AN ABSTRACT OF THE THESIS OF

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Title: An Assessment of Direct-push Electrical Conductivity for Identifying Chloride Migration Pathways in the Equus Beds Aquifer
Abstract approved: Marcia Schulmeister

The Equus Beds alluvial aquifer is the primary water source for Wichita, Kansas and surrounding communities. Hydrostratigraphic features may significantly influence the distribution and transport of a contaminant brine plume ($Cl^- > 2000$ mg/L) that threatens the aquifer. Conventional geophysical and drillers' logs have been used to characterize aquifer geology, but do not allow for detailed assessment of preferential lateral flow and irregular plume margins in heterogeneous sediments. Direct-push electrical conductivity (DP-EC) logging can detect thin, interbedded layers, and also identify the presence of conductive contaminants. This study evaluated the ability of DP-EC logging to refine existing models of contaminant distribution in the aquifer. Five DP-EC profiles were obtained along a transect across the plume margin and compared to adjacent conventional drillers' logs. A baseline EC log from an uncontaminated part of the aquifer corroborated the presence of three dominant sand layers and thin bounding clays identified in drillers' logs, and revealed new information about the layers. High EC values (>200 mS/m) associated with the clay layers in this profile were observed at similar depths in the other profiles, supporting previous assumptions of restricted vertical brine movement within the aquifer. In several cases, the EC logs identified additional clay layers or high permeability zones within clay layers, and clarified discrepancies between adjacent drillers' logs. Brine samples were collected at three depths near each EC log. The lateral specific conductance and Cl^- gradients observed across the site were coincident with increases in EC logs at depth. Associated EC values (<80 mS/m) in the most contaminated sand layers were below those for clay, identifying possible contaminant levels variations. The study demonstrates that EC logs may be used to better characterize and monitor brine migration in the aquifer.

AN ASSESSMENT OF DIRECT-PUSH ELECTRICAL CONDUCTIVITY FOR IDENTIFYING CHLORIDE MIGRATION PATHWAYS IN THE EQUUS BEDS AQUIFER

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by

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CHAPTER 1

INTRODUCTION

Chloride contamination of aquifers from natural and anthropogenic sources is a concern for many communities that rely on aquifers as their main source of freshwater. The detection and monitoring of chloride contamination to mitigate contaminant migration have become important aspects of maintaining and protecting aquifers. The Equus Beds Aquifer is the sole groundwater source for the Kansas communities of Wichita and Hutchinson, and is threatened by overuse and chloride contamination from existing oilfield brine pits and Permian salt deposits (Myers et al., 1996). Local wells have drawn down the aquifer to levels that may allow the migration of the chloride contamination into the freshwater areas of the aquifer. Remediation efforts in place to mitigate contamination include an artificial recharge system to replenish the aquifer and prevent the migration of the plumes. Monitoring wells have also been installed to evaluate the temporal changes in groundwater quality in the aquifer (Ross Schmidt et al., 2007) and the effectiveness of the remediation efforts. Fine-scale pathways of relatively high hydraulic conductivity may allow faster chloride ion migration. These pathways, which are not easily identifiable from existing data, complicate remediation efforts, and have been largely ignored. Identification of such migration paths is important, given the nature of the recharge project and the fully penetrating public water supply wells. This research examines direct-push electrical conductivity as a tool for identifying the presence and distribution of these preferential pathways, and illustrates their importance in chloride migration models of the Equus Beds Aquifer.

1.1 Need for Subsurface Characterization of Aquifers

Fine-scale hydrostratigraphic features have been shown to be an important factor in the prediction of contaminant transport in other studies (e.g. Schulmeister et al., 2003), however the characterization of these fine features is not routinely conducted due to high cost, limited technology and physical inaccessibility. Much of the current characterization is derived from drillers' observations of the material present in the auger cuttings as they are brought to the surface during the installation of individual wells in the area. The associated drillers' logs reflect the on-site geologist's experience and may vary in detail and interpretation. Auger cuttings provide general stratigraphic information, but often they cannot detect fine clay or sand lenses that could affect contaminant transport. Sediment cores may be obtained during drilling using a hollow auger with a sampler that is advanced through a removable plug. The sampler can then be retracted and opened, revealing the hydrostratigraphic features of the strata in a continuous sample. These continuous cores can be used to identify the presence of fine clay and sand lenses. Obtaining the complete, intact core in coarse unconsolidated sediment is problematic, however, as the loose materials commonly fall back into the borehole upon retrieval (Sara, 2003). As an alternative, arrays of monitoring wells can be used to obtain numerous soil and groundwater samples. These wells are expensive to install and are often too far apart to detect the migration paths of chloride contamination through the alluvium. A cost effective means of identifying these migration pathways is needed.

Direct-push (DP) technology has been demonstrated to effectively characterize fine-scale hydrostratigraphic details in unconsolidated low-salinity aquifers. When fluid salinity is high, variations in the fluid chemistry can also be detected using EC logs (Schulmeister et al., 2003). Saline fluids are electrically conductive, creating a positive response to the current imposed by DP-EC. In areas where the groundwater chemistry varies spatially, such as in the Equus Bed Aquifers, the distinction between clay and saline solutions, is harder to predict. In contaminated areas, the chemistry of the groundwater may become the predominant cause of the fluctuations in the EC logs and may mask the EC response associated with hydrostratigraphic features.

The goals of this study were to assess the effectiveness of DP-EC in identifying the presence of fine-scale hydrostratigraphic pathways in aquifers that possess both clay and high salinity fluids, and demonstrate how EC logs and groundwater samples can be used to create models of chloride migration and the aquifer's hydrostratigraphic features.

1.2 Direct-push Technology

Direct-push methods have been used for subsurface characterization for several decades (Sara, 2003) and have many advantages over conventional drilling approaches. DP methods do not require an existing well or borehole. The DP rig used in this study is a track-mounted, hydraulic slide and percussion hammer that is used to push a series of threaded rods into the subsurface. The footprint of the self-contained DP rig is less than 35 square meters (Geoprobe Systems, 2011), so the rig can be utilized in many locations without disturbing the locale. Since the rods are pushed into the ground, the method produces a minimal amount of waste since there are no auger cuttings to remove (Sara, 2003). The DP method also does not require drilling fluids be introduced into the holes as is common in some conventional drilling methods. The unit is self-contained and does not need support equipment or require a large crew, reducing the cost of obtaining the information needed to characterize a site. An EC probe can be fitted at the bottom of the rods and then driven into the ground to continuously record the electrical conductivity as the probe is advanced (Figure 1). Alternatively, a geochemical profiling screen with expendable solid tip can be used to extract fluid samples from a given depth (Geoprobe, 2001). The versatility and convenience of DP technology enhances the opportunities for site assessments.

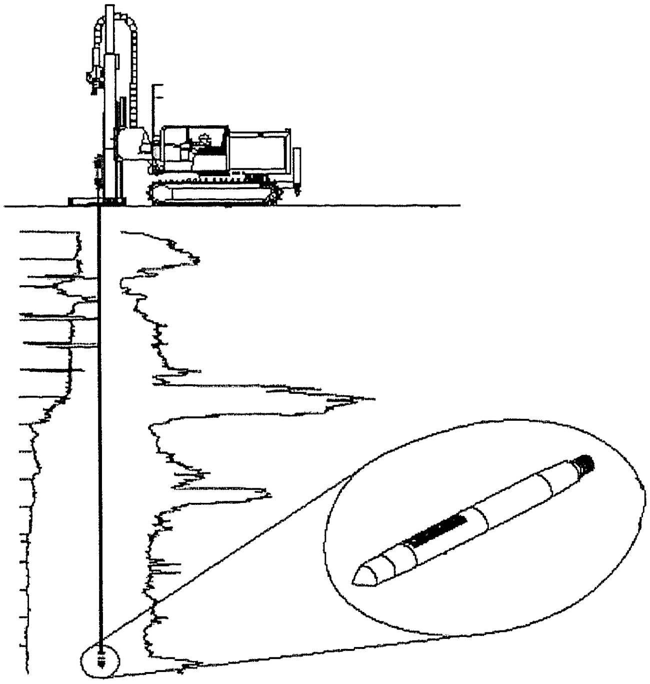


Figure 1. Direct-push unit and electrical conductivity probe (inset). The electrical conductivity of the strata (right) and probing speed (left) are logged continuously and reported at intervals of 0.5 feet (Schulmeister et al., 2003).

1.3 Direct-push Electrical Conductivity

Direct-push EC logging can be used for subsurface characterization (Karklins, 1996; McCall, 1996; Fetter, 2001; Schulmeister et al., 2003; Ohio EPA, 2005). DP-EC was developed in the mid-1990s (Christy et al., 1994). The EC probe is threaded on a series of hollow steel rods that are pushed into the ground to the prescribed depth. The

EC probe consists of a solid point probe with a dipole and Wenner array configuration to measure electrical conductivity (Figure 2). As the EC probe is advanced, a current is applied to the two outer electrodes and voltage is measured across the two inner electrodes. Given the applied current and the measured voltage, EC is calculated to produce a continuous log of the EC and depth (Geoprobe Systems, 2008). EC values are measured every 0.02 m and a potentiometer mounted on the mast of the DP unit tracks the depth and speed of advancement of the probe.

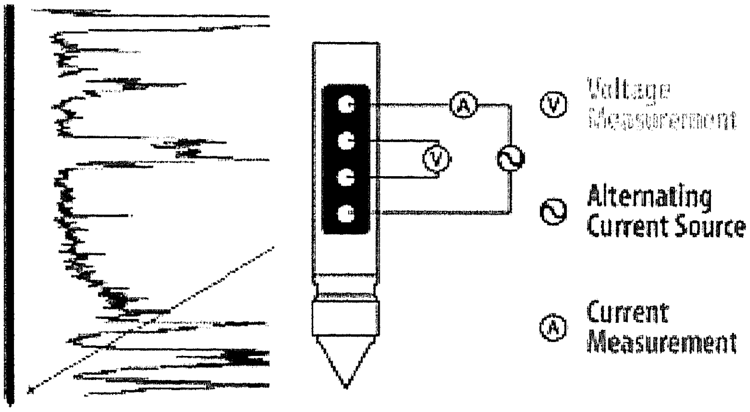


Figure 2. EC probe with Wenner array. An electric current is sent through the two electrodes and the voltage is measured across the other two. The ratio of current to voltage times a constant is the conductivity, measured in milli-Siemens per meter (mS/m) (Geoprobe Systems, 2008; modified by Neshyba-Bird, 2012).

There are several advantages to using DP technology for subsurface characterization over conventional borehole methods. The continuous log allows for the collection of detailed EC profiles, which provides insight concerning the lithologic structures in situ, as opposed to the conventional means of interpreting auger cuttings returned to the surface. The addition of an EC probe allows EC data to be captured as the probe is advanced into the subsurface. The time required for set up at a site is approximately one hour, and several logs can be obtained at a single site in one day. The

EC logs can then be used to characterize the fine-scale hydrostratigraphic features of the area. Also, pre-existing access wells required by other geophysical approaches are not necessary.

1.4 Using Electrical Conductivity to Detect Hydrostratigraphic Features

Electrical conductivity of aquifer materials is controlled by the salinity of the fluid residing in the pore spaces and the composition of the unconsolidated sediments. When the fluid chemistry is dilute, sediment composition is the main factor in determining the variations of the conductivity logs (Schulmeister et al., 2003). The collection of in situ EC logs is the key to identifying fine-scale hydrostratigraphic details such as clay lenses. The EC values can be used to identify the type of sediments based upon the conductivity of the materials. Clay particles conduct electricity because of their electrostatic charge, chemical composition and small particle size. Silt, sand, and similar covalently bonded geologic materials are not good conductors of electricity and produce a low conductivity signal. DP-EC technology uses this disparity to distinguish the fine-scale hydrostratigraphic features of sediments with a fairly dilute, homogenous fluid (Figure 3). DP electrical conductivity logs have been used to distinguish fine layers of clay and silt interspersed in sand/gravel alluvium (Schulmeister et al., 2003). Clay layers as thin as 0.025 m have been identified using DP-EC (Schulmeister et al., 2003).

