EDWARDS UNDERGROUND
WATER DISTRICT

Report 93-06

Defining the Edwards Aquifer Freshwater/Saline-Water Interface with Geophysical Logs and Measured Data (San Antonio to Kyle, Texas)

DEFINING THE EDWARDS AQUIFER FRESHWATER/SALINE-WATER INTERFACE WITH GEOPHYSICAL LOGS AND MEASURED DATA

(San Antonio to Kyle, Texas)

Prepared for the

EDWARDS UNDERGROUND WATER DISTRICT

SAN ANTONIO, TEXAS

By

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Contents

Illustrations

(Figures 1, 21, 22 and 23 also included as plates at back of report)

Tables

Forward

Edwards Underground Water District (EUWD) Reports 92-02 (Investigation of the Fresh/Saline-Water Interface in the Edwards Aquifer in New Braunfels and San Marcos, Texas) and 92-03 (Using Geophysical Logs in the Edwards Aquifer to Estimate Water Quality Along the Freshwater/Saline-Water Interface [Uvalde to San Antonio, Texas]) show that good agreement exists between calculated and measured values of specific conductance and total dissolved solids in Edwards aquifer water near the freshwater/saline-water interface. Additionally, results from both reports indicate that the downdip boundary of the interface can be more accurately positioned using a combination of both measured and calculated values.

This report contains both calculated and measured data which are well distributed along and near the freshwater/saline-water interface. Previous attempts to define the interface have been limited to employment of measured data only. The interface has been delineated in more detail as a result of the merging of the two sources of information.

The same methods and techniques were utilized in this study as in EUWD Report 92-03. This provides continuity and allows the observation of various changes in water quality trends over a very large area of the Edwards aquifer.

Geophysical logs and measured data were gathered from many more sources compared to the previous freshwater/saline-water interface study in the counties to the west (EUWD Report 92-03). A broader range of log interpretation techniques were employed for this investigation than for EUWD Report 92-03. Consequently, the same high quality results were obtained.

Purpose

The purpose of this study is to construct a series of water quality maps to determine the freshwater/saline-water interface of the Edwards aquifer between San Antonio, Texas (U. S. 281 South) and Kyle, Texas, utilizing geophysical logs. Geophysical logs run in water wells and oil and gas exploratory wells can be employed to obtain values of specific conductance and total dissolved solids which are required to accurately position the freshwater/saline-water interface. Many of these geophysical logs are from wells where no actual measurements of specific conductance or total dissolved solids were made of the Edwards aquifer water encountered, and are located in areas where more information is desired concerning the position and characteristics of the freshwater/saline-water interface.

Geophysical logs possess measurements which can be correlated to water quality data through quantitative log interpretation. An objective of this study is to show that there is a high degree of correlation between log-derived values of specific conductance and total dissolved solids and measured values of specific conductance and total dissolved solids. A high degree of confidence in the log-derived water quality data posted on maps will enhance the reliability of the position of the interface determined from this study.

A secondary objective of this report is to provide a comprehensive assemblage of actual water quality measurements that can be augmented with log-derived values to provide a more detailed delineation of the freshwater/saline-water interface.

A final objective is to give a general discussion concerning the influence of faulting on the position and characteristics of the freshwater/saline-water interface.

DEFINING THE EDWARDS AQUIFER FRESHWATER/SALINE-WATER INTERFACE WITH GEOPHYSICAL LOGS AND MEASURED DATA
(San Antonio to Kyle, Texas)

by
ALVIN L. SCHULTZ

ABSTRACT

One hundred twenty six geophysical logs from locations near and downdip from the current Edwards aquifer freshwater/saline-water interface between San Antonio and Kyle, Texas, were acquired and analyzed. Measured water quality data was obtained from eighty-one water samples taken from wells within the study area. Twenty wells possessed both usable geophysical logs and measured data which were used together to verify a high correlation between estimated and measured water quality parameters. This study and Edwards Underground Water District (EUWD) Reports 92-02 and 92-03 establish good agreement between calculated and measured values of specific conductance and measured and estimated values of total dissolved solids within the study area and near the freshwater/saline-water interface between Uvalde and Kyle, Texas.

The location of the freshwater/saline-water interface derived from this study closely parallels data published by the EUWD, such as EUWD Bulletin 51 (1992), but indicates that there is slightly less area occupied by freshwater than previously shown. Maps presented in this report can be used to infer additional water quality characteristics near the interface such as rate of change of total dissolved solids, concentrations of highly mineralized water, zones of dilution downdip and indications of freshwater flow patterns.

This study suggests that a very large area of moderately saline water exists in eastern Bexar County and western Guadalupe County. The transition from moderately saline water to brine is very rapid near the common corner of Bexar, Atascosa, and Wilson counties. The large area of moderately saline water changes to water containing higher total dissolved solids northward from Guadalupe County toward the San Marcos River. A re-entrant of very saline water, which is subparallel to the San Marcos River, terminates the moderately saline zone in Guadalupe County, extends to the northwest, and is present in the City of San Marcos.

INTRODUCTION

Abundant control comprised of data derived from geophysical log analysis and measured specific conductance and total dissolved solids values from wells located in the study area (Figure 1, Plate 1) from San Antonio to Kyle, Texas, yields a more accurate and detailed 1000 mg/L (milligrams per liter) total dissolved solids contour and defines the interface between the freshwater and saline-water zones. This interface is reasonably well defined in published data such as EUWD Bulletin 51 (Brown, et al, 1992), and modified by changes proposed in EUWD Report 92-02 (Poteet, et al, 1992). However, a more precise trace of the interface has been established by extracting measured data from nearly fifteen sources and combining this data with the results of quantitative log analysis performed on the logs in the study area. This outline of the interface reveals approximately 35 square miles of area previously believed to be occupied by freshwater that is now shown to contain water with total dissolved solids exceeding 1000 mg/L.

The mapped location of the freshwater/saline-water interface closely parallels the 1000 mg/L contour provided by the EUWD. Changes were made on the new maps whenever justified by additional control. The findings of this study also endorse the proposed changes recommended in EUWD Report 92-02 concerning the repositioning of the freshwater/saline-water interface in New Braunfels and San Marcos, Texas.

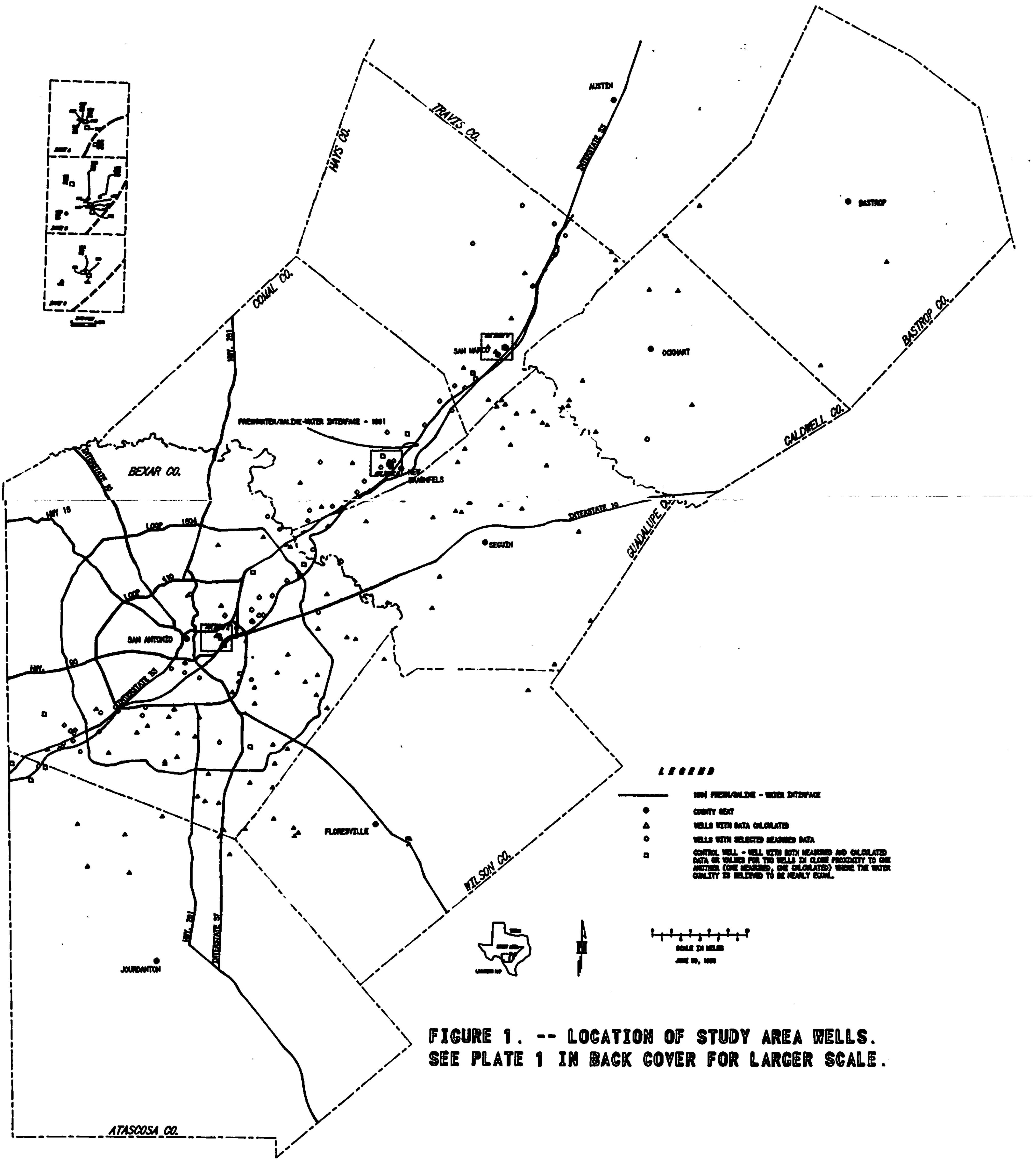


FIGURE 1. -- LOCATION OF STUDY AREA WELLS. SEE PLATE 1 IN BACK COVER FOR LARGER SCALE.

The bulge of moderately saline water displayed on the maps in EUWD Report 92-03 is still present after an extensive search for additional measured data yielded extra control in the overlapping area of the two studies. Additionally, acquisition of geophysical logs for well 7AL (Plate 1) is very significant because analysis reveals the presence of brine with total dissolved solids exceeding 80,000 mg/L. This concentration of highly mineralized water quickly terminates the broad zone of slightly and moderately saline water which extends into northern Atascosa County. However, moderately saline water continues to be present in eastern Bexar County and continues to extend over a broad area of western Guadalupe County. In northern Guadalupe County there is a gradual increase in total dissolved solids which reaches the level of highly saline near the San Marcos River. This band of very saline water, which is subparallel to the San Marcos River, extends as a re-entrant to the northwest and is present in the City of San Marcos, where highly mineralized waters have been documented to exceed 10,000 mg/L (Poteet, et al, 1992). The very saline water is on the downthrown side of a fault, while only freshwater measurements have been documented on the upthrown side. North of San Marcos, the contours on the total dissolved solids map diverge and form a pattern which includes the transitional phases from freshwater to brine.

ACQUISITION OF DATA

Commercial base maps, USGS topographic maps, ground-water publications by various government agencies, and maps from private sources were employed in locating wells with geophysical logs recorded over the Edwards Group and/or where samples of Edwards water had been measured. Well locations were obtained from sources which appeared to be most accurate and were presented to the EUWD to be digitized. Figure 1 and Plate 1 were generated by the EUWD staff utilizing the locations acquired from the various sources. Whenever possible, locations were verified with another source, such as a scout ticket, another commercial map, log heading, or a USGS topographic map with well locations posted from their data. When sources revealed different locations and were within 500 feet of each other, the most logical location was selected. If the discrepancy exceeded 500 feet, additional sources were sought to resolve the difference. If a test well or other research is dependent upon a very accurate location of a well or wells presented in this report, the position of the well or wells in question should be located and surveyed, since locations may differ among various sources.

Extreme difficulty was experienced in determining the location of well 12DX (Plate 1). After unsuccessful attempts to locate a document showing its location, and after attempting to find the old drill site in the field, an estimated location was obtained from the engineer who had supervised drilling of the well. Also, location 10BU is a composite of three well locations and is positioned near the center of these wells. The exact location of any of the three wells where Edwards formation water was measured could not be determined, but the composite location is believed to be within 1000 feet of the center of the 3-well area. This location is important since it provides measured data approximately 17 miles downdip from the freshwater/saline-water interface.

Geophysical logs were gathered on 126 wells in the study area. The sources for these logs included a local log library, the USGS, the EUWD, major oil companies, private companies, and individuals. From this assemblage of data, quantitative interpretation was performed on 114 wells. Gamma ray neutron surveys only were run in 4 of the wells. The lack of an Edwards interval with sufficient porous zones surveyed, or a log not recorded over the Edwards zone eliminated 6 wells. Inadequate log quality prevented completion of water quality calculations on 2 wells.

LOG QUALITY

Successful interpretation of geophysical logs requires data that is reasonably accurate. No log is perfect in every detail. As a result, various methods and techniques must be used to determine the validity of the recorded curves. The following method, after examination of logs from over three hundred wells penetrating the Edwards Group, was used to acquire log values suitable for performing quantitative interpretation in the study area:

(1) Examine the entire log - heading, calibrations, repeat runs (if any are presented), scales, remarks, and check for obvious operational problems.

(2) Verify scales and/or determine values of local stratigraphic markers which can be used to confirm recorded scales.

(3) Examine curves for shape and character commensurate with type of device generating the measurement.

(4) Complete several calculations and compare with data from surrounding area. Observe if the values are reasonable.

Electric logs from the Edwards aquifer are used as examples to help explain some of the key aspects of evaluating log quality. The same basic approach is applicable to any type of log.

The first step in evaluating a log is to examine the entire log. Log headings frequently reveal very important information which can be used to check log responses. Casing size, depth, and weight aid in determining usable zeros for normal resistivity devices, accuracy of hole sizes shown by caliper logs, reliability of transit time from sonic logs, and validity of other information recorded by tools. A quality log will have data reported concerning borehole fluid measurements, bottom hole temperature, and operational information related to tool or borehole problems. The log should be very carefully reviewed for proper scales and scale changes.

To illustrate, well 68AY (also known as J-17) has scale information noted on the log heading and the main body (Figure 2). Additionally, the scale of a section re-logged on a different scale superimposed over the original recording is labeled. Casing data is not presented on the heading; however, from the responses of the spontaneous-potential (SP) and normal resistivity curves, the bottom of the casing is located at 496'. Also, mechanical zeros are not shown, but the reading of the short-normal curve in casing indicates the zero is satisfactory. The absence of a repeat run and before and after survey calibrations is common for the majority of geophysical logs available for studying the Edwards aquifer. The SP curve has been mechanically shifted two divisions to the left at 662', which does not decrease the validity of the log. Examination of the resistivity curves reveals normal responses for the borehole conditions consisting of a hole size diameter of approximately 7" (from caliper survey, not shown) filled with freshwater. The shapes of the resistivity curves are correct through the dense intervals possessing thicknesses less than the tool spacings. Calculation of specific conductance yields a value of 474 microsiemens per centimeter (uS/cm) which is reasonable in the freshwater zone of the aquifer. (Microsiemens per centimeter

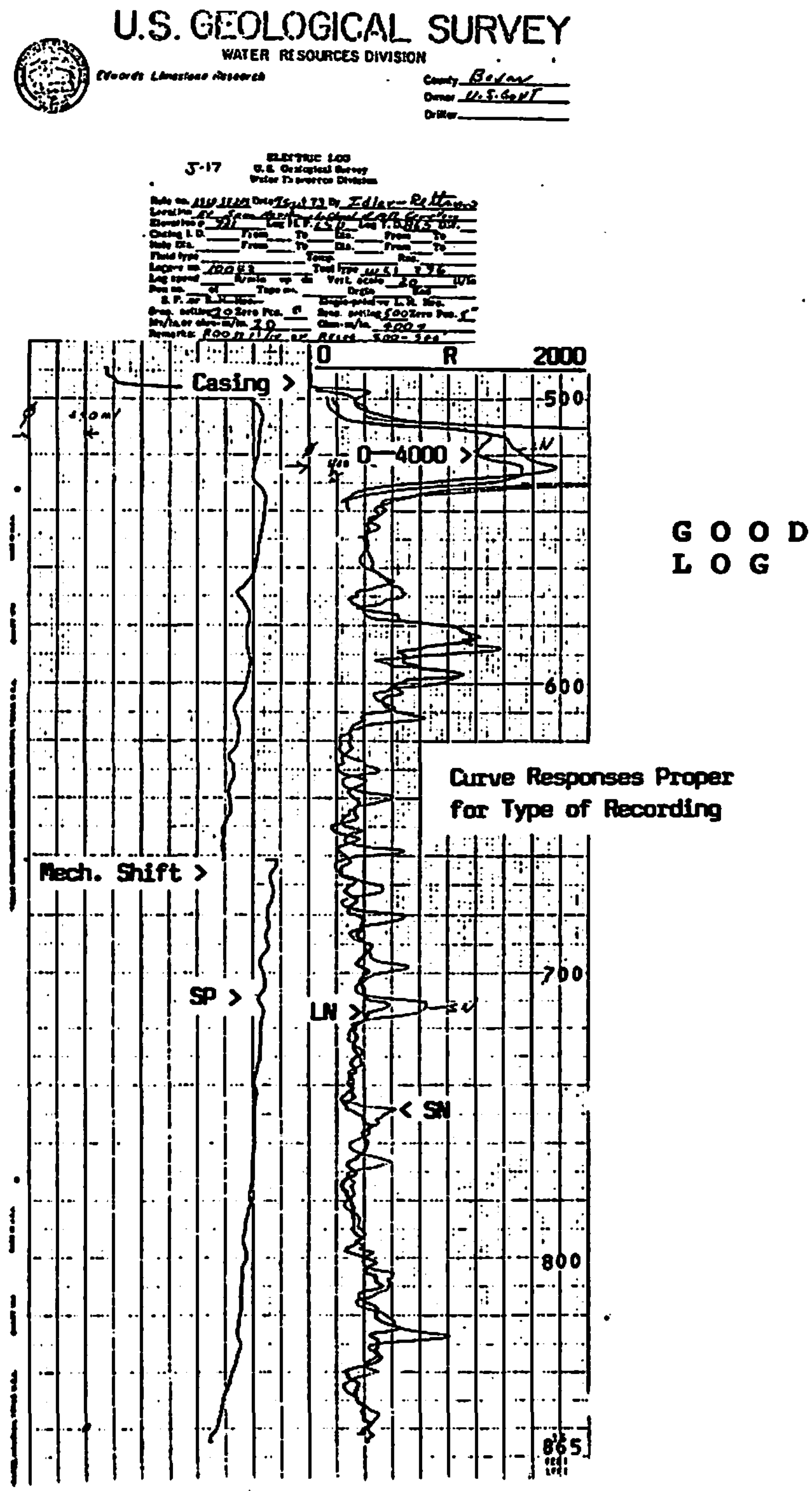


Figure 2. Example of a log with recordings usable for calculating specific conductance. Example log is AY-68-37-203, (68AY) in Bexar County, commonly known as J-17. Resistivity in ohm-meters.

and micromhos per centimeter, as presented in EUWD Report 92-03 (Schultz, 1992), can be used interchangeably since they are equivalent units of measurement.) Evaluation of the above information indicates the electric log recorded in well 68AY is of good quality and is usable.

