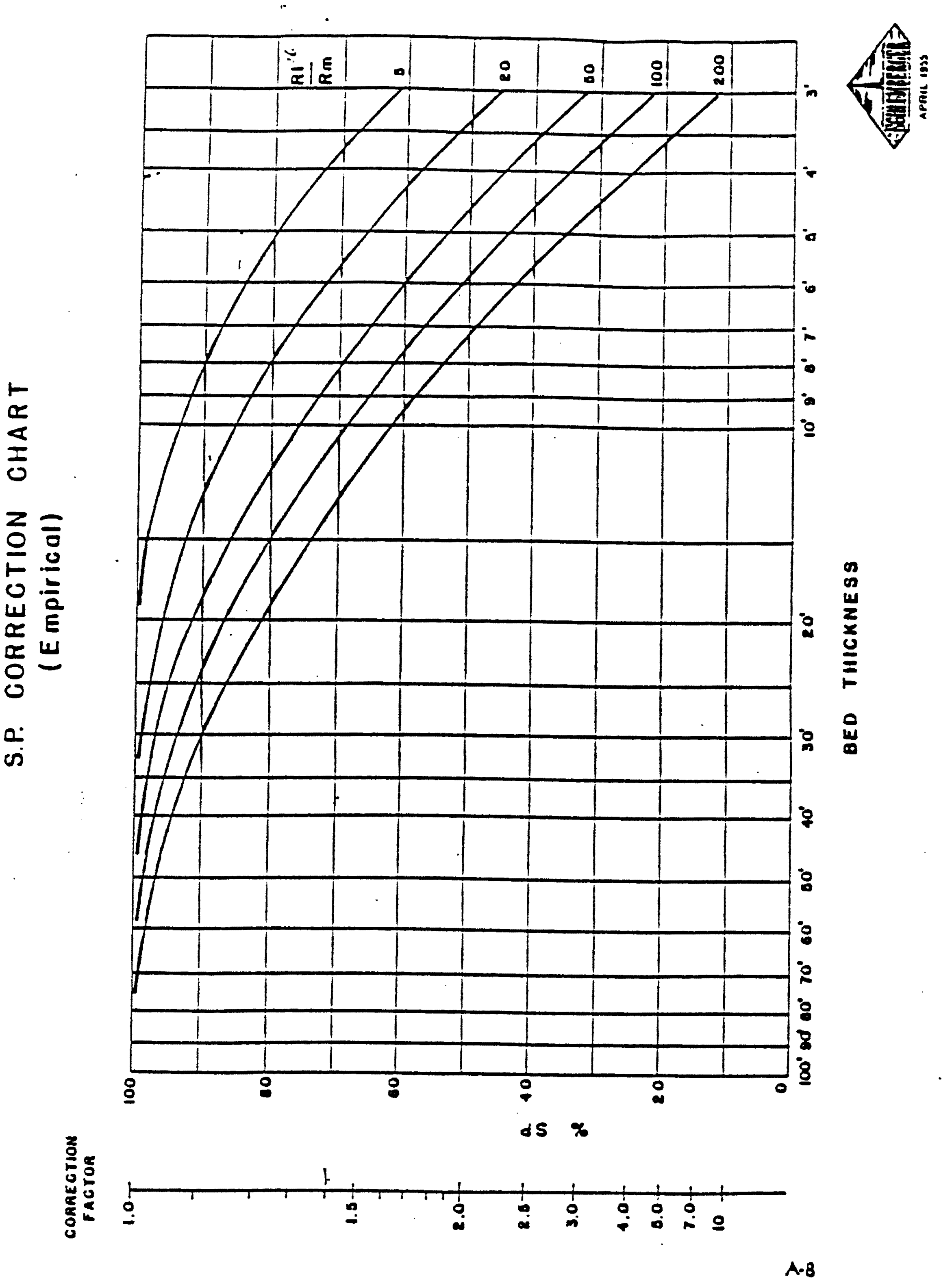
EXAMPLE: BHT is 200°F at 11,000' (Point A).
Temperature at 8,000' is 167°F (Point B).

Temperature Gradient Conversions: 1°F/100 ft = 1.823°C/100 m
1°C/100 m = 0.5486°F/100 ft