Chloride (Cl^-) ions are electrically charged. Fluid containing high concentrations of chloride ions will conduct electricity. Since DP-EC signal is greater in clay deposits and is lower in sand and gravel deposits, areas of high chloride ion levels will present a clay-like profile (Schulmeister et al., 2003). A comparison between EC logs, established lithologic stratum, and Cl^- concentrations in the groundwater allow high chloride concentrations to be predicted using EC logs.

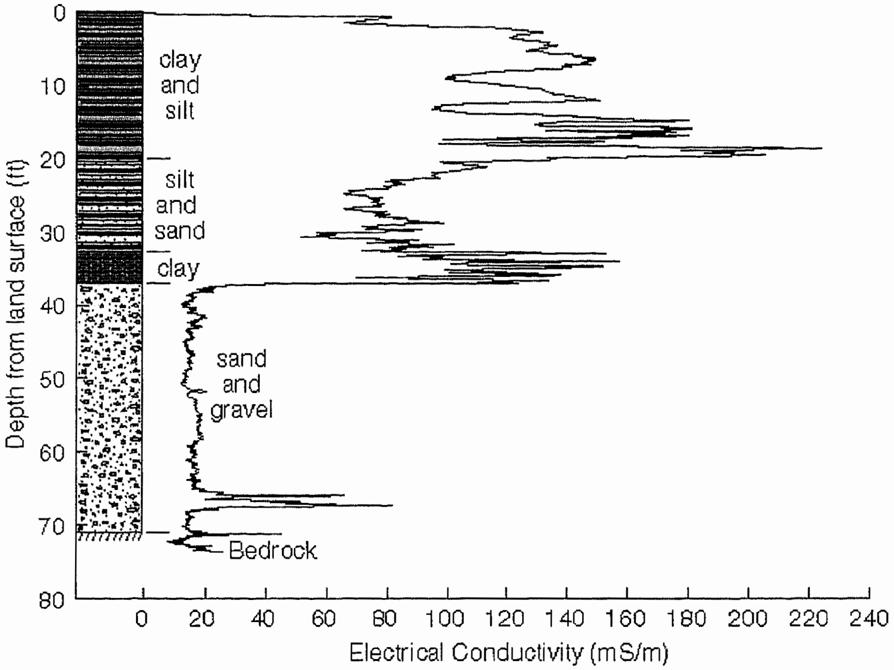


Figure 3. Example electrical conductivity log and its relationship to site stratigraphy (Schulmeister et al, 2003).

1.5 Direct-push Geochemical Profiling Technology

DP technology is also used to characterize the groundwater geochemistry (Hess, 2005). To obtain samples of groundwater for Cl^- or other solute analysis, Direct-push geochemical profiling may be used. A geochemical profiling screen with expendable solid tip can be fitted at the bottom of the hollow rods (Figure 4). The rods are then driven into the ground and when the prescribed depth is reached, the expendable plug is detached and the rod is retrieved to expose the desired screen length (Figure 4). Once the DP installation is purged, a fluid sample can be collected using a peristaltic or check-value pump.

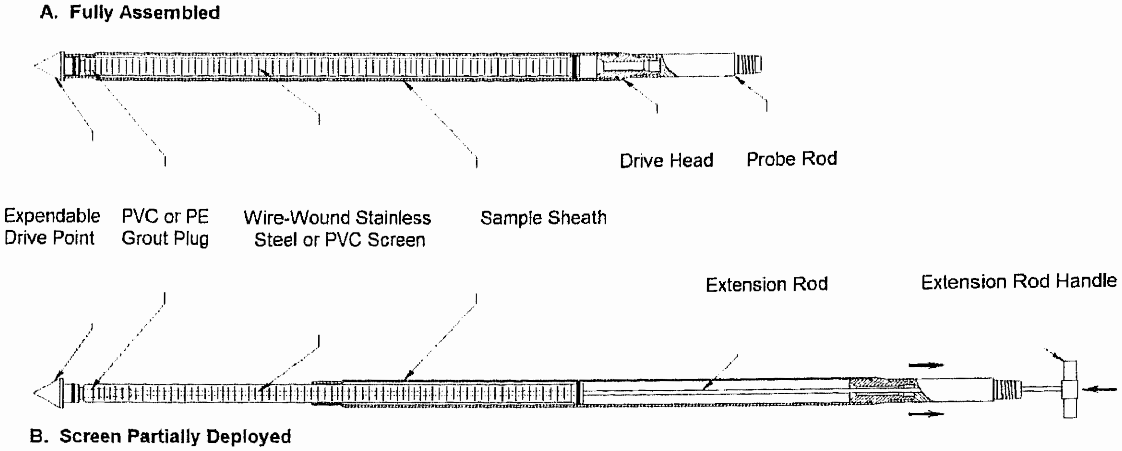


Figure 4. Geochemical profiling screen insert (modified), (Geoprobe, 2001).

DP geochemical profiling modifications allow reliable field samples to be obtained quickly from discrete zones (Hess et al., 2005) and, when coupled with EC logs, have been shown to be an effective means of characterizing inorganic constituents (Schulmeister et al., 2004). The EC logs can be compared to the chloride concentrations of samples obtained by geochemical profiling at specific depths. Coupling EC data with fluid samples obtained in the DP probe holes provide a means of distinguishing the fluid chemistry fluctuations from the hydrostratigraphic features. This distinction may enable the delineation of the chloride contaminant boundaries and determine the contaminant movement through the groundwater.

1.6 Equus Beds Aquifer

The Equus Beds Aquifer is a local aquifer located in South-Central Kansas (Figure 5). The aquifer is a major groundwater source for Wichita, Kansas. It is the only source of drinking water for many of its surrounding communities (Ross et al., 2007).

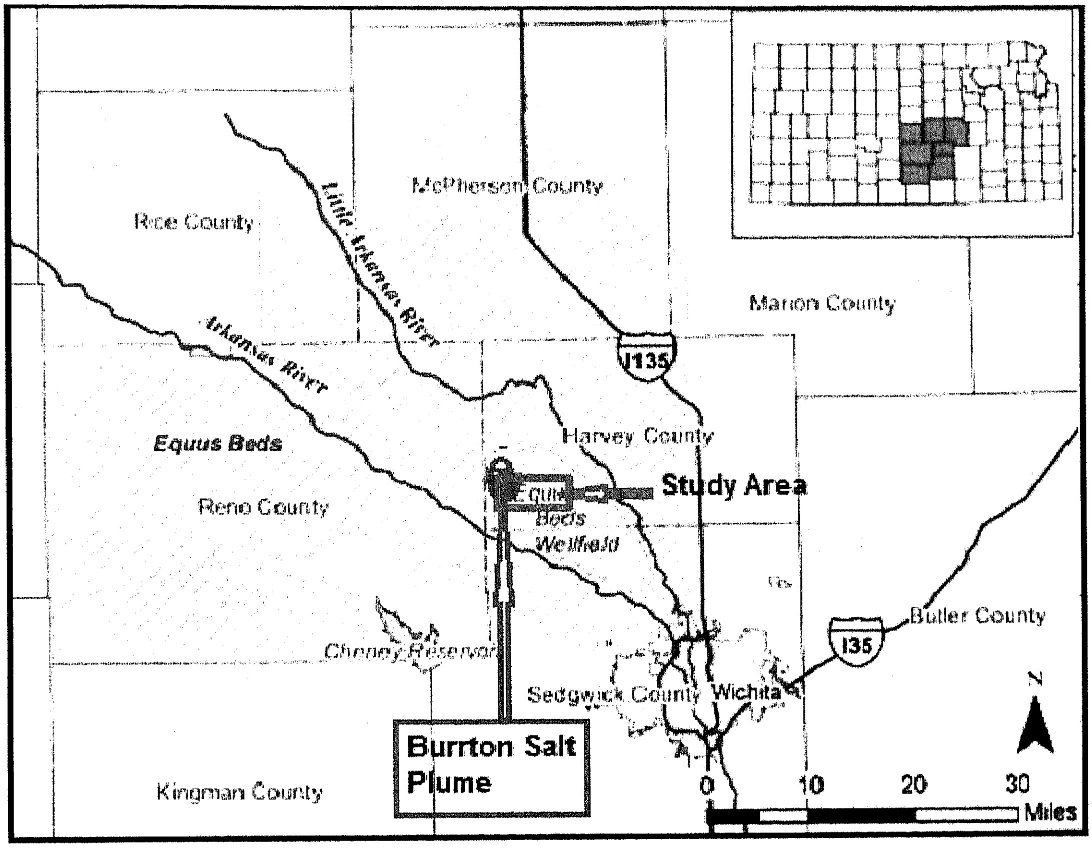


Figure 5. Map of South-Central Kansas shows the contamination study area (box) with reference to its location within the Equus Beds Aquifer and existing monitoring well field. The aquifer boundary has been truncated in Reno, Sedgwick, and Rice counties.

1.6.1 Hydrologic Setting of the Equus Beds Aquifer

The south-central area of Kansas has a temperate climate and averages 28-32 inches of precipitation per year (Hansen et al., 2003). Most of the precipitation occurs in the spring as rain or in the winter as snow, which recharges the aquifer via infiltration. Other sources of recharge are seepage through the beds of streams and rivers, downward percolation of irrigation water and groundwater inflow from underlying permeable rock. The average annual runoff for the area is 10 inches and includes surface and ground discharge into streams. Valley fill located along the Arkansas River is considered part of the aquifer when it is hydraulically connected to it. The valley fill allows water to flow directly between the stream and aquifer and back. Hot, dry summers cause water loss due to evapotranspiration. The specific yield of the Equus Beds Aquifer, which is the ratio of the volume of water that the saturated aquifer material would yield by gravity to the volume of the aquifer material (Fetter, 2001), is estimated as 20 percent (Hansen et al., 2006). In the Wichita well field, the aquifer consists of about 80 percent solid materials and about 20 percent open pore space where ground water is stored (Stramel, 1956).

The Little Arkansas, Arkansas and Ninnescah rivers, as well as several smaller creeks drain the area overlying Equus Beds. Cheney Reservoir is located on the southern edge of the aquifer. It was built on the north fork of the Ninnescah River by the Bureau of Reclamation, U.S. Department of the Interior between 1962 and 1965. The reservoir serves as an additional water source for Wichita, and recharges the aquifer by infiltration. The hydraulic gradient of the aquifer has increased from 12 feet/mile to 8 feet/mile since 1992, when the City of Wichita began to utilize Cheney as a major source of surface water (Ziegler, 2010) and limit its pumping from the aquifer.

The depth to water table has varied significant over the past 20 years. Record low water levels were recorded in 1992, but the water table is recovering significantly (Ziegler, 2010). The depth to water is shallowest near the Arkansas River (10 feet). The level is deeper towards the Little Arkansas River, depending upon the elevation and pumping activity. (Ross Schmidt, 2007). There is a diversion dam on the Little Arkansas River, which provides a source of recharge for the aquifer.