Verification of scales and zeros is very important since incorrect scales can result in grossly erroneous values. The log may look perfectly normal and still possess a major flaw. As an example, after scanning a portion of the induction-electric log from well 4KX (Figure 3), it is evident that the zeros are positioned correctly and the resistivity curve shapes and character are satisfactory. (The comparison of the mechanical zero and the reading of the short-normal (R16") curve inside casing above 164' at the top of the log is of interest for future reference. The resistivity recorded by a short-normal in casing is zero ohm-meters. Therefore, in the absence of a recorded mechanical zero, values in casing can be considered zero for all practical purposes.) An anomaly, probably an object composed of iron or some type of metal, is present from 2480' to 2484'. Further examination of this log compared to other logs in the area, such as well 13KX (see Figure 17, p. 41), indicates that the Del Rio Clay from 242' to 287' reads approximately 10 ohm-meters, double the value observed in other wells in the area. The scale on this log was changed from a 100 ohm-meter to a 50 ohm-meter per track scale and the conductivity was revised to a 200 millimhos/meter per

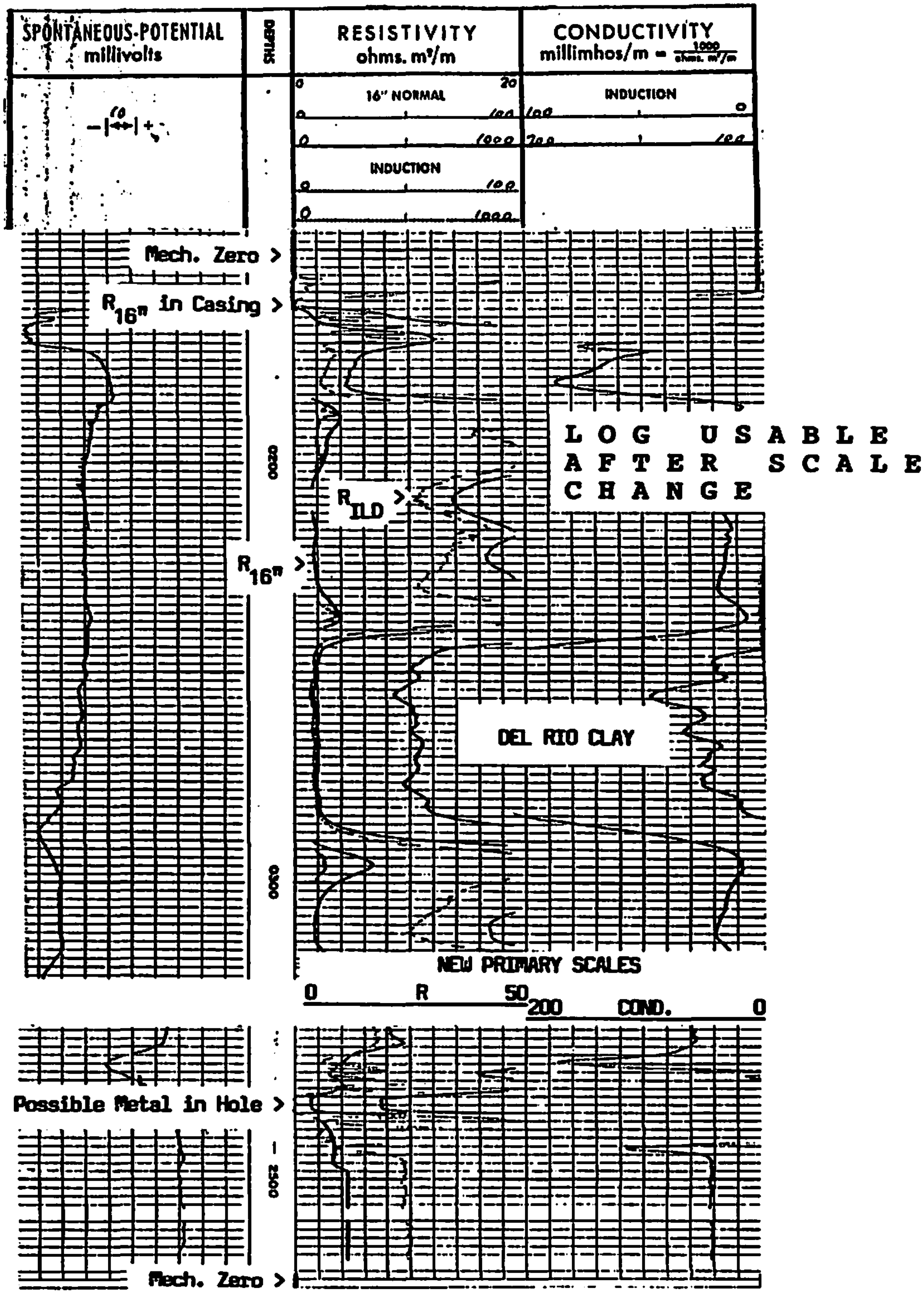


Figure 3. Example of comparison of 16 inch normal mechanical zero and casing recording. 0 to 100 ohm-meter scale was changed to 0 to 50 ohm-meter scale based upon consistent 5 ohm-meter values of Del Rio Clay in area. Example is the Blumberg #1 Sanders (4KX) in Guadalupe County. Resistivity in ohm-meters.

track scale.

Identification of operational problems can range from the very obvious to the very subtle. The portion of the electric log taken from well YP-69-51-4 in Uvalde County, Texas (Figure 4) is obviously of very questionable quality. Spikes and a long interval of dead short-normal (SN) are present. Additionally, the long-normal (LN) occupies areas (above 200') where the reading is less than zero. Given these curve responses, this log cannot be used for estimating water quality.

The electric log from well 6DX (Figure 5) also has two long sections of very low values on the short-normal (SN). The long-normal (LN) does not read near zero and the SN erroneously indicates that the casing is located between 223' and 284'. Good logs recorded in this well show casing present from 228' to 286'. The curves over the remainder of the log are abnormally rounded and smooth, uncharacteristic of normal formation readings. Concurrently, the very wide separation between the LN and SN is not justified for a 4" to 6" borehole diameter. This log was judged to be inferior and could not be used for quantitative evaluation.

Obvious operational problems can develop during logging and create doubt as to the validity of the entire log. The log run in well 13LR (Figure 6) presents such a case. All curves appear satisfactory in well 13LR from 900' to total depth; however, above 900' the LN curve is dampened and drifts to zero and reads behind zero at 830'. One would be tempted to use the bottom

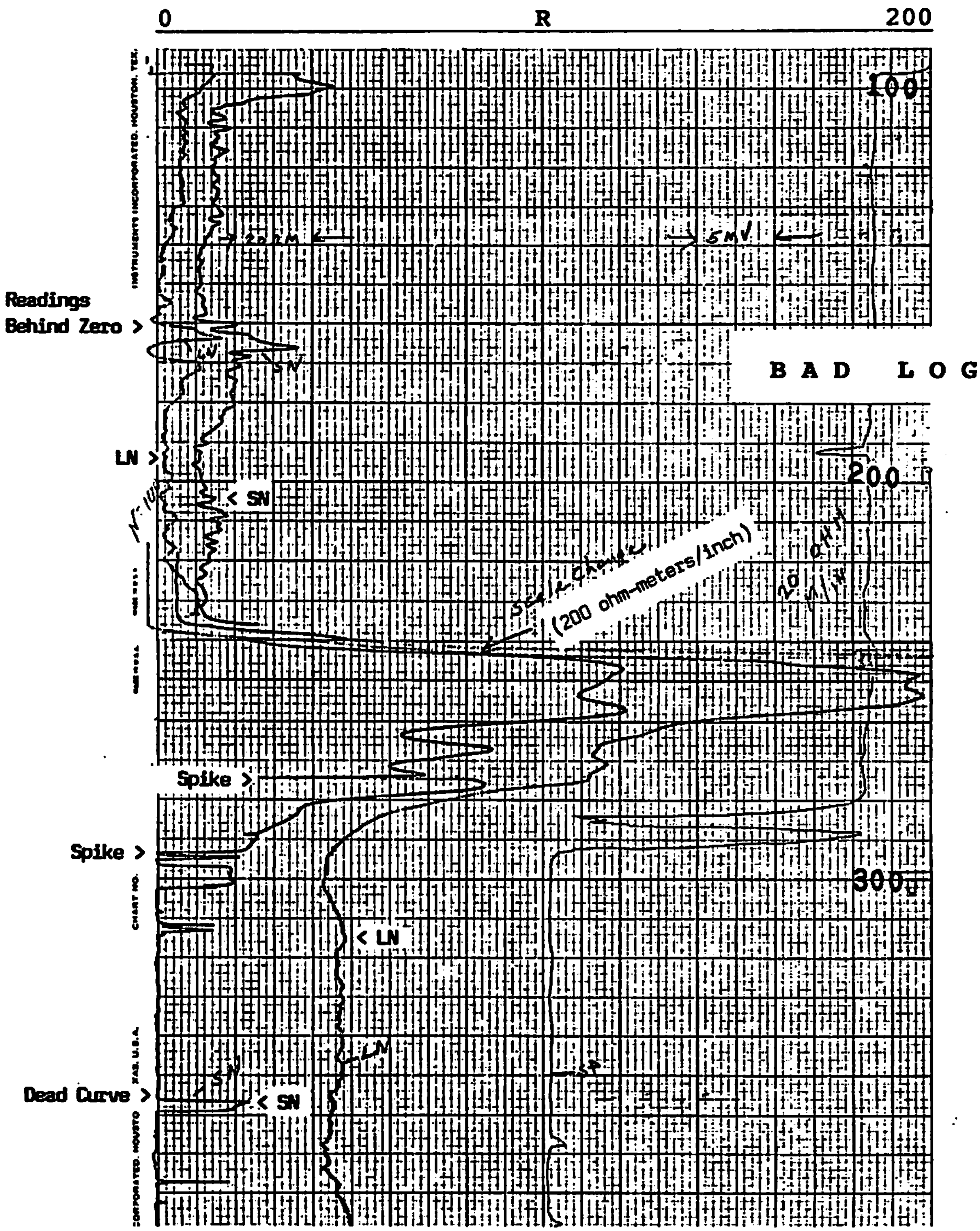


Figure 4. Example of poor quality log with erratic values, a dead curve, and recordings behind zero. Handwritten notes are on original copy. Example log is YP-69-51-4-- in Uvalde County. Resistivity in ohm-meters.

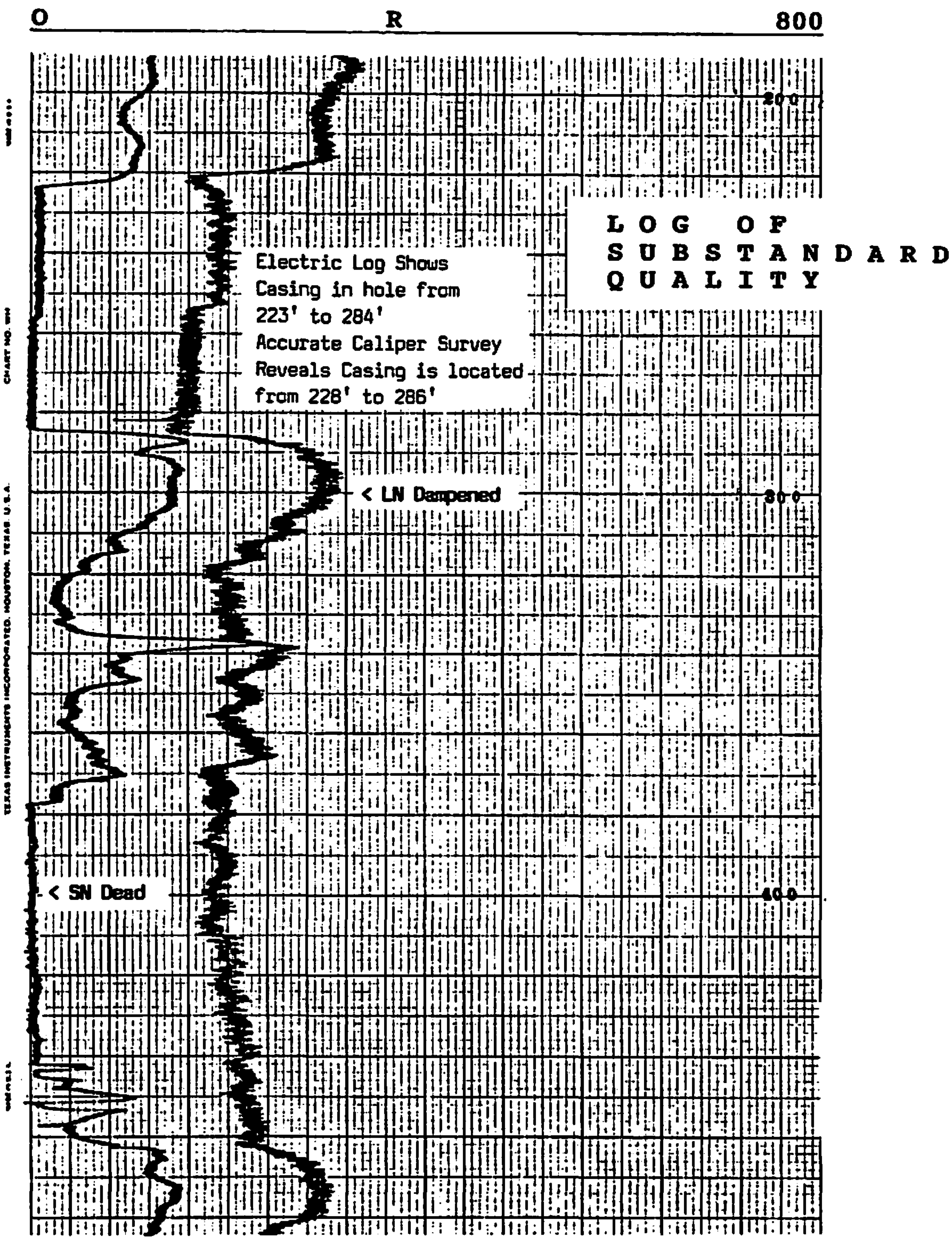


Figure 5. Substandard log quality caused by a dead curve, dampened response, and excessive separation between short-normal and long-normal readings. Example is well DX-68-16-602 (6DX) in Comal County. Resistivity in ohm-meters.

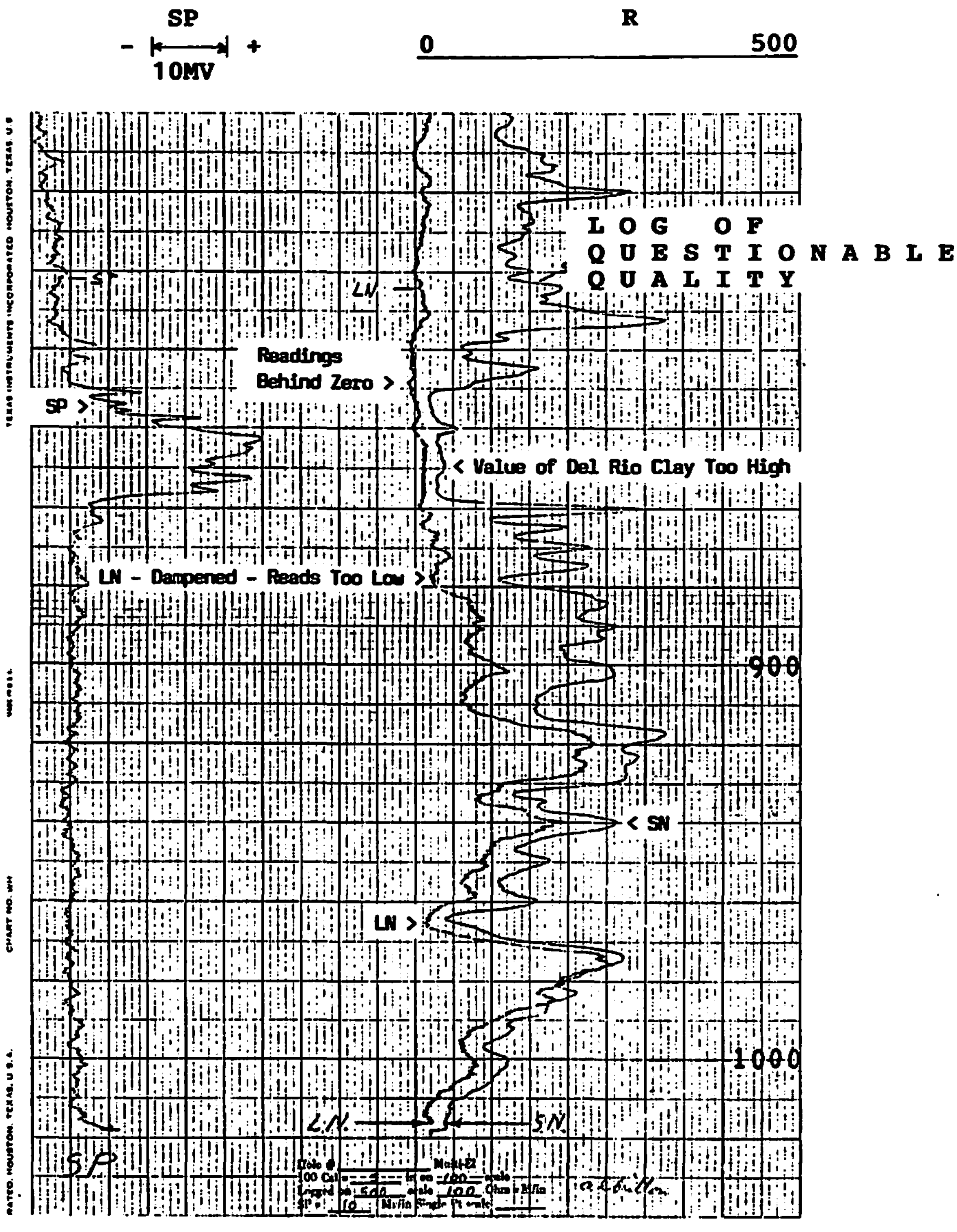
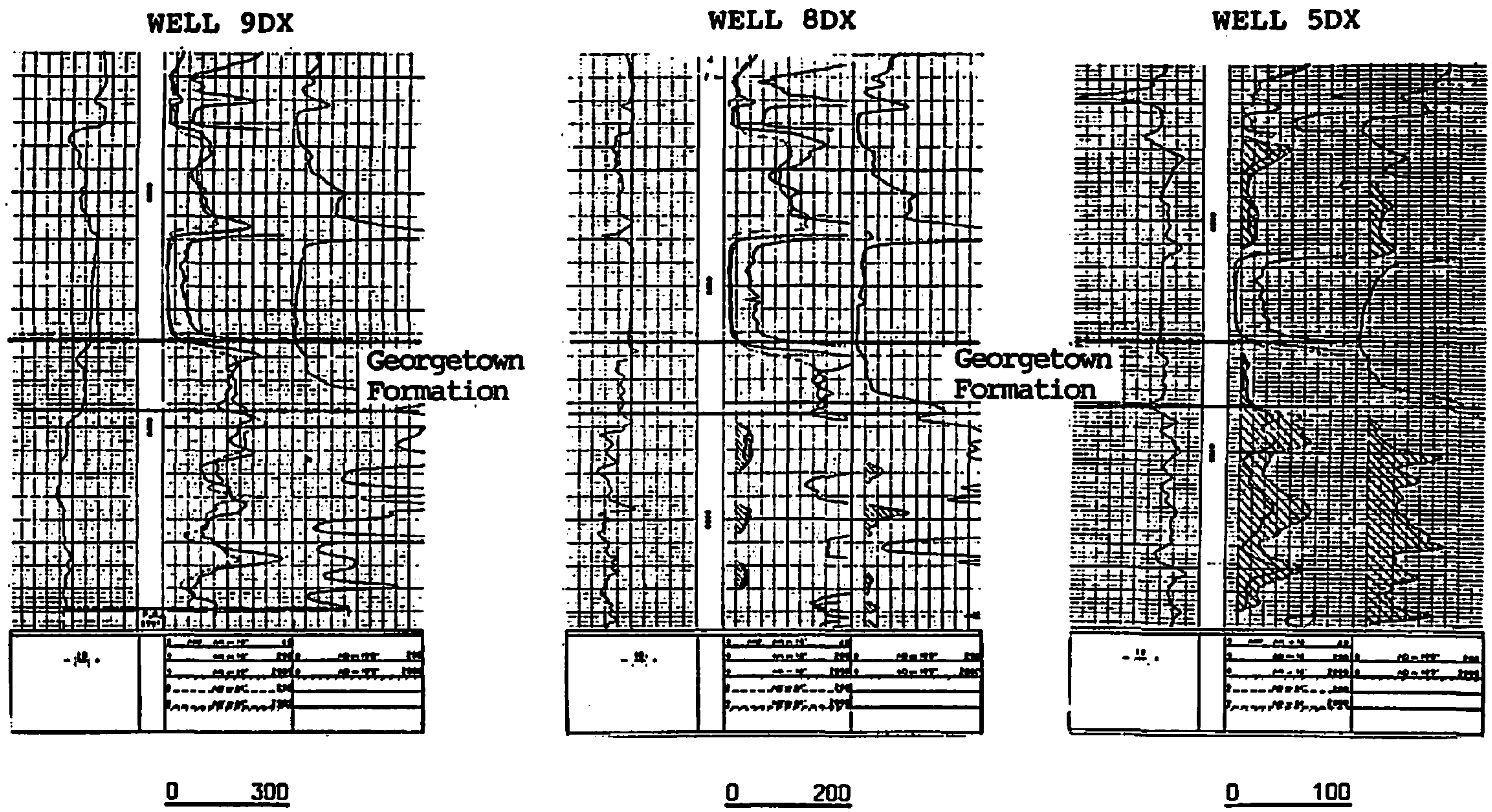


Figure 6. Example of operational problems with long-normal and short-normal curves occurring during recording. Entire log is questionable even though the interval below 900 feet appears satisfactory. Log is from well LR-67-09-4-- (13LR), in Hays County. Resistivity in ohm-meters.

section of the log and/or the SN curve in an emergency. This is a questionable practice since, in conventional electric logging, many systems utilize one or more common electrodes for both recordings, and a problem with one can adversely affect the other. This problem appears to have occurred, since the interval from 830' to 858' is believed to be Del Rio Clay and the SN registers 30 ohm-meters, which is grossly incorrect. This log was judged to be of unacceptable quality.