Gen-6

FIGURE 6

Schlumberger Formation Temperature Chart



A-8

FIGURE 7

Schlumberger SSP Correction Chart

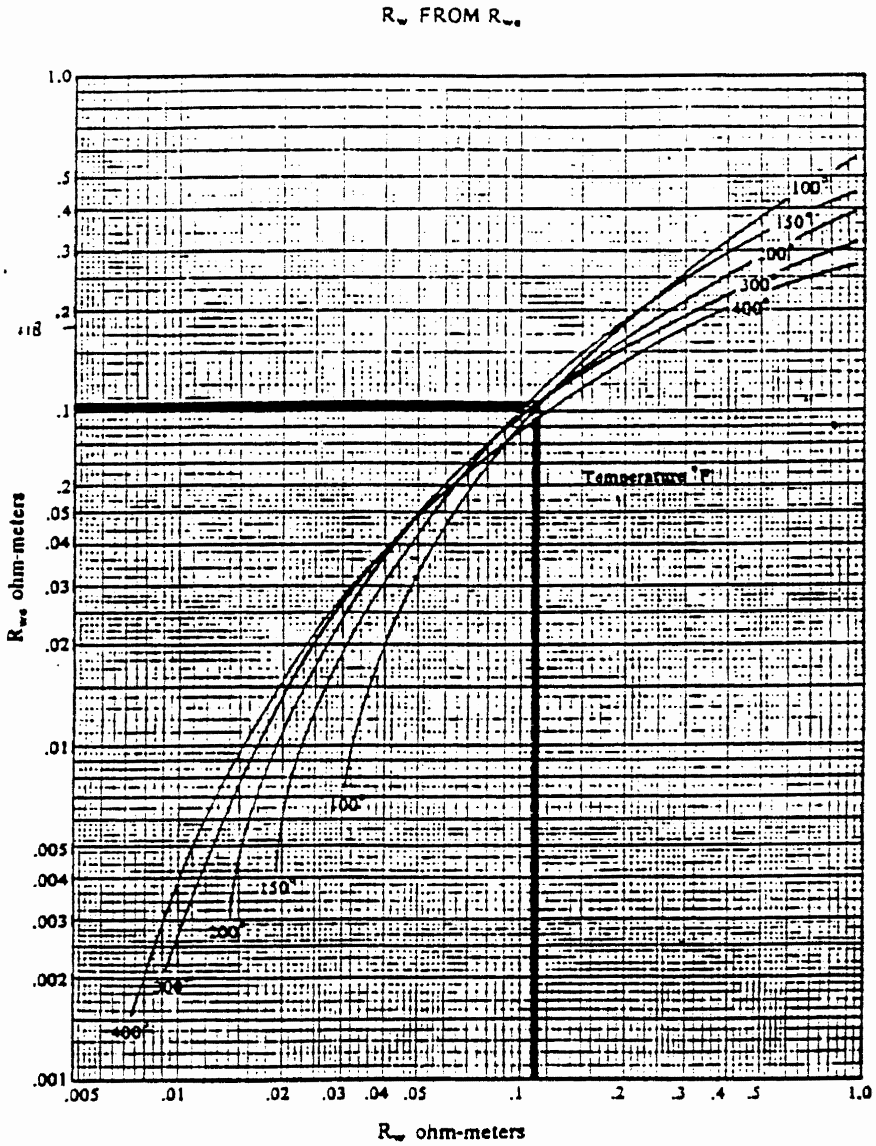


FIGURE 8

Schlumberger R_w/R_{we} Chart

APPENDIX B

USEPA Method

Determination of 3,000 and 10,000 ppm Dissolved Solids Water

The attached tables are designed to facilitate the picking of the approximate depth at which 3,000 and 10,000 ppm dissolved water occur as indicated by electric logs. The tables are useable for the average formation waters encountered, when the following limitations are observed:

1. It is limited to clean formations (free of silt and clay).
2. It should be used only on clean formations 20 feet or thicker. If used on beds less than 20 feet, it is necessary to adjust the SSP.
3. It cannot be used on gyp-based, oil-based, or calcium chloride based muds.
4. The formation water is essentially a NaCl solution.

Procedure

To use the tables, the following information is needed from the log heading (use the "Run No." column which includes the depths of interest:

1. Mud resistivity at a given temperature.
2. Bottom hole temperature (BHT).
3. Total Depth (first reading).

Determine the formation temperature at the depth of interest using Schlumberger Chart A-2 or GEN-6. Formation temperature to the nearest 10 degrees is sufficient. The mud resistivity at the formation temperature is determined by multiplying the mud resistivity by the temperature (given on the log heading) divided by the formation temperature.

Using the determined mud resistivity at formation temperature and the column corresponding to the determined formation temperature, the static SP (SSP). at which 3,000 or 10,000 ppm water occurs can be found in the following tables.

3,000 PPM DISSOLVED SOLIDS

Formation temperature

R_m	80^0	90^0	100^0	110^0	120^0	130^0	140^0	150^0
	-SSP	-SSP	-SSP	-SSP	-SSP	-SSP	-SSP	-SSP
.80	+10	+7	+4	+2	0	3	7	10
.85	+8	+5	+3	0	2	5	9	12
.90	+7	+3	+1	1	4	7	11	14
.95	+5	+1	0	3	5	8	13	16
1.00	+4	0	2	4	7	10	15	17
1.05	+2	2	4	5	8	12	17	19
1.10	+1	3	5	6	10	13	18	21
1.15	0	4	6	8	11	14	19	22
1.20	1	6	8	10	13	16	21	24
1.25	3	7	9	12	14	17	23	25
1.30	4	8	10	13	15	19	24	27
1.35	5	9	11	14	16	20	25	28
1.40	6	10	13	15	18	21	26	29
1.45	7	12	14	16	19	22	27	30
1.50	8	13	15	17	20	23	29	32
1.55	9	14	16	18	21	24	30	33
1.60	10	15	17	19	22	25	31	34
1.65	11	16	18	20	23	26	32	35
1.70	12	17	19	21	24	27	33	36
1.75	13	17	20	22	25	28	34	37

1.80	14	18	20	23	26	29	35	38
1.85	15	19	21	24	26	30	36	39
1.90	16	20	22	25	27	31	37	40
1.95	16	21	23	25	28	32	37	41
2.00	17	21	24	26	29	32	38	42
2.05	18	22	25	27	30	33	39	43
2.10	19	23	25	28	31	34	40	44
2.15	20	24	26	29	31	35	41	44
2.20	20	24	27	29	32	36	42	45
2.25	21	25	28	30	33	36	42	46
2.30	22	26	29	31	34	37	43	47
2.35	22	26	29	31	34	38	44	47
2.40	23	27	30	32	35	39	44	48
2.45	24	28	30	32	36	39	45	49
2.50	24	28	31	33	36	40	46	50
2.55	25	29	31	34	37	41	46	50
2.60	25	30	32	34	37	41	47	51
2.65	26	30	32	35	38	42	48	52
2.70	27	31	33	35	39	43	49	52
2.75	27	31	34	36	39	43	49	53
2.80	27	32	34	37	40	43	50	54
2.85	28	32	35	38	40	44	50	54
2.90	28	33	35	38	41	45	51	55
2.95	29	33	36	38	41	45	51	55
3.00	30	34	36	39	42	46	52	56
3.05	30	34	37	39	42	47	53	56
3.10	31	35	38	40	43	47	53	57