1.6.2 Geologic Setting of the Equus Beds Aquifer

The Equus Beds Aquifer consists mainly of unconsolidated Quaternary and Tertiary sand and gravel (Young et al., 2001) deposited as stream bed alluvium on

Cretaceous and Permian rocks consisting mostly of shale, sandstone, gypsum, anhydrite dolomite, limestone and halite (Williams et al., 1949). The Equus Beds Aquifer is considered part of the High Plains Aquifer, which is located throughout portions of Western Nebraska, Western Kansas, Eastern Colorado, Northwest Texas and the Oklahoma Panhandle (Hansen et al., 2003). In general, the aquifer consists of three layers of sand and gravel. The unconsolidated layers of sand and gravel are interspersed with thin layers of silt and clays (Hansen et al., 2003). The aquifer's saturated thickness generally exceeds 30 m (100 ft) and is as thick as 76 m (250 ft) in this area (Whittemore et al., 2007). These layers may act as a leaky confining layer at best, because of their limited thickness, discontinuity or complete absence (Young et al., 2001). The McPherson channel consists of unconsolidated sediments, which creates a trough that provides a pathway for groundwater movement through the aquifer (Ross Schmidt, 2007).

1.6.3 Chloride Contamination Threat

Two separate saltwater sources are threatening the Equus Beds Aquifer. The southern plume is caused by naturally high chloride levels derived from the dissolution of Permian salt deposits (Young et al., 2001). Groundwater percolates through the salt layers dissolving the salt and other minerals. The salinity increases when this groundwater is hydraulically connected to the aquifer (Rubin et al., 2001). Currently, the salinity of groundwater increases westward from the Arkansas River, where it reaches levels considerably above 500 mg/L. (Whittemore et al., 2007). The Kansas Department of Health and Environment (KDHE) maintains that levels above 500 mg/L are not suitable for irrigation and public consummation. The Arkansas River acts as a confining unit, keeping the higher salinity water from mixing with the freshwater east of the river. A recent study (Young et al., 2001) indicates that the Arkansas River confining unit may have been breached northwest of Hutchinson, allowing the higher levels of saltwater to be introduced into the Equus Beds freshwater aquifer to the east (Figure 5).

The northeastern contamination is derived from the residuals of oil field brine pits near Burrton, Kansas (Whittemore et al., 2007). Oil-field brine pits were commonly used in the 1930s to dispose of the saltwater brines accompanying oil production (Whittemore et al., 2007).

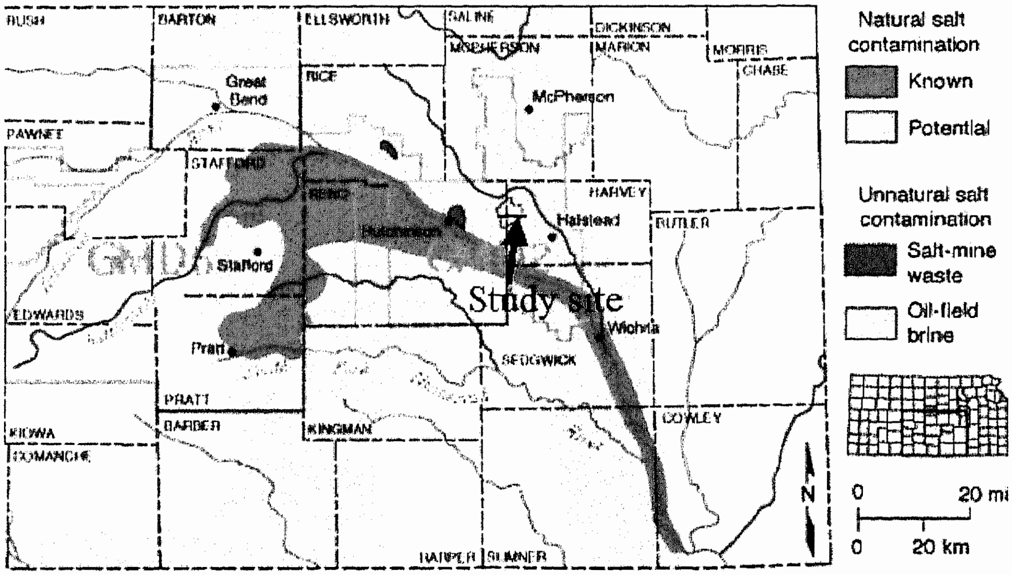


Figure 6. Saltwater contamination in south-central Kansas within study area indicated (Young, et al, 2001).

In the case of the Burrton oil pits, the rate of brine infiltration into the aquifer was relatively high because the silt and clay layers overlaying the aquifer are relatively thin. In some cases, the bottom of the pit may have actually breached the sand and gravel layers of the aquifer (Whittemore et al., 2007). Salt concentrations up to 2000 mg/L have been identified (Figure 7; Klock, 2007, Whittemore et al., 2007). The contamination in the shallow aquifer is being diluted by rainwater and recharge. At the lower depths, the contamination has migrated laterally (Whittemore et al., 2007), generally to the east. The lateral migration is dependant upon many factors including the aquifers hydraulic gradient, chloride concentration, and the presence of fine-scale pathways that would facilitate the lateral migrations, resulting in irregular encroachment boundaries. Chloride contamination in the groundwater has migrated down-gradient over three miles during the past 45 years (Ziegler et al., 2010). The declining water levels due to overuse and drought have allowed the contaminated water to approach the limits of the freshwater in the aquifer (Young et al., 2001, Hansen et al., 2006, Ross Schmidt et al., 2007, Ziegler et al., 2010). The chloride contamination had reached levels of 500 mg/L near the Reno/Harvey County boundary at the middle depths (between 15 m to 46 m).

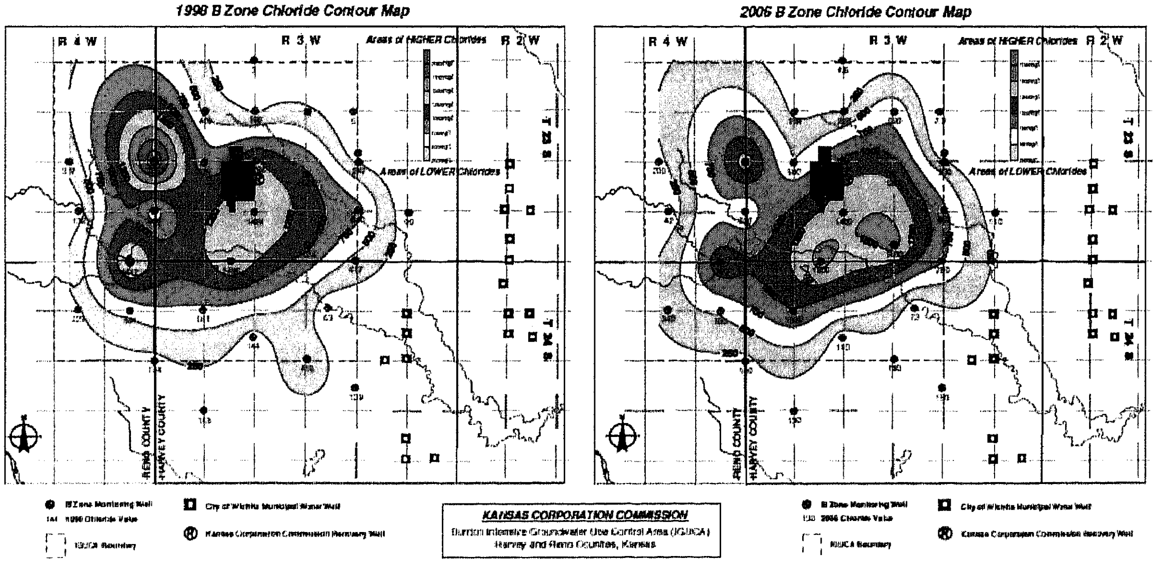


Figure 7. Burrton Oil Field map (Klock, 2007) depicting the mid-level migration of the chloride contamination between 1998-2006. The chloride has migrated southeast towards the City of Wichita municipal wells (blue squares). Groundwater chemistry is monitored in existing monitoring wells (blue dots).

The Kansas Corporation Commission maps modeling chloride contamination in the shallow and deeper areas of the aquifer are included in Appendix B.

1.6.4 The Equus Beds Groundwater Management District #2

The Groundwater Management District #2 (GMD#2) was authorized by the Kansas legislature in 1972 to manage the Equus Beds Aquifer. GMD#2 operates according to two principles. The first is the concept of safe-yield where withdrawals are limited to annual recharge. The second is to maintain the natural water quality by remediation and protection (GMD#2, 2011). The GMD#2 has installed multiple monitoring wells, which are sampled at least biannually to determine the water quality and quantity of the aquifer (Boese, 2009). GMD#2 is also responsible for setting pumping limits for local water wells.

1.6.5 City of Wichita and Surrounding Communities

The Equus Beds Aquifer is the primary water resource for Wichita and its surrounding communities. Over 17,000 acre-feet per year are pumped from the aquifer annually to supply municipal needs (Hansen, 2006). Additional amounts exceeding 20,000 acre-feet per year are also withdrawn by irrigation wells (Hansen, 2006). The storage volume of the aquifer declined over 250,000 acre-feet from between 1940 and 1992 (Hansen, 2006). Overuse has led to a decline in groundwater quality due to the migration of saltwater from nearby areas of contamination (Rubin et al., 2001; Ziegler et al., 2010). In 1993, the City of Wichita changed it water use policy and began to rely more on surface water and less on the aquifer (Ziegler et al., 2010). Large-scale recharge and recovery efforts by Wichita and the U. S. Geological Survey are underway to protect and sustain the aquifer (Ross Schmidt et al., 2007) and to accommodate projected population growth. Remediation includes an artificial recharge system (ASR), which is replenishing the water in the aquifer, and may prevent further encroachment from the contaminated water (Ziegler et al., 2010). These efforts to remediate the aquifer are confounded by the threat of chloride contamination from the multiple sources (Young et al., 2001) including the Burrton oilfield brine pit.

1.6.6 Artificial Recharge Storage and Recovery (ASR)

In 1997, Wichita started a study on the feasibility of artificially recharging the Equus Beds Aquifer. It created two recharge sites: one nearby the City of Halstead, the other in Sedgwick County. These sites divert excess water from the Little Arkansas River (Ross Schmidt et al., 2007). After the water is treated, it is inserted in the aquifer via basin, trench and injection wells. During its testing period (1997-2002), the artificial recharge contributed 3% of the municipal use by Wichita (Ross Schmidt et al., 2007). The feasibility study results, which showed localized water level increases near the Halstead and Sedgwick recharge sites, ended in 2002, but recharge continues when the stream flow of the Little Arkansas River permits. Starting in March 2007, Wichita began its large-scale artificial recharge program, adding 1,933 acre-ft of water into the aquifer from its various sites (Hansen, 2009). The plan for full production will add millions of gallons of water per day that would be available for city use during times of need.

1.7 Goal of the Study

This study examines the importance of sediment composition and fluid chemistry in influencing EC profiles by first correlating DP-EC logs obtained in low and high Cl^- regions of the aquifer against known lithologic logs obtained from existing GMD and City of Wichita monitoring wells. Analyzing the EC logs and fluid samples obtained in the DP probe holes provides a means of distinguishing the fluid chemistry fluctuations from the hydrostratigraphic features. This distinction enables the delineation of the chloride contaminant boundaries and the contaminant movement through the groundwater in the upper part of the aquifer.