Establishing formation values as a standard to evaluate log quality appears to be a very practical approach in the Edwards aquifer because there is an abundance of logs and a reasonable degree of consistency within several stratigraphic units of the Edwards aquifer and associated formations. To illustrate how one of the markers can be utilized in a local area to assist in rendering a group of logs more usable, logs on wells 5DX, 8DX, and 9DX are presented for study (Figure 7). All three logs have the same scale recorded; however, an examination reveals radically different values over equivalent intervals that are not part of the porous aquifer. For example, the Georgetown Formation interval (from 474' to 490') in well 9DX (Figure 7) reads about 100 ohm-meters, while the same interval in well 8DX possesses a resistivity of 150 ohm-meters and well 5DX registers nearly 300 ohm-meters.

To rectify this situation, scales need to be adjusted so that the Georgetown Formation reads the same resistivity in all three wells. To assist in determining a common resistivity for



New Primary Scales to Duplicate Georgetown Formation Resistivity

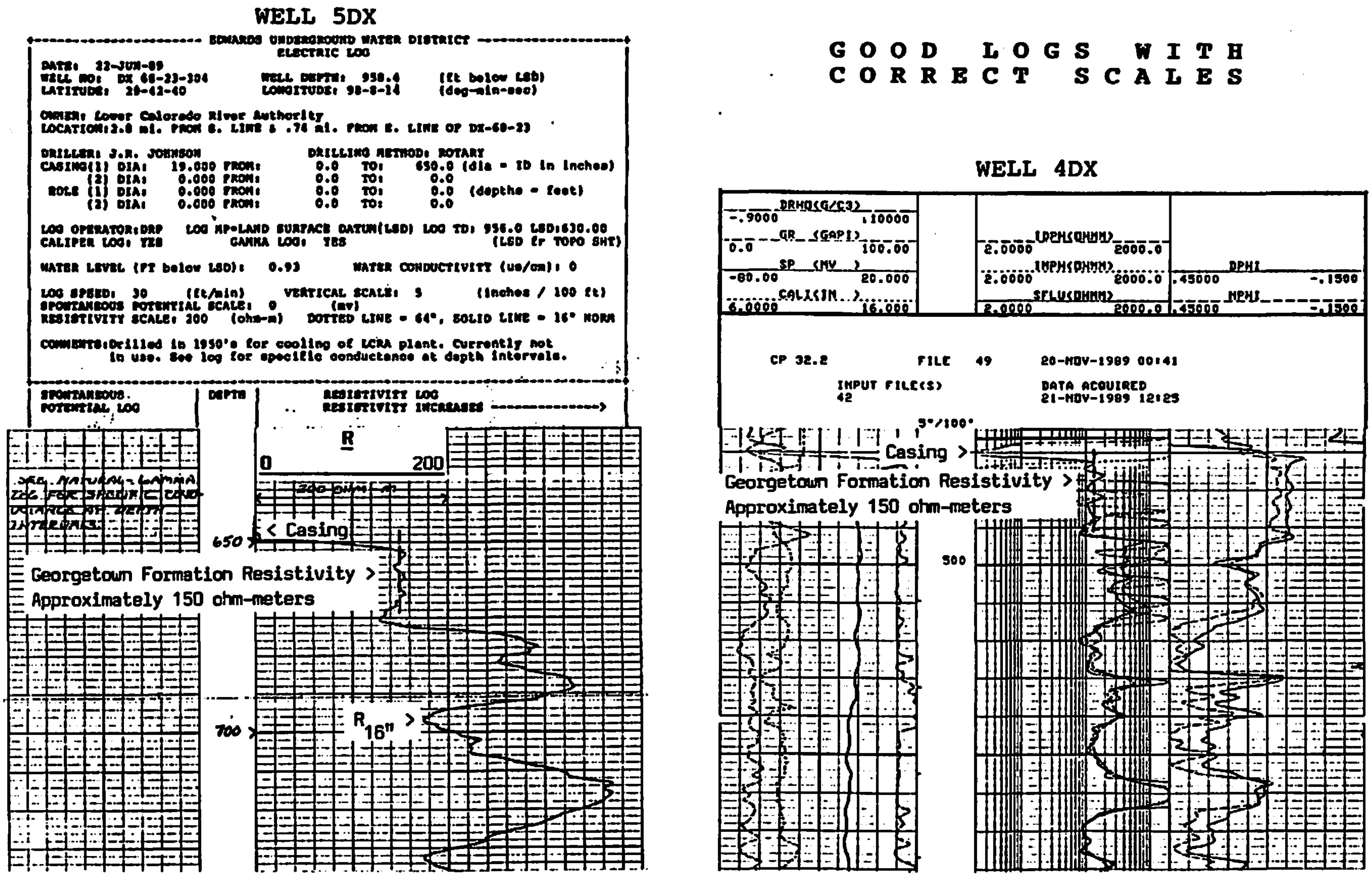
Figure 7. Example of 3 wells in New Braunfels with different scales. Two wells (8DX and 5DX) are incorrectly scaled. New scales are based upon a consistent resistivity of 150 ohm-meters for the Georgetown Formation. Examples are wells DX-68-23-304 (5DX), DX-68-23-6-- (8DX), and DX-68-6-- (9DX) all in Comal County. Resisitivity in ohm-meters. (This presentation is not a cross-section.)

the Georgetown Formation, another log recorded on well 5DX was consulted. This log (Figure 8) shows the resistivity of the Georgetown Formation to be approximately 150 ohm-meters. Additionally, a dual-induction log in well 4DX (Figure 8) reveals the same interval has an average value of 150 ohm-meters. This log is recorded on a logarithmic scale which is more difficult to mislabel, since errors will be magnified in terms of one or more decades (10's) and are usually very evident. Apparently the scale on well 8DX is correct as recorded, having accepted a common resistivity of approximately 150 ohm-meters for the Georgetown Formation. The scale for well 5DX (Figure 7) will require a new scale of 100 ohm-meters/track and well 9DX needs to be re-scaled with a 300 ohm-meter/track scale for both wells to indicate a resistivity of approximately 150 ohm-meters through the Georgetown Formation.

METHOD USED TO ESTIMATE WATER QUALITY

Various methods of estimating water quality have been reviewed since completion of the first study of the freshwater/saline-water interface using geophysical logs (Schultz, 1992), including the method used in the first study, and other methods both published and unpublished. The method (and associated techniques) employed by Schultz (1992) was selected, after careful review, for utilization again in this study for the following reasons:

(1) The method incorporates porosity changes into



- 20 -

Figure 8. Wells used to verify Georgetown Formation resistivity is approximately 150 ohm-meters. Examples are wells DX-68-23-304 (5DX) and DX-68-23-617 (4DX) in Comal County. Hand written notes are on original copy. Resistivity in ohm-meters.

the calculation of specific conductance.

(2) The statistical plots are simple and tend to normalize for unknowns such as cementation exponent in the formation factor equation and the possible effect of surface conductance.

(3) Changes in formation temperature due to the wide range of depths within the study area are included in the process involved in converting apparent formation water resistivity to specific conductance.

(4) The method allows for elimination of questionable data and permits the input of local knowledge.

(5) Using the same method and technique enhances continuity between this study and the previous study between Uvalde and San Antonio, Texas (Schultz, 1992).

For completeness, convenience, and continuity, the basic equations used in the resistivity-porosity method (MacCary, 1980) are taken from EUWD Report 92-03 (Schultz, 1992) as follows:

The heart of the method involves computing apparent water resistivity (Rwa) by the equations

$$Rwa = \frac{Rt}{F} \quad \text{(Schlumberger, 1972)} \qquad (1)$$

where

F = the formation factor (computed from porosity sensitive logs or estimated from porosity values from nearby wells)

Rt = resistivity of the formation beyond the invaded zone (In this study, Rt is considered equal to Ro, the resistivity of a zone fully saturated with formation water. Whenever a zone is water bearing, Rwa reaches a minimum value equal to the formation water resistivity (Rw) (Schlumberger, 1972). Minor oil and gas shows are considered insignificant in equating Ro to Rt in this study.),

and

$$F = \frac{1}{\phi^m} \qquad (2)$$

where

ϕ = porosity (the fraction of the total volume occupied by pores or voids)

m = cementation factor (A cementation factor of 2 is a common value for carbonates. This has been used for the Edwards Group of South Texas [Coates and Dumanoir, 1974] and will be used in this study.)

Combining equations (1) and (2) gives

$$Rwa = Rt\ \phi^2 \qquad (3)$$

where Rt is obtained from the most appropriate deep investigating resistivity curve available on the log of the well being analyzed.

SELECTION OF INTERVALS TO EVALUATE

The objective of interval selection is to choose those zones which will yield water when either tested or produced. In this study, as well as in the previous study of this type (Schultz, 1992), the assumption is made that the water we are interested in analyzing is located in the intervals which possess the higher porosities. Interval porosities chosen usually exceeded 20 percent and zones of sufficient thickness were frequently available so that thin bed corrections were not required, or were insignificant. Log quality and the possibility of borehole conditions adversely affecting log responses were also taken into consideration prior to selection of a zone for quantitative evaluation. Additional information concerning interval selection is found in EUWD Report 92-03 (Schultz, 1992).

POROSITY DETERMINATION

Accurate porosity (ϕ) data is important in calculating apparent water resistivity (Rwa) since it is an integral part of the Rwa equation (3). The effect of porosity changes is amplified in the relationship since true formation resistivity is linear and the porosity is squared. Sources used for porosity determination included various types of neutron logs, density logs, and sonic logs employed either individually or in a crossplot arrangement with a tool of a different type, such as a density - neutron crossplot. Whenever porosity sensitive devices were not available, porosity was estimated using nearby well control and/or local knowledge.

The unavailability of core data necessitates reliance upon geophysical logs for the main source of porosity data in the study area. However, it has become common practice to use porosity data derived from geophysical logs in the calculation of formation fluid parameters. Comparisons of the two sources of porosity have been made in the Edwards Group in the past. A petrophysical study was conducted on the Edwards interval in the

Person complex of fields in Karnes County by Shell Oil Company personnel (Kozik and Richter, 1974). Porosities (above 6 percent) which were derived from both core analysis and acoustic (sonic) log data were compared. Arithmetic mean porosities from core analysis averaged 12.71 percent versus a weighted average of 13.08 percent for acoustic derived values.

A comparison between core derived porosities and density-neutron crossplot derived values for well 9LR (Plate 1) is shown in Table 1. The average values are in good agreement: 26.87 percent for the core porosities and 27.34 percent for porosities obtained from the density-neutron crossplot.

A more visual method of comparison has been constructed graphically (Figure 9) by the USGS (Maclay and Small, 1976). This presentation reveals the scattering of two sets of data at correlatable depth intervals and allows for comparison of individual zones. Variations in porosity can be caused by the large difference of rock volume being measured by the two methods, difficulty in correlating core and log depths, damage to cores during and after coring operations, the statistical nature of density and neutron logs, and/or other causes.

Composition of the rock matrix must be known to effectively determine porosity with geophysical logs. A crossplot of density and neutron values was used to determine general matrix composition (Figure 10). Figure 10 was constructed from log data from wells 69AY, 70AY, 3DX, and 7LR (Plate 1 and Table 2, pp. 71-79). The values and intervals selected for acquisition

Table 1. Comparison of porosities for well LR-67-09-110 (9LR)

Depth	Sample Number	Core Porosity	Porosity Neutron	Bulk Density	Porosity Density	N-D Log Porosity
230	6	32.700	35.00	2.32	22.81	30.94
255	2	6.700	9.00	2.58	7.60	8.53
320	3	15.300	33.00	2.25	26.90	30.97
335	9	31.300	33.00	2.35	21.05	29.02
360	7	34.200	31.00	2.35	21.05	27.68
370	1	24.100	36.00	2.25	26.90	32.97
395	8	32.200	27.00	2.35	21.05	25.02
407	4	35.300	33.00	2.20	29.82	31.94
410	10	30.000	30.00	2.25	26.90	28.97
AVERAGE:		26.867	29.67	2.32	22.68	27.34

All Porosity values are in percent

Porosity Neutron - Porosity obtained from sidewall epithermal neutron log assuming a limestone matrix

Porosity Density - Porosity computed from Bulk Density using a grain density of 2.71 gm/cc (Limestone)

N-D Porosity - Porosity obtained from crossplot of Bulk Density and Porosity Neutron using Schlumberger Chart CP-1b (Schlumberger, 1972). Algorithm for range of chart utilized is :
Porosity N-D = Porosity Neutron - (Porosity Neutron - Porosity Density)/3

(Source for core data: Small & Maclay, 1982, p.65)

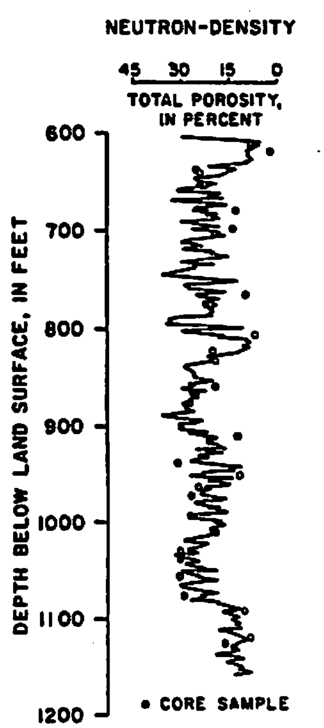


Figure 9. Comparison of porosity values derived from Neutron-Density logs and core samples. Example is well 62AY (AY-68-30-807) in Bexar County. (from Maclay and Small, 1976, p.47)

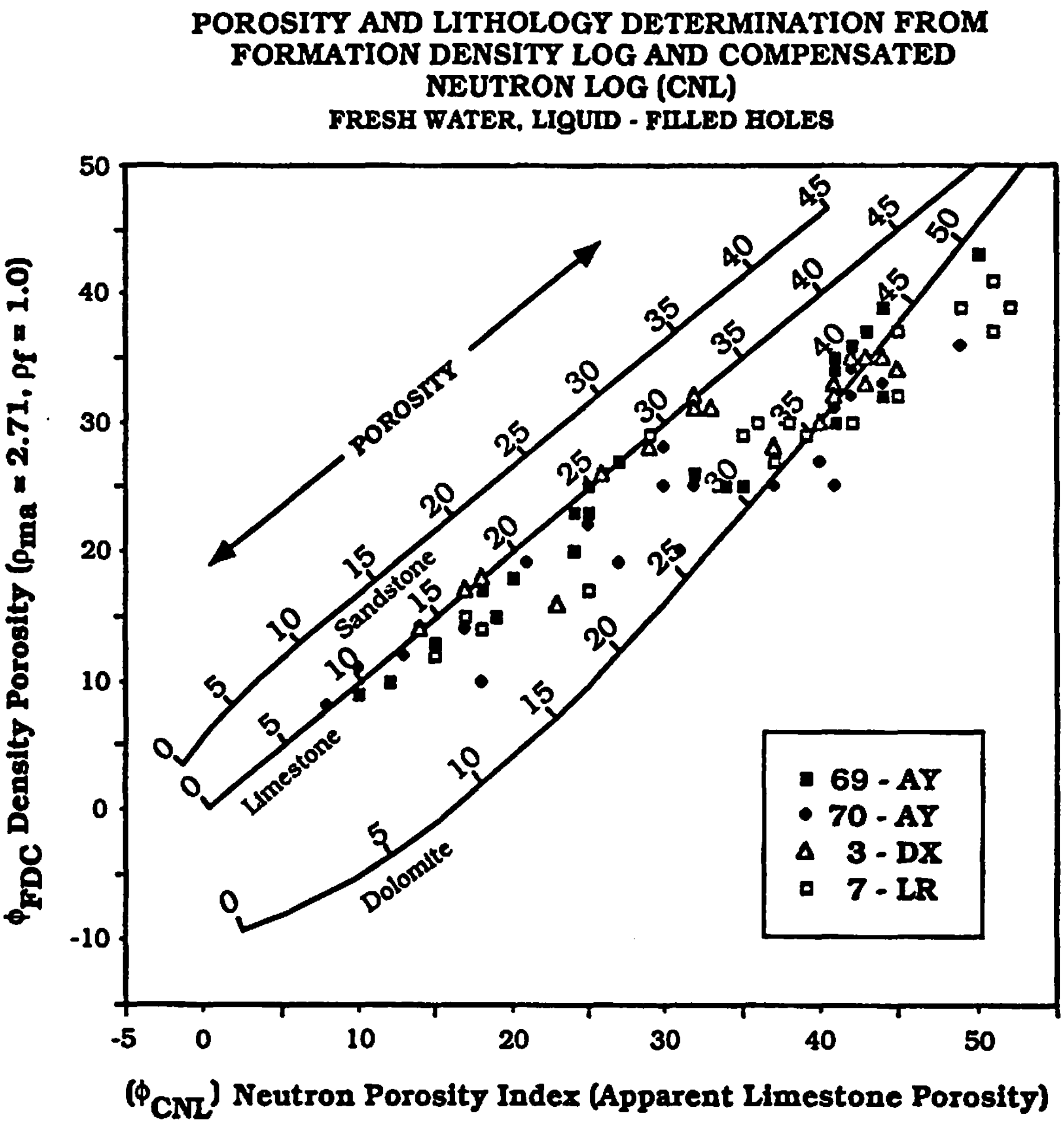


Figure 10. Porosity and lithology determined from compensated density and compensated neutron logs. Crossplot indicates that zones with porosity exceeding 30 percent are very dolomitic and those with less than 20 percent are mostly limestone. Data are from wells 69AY, 70AY, 3DX, and 7LR. (Log interpretation chart after Schlumberger, 1979.)

of data for Figure 10 were hand-picked to insure the highest quality data was utilized. Inspection of Figure 10 indicates that the rock matrix is predominantly dolomite in the higher porosities and mostly limestone in the porosities less than 20 percent. This observation is in agreement with the results of the freshwater/saline-water study conducted in New Braunfels and San Marcos by the EUWD (Poteet, et al, 1992).

Whenever possible, compensated neutron or sidewall neutron and compensated density logs were crossplotted to determine porosity, since the crossplot method eliminates a major portion of matrix effect in relatively clean carbonates. The range of values above 20 percent porosity is typical of the range of values selected for calculating specific conductance (Ca). Notice that there are many points above 30 percent porosity, which is common in the study area in the more porous zones. In comparison, values used in the previous study of the counties to the west (Schultz, 1992) were generally 10 percent lower (20% porosity range).