3.15	31	35	38	40	43	48	54	57
3.20	32	36	39	41	44	48	54	58
3.25	32	36	39	41	45	49	55	59
3.30	33	37	40	42	45	49	55	59
3.35	33	37	40	42	46	50	56	60
3.40	34	38	40	43	46	50	56	60
3.45	34	38	41	43	47	51	57	61
3.50	34	39	41	44	47	51	57	61
3.55	35	39	42	44	47	52	58	62
3.60	35	39	42	45	48	52	58	62
3.65	36	40	42	45	48	53	59	63
3.70	36	40	43	46	49	53	59	63
3.75	36	41	43	46	49	54	60	64
3.80	37	41	44	47	50	54	60	64
3.85	37	42	44	47	50	54	61	65
3.90	38	42	45	47	50	55	61	65
3.95	38	42	45	48	51	55	62	66
4.00	38	43	45	48	51	56	62	66

10,000 ppm Dissolved Solids

Formation Temperature

R_m	80^0	90^0	100^0	110^0	120^0	130^0	140^0	150^0
	-SSP	-SSP	-SSP	-SSP	-SSP	-SSP	-SSP	-SSP
.80	12	15	18	22	24	28	32	35
.85	14	16	20	24	26	30	35	37
.90	16	18	21	25	28	32	37	39
.95	18	20	23	27	30	34	38	41
1.00	20	21	25	29	31	36	40	43
1.05	21	22	26	31	33	37	42	44
1.10	22	24	28	32	34	39	43	46
1.15	24	25	29	33	36	40	44	47
1.20	25	26	30	34	37	42	46	49
1.25	26	28	31	35	38	43	47	50
1.30	27	29	33	37	40	44	49	52
1.35	28	30	34	38	41	45	50	53
1.40	30	31	35	39	42	47	51	54
1.45	31	32	36	40	43	48	53	55
1.50	32	33	38	41	45	49	54	56
1.55	33	34	39	42	46	50	55	57
1.60	34	35	40	43	47	51	56	59
1.65	34	36	40	45	47	53	57	60
1.70	35	37	41	46	48	54	58	61
1.75	36	38	42	47	49	54	59	62
1.80	37	39	43	47	50	55	60	63

1.85	38	40	44	48	51	56	61	64
1.90	39	41	45	49	52	57	62	65
1.95	40	42	45	50	53	58	63	66
2.00	40	42	46	51	53	59	63	67
2.05	41	43	47	52	54	60	64	68
2.10	42	44	48	52	55	61	65	69
2.15	42	45	48	53	56	61	66	69
2.20	43	45	49	54	56	62	66	70
2.25	44	46	50	54	57	63	67	70
2.30	45	47	51	55	58	64	68	71
2.35	45	48	51	56	59	64	69	72
2.40	46	48	52	57	59	65	70	72
2.45	47	49	53	57	60	66	70	73
2.50	47	49	54	58	61	66	71	74
2.55	48	50	54	58	61	67	72	75
2.60	49	50	55	59	62	68	73	75
2.65	49	51	55	60	62	68	73	76
2.70	50	52	56	61	63	69	74	77
2.75	50	52	56	61	64	70	75	77
2.80	51	53	57	62	64	70	75	78
2.85	51	53	57	63	65	71	76	79
2.90	52	54	58	63	66	72	77	79
2.95	52	54	59	63	66	73	78	80
3.00	53	55	59	64	67	74	78	80
3.05	53	55	60	64	67	74	79	81
3.10	54	56	60	65	68	75	79	81
3.15	54	56	61	65	68	75	80	82

3.20	55	57	61	66	69	76	80	82
3.25	55	57	62	66	69	77	81	83
3.30	56	58	62	67	70	78	81	83
3.35	56	58	63	67	71	78	82	84
3.40	57	59	63	68	72	79	82	85
3.45	57	59	64	68	72	79	83	85
3.50	58	60	64	69	73	79	83	86
3.55	58	60	65	69	73	80	84	86
3.60	59	61	65	70	74	80	84	87
3.65	59	61	65	70	74	81	85	87
3.70	59	62	66	71	75	81	85	88
3.75	60	62	66	71	76	82	86	88
3.80	60	62	67	72	77	82	86	89
3.85	61	63	67	73	77	83	87	89
3.90	61	63	68	73	78	83	87	89
3.95	61	64	68	74	78	83	87	90
4.00	62	64	69	74	79	84	88	90

APPENDIX C

Averaged USEPA Base of USDW Elevation Data

Sec./Twnshp/Rge	Quarter Section	Averaged Base of USDW Elevation
3/22N/8E	SE/4	723
10/22N/8E	SW/4	587
15/22N/8E	SW/4	599
16/22N/8E	NE/4	766
29/23N/8E	NW/4	644
30/23N/8E	NW/4	615
30/23N/8E	SW/4	611
31/23N/8E	NW/4	634
33/23N/8E	NE/4	466
33/23N/8E	SE/4	458
34/23N/8E	NW/4	677
2/22N/8E	NW/4	711
13/22N/8E	NE/4	492
13/22N/8E	NW/4	469
25/23N/8E	SE/4	637
26/23N/8E	NE/4	616

35/23N/8E	SW/4	562
1/23N/8E	SE/4	688
10/23N/8E	NE/4	780
11/23N/8E	SW/4	638
12/23N/8E	NE/4	499
12/23N/8E	NW/4	497
12/23N/8E	SE/4	540
13/23N/8E	NE/4	550
13/23N/8E	NW/4	525
3/23N/8E	SW/4	650
4/23N/8E	SW/4	791
5/23N/8E	SW/4	738
5/23N/8E	SW/4	803
7/23N/8E	NW/4	724
7/23N/8E	SW/4	668
8/23N/8E	NE/4	758
8/23N/8E	NW/4	773
8/23N/8E	SE/4	691
8/23N/8E	SW/4	769
9/23N/8E	NE/4	751
9/23N/8E	NW/4	751
9/23N/8E	SE/4	705
9/23N/8E	SW/4	740
16/23N/8E	NE/4	695
16/23N/8E	NW/4	732
18/23N/8E	SW/4	599
19/23N/8E	NE/4	660