CHAPTER 2

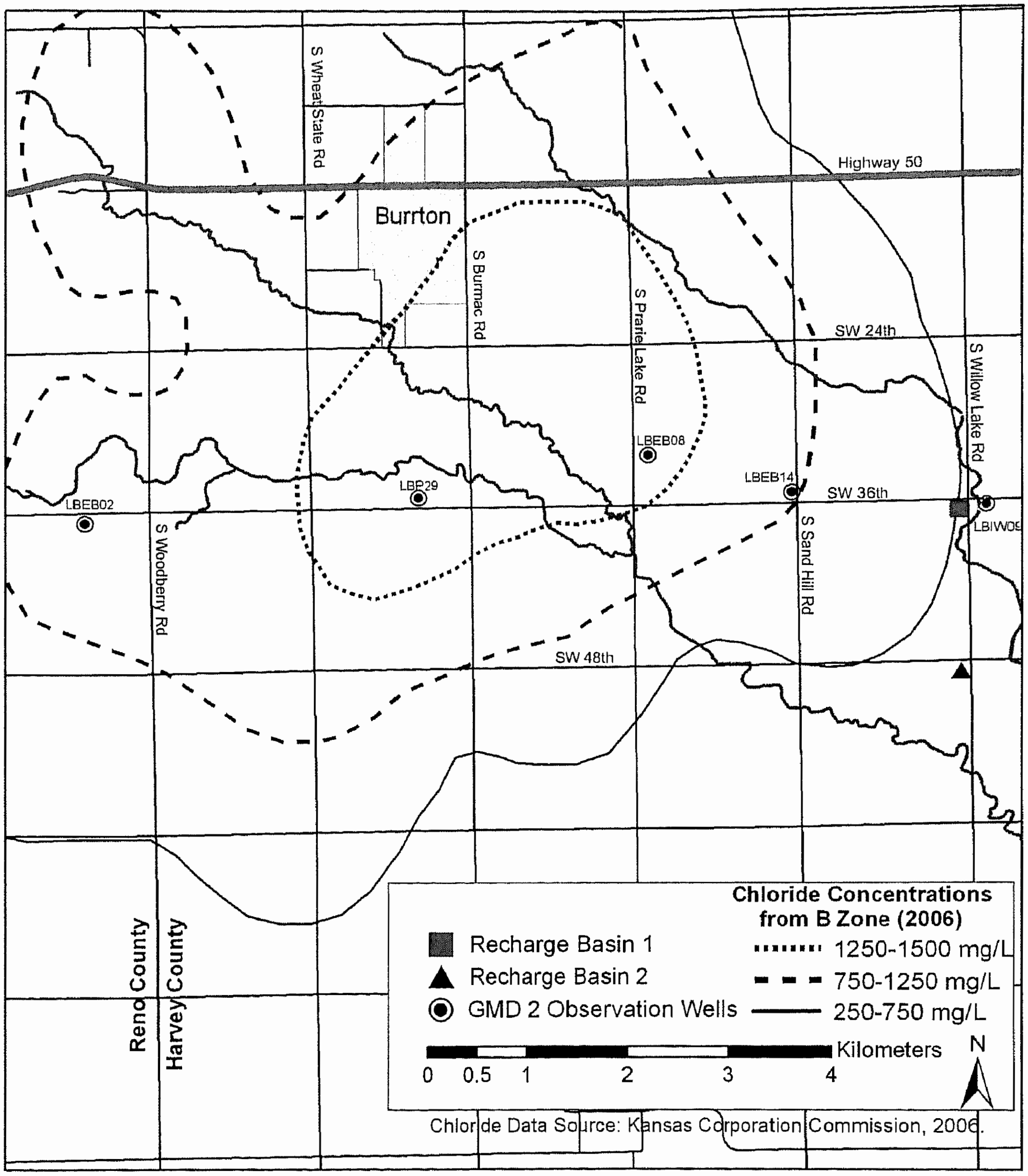
METHODS

This chapter outlines the design and methods (field, lab and analytical) used in this study. It describes the rationale for site selection, and the methods that were used to collect information to determine the effectiveness of DP-EC logs in evaluating chloride contamination and identifying fine-scale hydrostratigraphic pathways that would enable the contamination to migrate.

2.1 Experimental Design

A transect through the Burrton oil field brine plume was selected for the evaluation of DP-EC logging and geochemical sampling (Figure 8). EC logs were obtained within 15 meters of selected wells along an east-west transect that crosses the contaminant plume (Figure 8). The logs were obtained at a target depth of 34 m, which approach the limitations of DP unit. The EC logs were compared to driller's logs from nearby monitoring wells, to identify the relationship between sediment types and EC signals. To assess the influence of Cl^- contamination signals on the EC logs, side-by-side comparisons between EC and lithologic logs were created for each probe location.

Additionally, cross sections that span the entire transect were created using the all drillers' and EC logs data to aid in the chloride migration assessment. Groundwater samples at each of the five locations were collected from three sand layers using a DP geoprofiling tool. Specific conductance (SpC) and chloride concentrations were measured in these samples. Specific conductance measures the ability of the fluid to conduct electricity due to the dissolved ions present in the water and can be directly compared to electrical conductivity measurements obtained during electrical conductivity logging. Because chloride was expected to significantly influence SpC, chloride concentrations and SpC values were compared. Since the fluid SpC contributes to the electrical conductivity signal of the producing layers, the specific conductance of the fluid samples was compared to the EC at the sampled depth (averaged over the screen length) to establish their relationship. The EC probes measures the electrical conductivity of the substance it pass through in millisiemens per meter (mS/m). EC is affected not only the by sediment types, but also by the presence of fluid and dissolved mineral concentrations. Once the EC–SpC relationship was quantified, the chloride concentration could then be modeled. A geochemical cross section was constructed from these data.



Chloride Data Source: Kansas Corporation Commission, 2006.

Figure 8. The EC and geochemical sampling transect evaluated by the study. The wells lie along a 10.5 km transect across chloride plume boundaries, between the cities of Burrton and Halstead, Zone B between 15-46 m in depth. The prefix LB indicates EC boreholes at each well site. (Adapted from Kansas Corporation Commission data and Klock, 2007). Map created by John Barker, 2011.

2.2 Site Selection

Deep wells (deeper than 50 meters) with detailed drillers' logs (WWC5, 2009) located along an east-west transect that crosses a contaminant plume between Burrton and Halstead, Kansas (Figure 8) were chosen for this study. The selected well locations are close to Wichita municipal or GMD#2 monitoring wells, with multiple wells of varying depths located at each site (except P29 – which has only one well). Water well completion records and drillers' logs obtained from the Kansas Geological Survey Water Well Completion (WWC) database and GMD#2 (Boese, 2009) for this study are included in Appendix B. The drillers' logs have been used in previous studies to construct a model for the Equus Beds Aquifer in this area that indicated the aquifer consisted of three sand layers interspersed with clay lenses and separated by clay layers of varying thicknesses (Ziegler et. al., 1997). Multiple well logs, representing various depths, were available for four of the five locations. The deepest wells logs were used to create the lithologic profiles. The drillers' logs were detailed, although some co-located logs had different interpretations of the material found in the cuttings, illustrating the difficulty using drillers' logs for lithologic study at this site.

The five locations (IW09, EB14, EB08, P29, EB02) along an east-west transect were chosen to cross the contaminant plume from an area of low salinity towards higher salinity, as inferred from a model obtained from the Kansas Corporation Commission (Figure 7). DP-EC logs were obtained within 15 m of each well. The fieldwork was conducted in two sessions: June 23-26, 2009 and July 7-8, 2009, due to scheduling conflicts and equipment availability. The naming convention adopted for the EC and geochemical profile locations were the well identifiers preceded by the letters LB:

LBIW09, LBEB14, LBEB08, LBP29, LBEB02. The easternmost groundwater sample, LBIW09 (least contaminated) was used to establish a baseline for the geochemical profiling, as well as EC logs. The chloride concentrations in the samples collected at this location were compared to the concentrations from the other well locations in an attempt to characterize the presence and extent of the chloride contamination in the upper levels of the aquifer.

2.3 Field Methods

2.3.1 Direct-push Electrical Conductivity

A Geoprobe model 6610 DT Direct-push Unit was used to obtain the EC logs. A probing depth of 34 m was chosen, based upon the lithologic model derived from the drillers' log and the limitations of the DP equipment. At the site EB14, the desired depth was not obtained because the probe could not be advanced through a resistant stratum. A SC400 Wenner array EC probe was used to obtain the logs.

2.3.2 Direct-push Geochemical Profiling

Groundwater samples were collected at two or three depths within two meters of the EC probe locations at each DP geochemical profile location. The EC logs and cross sections were used to identify the depths to the sand layers, in order to obtain geochemical fluid samples. After evaluating the EC logs, samples were obtained at three depths at each location that represented the three sandy zones within the aquifer. Selected areas with low electrical conductivity (as indicated in the EC logs) were sampled using a DP rod with an expendable point, and a three-foot sampling rod (screen-point 30 DP) with 12 inches of vertically slotted screen exposed (Figure 3). The DP installations were purged of more than three-rod volumes, sampled using a mechanical actuator, and filtered in the field using a 0.45-micron filter. Samples were collected in labeled, polyethylene bottles according to standard field methods (Sanders, 1998) and placed in coolers on ice to maintain quality control. Samples were later stored in a sample refrigerator at the Emporia State University (ESU) Hydrogeology Laboratory. Chain of custody forms were completed in accordance with standard field methods (Sanders, 1998). As described above, the samples were evaluated for chloride (Cl^-) concentrations and specific conductance (SpC) in the field.

After the EC logs and geochemical profiling activities were completed, the DP and EC probe holes were grouted with an injection machine or bentonite chips. All holes were plugged according to standard field methods (Sanders, 1998).

2.3.3 Field Analytical Methods

Because fluid chemistry influences the EC signal, both the chloride ion concentration and specific conductance (SpC) were measured in all profiles. SpC was measured in the field using a calibrated EC/TDS/Temperature meter (Model HI98311; Hanna, 2009). All samples were analyzed for Cl^- concentrations using two analytical field methods to evaluate the accuracy of the field methods. Analysis conducted with the Hach Chloride QuanTab Test Strips (Hach, 2009) and Chemetrics Cl^- titret kits (Chemetrics, 2009) were compared. The QuanTab test strips measured Cl^- range between 30-600 mg/L, within 10-20 increments. The Cl^- titret kits used mercuric nitrate titrant in an acid solution with diphenylcarbazone as the end point indicator (Chemetrics, 2010). Three kits, with various titration ranges (2-20 mg/L, 20-200 mg/L and 50-500 mg/L), were used. The titret has a 10% error and the minimum detection level is equal to the smallest unit of the range. Initially, the range was determined with the QuanTab test strip, and then the appropriate titret kit was used to determine the chloride concentration in mg/L. Chloride values from each method ranged from 6 mg/L to 1130mg/L and were consistently within 10 mg/L of each other. The average of both chloride values at each depth was used in subsequent analyses. The average chloride concentrations and specific conductance of the samples are shown in Table 1.

Sample Name (bore–depth)	Average Chloride Concentration (mg/L)	SpC (μS/cm)	EC (mS/m)	Depth (Meter)
LBIW09-31	6	34.3	10.58	10
LBIW09-50	6.2	38.8	10.09	15.1
LBIW09-96	187.5	112.1	24.94	27.2
LBEB14-24	72.5	102.2	19.61	7.3
LBEB14-56	78.5	66.1	21.51	16.9
LBEB14-101	520	210.4	N/A	30.5
LBEB08-33	225	178.4	37.12	10
LBEB08-55*	11.7*	054.2*	36.81	16.6
LBEB08-93	500	189	48.32	28.1
LBP29-35	230	130.5	26.13	10.6
LBP29-60	205	118.6	23.08	18.1
LBP29-95	1130	392.9	53.28	28.7
LBEB02-40	700	235.5	39.65	12.1
LBEB02-54	1128	379.4	53.28	16.3
LBEB02-83	175	118.4	98.27	25.1

Table 1. These chloride concentrations, EC and Specific conductance results were used in analysis. DP-EC was not available for LBEB14-101 due to EC probe malfunction. (* Indicates deonized H_2O added while obtaining this sample and may have altered the chloride and SpC values; no other fluid could be obtained).

In samples where the chloride concentrations exceed the limits of the field methods (over 500 mg/L), the samples were diluted with distilled water to achieve appropriate concentration that could then be quantified. The concentrations of both the dilute and the original samples are recorded in the data tables located in Appendix D.