Porosity values from Figure 10 were plotted versus interval transit time for the same zones (Figure 11) to facilitate the selection of a matrix velocity, or verify that a special relationship may be required for the aquifer being studied. Figure 11 shows lower than expected transit time for the higher porosities because points on the graph plot a considerable distance above the average dolomite line typical of field observations (dashed line) and the 26,000 feet per second matrix

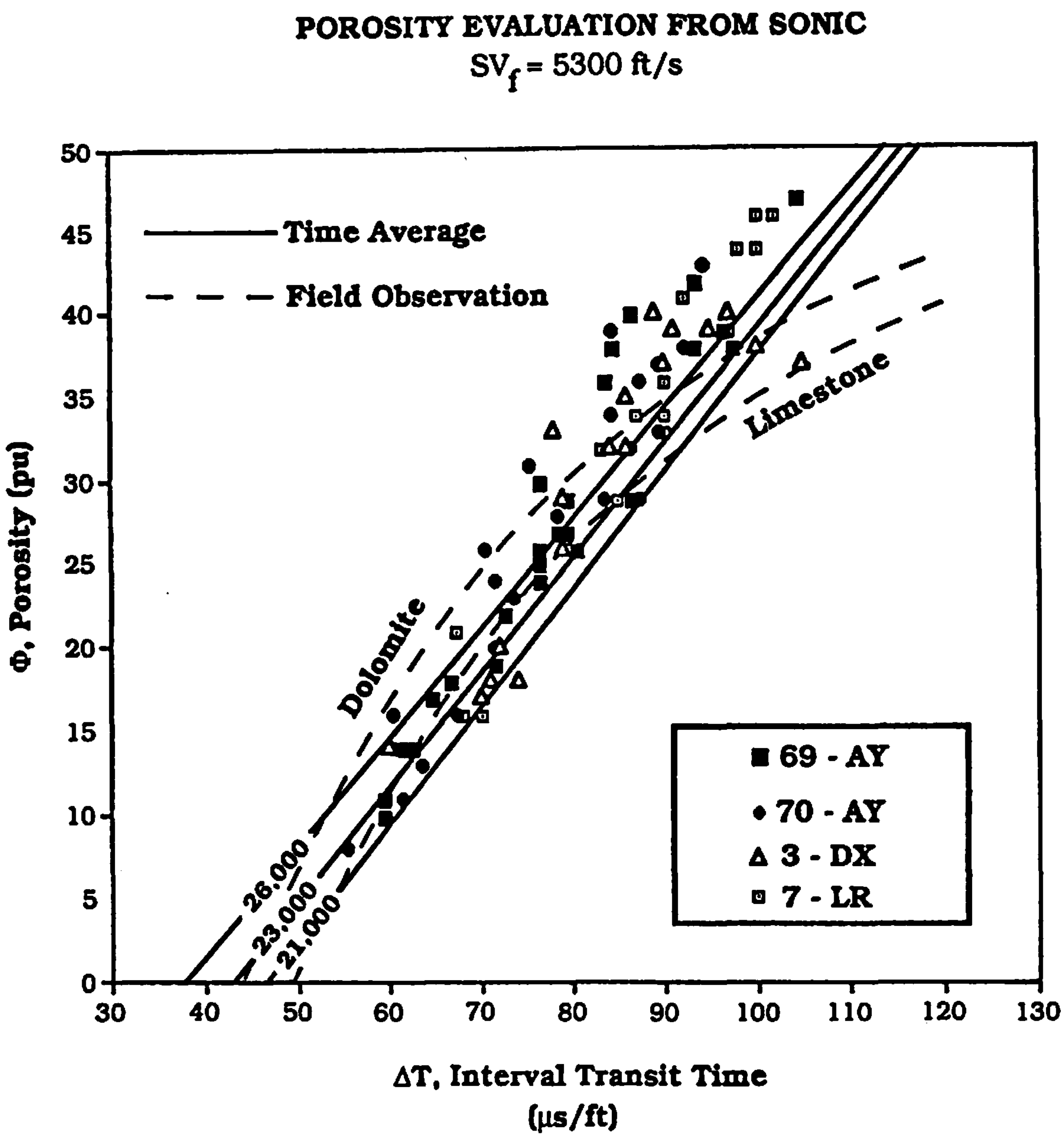


Figure 11. Density and neutron log-derived porosity plotted versus interval transit time, used to select a matrix velocity or to indicate that another solution is required. Abnormally low transit times with porosity values above 20 percent indicate that the Edwards aquifer possesses a high percentage of secondary porosity and therefore a special empirical relationship is required for more accurate porosity calculations from sonic logs used as a single porosity source. (Log interpretation chart after Schlumberger, 1986.)

velocity line. These results indicate a high percentage of secondary porosity. Consequently, a method was devised to handle this characteristic of the Edwards aquifer in the study area. The same data was used to determine an empirical relationship for calculating porosity from a sonic log (Figure 12). The correlation between density-neutron porosity and transit time is very good, with a correlation coefficient squared of .955. The relationship in Figure 12 has been rounded off and the following equation was used to determine porosity when a sonic log was used as a single source:

$$\phi \text{ (sonic)} = .82(\text{DT log}) - 38 \qquad (4)$$

where DT log = recorded sonic transit time in microseconds per foot.

Uncompensated count-rate scaled density logs were only used as qualitative porosity indicators, because the lack of a compensation curve, the inability to determine the effect of borehole rugosity, and the inability to determine satisfactory detector skid contact are sources for generating large errors when attempting to determine porosity using an uncompensated count-rate scaled density log.

Count-rate scaled neutron logs were used to estimate porosity whenever other more reliable sources were not available. A comparison of sidewall neutron recorded porosity and count-rate neutron data indicates that satisfactory estimated porosity values can be obtained from count-rate scaled neutron logs (Stevens, 1974). The count-rate neutron logs used

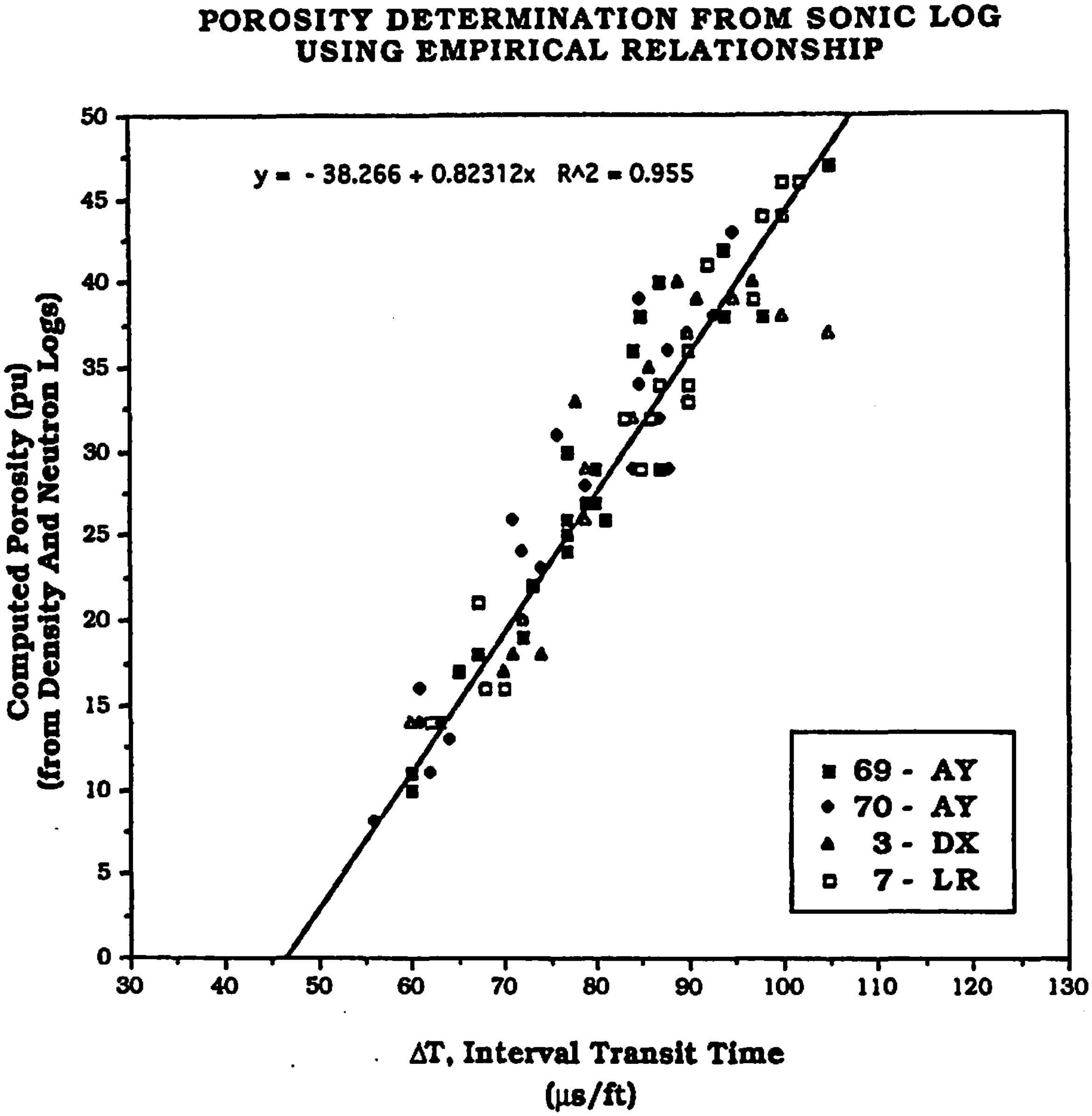


Figure 12. Plot of density and neutron log-derived porosity versus interval transit time, used to derive empirical relationship for determining porosity from sonic logs in the study area. Relationship is: Porosity (Sonic) = .82 (DT log) -38.

in this study were scaled in porosity units on a well by well basis using the logarithmic porosity overlay technique (Hilchie, 1979; Gearhart-Owen, 1975). This technique involves the selection of a low and a high porosity value over an interval where it is believed that the borehole environmental conditions are fairly uniform. A logarithmic porosity scale is placed over the log in such a manner that the low porosity value of the scale overlays the zone with a known or estimated low porosity value and the high value of porosity is placed over the known or estimated high porosity marker or estimated high porosity point.

For the low porosity markers, the regional dense member of the Edwards Group, the Georgetown Formation, or other selected tight zones (where reasonable nearby control existed to establish an estimated value) were used. The high porosity values were selected primarily from observed values exceeding 30 percent porosity in offset wells, local knowledge, and log values in the Del Rio Clay. The regional dense member frequently has a porosity near 9 percent in the study area. The Georgetown porosity is approximately 15 percent in some areas. The Del Rio Clay has a neutron response indicating a porosity of approximately 40 percent. Maximum values are generally fairly easy to establish from area to area and will vary from close to 30 percent in Atascosa County to 45 percent near the freshwater/saline-water interface between San Antonio and San Marcos. (The logarithmic porosity overlay technique is further discussed in Demonstration of Method and illustrated in Figure 18.)

CONVERSION OF Rwa TO APPARENT SPECIFIC CONDUCTANCE

Specific conductance is the electrical conductivity of a water sample at 25°C (77°F) expressed in microsiemens per centimeter (uS/cm). To convert Rwa to apparent specific conductance (Ca), the following equation is used:

$$Ca = 10{,}000/Rwa \qquad (5)$$

where Rwa is in ohm-meters at 77°F.

However, since values of resistivity used in the Rwa equation (3) are at formation temperature (FmT), Rwa needs to be converted to 77°F. This is accomplished through the Arps formula (Schlumberger, 1969; Jorgensen, 1989):

$$Rwa\ (77°) = Rwa \times (FmT + 7)/84 \qquad (6)$$

Equations (5) and (6) can be combined to provide the following:

$$Ca = 10{,}000/Rwa\ (FmT + 7)/84 \qquad (7)$$

$$Ca = 840{,}000/Rwa\ (FmT + 7) \qquad (8)$$

Formation temperatures (FmT) for wells in the study area were estimated by combining the mean annual surface temperature and a geothermal gradient of 1½°F per hundred feet of depth from the surface to the interval being analyzed within the Edwards aquifer. A review of the literature produced the following mean annual temperatures for various cities in or associated with the study area: San Antonio, 68.8°F (Arnow, 1959); San Marcos 67.8°F (DeCook, 1963); Luling, 68°F (Follett, 1966); and Seguin, 69.2°F (Shafer, 1966). After reviewing this information and the proximity of the wells to these mean annual temperature points, mean annual temperatures were selected for the counties included in the study area as follows: Atascosa, 70°F; Bexar and Wilson, 69°F; Bastrop, Caldwell, Comal, and Guadalupe, 68°F. Values of Ca are shown for wells in the study area in Table 2.

VERIFICATION OF METHOD

Data was gathered from 20 wells in the study area to verify that log-derived specific conductance can be used to estimate water quality (Table 3, pp. 80,81). Measured data was compared to results determined from geophysical log interpretations. Specific conductance was calculated in the various wells over intervals from which actual samples were taken and measured. Water sample measurements included both specific conductance and total dissolved solids (TDS) from most of the wells. Only a specific conductance measurement was available on wells 8LR and 11LR. Wells 69AY, 70AY, 3DX, 4DX, 6LR, 7LR, 8LR, 10LR and 11LR possessed data indicating variable values from multiple intervals in each well (Table 3). This data reveals the transitional nature of the water quality vertically. Of interest are wells 70AY, 71AY, 3DX, and 11DX where freshwater and water of increasing salinity are found in the same wells. All wells used for verification of the method are identified in Plates 1 and 2, and Table 2. Well locations shown are identified by the standard well numbering system used by the Texas Water Commission and are on file at the EUWD.

Since the main parameter to be determined in this study is specific conductance (Ct), measured specific conductance values have been graphically compared to log-derived specific conductance (Ca) values (Figure 13) using the data in Table 3. Figure 13 displays a simple fit straight line through the data, revealing a well defined trend. The correlation coefficient squared (r^2) is 0.982, showing a high degree of correlation and indicating the method can be used to accurately estimate specific conductance.

The results of comparison of Ca to Ct in this study are very close to the results obtained in the freshwater/saline-water interface study of the counties to the west (Schultz, 1992). The same graphic and curve fitting techniques were used in both studies, and the same methods were applied in the following series of graphs (Figures 13-16) as were applied in the previous study (Schultz, 1992). Figure 13 reveals little departure between Ca and Ct. For instance, when Ca = 1000 uS/cm, Ct (as determined by the relationship in Figure 13) is equal to approximately 1050 uS/cm. This close agreement between measured and calculated specific conductance indicates that the parameters employed in the Rwa equation, the various methods used to determine porosity, and the technique selected to estimate formation temperature combine well to produce excellent

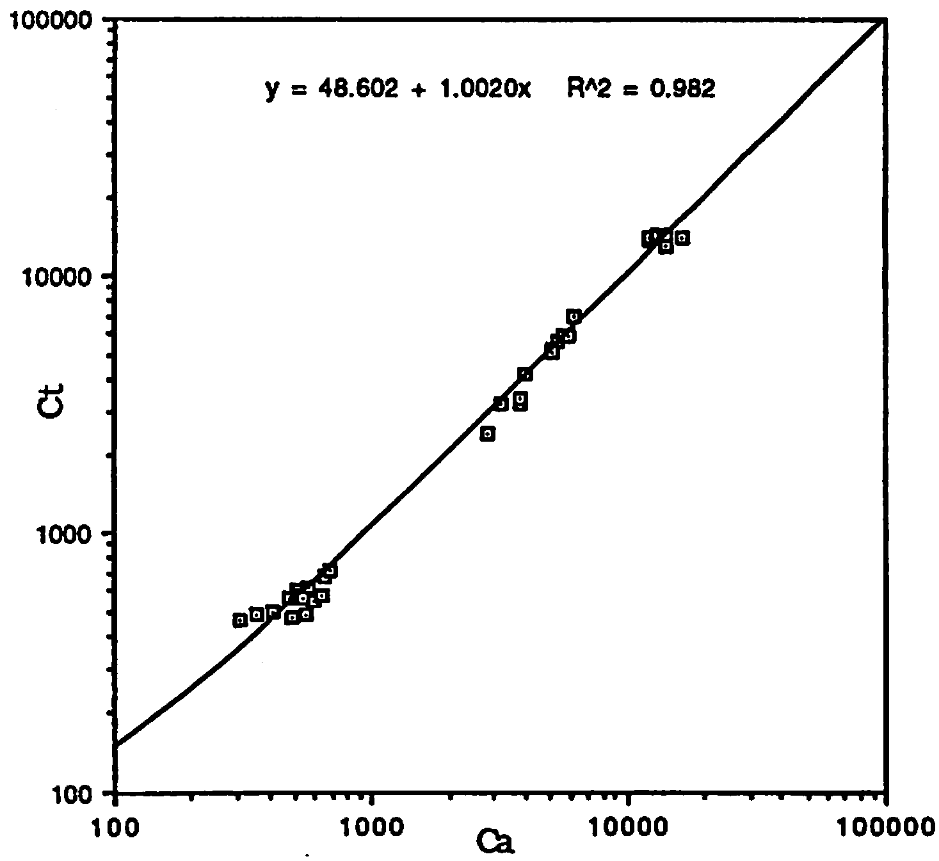


Figure 13. Correlation between measured specific conductance (Ct) and geophysical log-derived specific conductance (Ca) for control wells (Table 3). Specific conductance in microsiemens/cm, R^2 = r^2 (correlation coefficient squared).

results.

Since specific conductance is a function of total dissolved solids (TDS) (Alger, 1966), measured specific conductance (Ct) was plotted versus measured TDS (Figure 14) from the control data (Table 3). As indicated by Figure 14, excellent correlation exists between Ct and TDS, with r^2 = .992. The group of points possessing values less than 500 mg/L each which fall below the straight line plot is of interest (Figure 14). It appears that this phenomenon is caused by a change in the hydrochemical facies between the freshwater zone and other zones having higher TDS (Poteet, et al, 1992). The scattering of points is amplified when TDS is plotted versus Ca (Figure 15) since additional variables indigenous to quantitative log interpretation of freshwater carbonates are involved. However, a high correlation coefficient squared (r^2 = .964) is still present, indicating TDS values are acceptable. The concentration of points (possessing less than 500 mg/L TDS) below the straight line plot is not present on the equivalent graph presented in the first freshwater/saline-water interface study (Schultz, 1992); indicating a more noticeable change in the hydrochemical facies in the area east of San Antonio as compared to the counties to the west where the freshwater/saline-water interface is present.

When the amplification of the lower TDS values (Figure 15) provided by log-log scaling is compared to the same data plotted on a linear scale in Figure 16, the cluster of points having TDS

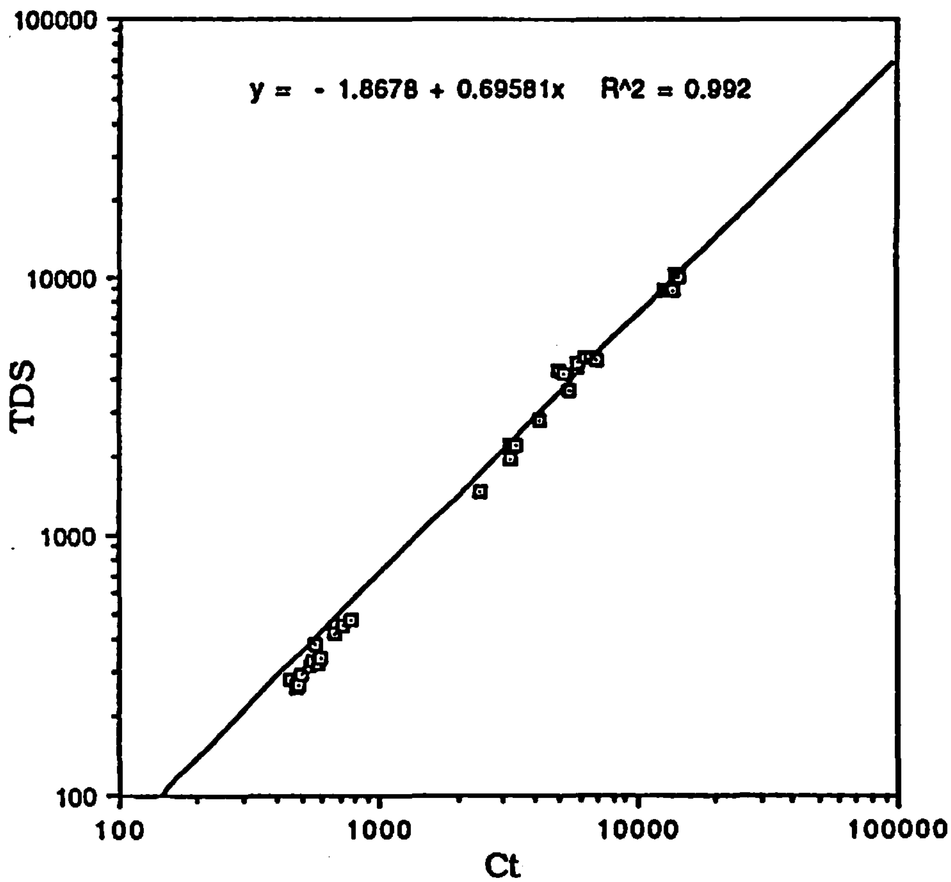


Figure 14. Relationship of measured total dissolved solids (TDS) to measured specific conductance (Ct) for control wells (Table 3). Total dissolved solids in mg/L. Specific conductance in microsiemens/cm. R^2 = r^2. Concentration of points having TDS <500 mg/L, which are positioned under the simple fit line, is interpreted to be the result of a change in the hydrochemical facies between the freshwater zone and saline zones.