35/23N/8E	SW/4	562
1/23N/8E	SE/4	688
10/23N/8E	NE/4	780
11/23N/8E	SW/4	638
12/23N/8E	NE/4	499
12/23N/8E	NW/4	497
12/23N/8E	SE/4	540
13/23N/8E	NE/4	550
13/23N/8E	NW/4	525
3/23N/8E	SW/4	650
4/23N/8E	SW/4	791
5/23N/8E	SW/4	738
5/23N/8E	SW/4	803
7/23N/8E	NW/4	724
7/23N/8E	SW/4	668
8/23N/8E	NE/4	758
8/23N/8E	NW/4	773
8/23N/8E	SE/4	691
8/23N/8E	SW/4	769
9/23N/8E	NE/4	751
9/23N/8E	NW/4	751
9/23N/8E	SE/4	705
9/23N/8E	SW/4	740
16/23N/8E	NE/4	695
16/23N/8E	NW/4	732
18/23N/8E	SW/4	599
19/23N/8E	NE/4	660

19/23N/8E	SE/4	674
19/23N/8E	SW/4	691
20/23N/8E	NW/4	733
20/23N/8E	SE/4	771
20/23N/8E	SW/4	733
1/24N/8E	NE/4	389
10/24N/8E	SE/4	625
11/24/8E	NW/4	538
11/24N/8E	SW/4	557
12/24N/8E	SE/4	628
13/24N/8E	NE/4	615
15/24N/8E	SE/4	538
22/24N/8E	NE/4	572
22/24N/8E	SE/4	608
23/24N/8E	SE/4	585
23/24N/8E	SW/4	530
24/24N/8E	NW/4	550
24/24N/8E	SE/4	620
24/24N/8E	SW/4	583
26/24N/8E	NW/4	640
26/24N/8E	SE/4	603
26/24N/8E	SW/4	609
34/24N/8E	SE/4	645
36/24N/8E	NE/4	420
36/24N/8E	NW/4	445
5/23N/8E	NW/4	767
2/23N/8E	NE/4	748

4/23N/8E	NW/4	821
3/23N/8E	NW/4	606
7/24N/8E	NE/4	815
7/24N/8E	NW/4	815
10/24N/8E	NW/4	623
10/24N/8E	SW/4	587
15/24N/8E	SW/4	651
16/24N/8E	SE/4	623
18/24N/8E	SE/4	673
18/24N/8E	SW/4	766
27/24N/8E	NW/4	525
27/24N/8E	SW/4	555
28/24N/8E	SW/4	725
28/24N/8E	NW/4	626
28/24N/8E	SW/4	625
30/24N/8E	NE/4	764
32/24N/8E	NE/4	657
32/24N/8E	SE/4	552
33/24N/8E	SE/4	625
33/24N/8E	SW/4	576
14/24N/7E	SW/4	551
15/24N/7E	NE/4	585
15/24N/7E	NW/4	605
15/24N/7E	SW/4	688
15/24N/7E	SW/4	582
16/24N/7E	NE/4	631
16/24N/7E	SE/4	627

21/24N/7E	NE/4	557
22/24N/7E	SE/4	611
22/24N/7E	NE/4	652
22/24N/7E	NW/4	625
22/24N/7E	SE/4	645
23/24N/7E	SW/4	648
23/24N/7E	NW/4	580
24/24N/7E	SW/4	702
24/24N/7E	NE/4	641
25/24N/7E	SE/4	689
25/24N/7E	NE/4	689
27/24N/7E	NW/4	636
27/24N/7E	NW/4	642
27/24N/7E	SE/4	686
27/24N/7E	SW/4	659
35/24N/7E	NE/4	625
35/24N/7E	NW/4	885
1/24N/7E	NE/4	737
1/24N/7E	NW/4	735
4/24N/7E	NW/4	608
4/24N/7E	SW/4	622
9/24N/7E	NE/4	600
9/24N/7E	NW/4	600
11/24N/7E	NE/4	757
25/24N/7E	NE/4	815
25/25N/7E	SE/4	815
32/25N/7E	SE/4	615

32/25N/7E	SW/4	597
36/25N/7E	SW/4	837
6/25N/8E	NW/4	726
6/25N/8E	SW/4	726
30/25N/8E	NE/4	736
30/25N/8E	NW/4	805
30/25N/8E	SE/4	710
30/25N/8E	SW/4	926
31/25N/8E	NE/4	823
31/25N/8E	NW/4	820
25/25N/7E	NE/4	815
25/25N/7E	SE/4	810
36/25N/7E	NE/4	507
21/24N/7E	SE/4	865

APPENDIX D

USEPA Base of USDW Elevation Data

Qtr Sec	Sec/Twn /Rge	Legal	Base of USDW below GL	Surf. Ele.	Date Drilled
NE	1/24N/7E	660N, 660E	305	1040	7/11/80
NE	1/24N/7E	330S, 330E	300	1033	8/10/78
NW	1/24N/7E	100N, 300E	310	1045	11/15/79
NW	4/24N/7E	990S, 330W	460	1068	10/22/51
SW	4/24N/7E	330N, 330W	468	1068	7/22/51
SW	4/24N/7E	990S, 330W	455	1055	8/1/51
SW	4/24N/7E	990N, 990W	420	1078	11/5/51
SW	4/24N/7E	330S, 990W	420	1064	6/18/53
SW	4/24N/7E	330N, 990E	730	996	11/26/64
NE	9/24N/7E	300S, 300E	398	998	4/29/36
NE	9/24N/7E	680S, 300W	435	1018	9/14/36
NE	9/24N/7E	980S, 980E	429	1029	6/14/36
NE	9/24N/7E	330S, 980W	386	986	4/8/36
NW	9/24N/7E	330S, 990W	470	1070	6/11/59
NW	9/24N/7E	1646S, 943W	473	1073	8/1/55