2.4 ESU Hydrogeology Laboratory Methods

At the ESU Hydrogeology laboratory, the field EC/TDS/Temperature meter was calibrated using fresh calibration solution. All samples were retested for specific conductance. The samples were also retested for chloride content using the Hach Chloride QuantTab Test Strips (Hach, 2009) and the Chemetrics Cl^- Titret kits (Chemetrics, 2009). SpC in field and ESU laboratory tests are well correlated (coefficient of determination, $R^2 = 0.99$) (Appendix G). The results from the external lab can be found in Appendix H. In general, the external lab results were well correlated with the field results ($R^2 = 1.0$). The field measurements for chloride concentrations less than 20 mg/L tended to be significantly lower (< 4 mg/L) than the external lab results but were within the intrinsic error for the field method. The field results for higher concentrations were higher than the lab. Additionally, Cl^- in samples from LBIW09 and LBP29 were measured using the Hach Spectrometer. These samples contained the least and greatest chloride concentrations (respectively) at the site. The chloride values from both methods (spectrophotometer and field) for LBP29 equaled 1130 mg/L. The concentrations obtained using the field methods for the lower contamination differed significantly (6.2 mg/L and 14.9 mg/L).

2.5 Cross section Modeling Methods

Cross sections displaying hydrostratigraphic features, EC, Cl^- distributions and modeled predictions were contoured with SURFER spatial modeling software (Bresnahan, 2008). SURFER can produce a contour model of a cross section based on an input data file. In this study, there was greater resolution on the vertical axis provided by the EC logs (data reported every 0.15 m to a depth of 34 m). On the horizontal axis, the five locations where data was obtained spanned 10.2 kilometers. The contouring software allows for the interpolation between the locations. These interpolations are an approximations of the stratigraphy based on the input files. The SURFER interpolates irregularly spaced XYZ data files into a regularly spaced grid (Bresnahan, 2008). Other parameters used to create the grid file included the depth in m ASL (Y coordinate) and the distance along the transect in kilometers (X coordinate). Given the disparity in the amount of data available in the Y and X axis, an anisotropy of 0.1 (lowest possible) was selected. The number of lines parameter included x-10, y = 1000 and a linear expression was chosen. This grid file was then contoured with the SURFER.

A drillers' log model was first generated. The different strata in the drillers' logs were assigned numerical values based on their expected conductivity. Sand was assigned a value of zero. Sandy with some clay was given a value of 30. Silty clay was given a numerical value of 60. Clay was assigned a value of 90. Numerical values were assigned to strata depths and combined with location coordinates to create a model lithology XYZ grid file. This numerical grid was then used as an input file to the SURFER software, along with elevation above sea level (ASL) and distance along the transect. The grid node values were approximated using the SURFER kriging option, with an anisotropy ratio of one tenth. The low anisotropy value was chosen because the amount of data representing the vertical (depth) was much greater proportionally than the data obtained horizontally (five sites). The horizontal line parameter was set at 10, and at 50 for the vertical to accommodate the greater amount of vertical data. EC and Cl^-

distributions were also compiled as cross sections using the same set of SURFER parameters as used for the drillers' log model. Electrical conductivity models were first used to predict textural variations. Chloride models based on the relationship between EC and SpC were then generated, and used to discern between fluid and clay contributions to the DP-EC values. Sediment and chloride cross sections that assumed typical aquifer porosities were created.

CHAPTER 3

RESULTS

In this chapter, a comparison of the information collected by the EC study with existing information about the site obtained from the monitoring well drillers' logs are presented. The different strata in the drillers' logs were assigned numerical values based on their expected conductivity. This information was then modeled. The EC logs are presented in similar formats, so side-by-side comparisons can be made between the drillers' logs and the electrical conductivity logs. The geochemical profiles obtained at each location are also presented in a line graph format.

3.1 Comparison of EC logs with Drillers' logs

Profiles were created from the EC and driller's log (Figure 9) for LBIW09 to assess how useful EC logs can be in indicating hydrostratigraphic details. This location is the most eastern well in the study, located adjacent to the Equus Beds Aquifer Storage and Recovery Basin (ASR) and represents the location with the least contamination according to the GMD#2 water quality report (Boese, 2009). The drillers' log indicated three sand layers separated by a thin clay lens at 426 m above sea level (ASL), and a thicker clay layer between 414 m and 420 m ASL. The corresponding EC log profile contains low conductivity zones that correlate with the sand layers. The thick clay layers indicated in the driller's log correlate with alternating high and low conductivity in the EC logs. The EC log suggest that alternating sandy and clay-rich layers make up the layer at 414 m, which was interpreted as a homogeneous clay by the driller. The EC log indicated an area of clay at 427 m that correlates with a clay layer on the driller's log at this depth. The driller's log also indicated a sand layer from 408 m to 412 m that correlates with an area of low conductivity on the EC log. Both logs indicate a clay-like area below 408 m.

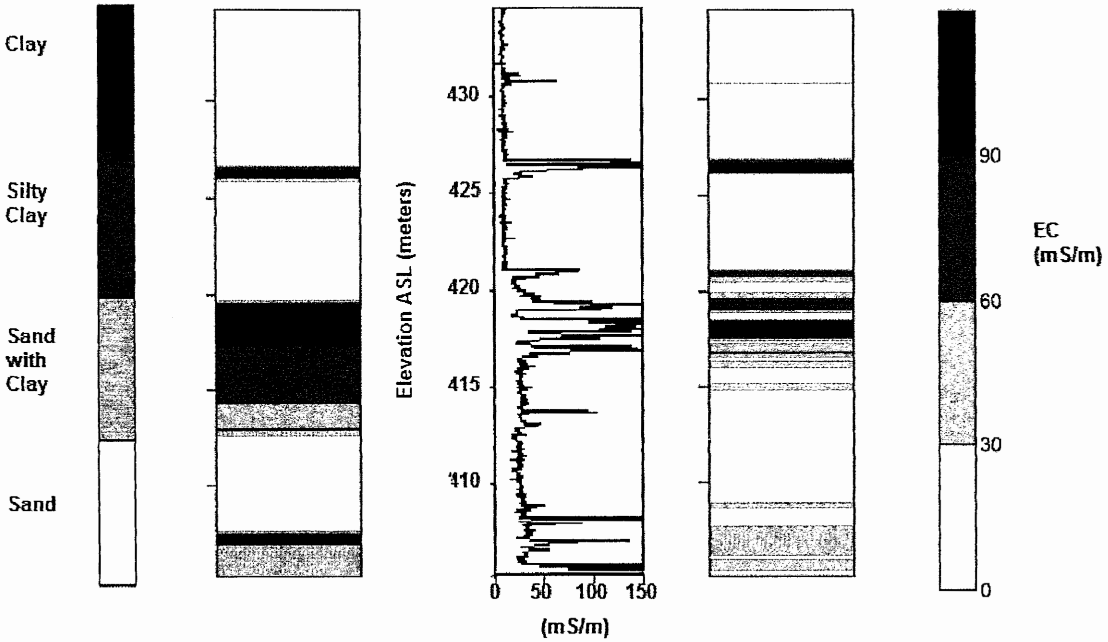


Figure 9. Comparison of driller's log (left), EC log (center) and lithology based on EC- Clay relationship at LBIW09, located on eastern edge (least contaminated) of the study transect. EC logs are truncated above 150 mS/m to reveal details of the sand/clay interface.

Progressing westward (Figure 8), the EB14 lithologic profile indicates three coarse sand layers (Figure 10). Three drillers' logs from adjacent wells (separated by < 2 m) at this location are different from each other. The deepest log interpretation was used to create the lithologic log. The log for EB14B indicates the upper sand layer (above 432 m ASL) is separated from the second layer (below 431 m ASL) by a clay/sand mixture less than 1 m thick. In the driller's log for EB14C, this clay/sand mixture at 431 m ASL is absent. The second sand layer is confined on the bottom by a thick clay layer (between 424-426 m ASL) with a thin, inter-bedded silty-clay layer at 427 m ASL. Below this clay, another sand layer, 5 m thick, extends to 419 m ASL. The EC log obtained at LBEB14 indicates a thin (< 1 m) area of higher electrical conductivity at 430 m ASL, but the conductivity is not thought to be high enough to represent a clay lens. More likely, this area of higher conductivity could be a sand /clay mixture. Since this layer is quite thin (< 1 m), drillers' logs from both EB14B and EB14C could be accurate, indicating the upper layer located at 431 m ASL is a thin, discontinuous clay lens. An area of high conductivity is located between 426 m ASL and 424 m ASL. The bottom area of the low conductivity zone at 417m – 421 m ASL contains two area of higher conductivity (421m ASL and 418 m ASL) suggesting that the clay layer depicted in the lithologic logs is in fact composed of thin, discontinuous layers.

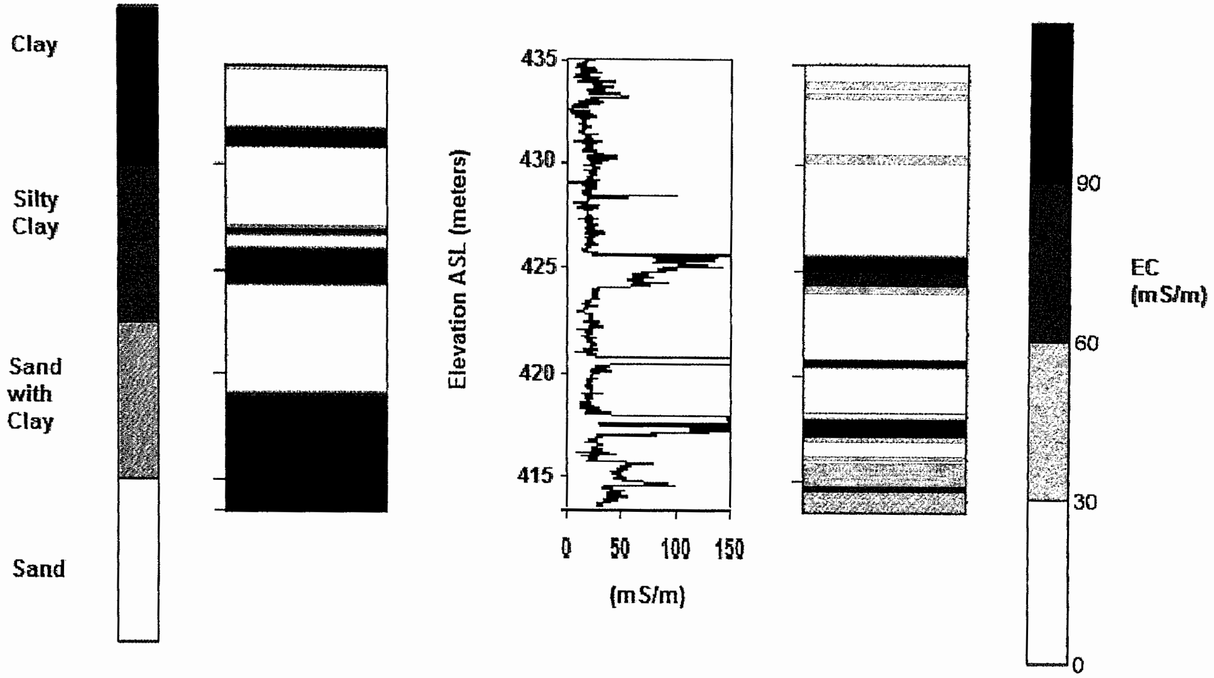


Figure 10. Comparison of driller's log (left), EC log (center) and lithology based on EC- Clay relationship (right) at LBEB14. The vertical boundary is based upon the water table. EC logs are truncated above 150 mS/m to reveal details of the sand/clay interface.