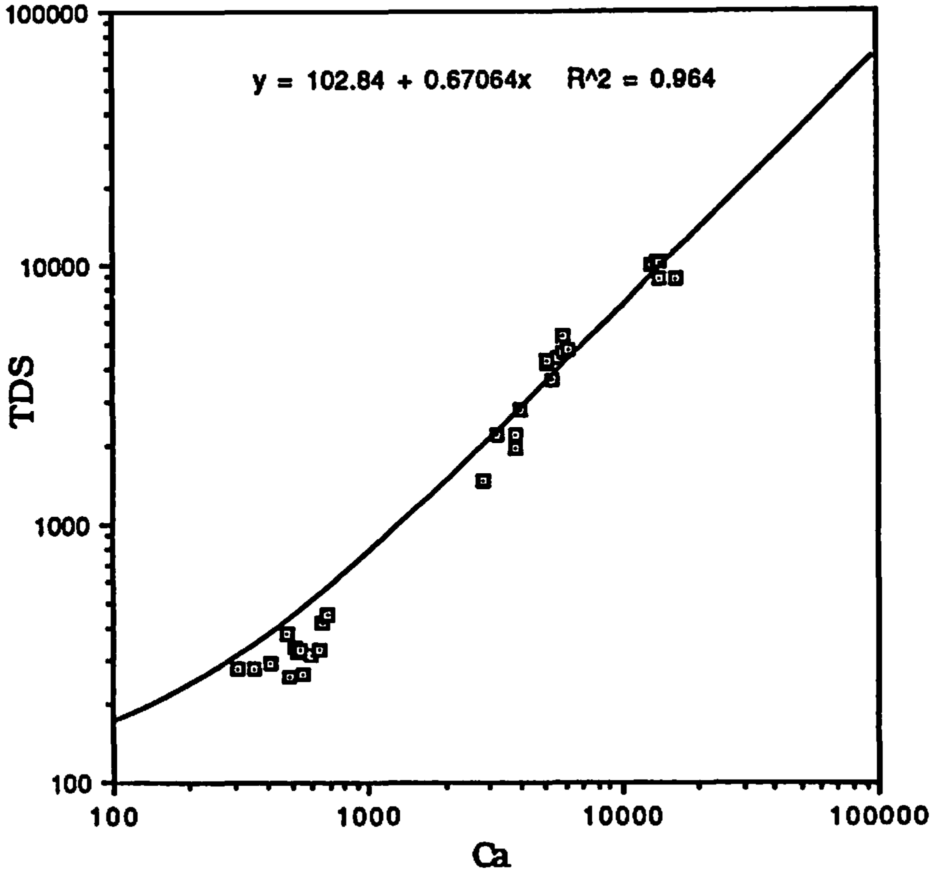


Figure 15. Correlation between measured total dissolved solids (TDS) and specific conductance (Ca), calculated from geophysical logs of control wells (Table 3). Crossplot reveals a well defined trend and a high correlation coefficient (r = .98). Total dissolved solids in mg/L. Specific conductance in microsiemens/cm. R^2 = r^2. Concentration of points having TDS <500 mg/L located below the plotted line is probably caused by changes in water type between freshwater and saline-water zones.

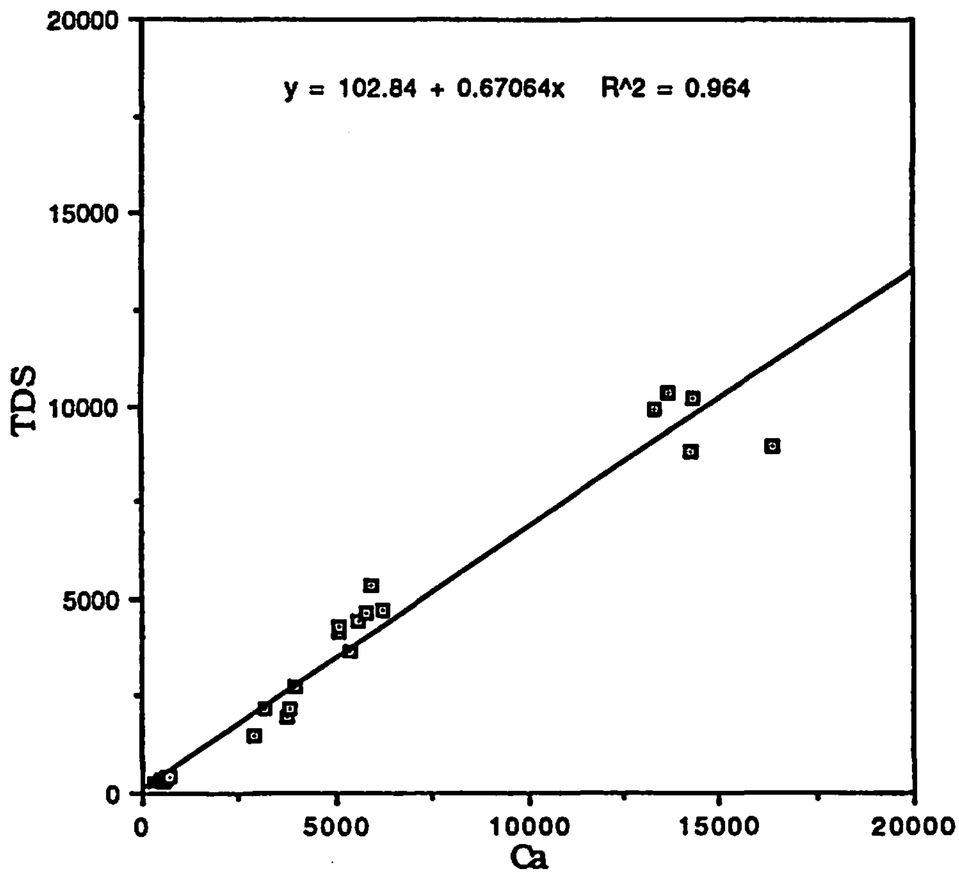


Figure 16. Correlation between measured total dissolved solids (TDS) and specific conductance (Ca), calculated from geophysical logs of control wells (Table 3) constructed on a linear scale. Crossplot is presented on a linear scale in order to show the contrast between logarithmic scaling (Figure 15) and linear scaling. Total dissolved solids in mg/L. Specific conductance in microsiemens/cm. R^2 = r^2. TDS values <500 mg/L do not appear scattered and are very close to the line. The equation for the simple fit line is the same for both presentations.

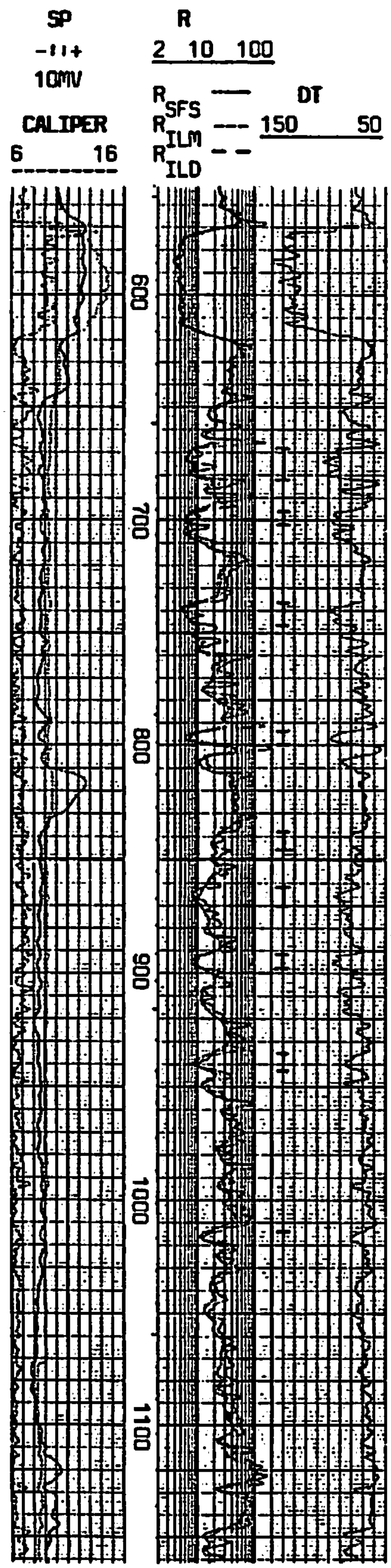
values below 500 mg/L appears less significant.

Comparison of estimated TDS (using Ca = 1500 uS/cm) in Figure 15 with the equivalent relationship in the previous study (Schultz, 1992) shows an estimated TDS = 1108 mg/L for this study, and TDS = 1030 mg/L for the earlier study (Schultz, 1992). This range is very close considering the data available, the method used to estimate TDS, and various water type changes that occur (Maclay, et al, 1980) between the two areas of the Edwards aquifer.

A review of the data and the relationships established from the various plots comparing Ca, Ct, and TDS (Figures 13, 14, 15, and 16), and the resulting high correlation co-efficients, indicates that values of Ca and estimated TDS obtained through geophysical log analysis are suitable for mapping the freshwater/saline-water interface between San Antonio and Kyle, Texas.

DEMONSTRATION OF METHOD

The technique for estimating water quality from geophysical logs can probably be more easily understood through the use of examples. Well 13KX (Plate 1) has a dual induction SFL log recorded over the Edwards Group. Intervals selected for estimating water quality parameters, log values, and various components for the necessary equations needed for the computations are presented in Figure 17. In this well, conductivity-feet have been determined for the Edwards Group



Well Designation 13 KX

Depth from	Depth to	DT	Por-S	Rt	Rwa	FmT	Ca	Ca-ft		Average Ca
668	682	95	0.40	8.0	1.25	78	7875	110257	from	
696	702	94	0.39	6.5	0.98	78	10057	60345		
736	746	95	0.40	6.5	1.02	79	9578	95780		
794	800	97	0.41	6.0	1.02	80	9472	56829		
838	846	80	0.27	19.0	1.42	81	6774	54192		
862	870	90	0.36	8.5	1.07	81	8918	71344		
892	898	91	0.36	8.0	1.06	81	9006	54037		
935	943	85	0.31	9.0	0.89	82	10633	85066		
1014	1020	80	0.27	11.0	0.82	83	11358	68149	to	9111

Average TDSest = .67Ca +103 = .67(9111) + 103 = 6207 mg/L

DT = Interval transit time for sonic log - in microseconds/ft

Por-S = Porosity calculated from DT - using empirical data shown in Figure 12 - where Por-S = .82DT - 38

Rt = R_{ILD} - Resistivity from Deep Induction Log

Rwa = Calculated apparent water resistivity at formation temperature

FmT = Estimated temperature of interval calculated (°F)

Ca = Calculated apparent specific conductance

Est. TDS = Total dissolved solids (mg/L), estimated from empirical relationship, from data shown in Figure 15 - where TDSest = .67Ca + 103

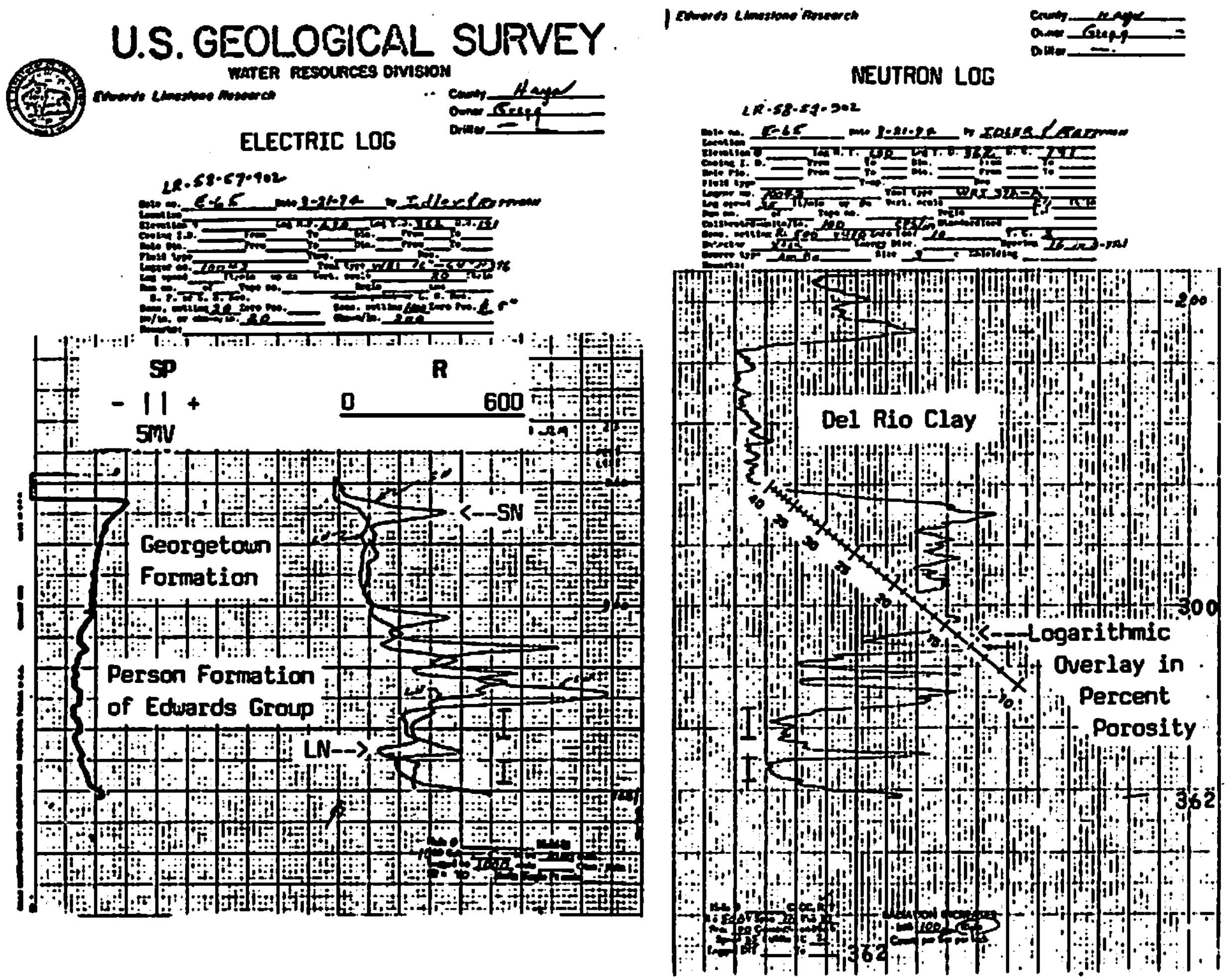
I = Symbol shown on log to indicate zones analyzed

FIGURE 17. Example of calculations made using a dual induction log and a sonic log. Example is Wehmeyer #1 Kraft (13KX) in Guadalupe County. Resistivity in ohm-meters, interval transit time in microseconds/ft.

from nine very porous zones. The total conductivity-feet was divided by the total footage of all zones analyzed to yield an average calculated specific conductance. According to the classification by Winslow and Kister (1956), an average estimated TDS of 6207 mg/L for the Edwards aquifer water in well 13KX would be classified as moderately saline (3000 to 10,000 mg/L).

The second example, well 5LR (Figure 18), illustrates the determination of calculated specific conductance (Ca) and estimated TDS using an electric log and a neutron log. The logs on this well were run by the USGS. A LN (64" normal) curve, a SN (16" normal) curve, and a count-rate neutron log were used to determine specific conductance and to estimate TDS. The two thickest zones with the higher, more uniform porosities were analyzed. The SN was used as a source for Rt. Such a decision is reasonable in this case since the hole size is less than 5 inches, the zones are thin, and the contrast between borehole fluid and formation water is insignificant.

Porosity was determined from the neutron log after selection of the resistivity values from the short-normal curve over the two zones. A scale is not shown on the main log; however, near the bottom of the log is a notation showing counts increasing to the right at 100 counts per inch. The zero for the neutron log is shown as 10, which may mean the left hand side of the grid is zero. A logarithmic porosity overlay was used, since this neutron log is not compensated and interpreta-



Por-N = Porosity from neutron log

Rt = R_{SN} - Resistivity measured from Short Normal resistivity

Rwa = Calculated apparent water resistivity

FmT = Estimated temperature of interval calculated (°F)

Ca = Calculated apparent specific conductance

Est. TDS = Total dissolved solids (mg/L), estimated from empirical relationship, from data shown in Figure 15 - where TDSest = .67Ca + 103

I = Symbol shown on log to indicate zones analyzed

Well Designation 5 LR

Depth from	Depth to	Por-N	Rt	Rwa	FmT	Ca	Ca-ft		Average Ca	Average TDSest
334	343	0.36	220	28.51	73	368	3314	from		
350	357	0.38	200	28.88	73	362	2537	to	366	348

Figure 18. Example of calculations made using an electric log, and a logarithmic porosity overlay to estimate porosity from a neutron log. Example is well LR-58-57-902 (5LR) in Hays County. Handwritten notes are on original copy. Resistivity in ohm-meters.

tion charts are not available for converting counts to porosity units. This technique has been employed for over thirty years and can provide satisfactory results if the borehole is reasonably uniform, lithology is fairly consistent, and good estimates of high and low values of porosity can be established for scaling. The technique can be applied on this well by assigning a low value of 16 percent porosity (based upon data from more modern logs recently run in San Marcos test wells 7LR and 8LR) to the Georgetown Formation. Additionally, a porosity of about 38 percent was selected for the high end of the scale. This value was obtained after studying the compensated density and compensated neutron logs run over the upper portion of the Edwards aquifer in wells 7LR, 8LR, and 6LR. Having selected the high and low porosity values, the logarithmic porosity scale is positioned over the neutron log so that the low porosity value lines up with the Georgetown Formation average reading and the high porosity value is set at the neutron response for the higher porosities in the Edwards aquifer. The Del Rio Clay, from 214' to 264', reads in the 40 percent porosity range when the porosity scale is in place. (This can only be used as a rough check against other high values since casing is at 260' and casing dampens the neutron log response, causing porosity to appear higher.) Calculations on the two zones yielded an average specific conductance of 366 uS/cm and an estimated TDS of 348 mg/L, which are reasonable values for a well in the freshwater zone.

The final example, well 56AY (Figure 19), demonstrates the determination of Ca and estimated TDS using a conventional electric log without a porosity log run in the well. In this instance, true resistivity was taken from the long-normal (LN) curve and porosity was estimated from porosity logs on other wells in the area and from local knowledge. The resistivities in this well are very high, exceeding 500 ohm-meters in some of the intervals to be analyzed. Whenever the LN (64" normal) readings are over approximately ten times the resistivity of the borehole fluid, a correction for borehole effect is appropriate (see Figure 20). Borehole corrections frequently need to be applied in highly resistive freshwater aquifer wells where the borehole fluid is formation water and no invasion is present. In most oil and gas wells, the drilling fluid usually possesses lower resistivity and has generally invaded the formation, causing the resistivity of some volume of the formation measured by the LN to be less in porous zones which actually possess a high resistivity. The result is that the effect of invasion of a low resistive fluid has frequently canceled out the borehole correction needed for the high contrast. For this, and possibly other reasons, the chart for borehole corrections is seldom used by most log analysts.

The log heading for well 56AY indicates that the borehole fluid measurement is nearly 20 ohm-meters. Values of the LN from the porous intervals are divided by 20 and entered into the borehole correction chart (Figure 20) at the bottom and a

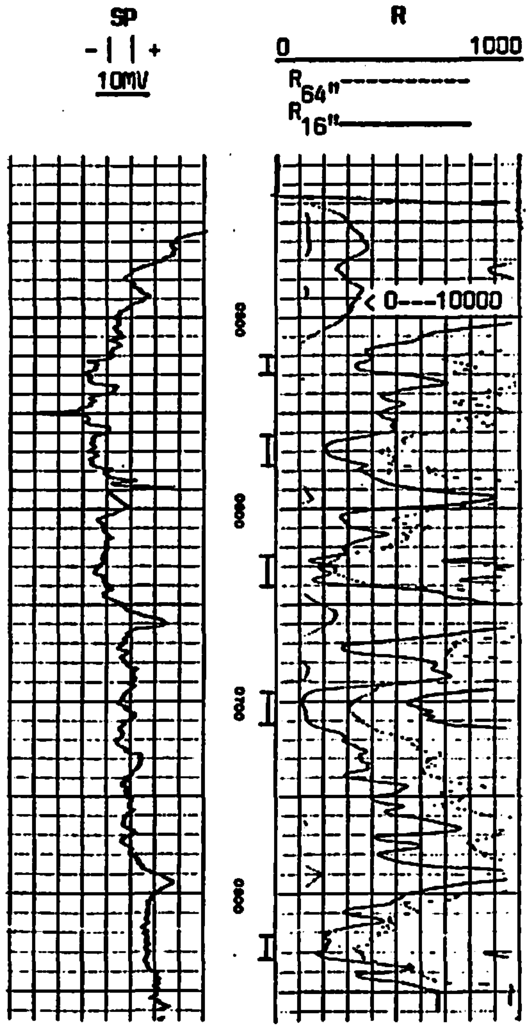


Figure 19. Example of calculations made using an electric log and estimated porosity. Example is AY-6829-702 (56AY) in Bexar County. Resistivity in ohm-meters.