NW	9/24N/7E	990S, 330W	468	1068	9/7/56
NW	9/24N/7E	2310S, 1650W	472	1072	4/1/56
NW	9/24N/7E	2310S, 330W	450	1062	3/20/52
NW	9/24N/7E	990S, 990E	469	1069	2/22/38
NW	9/24N/7E	990N, 330E	476	1076	10/6/37
NW	9/24N/7E	330S, 330E	420	1020	7/22/36
NE	1/24N/7E	330S, 990W	265	1022	6/11/62
SW	14/24N/7E	330S, 330E	333	884	6/8/58
NE	15/24N/7E	990S, 330W	388	973	6/26/64
NE	15/24N/7E	980S, 300W	420	1012	10/19/33
NW	15/24N/7E	980N, 835W	360	956	9/7/35
NW	15/24N/7E	330S, 990W	400	1027	3/22/35
SE	15/24N/7E	330S, 990W	270	942	10/19/57
SE	15/24N/7E	330S, 330W	250	935	5/20/57
SW	15/24N/7E	200N, 330W	450	1029	8/9/58
SW	15/24N/7E	835S, 305W	390	977	4/12/34
SW	15/24N/7E	330S, 990W	402	965	7/15/57
SW	15/24N/7E	2310S, 2310W	380	977	2/23/71
SW	15/24N/7E	900N, 835W	370	956	9/19/35
NE	16/24N/7E	300S, 300E	410	1029	5/5/33
NE	16/24N/7E	990S, 330E	332	972	11/4/33
NE	16/24N/7E	300N, 300E	350	965	11/20/33
NE	16/24N/7E	1013N, 300E	324	964	11/15/33
NE	16/24N/7E	300S, 986W	406	1046	1/15/34
NE	16/24N/7E	980S, 300W	406	1046	3/4/34
NE	16/24N/7E	300N, 300W	383	1023	6/11/34
NE	16/24N/7E	1020S, 983E	394	1034	1/26/35

NE	16/24N/7E	1650S, 990W	420	1036	5/10/59
NE	16/24N/7E	990S, 990W	450	1067	3/29/35
NE	21/24N/7E	330S, 330W	428	971	5/23/29
NE	21/24N/7E	330N, 300W	535	1075	5/20/34
NE	21/24N/7E	900S, 300W	437	1089	5/1/34
NE	21/24N/7E	300N, 990E	501	1044	6/1/34
NE	21/24N/7E	300S, 990W	553	1096	3/17/35
NE	21/24N/7E	980N, 330E	420	990	4/3/34
NE	21/24N/7E	990N, 990W	494	1037	6/7/35
NE	21/24N/7E	990S, 990E	502	1045	11/2/35
SE	21/24N/7E	300N, 300W	547	1090	11/25/33
SE	21/24N/7E	300N, 990E	502	1045	5/9/35
SE	21/24N/7E	990S, 308W	410	1060	6/8/35
SE	21/24N/7E	990N, 990W	546	1089	7/29/35
SE	21/24N/7E	300S, 990W	462	1112	11/15/35
SE	21/24N/7E	990N, 300E	377	1027	3/26/36
SE	21/24N/7E	990S, 990E	401	1051	8/5/36
SE	22/24N/7E	330S, 2310W	421	1071	11/26/55
NE	22/24N/7E	710N, 625W	333	985	5/16/57
NE	22/24N/7E	913S, 330W	350	1004	10/4/57
NE	22/24N/7E	1650N, 1650W	335	986	1/10/58
NE	22/24N/7E	300N, 300W	375	1020	3/25/34
NW	22/24N/7E	1650S, 1020W	349	969	7/3/57
NW	22/24N/7E	990S, 330W	375	993	6/25/57
SE	22/24N/7E	330S, 990E	330	975	1/18/78
SW	22/24N/7E	300SN, 300W	350	995	3/15/36
SW	22/24N/7E	330S, 2310W	370	1020	5/24/56

NW	23/24N/7E	1650S, 2310E	290	954	6/30/74
SW	23/24N/7E	990N, 990E	240	942	10/27/57
NE	24/24N/7E	960N, 990E	281	922	11/22/56
SE	24/24N/7E	300N, 1365W	230	919	4/8/77
NE	25/24N/7E	1050S, 530E	230	919	8/25/76
SE	25/24N/7E	660N, 660W	115	949	2/15/72
SE	25/24N/7E	990S, 330E	105	970	9/25/68
NE	27/24N/7E	330S, 660W	318	954	7/15/80
NW	27/24N/7E	330S, 980W	375	1005	5/31/38
NW	27/24N/7E	990S, 330W	410	1039	11/24/55
NW	27/24N/7E	2310S, 330W	402	1052	11/21/56
NW	27/24N/7E	1650S, 990W	370	1033	11/28/56
NW	27/24N/7E	1650S, 2460W	370	1001	6/22/60
NW	27/24N/7E	360S, 2340W	346	996	7/8/60
NW	27/24N/7E	300S, 300W	400	1039	5/4/33
SE	27/24N/7E	330S, 330W	440	1084	9/8/56
SE	27/24N/7E	990S, 1320W	350	1061	10/26/57
SE	27/24N/7E	330S, 1650W	301	1005	4/25/59
SW	27/24N/7E	900S, 300W	370	1022	5/3/37
SW	27/24N/7E	980N, 300W	415	1065	7/19/37
SW	27/24N/7E	980N, 980W	427	1077	1/1/38
SW	27/24N/7E	425S, 895E	370	1022	6/15/40
SW	27/24N/7E	980S, 980E	417	1067	9/23/41
SW	27/24N/7E	1650S, 2310W	370	1017	10/4/56
SW	27/24N/7E	2310S, 1650W	395	1045	11/14/56
SW	27/24N/7E	330N, 330W	340	1084	9/23/32
NE	35/24N/7E	330N, 330E	394	1019	11/20/51