The third location where EC logs were obtained is located 1 mile east and 1 mile south of Burrton. Higher levels of Cl^- contamination (500 mg/L) were observed at this location (Figure 8). The driller's log for EB08 indicated mostly sand with a small amount of clay above 423 m ASL (Figure 11). A considerable clay layer consisting of two clay partitions borders the sand strata. The first one occurred at 420 m ASL and is approximately 1 m thick. There was a thin (< 1 m) band of sand below 420 m ASL. The clay layer continued at 419 m ASL to 417 m. The bottom sand layer extended at least 7 m down and was separated from another sand strata at 409 m ASL by a thin (< 1 m) layer of clay. The EC log for LBEB08 values associated with the sand layer above 423 m ASL were much higher than that typically associated with sand (<50 mS/m). The EC log indicated that this sand layer must have some clay or other highly conductive material and consists of several bands of higher conductivity clay/silt lenses not more that 2 m thick with interbedded layers of lower conductivity (sand). Some of these areas of moderate conductivity may indicate chloride contamination, as the drillers' logs indicate a sand-producing layer. At 421 m ASL, two moderate EC layers (>90 mS/m) are separated by a thin (< 1m) zone of low conductivity. The high conductivity zone probably acts as a confining layer for the sand strata located below 418 m that extends to 411 m ASL (Figure 11). This alternating sequence of high and low conductivity bands that gradually thin may indicate a fining-upward sequence created as the alluvium was deposited. Another interpretation may be each layer was deposited independently.

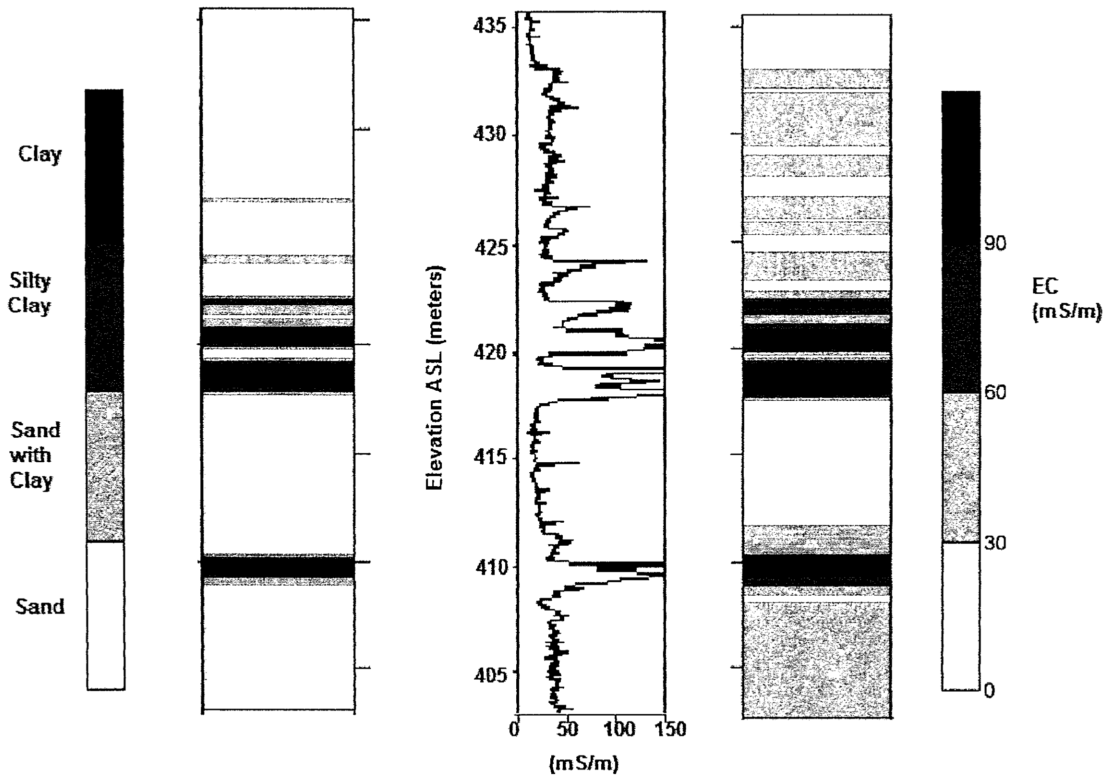


Figure 11. Comparison of driller's log (left), EC log (center) and lithology based on EC- Clay relationship (right) at LBEB08. EC logs are truncated above 150 mS/m to reveal details of the sand/clay interface.

The fourth EC location was located 1 mile directly south of Burrton (Figure 8). The lithologic profile based on the driller's log of P29 indicated three sand and clay layers (Figure 12). The upper clay layer at 432 m ASL consisted of a thin (< 2m) layer with sand-clay margins, totaling two meters inclusive. The clay layer located at 428 m ASL was thicker (>2 meters) than at 432 m ASL, with a mixture of sand and clay above and below it. The bottom clay layer, at 410 m ASL, is represented more as a clay layer that does not extend laterally towards the east based on comparison with the other logs (Figures 10 and 11). Comparing the driller's log to the EC log reveals that the middle clay layer above 426 m through 428 m was thicker than expected. However, the bottom clay layers (located between 405 and 410 m ASL) are really two separate lenses. The EC logs indicate the presence of higher conductivity material in the middle sand layer. The higher EC values (>50 mS/m) of the middle sand layer may indicate either the presence of clay or saline groundwater. It may also indicate the presence of other conductive minerals including gypsum. Another interpretation is that the alternating bands of low and high conductivity that trend higher as the depth increases (415-402 m ASL) may indicate a sequence of fining upward deposition.

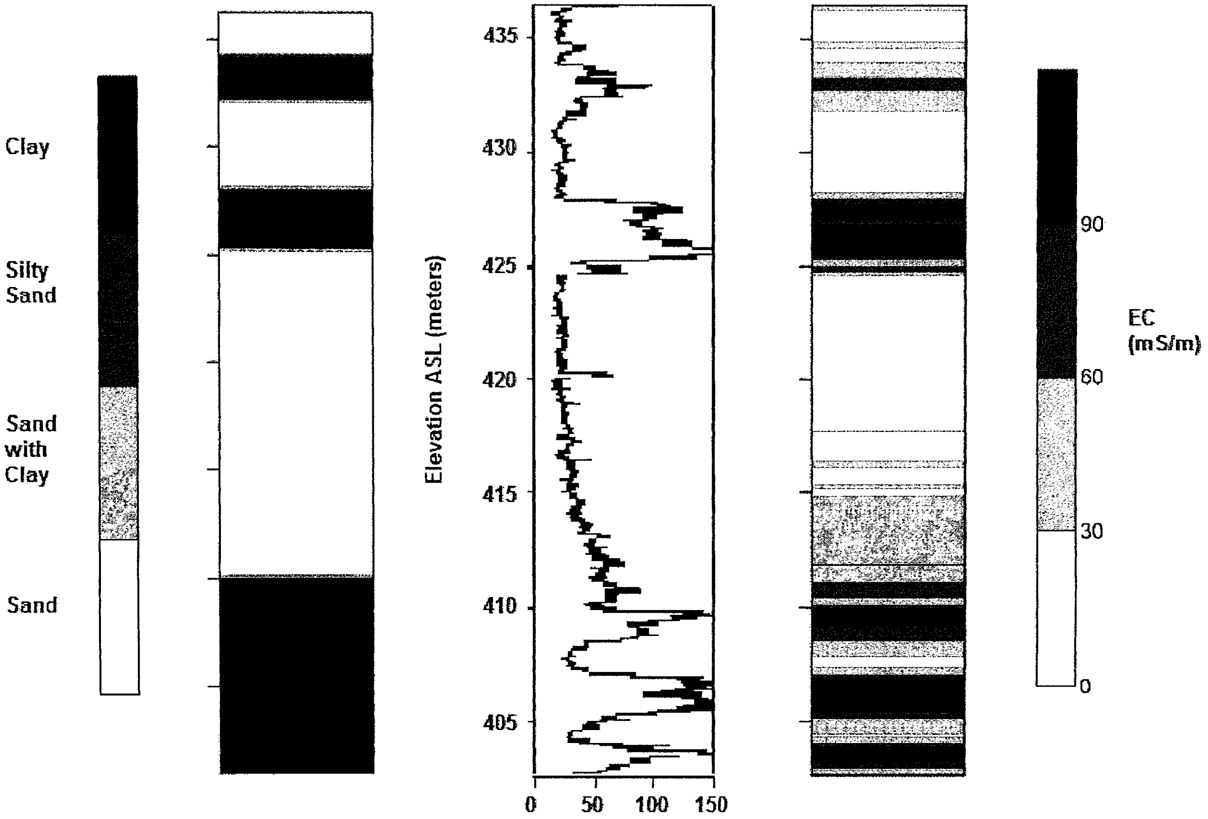


Figure 12. Comparison of driller's log (left), EC log (center) and lithology based on EC- Clay relationship (right) at LBP29. EC logs are truncated above 150 mS/m to reveal details of the sand/clay interface.

The final location where EC logs were obtained is located in the high Cl^- contamination west of Burrton (Figure 8). The Equus Beds monitoring well EB02 is located one and one-half miles south and west of the oil brine pit. The lithologic cross section derived from the drillers' log at this contaminated location indicated two sand layers separated by clay layers (Figure 13). The clay layer between 406 - 418 m ASL is depicted as a thick (12 m) clay layer with silty clay interspersed in the bottom 4 m. A clay lens less than 1 m thick at 427 m ASL separates the upper and lower sand layers. The EC log obtained at this site is likely to reflect higher salinity conditions. On the EC log, the upper section of the sand layers between 433 - 427 m ASL contains EC values less than 30mS/m, indicating sand. The lower sand layer appears to be saline as EC values are 20 higher times at this depth. At 418 - 423 m ASL, the EC values are over 90 times higher than observed at similar depths. This may indicate a saltwater lens above the clay layer at 416 - 417 m ASL. The driller's log indicated thick clay and sand layers corresponding to the layers present in LBEB08, however, the EC log profile appears to indicate the presence of finer grained material with many dark lines representing areas of high conductivity (over 90 mS/m). These dark lines may indicate clay layers, while the grey color (the mid-range EC values) could be indicating increased chloride content.

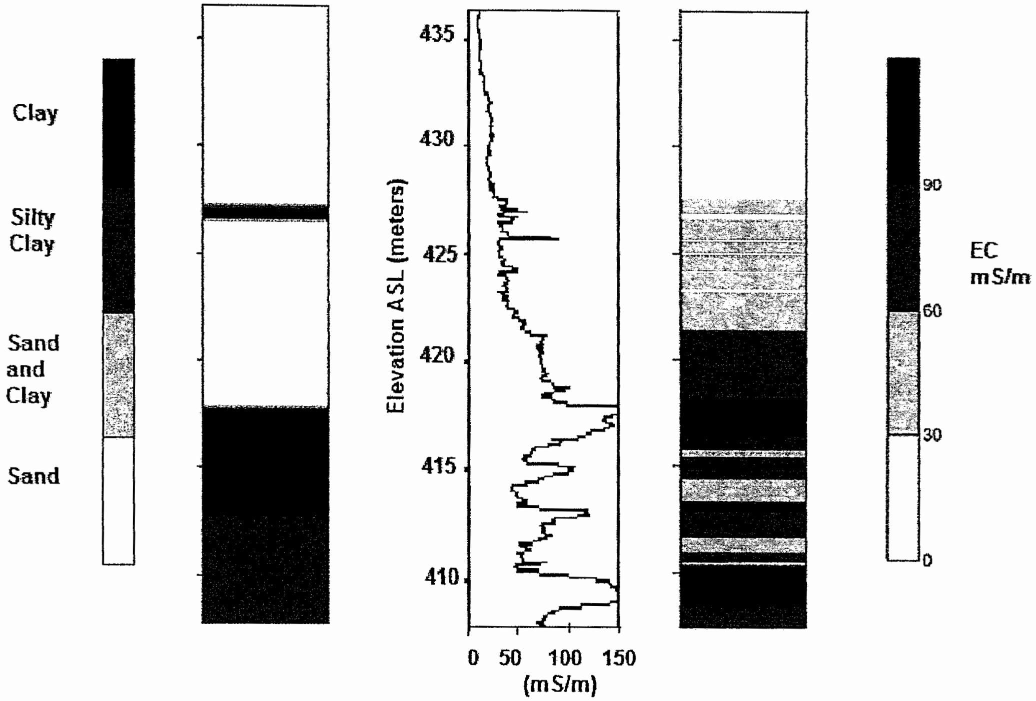


Figure 13. Comparison of driller's log (left), EC log (center) and lithology based on EC- Clay relationship (right) at LBEB02. These logs were obtained from the western-most, contaminated part of the study transect. EC logs are truncated above 150 mS/m to reveal details of the sand/clay interface.