Depth from	Depth to	Por-E	Rt	Rwa	FmT	Ca	Ca-ft		Average Ca	Average TDSest
520	530	0.24	600	34.56	77	290	2900	from		
562	578	0.28	340	26.66	77	373	5972			
624	640	0.32	180	18.43	78	534	8542			
695	712	0.28	260	20.38	79	477	8106			
822	834	0.30	300	27.00	81	352	4227	to	419	384

Por-E = Porosity estimated from nearby wells and/or local knowledge

Rt = Resistivity from Long Normal ($R_{64"}$) corrected for borehole conditions from data shown in Figure 20

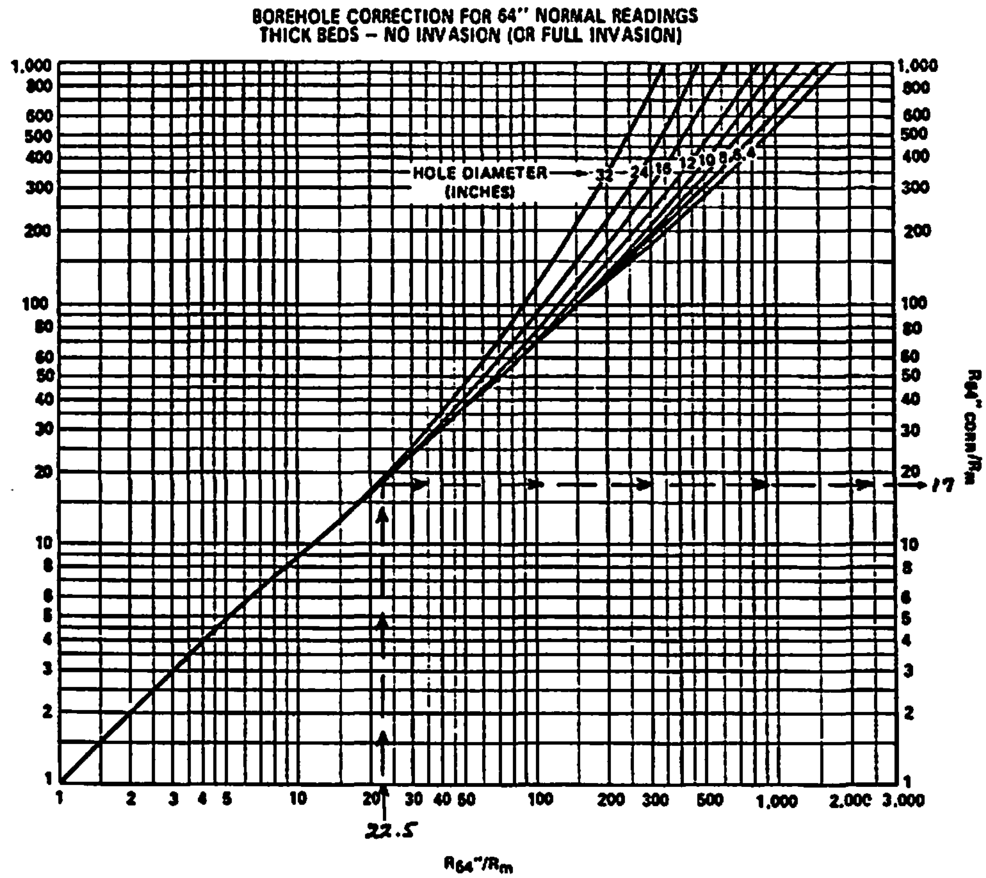
Rwa = Calculated apparent water resistivity at formation temperature

FmT = Estimated formation temperature of interval calculated (°F)

Ca = Calculated apparent specific conductance

Est. TDS = Total dissolved solids (mg/L), estimated from empirical relationship, from data shown in Figure 15 - where TDSest = .67Ca + 103

I = Symbol shown on log to indicate zones analyzed



USE

This chart corrects for the influence of the borehole on the 64" normal

INFORMATION REQUIRED

R_m - resistivity of borehole fluid at formation temperature
Hole diameter in inches
Apparent 64" normal resistivity reading from log

PROCEDURE

Enter $R_{64"}/R_m$ at the bottom of the chart and proceed to the solid curve for the appropriate hole size. Read $R_{64"corr}/R_m$ at the right or left margin.

EXAMPLE

Given: R_m for the zone from 562' to 578' in well 56AY is 20 ohm-meters
Bit size is shown as 11 3/4"
$R_{64"}$ = 450 ohm-meters
Solution: $R_{64"}/R_m$ = 450/20 = 22.5, $R_{64"corr}/R_m$ = 17

$R_{64"corr}$ = 340 ohm-meters

Figure 20. Borehole correction chart for 64 inch normal. Corrections are frequently needed wherever $R_{64"}$ exceeds approximately ten times the resistivity of the borehole fluid (from Gearhart-Owen, 1975).

straight line is extended up to the point representing the borehole size (11.75" shown on log heading), and then is drawn horizontally to the value shown for a R64"corr/Rm. The procedure is demonstrated for the zone from 562' to 578' (Figures 19 and 20). This value is divided by the resistivity of the borehole fluid to produce a more correct value of Rt. Porous intervals are selected over the zones where the SN(16" normal) reads the lower, more uniform values, since porous water-filled zones possess lower resistivity than the dense members of the aquifer. Five zones were analyzed in well 56AY and calculations produced an estimated specific conductance of 419 uS/cm and an estimated TDS of 384 mg/L which compares favorably with measured data in the area.

The results of all estimates and calculations for all the wells in this study are shown in tabulated form in Table 2.

SPECIFIC CONDUCTANCE MAP

Calculated and measured specific conductance values from Table 2 were posted on a base map of the study area (Figure 21, Plate 2). Appropriate contours were constructed beginning with the 1000 uS/cm contour. The contour intervals vary and are compatible with those used in EUWD Report 92-03 (Schultz, 1992). Additionally, for reference, the 1991 location of the fresh-water/saline-water interface (Brown, et al, 1992) is presented. Explanation of symbols and other identification is presented either on the specific conductance map or in Table 2. The

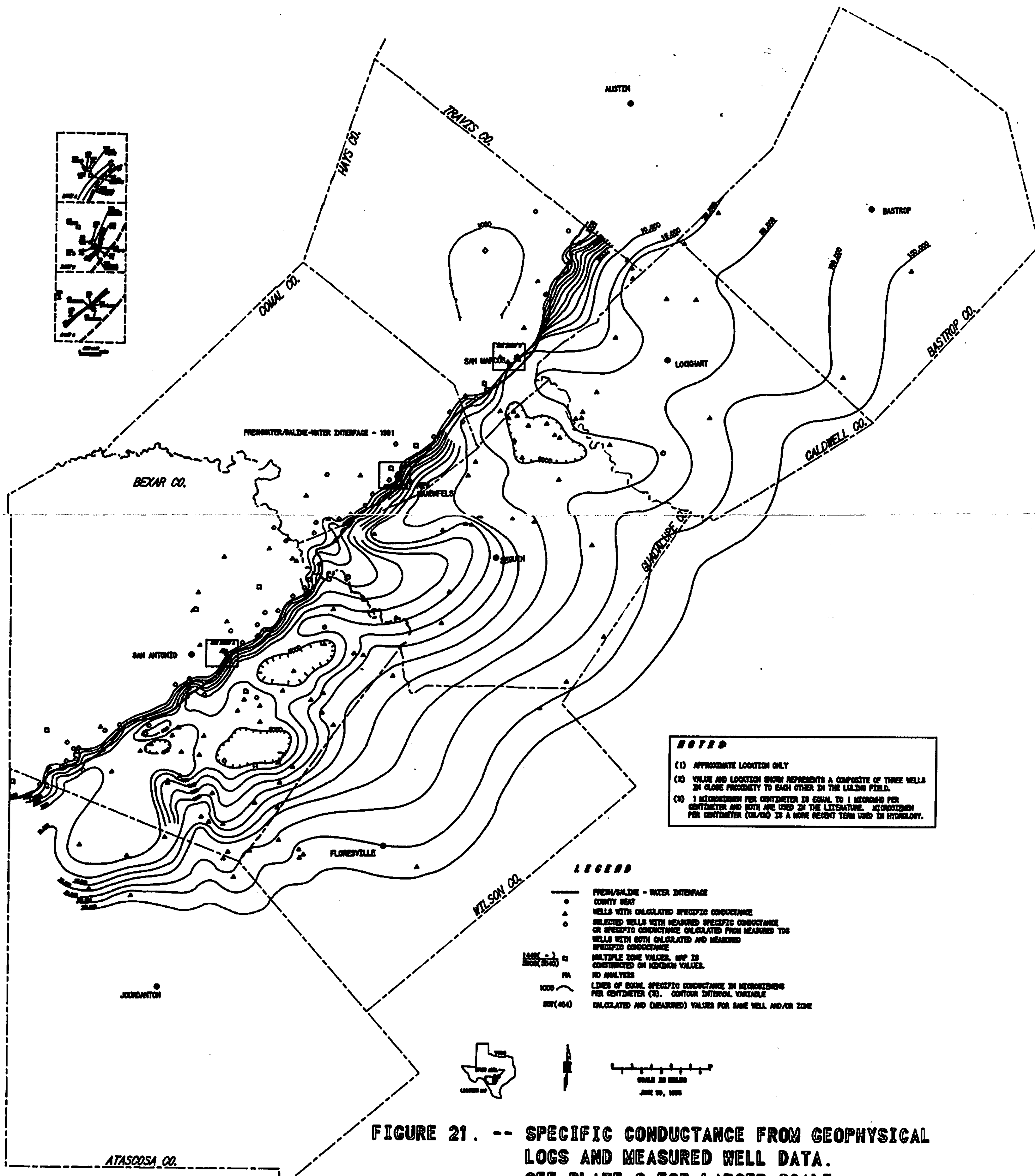


FIGURE 21. -- SPECIFIC CONDUCTANCE FROM GEOPHYSICAL LOGS AND MEASURED WELL DATA. SEE PLATE 2 FOR LARGER SCALE.

minimum value has been selected for contouring whenever multiple values are shown for a well.

A specific conductance map is an effective way to display the transition from freshwater to highly saline water in the Edwards aquifer. The specific conductance map (Figure 21, Plate 2) shows that over most of the study area, the distance between the 1000 uS/cm contour and the 4000 uS/cm contour is narrow compared to distances between contours of higher values. The bulge of diluted saline water (specific conductance values between 4000 uS/cm and 10,000 uS/cm) in southern Bexar County and northern Atascosa County, mapped in the previous study (Schultz, 1992), extends over most of southeastern Bexar County and continues northeasterly into most of western Guadalupe County. This configuration of specific conductance contours suggests that freshwater has significantly diluted the highly saline and brine water of the Edwards formations at some time in the past. In northern Atascosa County, the gradation from 10,000 uS/cm to 150,000 uS/cm is rapid, indicated by a relatively short distance between the two contours. However, the distance between the contours increases to the northeast until there is a separation of nearly 30 miles southeast of San Marcos. Concurrently, the 1000 uS/cm and 4000 uS/cm contour lines remain close and do not appear to be influenced by the gradual gradation observed in the specific conductance values exceeding 10,000 uS/cm.

Wells 73AY and 88AY possess specific conductance values higher than those immediately downdip, indicating an area where less water circulation has occurred compared to the freshwater zone and the area downdip.

Another anomaly occurs southeast of the common corner of Bexar, Comal, and Guadalupe counties where it appears that freshwater has diluted the highly saline zone. The anomaly may have been generated by freshwater flow downdip.

The area between the Comal-Hays County line and San Marcos displays a rapid change from freshwater to saline water. Specific conductance values of less than 1000 uS/cm increase to values exceeding 10,000 uS/cm within a very short distance.

The most extreme contrast between freshwater and highly mineralized water along the freshwater/saline-water interface occurs in San Marcos, where freshwater possessing a measured specific conductance of about 600 uS/cm is in close proximity to water with a measured specific conductance of 14,000 uS/cm.

TOTAL DISSOLVED SOLIDS MAP

Water quality comparisons are traditionally expressed in units of total dissolved solids (TDS). The groundwater classification used in Texas, based on dissolved solids, is as follows:

Water Quality	TDS (mg/L)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

(from Winslow and Kister, 1956)

All measured and estimated TDS values were posted on the base map. Estimated TDS values were derived using the formula for converting Ca to TDS (Figure 15). Contours representing values described in the classification system above were constructed (Figure 22, Plate 3).

Water quality data presented in the form of TDS isocons is more convenient for understanding the overall picture along the freshwater/saline-water interface since the units used are the same as those units used to delineate the 1991 interface (Figure 22, Plate 3). A direct comparison of the two interfaces is therefore possible. The freshwater/saline-water interface determined in this study and the 1991 interface are closely parallel. However, this report indicates that on average the interface is to the northwest of the 1991 interface and therefore intrudes into some of the area previously identified as freshwater. The area delineated between the two interface traces is approximately 35 square miles and the average distance between the two 1000 mg/L contour lines is approximately 0.4 mile from the Atascosa-Bexar County line to Buda, Texas. The areas where separations occur are frequently documented with actual measured data.

The TDS map (Figure 22, Plate 3), which is constructed from both measured and log-derived data, displays a large area of fresh to moderately saline water that is prominent in southeastern and eastern Bexar County and western Guadalupe County. The distribution and values of the TDS contours

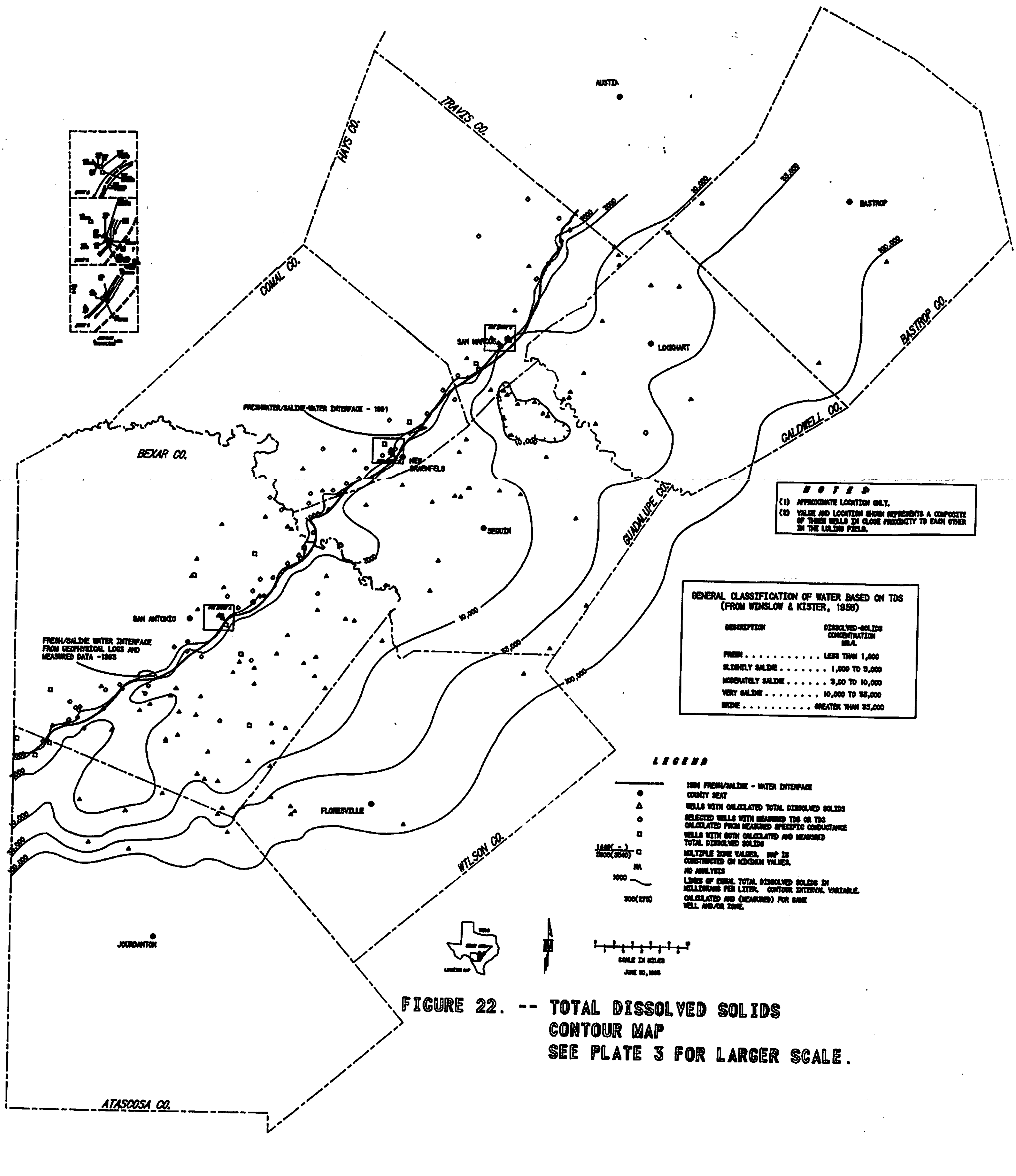


FIGURE 22. -- TOTAL DISSOLVED SOLIDS CONTOUR MAP

SEE PLATE 3 FOR LARGER SCALE.

indicates that freshwater has diluted the very saline water, since downdip the water is classified as brine (Figure 22, Plate 3). Since specific conductances are directly related to TDS values, the distance between the 1000 mg/L and 3000 mg/L contour lines are close together in a manner similar to the 1000 uS/cm and 4000 uS/cm contour lines on the specific conductance map.

The large lobe of moderately saline water extending north from Bexar County into most of the western half of Guadalupe County terminates near the Guadalupe-Caldwell County line. The 10,000 mg/L contour is present in the City of San Marcos where the total dissolved solids abruptly change from approximately 10,000 mg/L to freshwater. Additionally, the TDS values between the Hays-Comal County line and the San Marcos area display an extreme contrast, being either freshwater (TDS less than 1000 mg/L) or moderately saline (TDS 3000 to 10,000 mg/L) with an apparent lack of a transition zone (TDS 1000 to 3000 mg/L).

Northeast of San Marcos near the Hays-Travis County line, the transitional pattern from freshwater to brine shows a more normal distribution and compares to the transition seen in Guadalupe County. An anomalous condition is reported for well 18LR (north of San Marcos) where the measured TDS is 970 mg/L. This value is very close to the crossover from fresh to slightly saline water. Natural sulfur deposits and saline water have been reported in the lower Edwards north of San Marcos in this general area (Maclay and Small, 1984; Gary Bowman, personal communication, 1993).

INFLUENCE OF FAULTING ON THE FRESHWATER/SALINE-WATER INTERFACE

Water entering the Edwards aquifer recharge area seeks the path of least resistance from a position of higher head or higher energy toward a position of lower potential energy (Poteet, et al, 1992). As water moves from the western region to the large springs in the eastern part of the Edwards aquifer, faulting produces barriers, baffles, and restrictions which significantly influence the direction of groundwater flow (Maclay and Small, 1983). The presence of the freshwater/saline-water interface is the result of a lack of freshwater flow in the saline zone, and faults acting as barriers or baffles can cause the transition from freshwater to saline water to be very rapid, producing a very narrow zone on a specific conductance or TDS map between contours representing freshwater and varying degrees of saline-water. To demonstrate this concept, the area in northeastern Zavala County, southern Medina County, and northern Frio County reveals a wide transition zone between freshwater and slightly saline water (Figure 23, Plate 4). This area lacks the effect of faulting which would divert the flow of freshwater (Maclay and Small, 1984; Caran, et al, 1982). As a result, the distance between the 1000 mg/L contour and the 3000 mg/L contour (Figure 23, Plate 4) is approximately 3 miles, indicating a rather gradual transition from 1000 mg/L to 3000 mg/L TDS.