NW	35/24N/7E	1142S, 330W	230	1115	8/31/73
NE	9/25N/7E	990N, 990W	450	1058	1/7/85
SW	16/25N/7E	660N, 660E	590	1051	12/28/77
NE	17/25N/7E	2310N, 330E	450	1049	8/18/56
NW	17/25N/7E	330S, 990W	123	1075	5/18/57
SE	17/25N/7E	660N, 550E	500	1039	9/25/56
SW	17/25N/7E	660N, 330W	218	1081	10/14/70
NW	21/25N/7E	330N, 330E	445	1033	4/8/77
NW	23/25N/7E	990N, 990W	410	1120	10/24/80
NE	25/25N/7E	990N, 990E	200	1027	4/13/67
NE	25/25N/7E	990S, 330E	230	1032	2/6/54
SE	25/25N/7E	100S, 750E	210	1031	5/1/61
SE	25/25N/7E	200S,800E	250	1075	5/1/63
SE	25/25N/7E	2590S, 1320W	210	1035	9/8/66
SE	32/25N/7E	330S, 990W	400	1052	12/22/51
SE	32/25N/7E	990S, 330W	450	1043	2/19/52
SE	32/25N/7E	990S, 990E	400	1052	3/19/52
SE	32/25N/7E	330S, 330E	450	1042	5/15/52
SW	32/25N/7E	330S, 330E	410	1006	12/18/51
SW	32/25N/7E	990N, 330E	420	1015	2/11/52
SW	32/25N/7E	990S, 990E	410	1006	4/17/52
NE	36/25N/7E	330N, 330E	570	1077	10/30/54
SW	36/25N/7E	750S, 1300E	245	1082	6/19/79
NW	2/22N/8E	340S, 660W	200	907	7/18/83
NW	2/22N/8E	1000S, 600W	208	922	1/23/82
SE	3/22N/8E	100N, 1420E	210	944	10/27/82
SE	3/22N/8E	1660N, 300W	205	901	6/15/84

SW	10/22N/8E	990S, 2310W	340	927	6/30/57
NE	13/22N/8E	300S, 1424E	350	842	11/18/19
NW	13/22N/8E	310S, 790E	355	824	9/24/64
SW	15/22N/8E	330N, 330E	350	949	8/8/45
NE	16/22N/8E	2440N, 2180E	210	976	7/9/77
NE	1/23N/8E	300S, 1120W	400	789	11/1/51
SE	1/23N/8E	300N, 1020E	100	788	5/15/50
SW	3/23N/8E	550S, 330E	190	840	5/18/72
NW	4/23N/8E	330S, 333W	100	921	7/22/69
SW	4/23N/8E	1980S, 660W	100	891	6/29/67
NE	5/23N/8E	50N, 2612E	100	867	12/23/65
NE	5/23N/8E	1620N, 295E	190	963	12/18/65
NE	5/23N/8E	560N, 2080E	130	899	2/13/76
NE	5/23N/8E	1589N, 2524E	213	902	6/22/37
NE	5/23N/8E	2310N, 1550E	220	1058	2/4/86
NE	5/23N/8E	1130N, 1650W	211	930	11/25/89
NW	5/23N/8E	2310N, 200W	140	911	4/8/77
NW	5/23N/8E	480N, 1821W	100	867	6/13/56
SE	5/23N/8E	495S, 825E	275	1045	11/27/65
SE	5/23N/8E	1700S, 2030E	275	1044	2/1/76
SE	5/23N/8E	840S, 2345E	350	1057	12/11/84
SW	5/23N/8E	330S, 1310W	185	955	11/30/65
NW	7/23N/8E	990S, 825W	315	1039	3/3/76
SW	7/23N/8E	330N, 330E	380	1048	10/30/70
NE	8/23N/8E	2580N, 2065E	240	1009	8/24/76
NE	8/23N/8E	1360N, 200E	150	917	5/12/14
NE	8/23N/8E	400N, 2160E	240	950	11/11/80

NE	8/23N/8E	651S, 972W	170	941	1/9/65
NW	8/23N/8E	2494N, 1648W	265	1038	7/31/56
SE	8/23N/8E	660N, 50E	270	960	12/27/74
SE	8/23N/8E	940S, 2310E	360	1052	8/17/76
SE	8/23N/8E	1713S, 811E	250	941	9/1/56
SW	8/23N/8E	990S, 1200W	270	1039	8/10/76
NE	9/23N/8E	2310N, 2570E	115	862	8/25/74
NE	9/23N/8E	2310N, 1245E	180	934	8/24/74
NW	9/23N/8E	2360N, 610W	145	897	10/16/74
NW	9/23N/8E	2310N, 1760W	125	875	8/31/74
SE	9/23N/8E	1500S, 1295E	205	957	8/9/76
SE	9/23N/8E	1810S, 300E	270	927	3/21/17
SW	9/23N/8E	1313S, 1386W	230	980	12/19/56
SW	9/23N/8E	1245S, 2565W	225	974	11/17/74
SW	9/23N/8E	495S, 2245W	245	965	11/19/89
NE	10/23N/8E	990N, 990W	110	890	5/29/81
SW	11/23N/8E	330N, 330W	260	898	6/28/81
NE	12/23N/8E	330N, 990W	290	789	10/27/65
NW	12/23N/8E	330S, 740E	290	787	1/14/72
SE	12/23N/8E	1260S, 1320W	240	780	11/2/63
SE	12/23N/8E	610S, 1510E	220	760	7/21/74
NE	13/23N/8E	1440N, 1410E	260	785	6/29/74
NE	13/23N/8E	1940N, 1320W	250	775	5/27/74
NE	13/23N/8E	2610N, 2608E	260	787	9/26/80
NE	13/23N/8E	1320N, 1249W	280	778	10/2/80
NE	13/23N/8E	660S, 652W	680	779	10/1/80
NE	13/23N/8E	660N, 80E	320	777	9/23/80