3.2 Electrical Conductivity Logs

Side-by-side comparisons of the EC logs from each location (Figure 14) indicate that the middle clay layer is the most continuous clay layer in the study area. This layer may restrict vertical groundwater movement in the aquifer. This clay layer is quite evident in the EC logs for LBIW09, LBEB14 and LBEB08. In the log for LP29, however, the clay layer shows up at a higher elevation (above 425 m ASL) as opposed to below 425 m ASL at the first three locations. The western most location LBEB02 indicates a very small area of higher conductivity in the middle strata (426 m ASL) less than 1 m thick. The western EC locations (LBP29 and LBEB02) have higher levels of conductivity in the depths described as sand layers on the drillers' logs. These areas of higher conductivities (approaching 100 mS/m) may indicate higher levels of chloride contamination migrating between clay lenses.

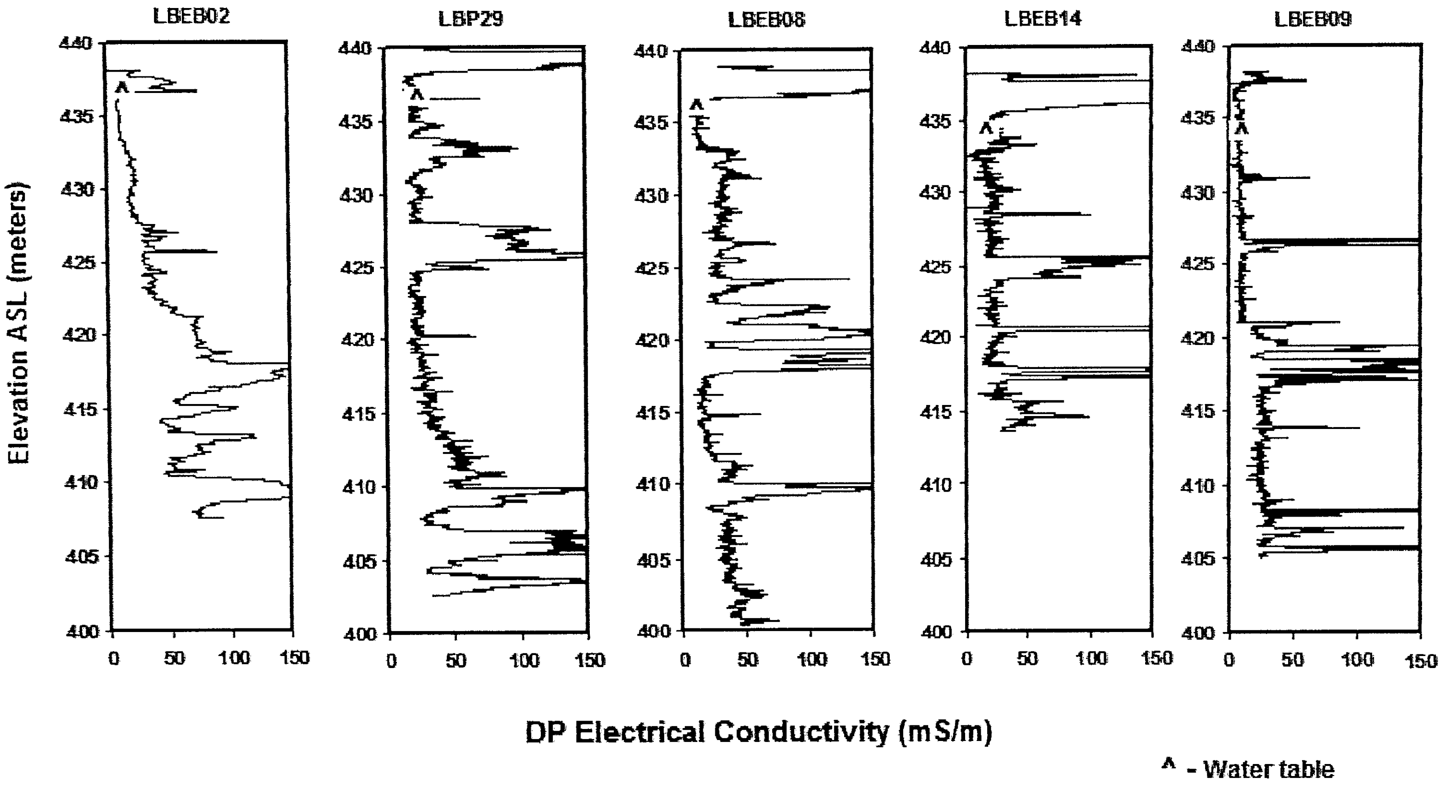


Figure 14. EC logs obtained at indicated well locations. These log include both saturated and unsaturated sediments. The water table in each log is indicated by ^. EC logs are truncated above 150 mS/m to reveal details of the sand/clay interface.

3.3 Specific conductance and Chloride Concentration

As discussed previously, Specific conductance (SpC) and chloride (Cl^-) concentrations were obtained at three depths at each well location. SpC ranged from 34.3 mS/m to 392.9 mS/m and Cl^- concentrations ranged from 6 mg/L to 1130 mg/L (Table 1). A strong correlation (coefficient of determination, $R^2 = 0.96$) between chloride concentration and SpC was observed when values obtained for each in all samples were compared (Figure 15). This result demonstrates the SpC values are primarily a reflection of the Cl^- concentrations. The influence of Cl^- contamination on the DP-EC values was further examined by comparing SpC to EC values measured within the sampling interval (Figure 16). SpC was compared to the average EC values for a 1-foot sampling interval at each sample depth. Fluid SpC and DP-EC appear highly correlated. The high degree of correlation between these variables indicates that Cl^- significantly affects the DP-EC electrical conductivity and that high EC values may indicate Cl^- contamination. This relationship may allow Cl^- migration models to be constructed from EC logs.

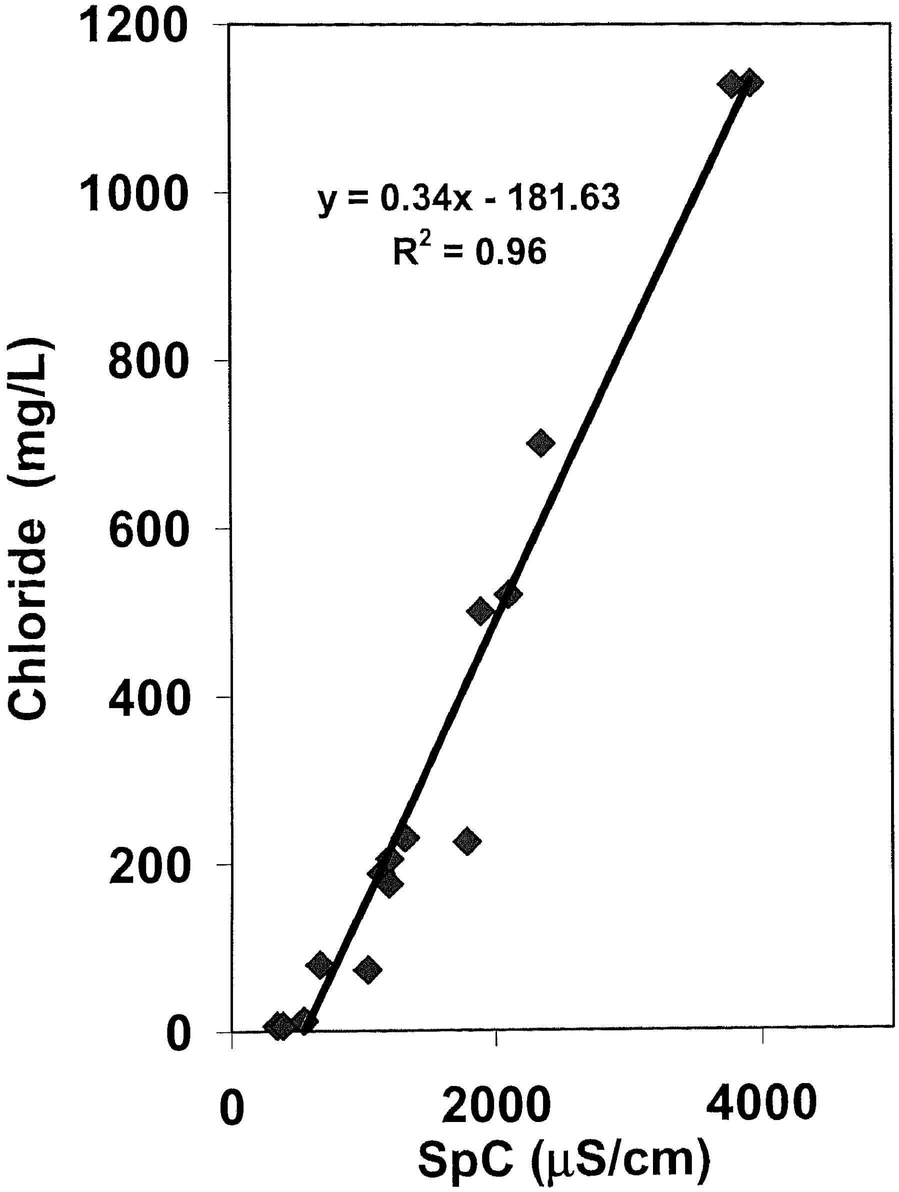


Figure 15. Chloride concentration and the specific conductance of the fluid samples fitted with a linear trend line with good correlation. Intrinsic uncertainty is within the symbol size (2% for SpC and 10 mg/L for chloride).

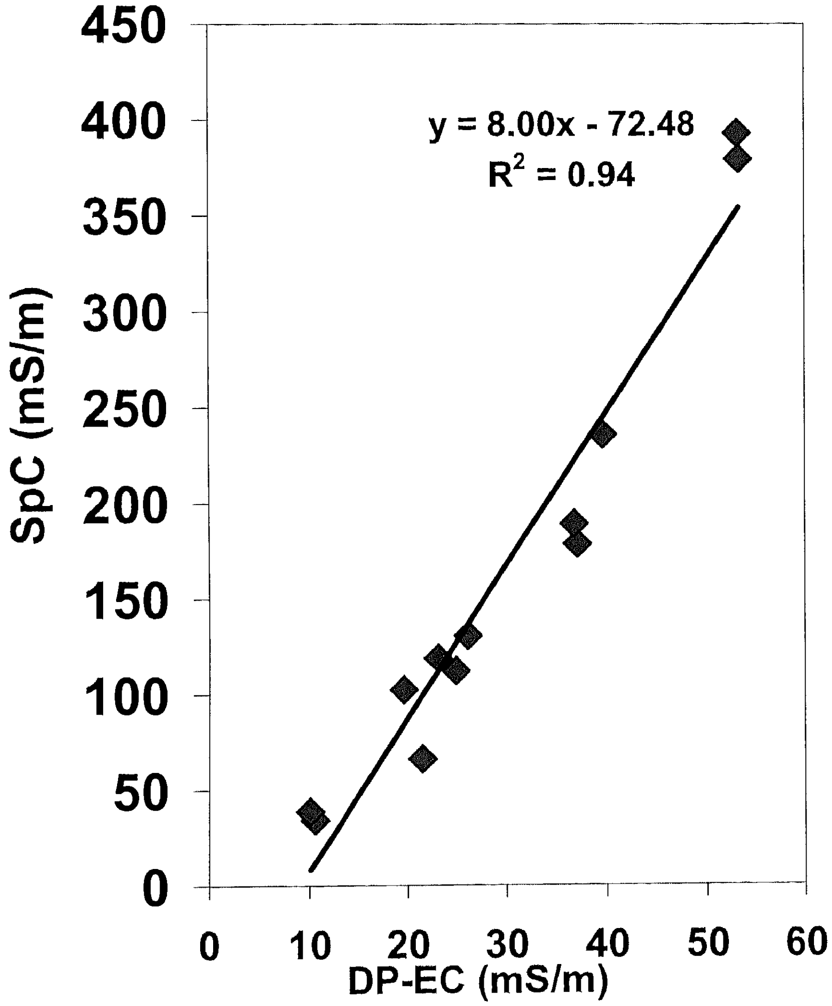


Figure 16. The relationship between the sample specific conductance (SpC) and sediment electrical conductivity recorded by the EC probe at each location indicated a linear relation with good correlation. Intrinsic uncertainty is within the symbol size (2% for SpC).