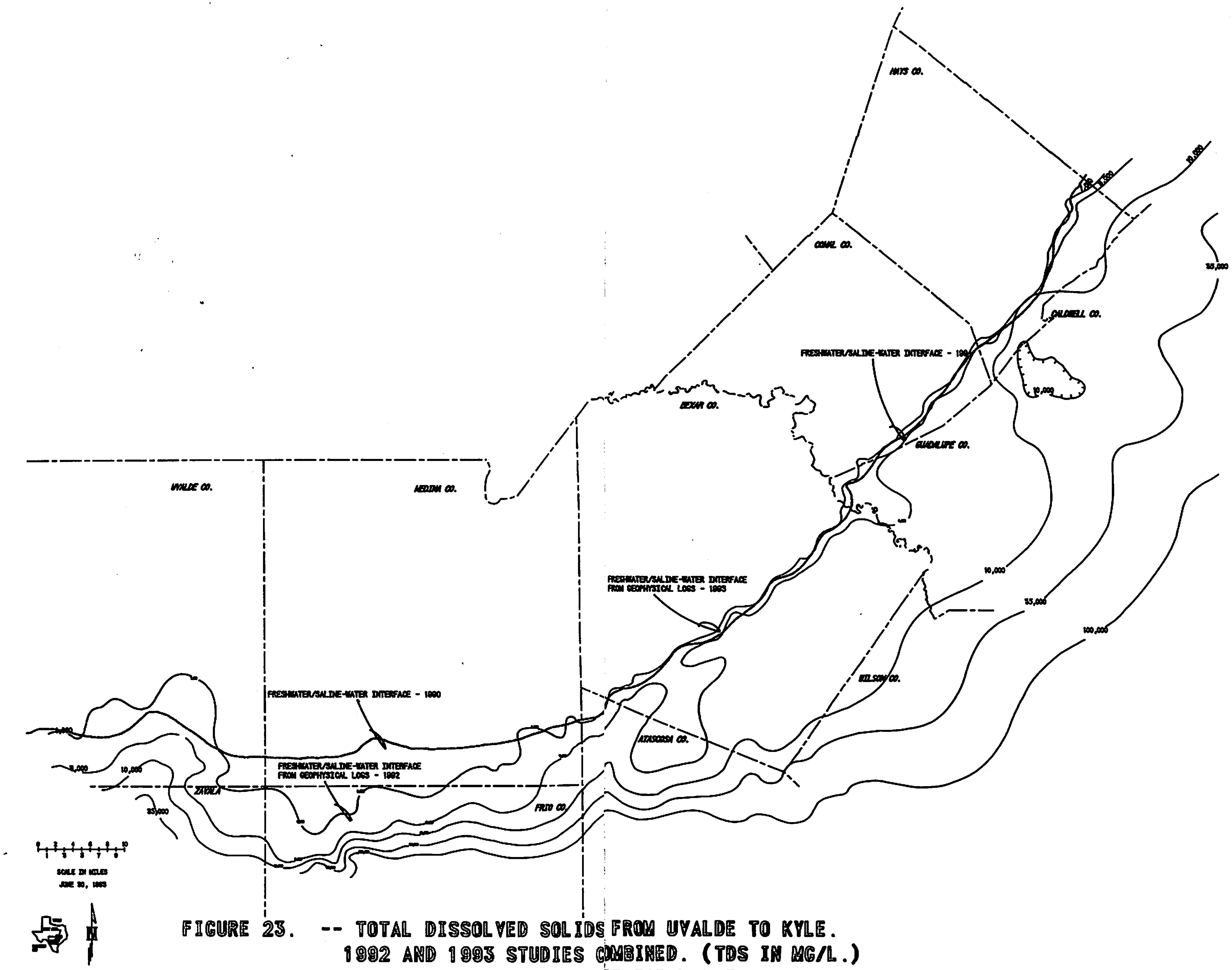


FIGURE 23. -- TOTAL DISSOLVED SOLIDS FROM UVALDE TO KYLE.
1992 AND 1993 STUDIES COMBINED. (TDS IN MG/L.)
SEE PLATE 4 IN BACK COVER FOR LARGER SCALE.

The distance between the 1000 mg/L and 3000 mg/L TDS contours decreases in eastern Medina County and southwestern Bexar County where major faulting is present. The faulting creates barriers which divert the freshwater flowpaths. One of these paths is on the south side of the Pearson Fault (Figure 24). Water on the south side of the fault is diverted in an easterly and northeasterly direction near the Medina-Bexar County line (Maclay and Small, 1983). Other northeast/southwest striking faults from the Medina-Bexar County line to the Bexar-Comal County line appear to act as baffles and to focus the flow toward the northeast (toward the major springs). The interval between the freshwater and slightly saline zones is narrow and is approximately 1 mile wide over most of the interface area in Bexar and Comal counties, with the exception of two major anomalies.

An anomaly occurs in southern Bexar County (Figure 23, Plate 4) where a very large area of slightly saline water (between the 1000 mg/L and 3000 mg/L contours) appears to have been generated by faults in that area which have diverted some of the freshwater into the very saline brine downdip. More detailed maps (Petitt, 1956) show additional faulting which strikes northwest/southeast in the area near the Medina River south of the Pearson Fault. The dilution of the saline zone by the freshwater bypassing or escaping through the fault complex along the freshwater/saline-water interface in Bexar County diminishes in extreme northeastern Bexar County. A weak

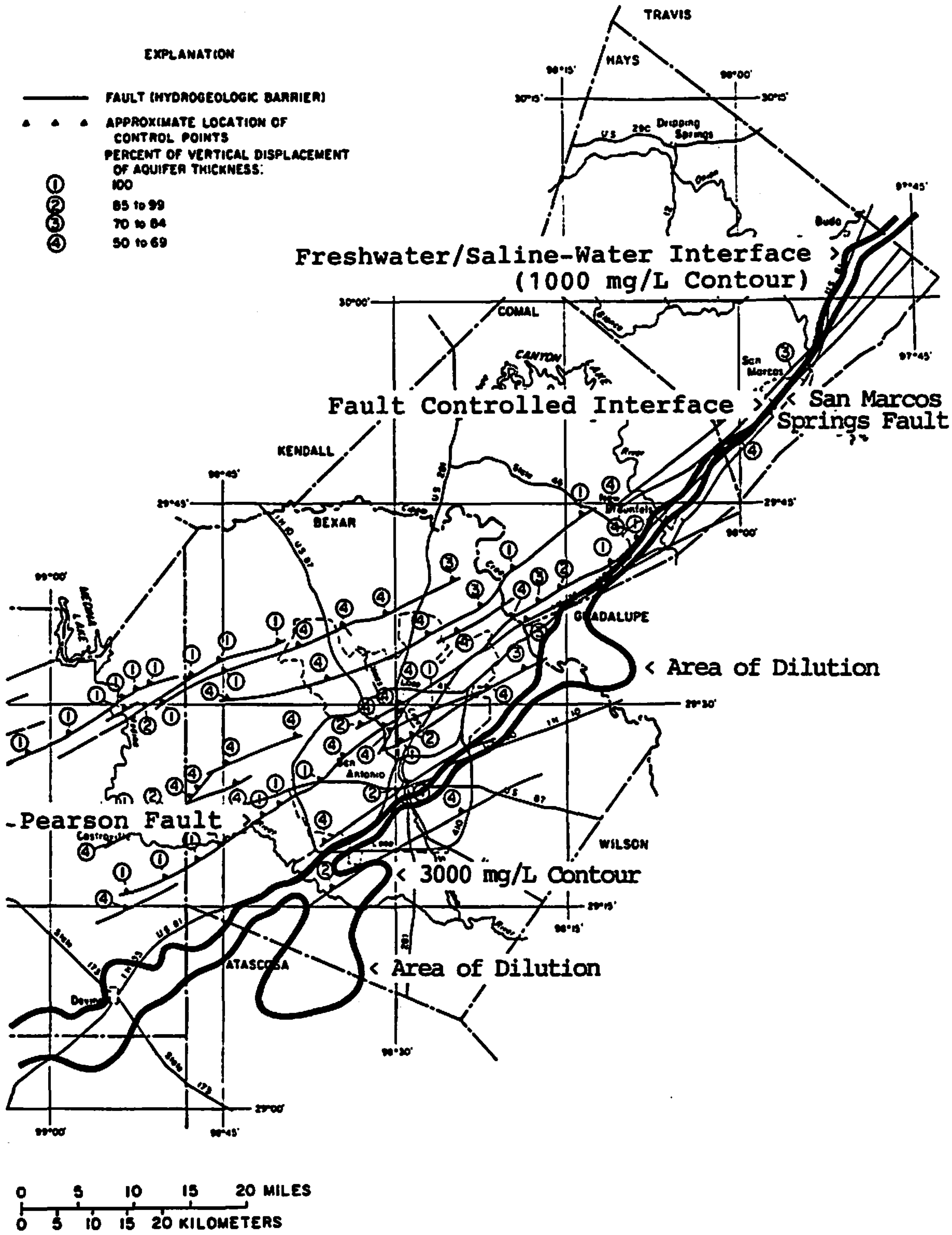


Figure 24. Map showing relationship of freshwater/ saline-water interface to major faulting in the eastern part of the Edwards aquifer (Modified after Maclay and Small, 1984).

re-entrant is indicated near Well 81AY (Plate 2) which appears to separate the anomaly in southeastern Bexar County from another strong indication of dilution of the saline zone in western Guadalupe County. This dilution is portrayed by an extension downdip of the 7000 uS/cm contour on the specific conductance map (Figure 21, Plate 2). This anomaly appears to have its origin near and parallel to the Cibolo Creek area at the common junction of Bexar, Comal, and Guadalupe counties. A convergence of the faults northeast of San Antonio, combined with decrease in throw along these faults (until they cease to be effective barriers) near the Cibolo Creek area, allows freshwater to move through the fault complex and flow downdip, diluting the brine.

Northeast of this anomaly, faulting influences the position and transitions associated with the interface in a manner similar to that observed in Bexar County. From the Hays-Comal County line to the San Marcos area faulting appears to control the position of the freshwater/saline-water interface, as shown by the interface following fault traces (Figure 24) and by the large contrast in TDS values possessed by the water on either side of the faulting (Figure 22, Plate 3). The faulting generates an effective barrier, separating freshwater from the more saline water. This barrier extends from a location near the Comal-Hays County line to an area about 3 miles northeast of San Marcos Springs, and is the probable reason for the re-entrant of the 20,000 uS/cm contour subparallel to the San

Marcos River (Figure 21, Plate 2). The effect of the barrier is shown by the high concentration of TDS southeast of San Marcos which has less dilution by freshwater flow than any other location near the freshwater/saline-water interface in the study area. Faulting does not appear to be an effective barrier near the Hays-Travis County line where the transition is more gradual from fresh to very saline water.

SUMMARY AND CONCLUSIONS

This study demonstrates that good agreement exists between measured specific conductance and TDS values and calculated specific conductance and estimated TDS values derived from geophysical logs. There is a high degree of correlation between calculated and measured results, with correlation coefficients exceeding .97.

An increase of approximately 10 percent porosity is observed in the more porous intervals in the Edwards Group in the study area as compared to the area near the freshwater/saline-water interface in the counties west of San Antonio.

The freshwater/saline-water interface is parallel to the 1991 trace of the interface and is in a position which displaces approximately 35 square miles previously classified as freshwater. The average width of this area is nearly 0.4 mile.

The position of the freshwater/saline-water interface and the rate of increase in TDS between freshwater and brine is influenced by faulting. The complex faulting of the Balcones

Fault Zone produces barriers, baffles, and restrictions which help direct the ground-water flow along the path of least resistance toward points of lower potential energy, frequently the major springs. There is a direct correlation between the width of the distance between the 1000 mg/L and 3000 mg/L TDS contours and the intensity and magnitude of faulting. The distance between the two contours is approximately 3 miles in the area to the west of the Atascosa-Medina County line where faulting does not hinder the ground-water flow, and about 1 mile over most of the area in Bexar, Comal, and Hays counties.

The anomalous area of lower salinity in the saline zone downdip in southern Bexar County and northern Atascosa County and the anomalous area southeast of the common junction of Bexar, Comal, and Guadalupe counties appear to have been generated by faulting. A decrease in the displacement of of faults, and/or discontinuity in faulting allows some of the freshwater moving toward Comal and San Marcos springs to be diverted and to escape through the complex system, thus diluting the saline zone downdip.

The area in which TDS exceeds 8000 mg/L in Hays County parallel to the interface and adjacent to San Marcos Springs is controlled by faulting. Faulting has formed an effective barrier separating freshwater from water with TDS exceeding 8000 mg/L with an apparent lack of a slightly saline zone (1000 mg/L to 3000 mg/L).

Mixed signals are generated concerning the potential for saline water existing in the Edwards aquifer on the upthrown (west) side of the San Marcos Springs Fault. Geophysical log interpretation indicates well 12LR encountered freshwater over the lower Edwards interval and is located about 1.5 miles west of San Marcos Springs. However, reports of saline water and native sulfur indicate there is saline water in the Edwards Group north of San Marcos.

The examples of poor quality logs point out the need for careful screening of logs whenever they are to be used for quantitative evaluation. Logs to be digitized and placed in a digital data base should first be checked for scale accuracy and normalized, if necessary, so that future log evaluation projects will be more accurate. Experience, ingenuity, and knowledge of the Edwards and associated formations is required to effectively utilize the wide range of logs available in Edwards aquifer wells.

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Table 2. Calculated and/or measured data from geophysical logs and other sources for wells in study area.

Atascosa County

Map I.D. Number	Other well identification	Depth interval from:	to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
1AL-6AL										See EUWD Report 92-03
7AL	Fina #1 Adams	4424	4454	128729			86351	11-88		
8AL	Bailey #1 Schultze	3410	3895	5589			3848	4-55		
9AL	Ark. Fuel #1 Jasik	4310	4320	30631			20626	?-47		
10AL	Tenneco #1 Suggs	4930	5510	64242			43145	3-69		
11AL	AL-68-50-301				912	586			4-85	(10)

Bastrop County

Map I.D. Number	Other well identification	Depth interval from:	to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
1AT	Skelly #1 Ray	1720	1960	27800			18729	11-56		
2AT	Ambassador #1 Anderson	1814	2024	24877			16771	12-61		
3AT	Howell #1 Wilhelm	5080	5377	110168			73916	9-80		
4AT	AAA #1 Lovejoy	5634	6002	164309			110190	2-84		

Bexar County

Map I.D. Number	Other well identification	Depth interval from:	to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
1AY-25AY										See EUWD Report 92-03
26AY	Tenneco #1 Herrera	2740	3202	8689			5925	12-67		
27AY	Parker & McCune #1 Goad	1820	2000	5426			3738	11-45		
28AY	Arnold #2 Dillon							10-53		No analysis(N/A)-not deep enough(NDE)
29AY	Arnold #1 Dillon	3370	3373	11429			7760	3-52		
30AY	APCO #1 Yturri	1600	2012	5099			3519	6-48		
31AY	Brown #1 Gembler	1490	1500	5858			4028	5-50		
32AY	Katz #1 Keeper	3470	3474	9203			6269	2-52		
33AY	H&J #1 Lamm									N/A-interval is too tight
34AY	H&J #1 Chapaty	4198	4204	31221			21021	12-56		

Table 2. Continued

Map I.D. Number	Other well identification	Depth interval from:	to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
35AY	AY-68-45-301	1770	2036	5123	5020	4280	3535	9-74	7-70	3
36AY	AY-68-45-901	2540	2758	5058	5190	4150	3492	3-74	1-73	3
37AY	Staccatto #1 Jasik	3490	3531	17298			11693	12-82		
38AY	Tomlinson #1 Island Park	2669	2710	5141			3547	5-82		
39AY	Teagle #1 Lemelle	2462	2473	9298			6333	7-46		
40AY	Elliott #1 Laub	1990	2480	8104			5533	4-53		
41AY	Starr #1 Cochran	2990	3000	8275			5647	3-49		
42AY	Hazel #1 Zigmond	1736	1746	7601			5196	4-64		
43AY	Ark. Fuel #1 Burkhardt	2270	2575	9133			6222	11-47		
44AY	Fair #1 Lyro	1810	2130	8972			6114	12-46		
45AY	Philtop #1 Patton	1700	2090	4529			3137	12-38		
46AY	Brown #1 Schroeder	880	1206	6297			4322	6-65		
47AY	Security Drilling #2 Englemann	380	640	607			510	4-55		
48AY	Stuart #1 Eckert	1618	1935	5392			3716	6-52		
49AY	Thomas #1 Schwenn	1330	1741	5949			4089	6-61		
50AY	Morrison #1 Huber	1710	1785	6269			4303	8-61		
51AY	Renlee #1 Theis							9-55		N/A-logged below Edwards Formation
52AY	Hill #1 Rawlings	1920	1940	7469			5107	8-50		
53AY	Geiselman #1 Ciomperlik	1690	1718	5223			3602	3-64		
54AY	Butler-Arthur #1 Gembler	1710	1720	5509			3794	12-42		
55AY	Jacobs #1 Dickey Clay Mfg.	2924	3118	7747			5293	10-56		
56AY	AY-68-29-702	520	834	419			384	2-65		
57AY	AY-68-30-5E	358	545	505			441	4-78		
58AY	AY-58-30-109							5-73		N/A-too many caverns in Edwards Formation

Table 2. Continued

Map I.D. Number	Other well identification	Depth interval from:	to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
59AY	AY-68-29-913	479	730	353	483	274	340	7-68	3-72	(3)
60AY	AY-68-30-616	526	540	1449			1074	5-73		
		562	570	2157			1548			
		620	917	5908		5340	4061		9-42	(7)
61AY	AY-68-30-211	314	764	469			417	11-73		
62AY	AY-68-30-807	654	665	1132			861	7-72		
		788	1074	6200	6950	4680	4257		11-72	(3)
63AY	AY-68-37-519	974	1304	557	484	263	476	10-75	7-90	(9)
64AY	AY-68-37-402							10-65		N/A-Gamma Ray Neutron(GRN) only
65AY	AY-68-37-705							3-57		N/A-excess faulting
66AY	AY-68-37-106	600	910	494			434	12-62		
67AY	AY-68-37-104	618	880	306	457	275	308	1-63	7-70	(3)
68AY	AY-68-37-203	616	797	474			421	9-73		
69AY	AY-68-37-521	1014	1026	3213	3198	2200	2256	1-85	7-85	(5)
		1040	1064	3827	3324	2200	2667	1-85	7-85	(5)
		1276	1489		6650	4800			7-85	
70AY	AY-68-37-524	832	859		772	470			12-85	(5)
		1071	1236	5614	5860	4400	3864	11-85	12-85	(5)
		1270	1311	5829	5870	4600	4008	11-85	12-85	(5)
71AY	AY-68-37-526	868	1010	484	475	260	427	3-86	3-86	(5)
		1158	1384		6380	4800			3-86	(5)
72AY	AY-68-43-607	1710	2085	580			492	3-55		
73AY	AY-68-45-101		1875		5380	4180			7-77	(3)
74AY	AY-68-45-102				5060	3990			7-70	(3)
75AY	AY-68-51-201		2219		4850	3660			9-73	(3)
76AY	AY-68-44-404		1660		2480	1820			7-70	(3)
77AY	AY-68-36-908		1708		477	270			12-73	(3)
78AY	AY-68-37-202		702		461	261			3-72	(3)
79AY	AY-68-37-602		1100		1770	1070			1-73	(3)
80AY	AY-68-38-103		884		1790	1302			3-76	(3),(16)
81AY	AY-68-38-301		854		7330	5014			3-76	(3),(16)

Table 2. Continued

Map I.D. Number	Other well identification	Depth from:	interval to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
82AY	AY-68-30-102		418		460	277			7-74	(3)
83AY	AY-68-30-219		850		617	359			3-72	(3)
84AY	AY-68-30-802		750		511	294			3-72	(3)
85AY	AY-68-30-805		576		547	469			4-76	(3),(16)
86AY	AY-68-45-302		1715		5840	4542			8-72	(3)
87AY	AY-68-44-502		1860		5290	3647			3-69	(3),(7),(16)
88AY	N-13		1767			4500			5-44	(11),(17)
89AY	AY-68-37-304		685		356	219			6-74	(6)
90AY	AY-68-37-602		1100		1070	1770			1-73	(10),(3)
91AY	AY-68-37-603		797		697	570			1-70	(6),(17)
92AY	AY-68-37-604		1091		495	380			5-68	(6)
93AY	AY-68-37-507		1108		495	371			4-67	(6)
94AY	AY-68-37-508		1318		498	375			3-68	(6)
95AY	AY-68-37-520		1000		492	368			11-65	(6)
96AY	AY-68-37-710		1510		480	373			11-65	(6)
97AY	AY-68-38-107		773		496	288			3-71	(6)
98AY	AY-68-38-110		1042		727	590			8-73	(6),(17)
99AY	AY-68-38-101		900		1180	894			11-73	(10),(16)
Caldwell County										
1BU	Geochemical Surveys #1 Gwyn & Storey	1704	1952	34410			23158	1-78		
2BU	Wallace Company #1 Green Valley	1537	1896	23545			15878	9-78		
3BU	Steffenson #1 Adams	1240	1580	22027			14861	9-57		
4BU	Dow #1 White	1160	1488	24556			16556	8-78		
5BU	Dow #1 Ohlendorf	1014	1120	22912			15454	12-78		
6BU	Woodward #1 King	1930	2260	39674			26685	4-55		
7BU	M&G(Texas City Rfg.) #1 Dubose	1926	2350	16757			11330	9-80		