NE	13/23N/8E	80N, 652E	280	778	8/23/80
NE	13/23N/8E	80N, 80E	280	777	8/17/80
NE	13/23N/8E	1320N, 1254W	280	780	8/30/80
NE	13/23N/8E	1320N, 80E	280	775	8/8/80
NE	13/23N/8E	660S, 80E	280	775	8/2/80
NE	13/23N/8E	810N, 300W	250	793	8/21/24
NW	13/23N/8E	600N, 660E	250	799	3/9/61
NW	13/23N/8E	270N, 1650W	250	800	3/3/74
NW	13/23N/8E	600N, 1280W	250	795	2/26/74
NW	13/23N/8E	990N, 990W	250	802	3/3/74
NW	13/23N/8E	920N, 1650W	250	796	5/13/74
NW	13/23N/8E	660S, 652E	210	781	8/30/80
NW	13/23N/8E	1145N, 75E	284	794	8/21/80
NW	13/23N/8E	660S, 30E	280	780	8/23/80
NE	16/23N/8E	50N, 1320E	200	940	11/18/74
NE	16/23N/8E	300N, 300E	275	924	6/1/17
NW	16/23N/8E	50N, 2615W	230	943	11/1/74
NW	16/23N/8E	50N, 1320W	230	944	12/27/74
NW	18/23N/8E	1812S, 1520W	160	929	11/20/64
SW	19/23N/8E	990S, 330E	400	999	1/30/56
NE	19/23N/8E	100S, 660E	300	960	11/17/75
NE	19/23N/8E	800S, 950E	308	968	7/21/77
SE	19/23N/8E	75N, 350W	300	1007	7/19/76
SE	19/23N/8E	300N, 300E	300	950	5/5/76
SE	19/23N/8E	650S, 1050W	300	998	11/8/76
SW	19/23N/8E	50S, 1320W	300	994	9/4/75
SW	20/23N/8E	1040N, 1200E	300	987	9/3/75

NW	20/23N/8E	960S, 300E	158	891	7/3/76
SE	20/23N/8E	400N, 300E	100	908	5/9/24
SE	20/23N/8E	1045S, 1045W	209	942	10/15/23
SW	25/23N/8E	960N, 250W	264	997	8/2/76
SE	26/23N/8E	700S, 300W	215	852	7/23/39
NE	29/23N/8E	200S, 1127E	200	816	2/6/84
NW	30/23N/8E	420N, 932E	404	1048	5/4/62
NW	30/23N/8E	300N, 200W	348	963	7/23/75
SW	30/23N/8E	1900S, 560W	341	956	12/19/72
SW	30/23N/8E	1150S, 765W	367	982	11/23/73
NW	31/23N/8E	20S, 830W	410	988	9/25/72
NW	31/23N/8E	1233S, 804W	320	1022	6/1/54
NW	31/23N/8E	380N, 700W	380	1024	7/6/72
NE	33/23N/8E	990S, 330W	449	915	5/4/58
SE	33/23N/8E	330N, 990E	448	906	12/23/57
NW	34/23N/8E	300N, 300E	220	892	4/25/23
NW	34/23N/8E	990S, 330W	151	839	2/22/57
SW	35/23N/8E	330S, 330E	240	802	2/15/84
SW	36/23N/8E	880S, 330W	190	792	11/4/83
SW	5/24N/8E	1650S, 2310W	328	1025	7/28/53
SW	5/24N/8E	1235S, 1075W	295	1007	4/7/70
NW	6/24N/8E	3--N, 300E	337	1063	3/27/76
NE	7/24N/8E	300N, 990E	240	1055	2/9/67
NW	10/24N/8E	990S, 990E	290	913	3/20/77
SE	10/24N/8E	330S, 330E	360	954	5/31/57
SE	10/24N/8E	1650S, 990E	270	844	7/24/57
SE	10/24N/8E	990N, 330W	360	926	7/17/69

SE	10/24N/8E	990S, 310E	312	920	11/1/56
SW	10/24N/8E	1140S, 990E	390	943	3/26/77
SW	10/24N/8E	330N, 330W	390	1033	8/1/78
SW	19/24N/8E	990S, 330W	339	905	4/9/54
NW	11/24N/8E	990S, 990W	340	878	2/18/64
SW	11/24N/8E	330S, 330W	284	843	7/20/54
SW	11/24N/8E	1550S, 330W	290	849	10/12/56
SE	12/24N/8E	100S, 1680E	375	1003	10/27/55
NE	13/24N/8E	990N, 330E	350	965	3/30/78
SE	15/24N/8E	810N, 770E	239	860	7/26/46
SE	15/24N/8E	1050S, 350W	370	908	7/6/55
SW	15/24N/8E	1020N, 543E	233	884	5/25/65
SE	16/24N/8E	800N, 200W	350	990	11/20/56
SE	16/24N/8E	1320S, 330E	430	1035	5/28/83
SE	18/24N/8E	300S, 300E	300	973	2/26/37
SW	18/24N/8E	990S, 330W	160	926	12/23/57
NE	22/24N/8E	990S, 330W	350	922	10/17/34
SE	22/24N/8E	565N, 580W	341	949	1/6/52
SE	23/24N/8E	1370S, 50E	340	925	11/21/61
SE	23/24N/8E	1340S, 1320E	340	936	2/23/62
SE	23/24N/8E	187N, 1185E	340	833	3/17/66
SW	23/24N/8E	50S, 50E	360	890	12/10/67
NW	24/24N/8E	330N, 990W	300	833	4/29/54
NW	24/24N/8E	720S, 330W	295	825	6/24/54
NW	24/24N/8E	990S, 990W	295	824	7/3/54
NW	24/24N/8E	449S, 857E	330	889	6/6/56
NW	24/24N/8E	990S, 330E	320	888	8/5/57

NW	24/24N/8E	300N, 300W	250	822	6/2/34
SE	24/24N/8E	530S, 910W	200	820	9/5/58
SW	24/24N/8E	745N, 1240E	300	823	11/20/58
SW	24/24N/8E	800N, 300W	280	904	3/22/65
SW	24/24N/8E	800N, 400E	221	825	3/2/58
NW	26/24N/8E	880S, 850E	370	1004	11/26/67
NW	26/24N/8E	575N, 1100W	370	1016	12/22/67
SE	26/24N/8E	300S, 1087W	290	893	10/11/40
SW	26/24N/8E	50N, 575W	360	969	12/4/67
NW	27/24N/8E	330S, 1200E	400	925	12/8/70
SW	27/24N/8E	50N, 300W	330	885	12/21/71
NE	28/24N/8E	1180N, 870W	181	906	11/12/75
NW	28/24N/8E	515S, 1332W	355	910	10/26/55
NW	28/24N/8E	1110S, 740W	210	908	2/7/74
SW	28/24N/8E	330S, 1250W	210	834	1/1/54
SW	28/24N/8E	1800S, 870W	210	835	5/1/60
NE	30/24N/8E	330N, 330E	100	864	8/28/54
NE	32/24N/8E	1000N, 1000W	320	873	11/26/69
NE	32/24N/8E	36S, 1257E	270	895	8/1/81
NE	32/24N/8E	660S, 660E	270	895	6/1/79
NE	32/24N/8E	660S, 1320W	270	919	8/28/81
NE	32/24N/8E	31S, 660E	270	870	8/1/81
NE	32/24N/8E	666S, 757W	179	964	2/8/89
SE	32/24N/8E	660S, 1800E	280	841	9/8/67
SE	32/24N/8E	1650S, 330E	280	825	9/9/69
SE	33/24N/8E	1650S, 330W	210	835	3/15/86
SW	33/24N/8E	350N, 900W	250	826	6/7/75

SE	34/24N/8E	315S, 555W	138	816	9/24/65
SE	34/24N/8E	192S, 1082W	250	860	11/13/61
NE	36/24N/8E	300N, 300W	375	798	8/17/20
NE	36/24N/8E	320S, 950W	375	791	4/30/22
NE	36/24N/8E	660N, 660E	400	797	4/11/70
NW	36/24N/8E	1340N, 300W	375	820	6/9/17
NW	36/24N/8E	300N, 810W	375	815	3/1/28
SE	27/25N/8E	330N, 330E	430	1019	4/23/57
SE	27/25N/8E	990S, 990W	430	1043	9/26/58
SE	27/25N/8E	990N, 380W	480	1058	8/29/58
SW	27/25N/8E	200S, 1200W	520	1096	8/3/58
SW	28/25N/8E	300N, 1330W	353	1018	8/4/59
NE	29/25N/8E	330S, 1650W	303	1053	3/3/59
NE	29/25N/8E	990N, 990W	270	1073	8/13/80
NW	29/25N/8E	813S, 300E	410	1055	5/4/26
NW	29/25N/8E	1650S, 990W	350	1040	4/11/26
NW	29/25N/8E	300S, 300W	412	1057	9/10/26
SE	29/25N/8E	2310S, 2310W	366	1078	5/9/24
SE	29/25N/8E	1980S, 1320W	340	1018	6/2/60
SW	29/25N/8E	300N, 980W	340	1015	12/16/26
SW	29/25N/8E	1370S, 50E	354	1029	4/9/60
NE	30/25N/8E	990S, 2310W	319	1069	6/10/26
NE	30/25N/8E	1650S, 1650W	365	1075	7/30/26
NE	30/25N/8E	990S, 990W	350	1066	11/17/26
NE	30/25N/8E	300S, 980E	329	1041	12/8/56
NE	30/25N/8E	300N, 965W	300	1053	4/20/27
NE	30/25N/8E	1650S, 330W	292	2482	4/19/27

NW	30/25N/8E	2310S, 990W	220	1040	8/12/30
NW	30/25N/8E	980S, 971W	210	999	10/16/35
SE	30/25N/8E	1320N, 660E	320	1030	7/17/34
SE	30/25N/8E	50S, 2590W	292	1002	11/20/59
SW	30/25N/8E	1100N, 330W	130	1057	6/2/54
SW	30/25N/8E	330S, 330W	135	1061	10/18/51
NE	31/25N/8E	980N, 980W	160	983	7/10/30
NW	31/25N/8E	300N, 1320E	200	1020	3/8/27
NE	33/25N/8E	984N, 300E	385	1037	6/14/76

VITA

Dallas W. Tomlinson

Candidate for the Degree of

Master of Science

Thesis: THE IDENTIFICATION OF NATURALLY OCCURRING BRINE SEEPS RELATIVE TO THE BASE OF FRESH WATER WITH THE AID OF GEOGRAPHIC INFORMATION SYSTEMS

Major Field: Environmental Science

Biographical:

Personal Data: Born in Oklahoma City, Oklahoma, January 29, 1955 of Bill and Wilmath Tomlinson.

Education: Graduated from Nowata Senior High School, Nowata, Oklahoma in May, 1973; received Bachelor of Arts in Secondary Education from Oklahoma State University in May, 1984; completed requirements for the Master of Science degree from Oklahoma State University in December, 1994.

Professional Experience: Four years experience as an environmental analytical chemist; one year experience as an environmental consultant specializing in industrial regulatory compliance.