Table 2. Continued

Map I.D. Number	Other well identification	Depth interval from:	to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
8BU	Dietz #2 Blanks	1332	1534	18997			12831	12-56		
9BU	Conoco #1 Efird	2762	2785	84158			56489	12-62		
10BU	Mobil #5&#6 Byrd,& Graybury									
	#8-9 Hardeman				20266		13681		circa 1958	Location represents area covered by identified wells
Comal County										
1DX	DX-68-22-501	280	356	467			416	9-73		
2DX	DX-68-23-202	300	400	564			481	2-72		
3DX	DX-68-23-616	488	500	2868	2460	1460	2025	11-89	9-89	(12)
		554	625	3776	3170	1970	2633	11-89	9-89	(12)
		848	901	5385	5540	3640	3711	11-89	9-89	(12)
4DX	DX-68-23-617	515	528	514	595	338	447	11-89	10-89	(12)
		515	554	540	557	325	465	11-89	10-89	(12)
5DX	DX-68-23-304	700	746	265			281	?		Also logged by EUWD
6DX	DX-68-16-602		500		11700	8510		11-72	11-72	(3)poor log quality
7DX	DX-68-23-316	222	292	600	545	311	505	4-78	5-89	(1)
8DX	DX-68-23-6..	580	810	568			484	1-56		Comal Plant #2
9DX	DX-68-23-6..	514	570	749			605	1-56		Comal Plant #1
10DX	DX-68-16-701	214	396	640	578	327	532	9-73	4-76	(3)
11DX	DX-68-23-619	560	599	410	498	290	378	2-90	1-90	(12)
		618	688	522	578	319	453	2-90	1-90	(12)
		750	826	477	565	380	423	2-90	1-90	(12)
		906	938	3988	4190	2750	2775	2-90	2-90	(12)
12DX	Katy Drlg.Co. City of Marion #3	700	750	1096			837	8-68		Approximate location
13DX	DX-68-22-301		375		532	317			7-74	(3)
14DX	DX-68-22-902		240		514	283			7-89	(1)
15DX	DX-68-23-301				534	297			4-89	(1)
16DX	DX-68-23-318		620		3630	2300			3-85	(2)
17DX	DX-68-23-501		210		545	297			7-89	(1)

Table 2. Continued

Map I.D. Number	Other well identification	Depth interval from:	to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
18DX	DX-68-23-602		790		526	289			5-89	(1)
19DX	DX-68-23-701		300		556	320			3-85	(2)
20DX	DX-68-23-703		380		556	300			3-85	(2)
21DX	DX-68-23-708		380		2330	1500			7-85	(2)
22DX	DX-68-23-809		720		661	370			7-85	(2)
23DX	DX-68-23-807		515		3560	2250			10-72	(3)
24DX	DX-68-15-901				570	310			3-85	(2)
25DX	DX-69-16-502		230		562	320			3-85	(2)
26DX	DX-68-16-805				563	310			3-85	(2)
27DX	DX-68-23-706		450		1660	957			5-75	(3)
28DX	DX-68-23-707		450		1560	1148			7-77	(3),(16)
29DX	DX-68-30-312		645?		688	398			12-76	(3)
Guadalupe County										
1KX	Sutton #1 Kunde	1857	2244	8150			5564			
2KX	Sutton #1 Weinaug	2536	2968	22181			14964	3-63		
3KX	Standard #1 Schmidt	460	630	1733			1264	9-64		
4KX	Blumberg #1 Sanders	372	762	8510			5805	5-61		
5KX	Parsons & Norman #1 Timmerman	756	992	10263			6979	7-57		
6KX	Weinert #1 Lehman	1310	1720	13311			9021	9-51		
7KX	Calvert #1 Hagen	1870	2240	14640			9912	7-47		
8KX	Hueners #1 Boecker							7-54		N/A-GRN
9KX	Hughes #1 Zipp	1110	1467	7811			5336			
10KX	Meridian #1 Willman	1550	2020	13970			9463	1-69		
11KX	Dow #1 Munk/Cruz	1770	2168	17694			11958	3-79		
12KX	Parsons & Norman Voss #1	884	1118	14624			9901	4-57		
13KX	Wehmeyer #1 Kraft	668	1020	9111			6207	1-79		
14KX	Coates #1 Henk	822	1031	12492			8473			
15KX	Coates #1 Horne	1110	1492	14240			9644	11-60		

Table 2. Continued

Map I.D. Number	Other well identification	Depth from:	interval to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
16KX	Dillard #1 Hoehbary	1020	1296	14460			9791			
17KX	Dane, Bond, & Jones #1 Koepp	1144	1528	8155			5567			
18KX	Gurley #1 Petty	964	1195	14380			9738	6-51		
19KX	Sumik Drilling Inc. #1 Kraak	702	1090	14672			9933	2-81		
20KX	Seidman #1 Seidman									N/A-Edwards Formation not logged
21KX	Burke & Noel #1 Koehler	1016	1024	8513			5807	10-62		
22KX	Kraak #4 Kraak	962	1238	13978			9468	7-82		
23KX	Kraak #3 Kraak	701	1092	13438			9106	7-82		
24KX	Camp #1 Schubert									N/A-Edwards Formation not logged
25KX	Butler #1 Borman	1142	1162	11434			7764	3-48		
26KX	Abernathy #1 Borman							11-48		N/A-GRN
27KX	Gulf #1 Wells	4100	4425	77840			52256	3-61		
28KX	KX-68-30-601		565		3060	1980			7-77	(3)
29KX	Wise #1 Weinert	4382	4410	82216			55188	6-54		

Hays County

Map I.D. Number	Other well identification	Depth from:	interval to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
1LR	Gilliam									
1LR	#1 Alexander	1165	1485	14374			9734	12-48		
2LR	Woodward #1Graff	1107	1130	25270			17034	6-25		
3LR	Woodward #1 Schubert	1030	1362	31161			20981	2-55		
4LR	Mc Alpin #1 Lane									N/A-GRN
5LR	LR-58-57-902	334	357	366			348	3-74		
6LR	LR-67-01-812	478	490	14300	13000	8800	9684	7-90	6-90	(12)
		528	770	13669	14400	10300	9281	7-90	6-90	(12)

Table 2. Continued

Map I.D. Number	Other well identification	Depth interval from:	to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
7LR	LR-67-01-813	490	497	16365	14000	8900	11068	7-90	7-90	(12)
		544	550	14321	14300	10200	9698	7-90	7-90	(12)
		762	770	13335	14500	9900	9037	7-90	7-90	(12)
8LR	LR-67-01-814	516	566	12242	13800		8305	3-92		(10)
		610	749	12326	14050		8361	3-92		(10)
9LR	LR-67-09-110	166	286	619			518	3-73		
		310	374	4650			3219	3-73		
		394	518	10258			6976	3-73		
10LR	LR-67-09-105	180	305	655	672	417	542	3-71	?-71	(14)
		300	305	695	715	450	569	3-71	?-71	(14)
11LR	LR-67-09-106	264	294	563	622		480	3-71	3-71	(13)
12LR	LR-67-01-7..	276	329	541			465	3-76		
13LR	LR-67-09-4..							12-72		N/A-Poor log quality
14LR	LR-67-01-805	194	287	630			525	1-70		
15LR	LR-67-01-801		Spring		582	340			3-85	(2)
16LR	LR-67-16-603		200		1085	550			7-74	(3)
17LR	LR-58-57-303		315		604	340			8-85	(2)
18LR	LR-58-57-402		380		1480	970			8-85	(2)
19LR	LR-58-58-403		243		586	320			2-85	(2)
20LR	LR-58-58-701		492		1620	1000			3-85	(2)
21LR	LR-58-58-707		450		1510	930			3-85	(2)
22LR	LR-67-01-302		360		708	420			7-85	(2)
23LR	LR-67-01-806		128		616	350			3-85	(2)
24LR	LR-67-09-111		264		582	330			3-85	(2)
25LR	LR-68-16-601		200		1720	1060			3-85	(10)
26LR	F-7		655		1610	999			3-52	(10)
27LR	E-79		490		3430	2320			8-61	(10)

Wilson County

Map I.D. Number	Other well identification	Depth interval from:	to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
1ZL	Hankamer #1 Longley	4420	4570	54865			36863	5-53		

Table 2. Continued

Map I.D. Number	Other well identification	Depth interval from:	to:	Ca	Ct	TDSm	TDSest	Mo/Yr log recorded	Mo/Yr measured	Remarks
2ZL	Gorman-Delange #1 McKenzie	5030	5170	107131			71881	7-52		
3ZL	Tenneco #1 Jasik	4430	4545	53182			35735	10-59		
4ZL	Republic Natl. Gas #1 Mueller	5150	5210	105734			70945	8-53		
5ZL	Tenneco #1 McKenzie	5040	5594	104382			70039	1-68		
6ZL	Turner #1 Nickle	2180	2300	11240			7634	8-70		
7ZL	Sun #1 Bain	4585	4592	100382			67359	10-54		
8ZL	Sohio-Glassell #1 Southern	4850	5415	139652			93670	1-71		

Ca = Calculated specific conductance in microsiemens per centimeter(uS/cm)
Ct = Measured specific conductance in microsiemens per centimeter(uS/cm)
TDSm = Measured total dissolved solids in mg/L
TDSest = Estimated total dissolved solids in mg/L

Remarks: (1) through (15) are sources for water quality as follows:
(1) EUWD, Bulletin #49, 1990
(2) EUWD, Bulletin #45, 1987
(3) TX Dept. Water Res., LP-131, 1980
(4) Measured data supplied by EUWD, 1991
(5) USGS, OF-87-389, 1987
(6) TX Dept. Water Res., Report 237, 1979
(7) TX Board of Water Engineers, Ground-Water Resources of Bexar County, 1947
(8) Tx Board of Water Engineers, Bulletin #5911, 1959
(9) EUWD, Bulletin #50, 1991
(10) Measured data supplied by EUWD, 1993
(11) TX Board of Water Engineers, Bulletin #5608, V.II, Part III
(12) EUWD Report 92-02, 1992

Table 3. Calculated and measured specific conductance and measured total dissolved solids from selected area wells (used for construction of figures 13, 14, 15, and 16).

Well Number	Other well identification	Zone from:	calculated to:	Test interval or well depth from:	to:	Ct	Ca	TDS	Remarks
35AY	AY-68-45-301	1770	2036		2172	5020	5123	4280	(3)
36AY	AY-68-45-910	2540	2758		2920	5190	5058	4150	(3)
59AY	AY-68-29-913	479	730		784	483	353	274	(3)
60AY	AY-68-30-616	620	917		1003		5908	5340	(7)
62AY	AY-68-30-807	788	1074		1132	6950	6200	4680	(3)
		654	665				1132		
63AY	AY-68-37-519	974	1304		1304	484	557	263	(9)
67AY	AY-68-37-104	618	880		994	457	306	275	(3)
69AY	AY-68-37-521	1014	1026	965	1019	3198	3213	2200	(5)
		1040	1064	965	1071	3324	3827	2200	(5)
				1276	1489	6650		4800	(5)
70AY	AY-68-37-524	1270	1311	1240	1396	5870	5829	4600	(5)
		1071	1236	1070	1236	5860	5614	4400	(5)
				832	859	772		470	(5)
71AY	AY-68-37-526	868	1010	854	1052	475	526	260	(5)
				1158	1384	6380		4800	(5)
3DX	DX-68-23-616	488	500	444	506	2460	2868	1460	(12)
		554	625	535	634	3170	3776	1970	(12)
		848	856	799	937	5540	5385	3640	(12)
4DX	DX-68-23-617	515	528	472	530	595	514	338	(12)
		515	554	472	564	557	540	325	(12)
7DX	DX-68-23-316	222	292		350	545	600	311	(1)
10DX	DX-68-16-701	214	396		432	578	640	327	(3)
11DX	DX-68-23-619	560	599	518	613	498	410	290	(12)
		618	688	618	706	578	522	319	(12)
		750	826	715	827	565	477	380	(12)
		906	938	822	959	4190	3988	2750	(5)

Table 3. Continued

Well Number	Other well identification	Zone from:	calculated to:	Test interval or well depth from:	to:	Ct	Ca	TDS	Remarks
6LR	LR-67-01-812	478	490	403	508	13000	14300	8800	(12)
		528	770	509	707	14400	13699	10300	(12)
7LR	LR-67-01-813	490	497	416	520	14000	16365	8900	(12)
		544	550	520	584	14300	14321	10200	(12)
		762	770	746	920	14500	13335	9900	(12)
8LR	LR-67-01-814	516	566	Above	RDB	13800	12242		(10)
		610	749	Below	RDB	14050	12326		(10)
10LR	LR-67-09-105	180	305	245	300	672	655	417	(14)
		300	305	295	300	715	695	450	(14)
11LR	LR-67-09-106	264	294	250	395	622	563		(13)

Ca = Calculated specific conductance in microsiemens per centimeter(uS/cm)
Ct = Measured specific conductance in microsiemens per centimeter(uS/cm)
TDS = Measured total dissolved solids in mg/L

Remarks: See Remarks in Table 1 - Designation of sources for measured data is the same for Tables #1 & 2 of this report and EUWD Report 92-03.

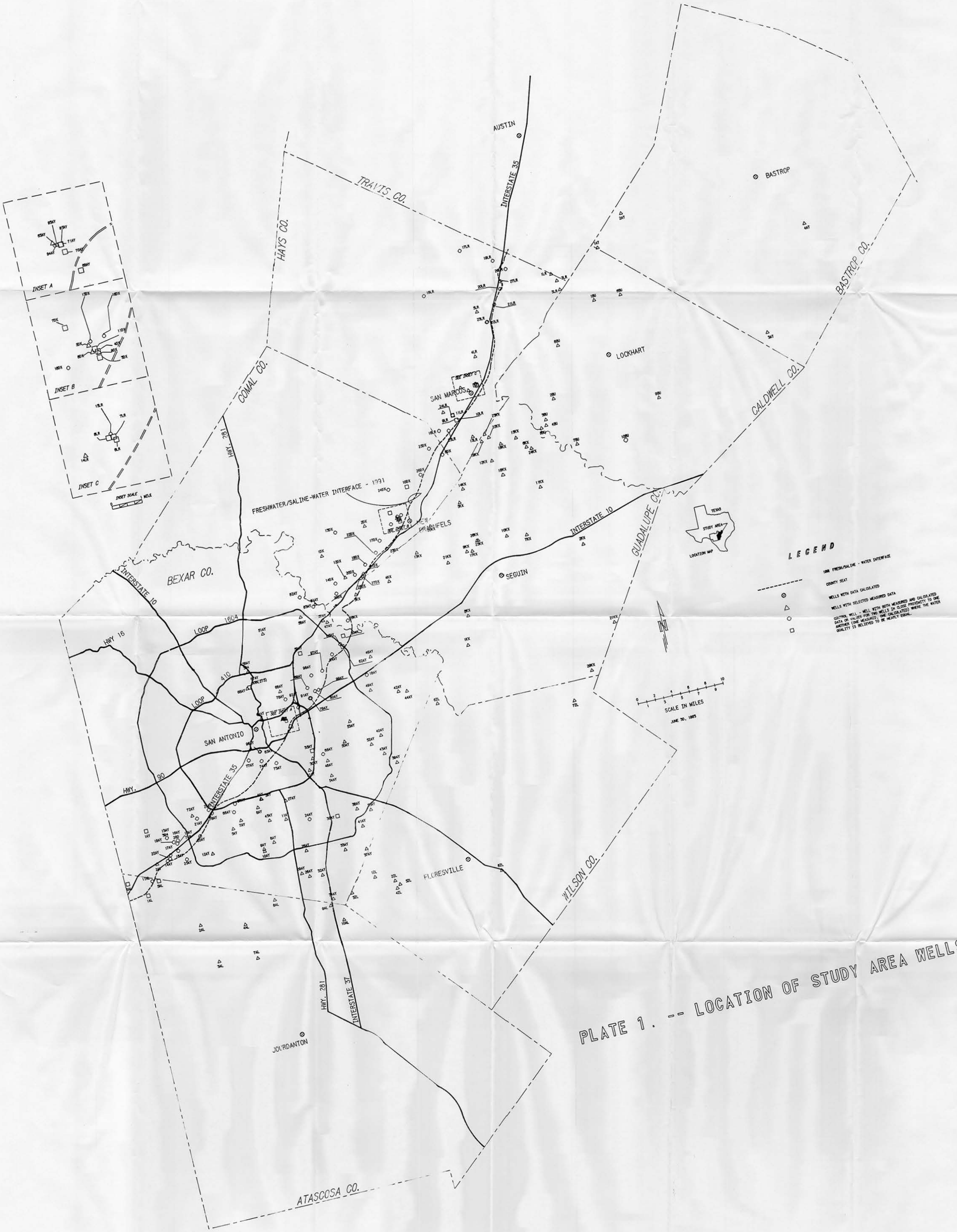

PLATE 1. -- LOCATION OF STUDY AREA WELLS

PLATE 2. -- SPECIFIC CONDUCTANCE FROM GEOPHYSICAL LOGS AND MEASURED WELL DATA.

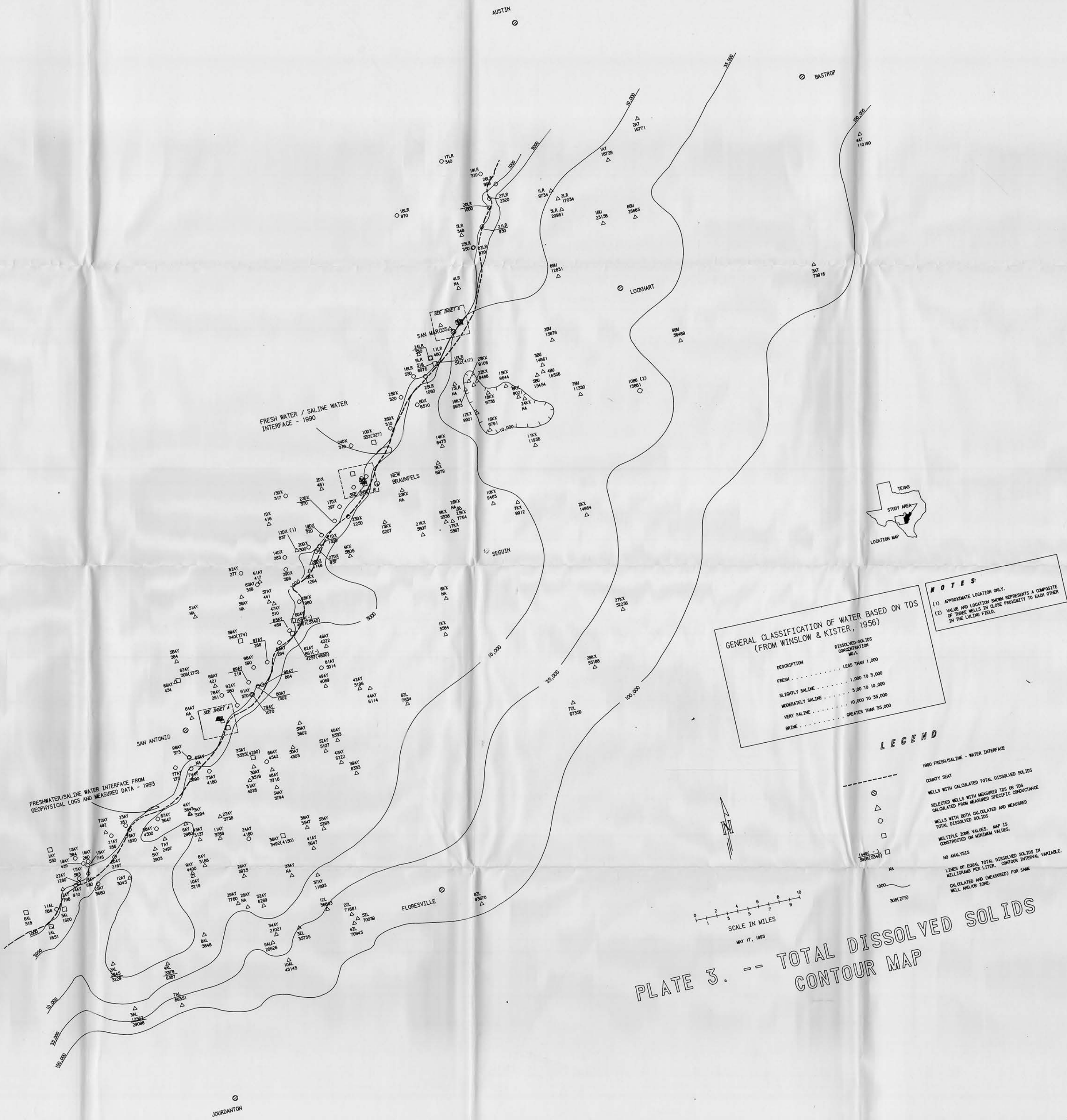

PLATE 3. -- TOTAL DISSOLVED SOLIDS CONTOUR MAP

PLATE 4. -- TOTAL DISSOLVED SOLIDS FROM UVALDE TO KYLE. 1992 AND 1993 STUDIES COMBINED. (TDS IN MG/L.)

Note: Large-format versions of the plates for this report are available at:

http://www.edwardsaquifer.org/documents/1993_Schultz_SalineInterfaceUvaldeKyle.pdf