CHAPTER 4

DISCUSSION

In this chapter, a cross section created from the EC logs is compared to a cross section created from the drillers' logs. Models of the clay layers and chloride contamination are also presented.

4.1 Modeling EC Values Based Upon the SpC Values of the Samples.

EC values were obtained from the EC logs at 15 water sampling depths to establish statistical relationships between sediment characteristics, water conductivity and EC values. Regression model equations were derived from the relationships obtained from the graphs of the SpC versus EC (Figure 16). Model values were then used as input into the equation obtained from the SpC versus Cl^- graph to calculate the predicted chloride concentrations for given EC values. The resultant model estimated chloride concentration values were then adjusted for aquifer porosity. Estimated porosity values of 25% and 15%, were chosen to represent the porosity range of the aquifer (Ziegler et al., 2010), and the predicted values were multiplied by 0.25 and 0.15. Markers (white and blue squares, respectively) on the EC logs indicate the derived SpC values corresponding to 15% and 25% porosities. Green triangles represent the derived data values obtained for Cl^- concentrations (Figure 17).

The model SpC and Cl^- values show good correlation at all depths with the EC data at the three locations where the low chloride concentrations were observed in monitoring well data (LBIW09, LBEB14 and LBEB08). At two sampling depths, LBP29 (lowest) and LBEB02 (middle), the modeled SpC value for 15% porosity (Ziegler et al., 2010) was a good fit, which may indicate a clay-rich layer. At these locations and depths, the modeled Cl^- was higher, perhaps due to the combined effects of ion content and clay rich matrix on the EC value. This EC value was then used to calculate the model Cl^- value indicated. The overall results suggest that aquifer porosity is within the 15% - 25% zone used in the model.

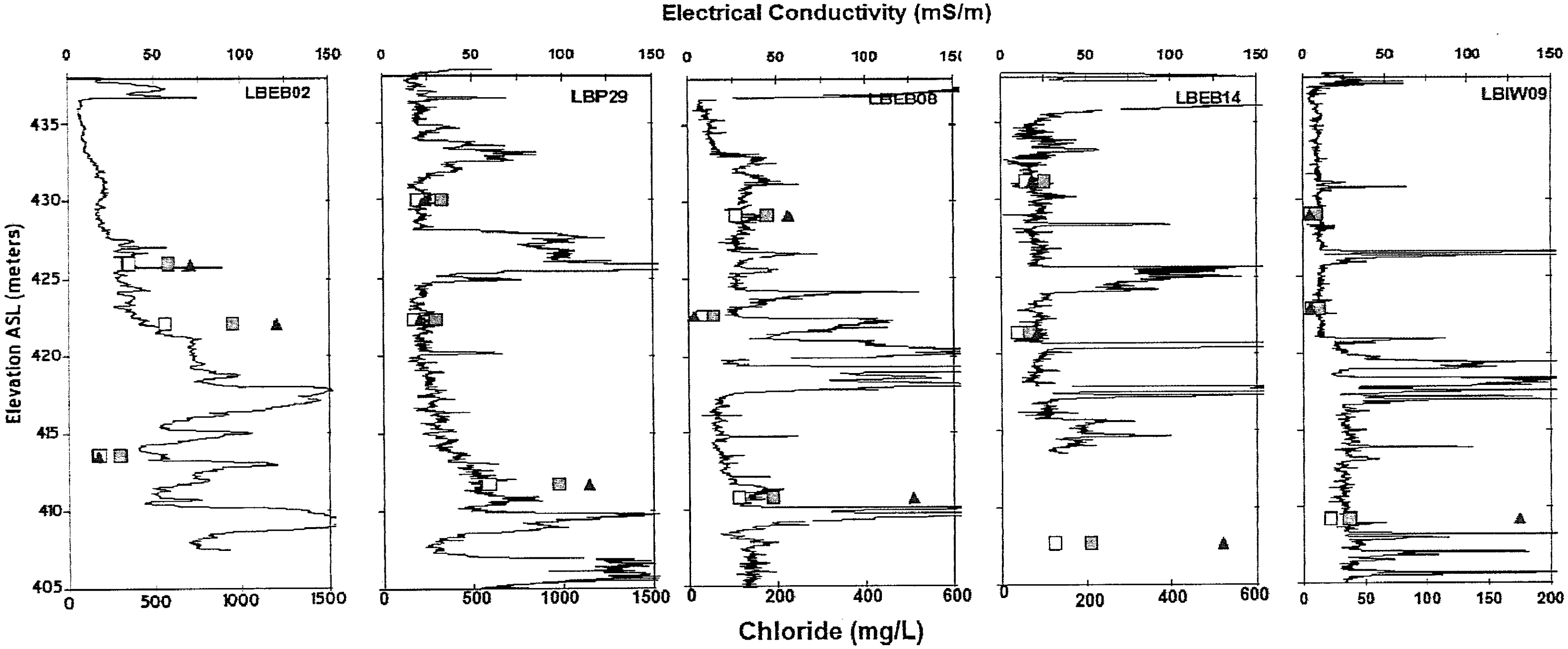


Figure 17. EC profiles with modeled values created from the SpC and Cl⁻ relationships obtained from the geochemical profiling samples. The values were modeled by assuming 15% and 25% intrinsic porosity to correlate to clay and sand strata respectively. The white square represents 15% and the blue square represents 25% porosity. The green triangle represents the chloride value. Note the different scales (top) on the various EC logs as representative of the range of values covered.

4.2 Lithologic Cross section of the Study Area Based On Drillers' Logs

A model cross section constructed based on drillers' logs (Figure 18) indicates two sand aquifers separated by a thin clay lens (approximately 0.6 m) at a depth about 425 m ASL. The deeper sand stratum is bordered below by a thick clay layer at 415 m ASL, which separates it from a third sand strata. The upper clay layer appears somewhat continuous across the site. This upper layer is thicker on the western side and thins towards the east. This model is in general agreement with that proposed by other authors (Ross Schmidt et al., 2007; Whittemore, 2007; Ziegler et al., 2010) and is used for comparison to EC and Cl^- models in the next section.

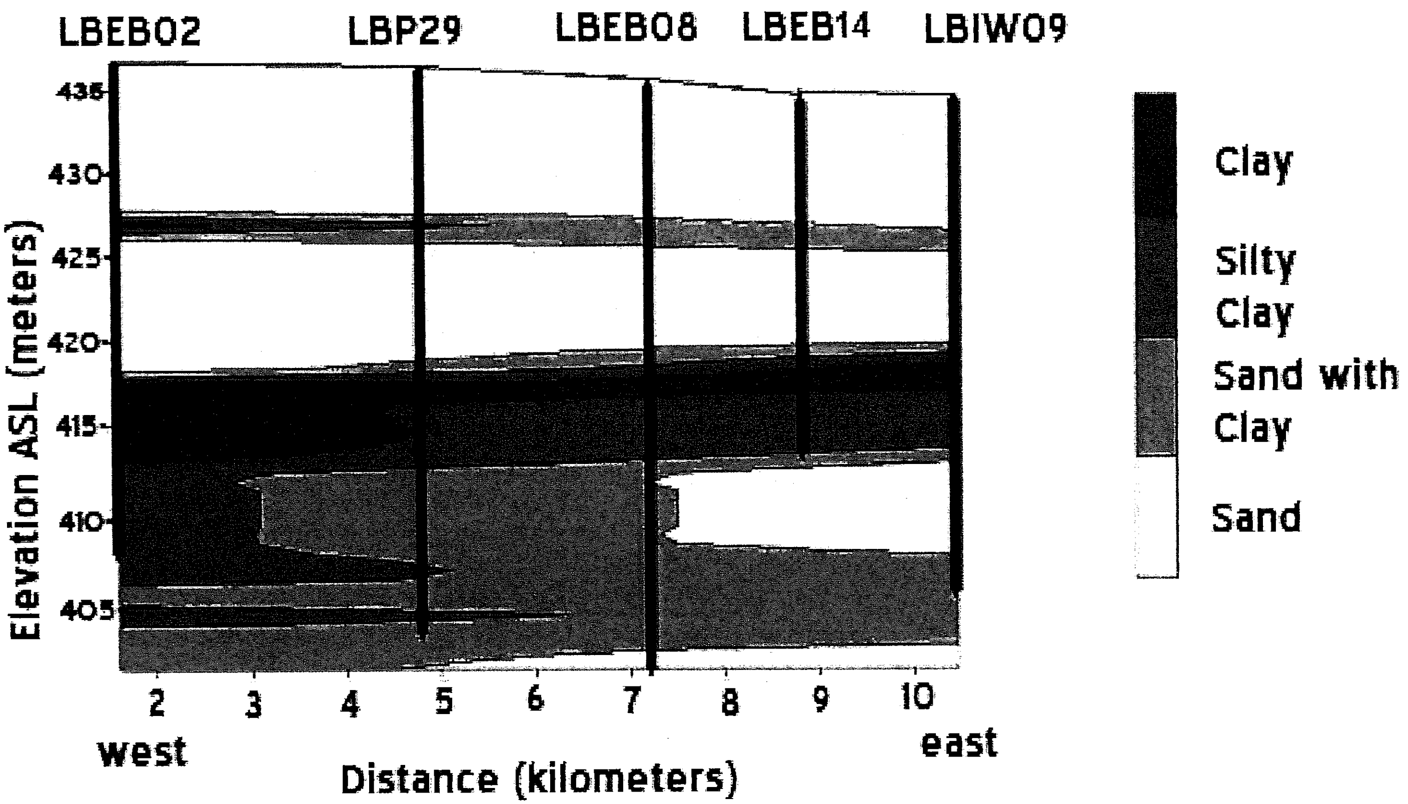


Figure 18. A lithologic cross section based on drillers' logs of adjacent monitoring wells. The model suggests the presence of two clay layers at 427 m and 412 m ASL. Vertical model boundaries include top of the water table deepest EC location.

4.3 Lithologic Cross section Based on EC Logs

A modeled cross section was generated based on the EC logs using the same model constraints used for the lithologic cross section (Figure 19). EC data were interpolated with blue values assigned to EC values greater than 90 mS/m and yellow was used for EC values below 30 mS/m, with gradients in between. The model indicates three layers of low conductivity partially separated by areas of higher conductivity of varying thickness and length (Figure 19). The upper layer of high EC values is quite thin (less than 1 meter). Several other areas of high EC values are indicated at depths below 415 m in the westernmost site. These high EC layers are not present in the eastern portion of the cross section, indicating the high EC areas are not continuous throughout the sites.

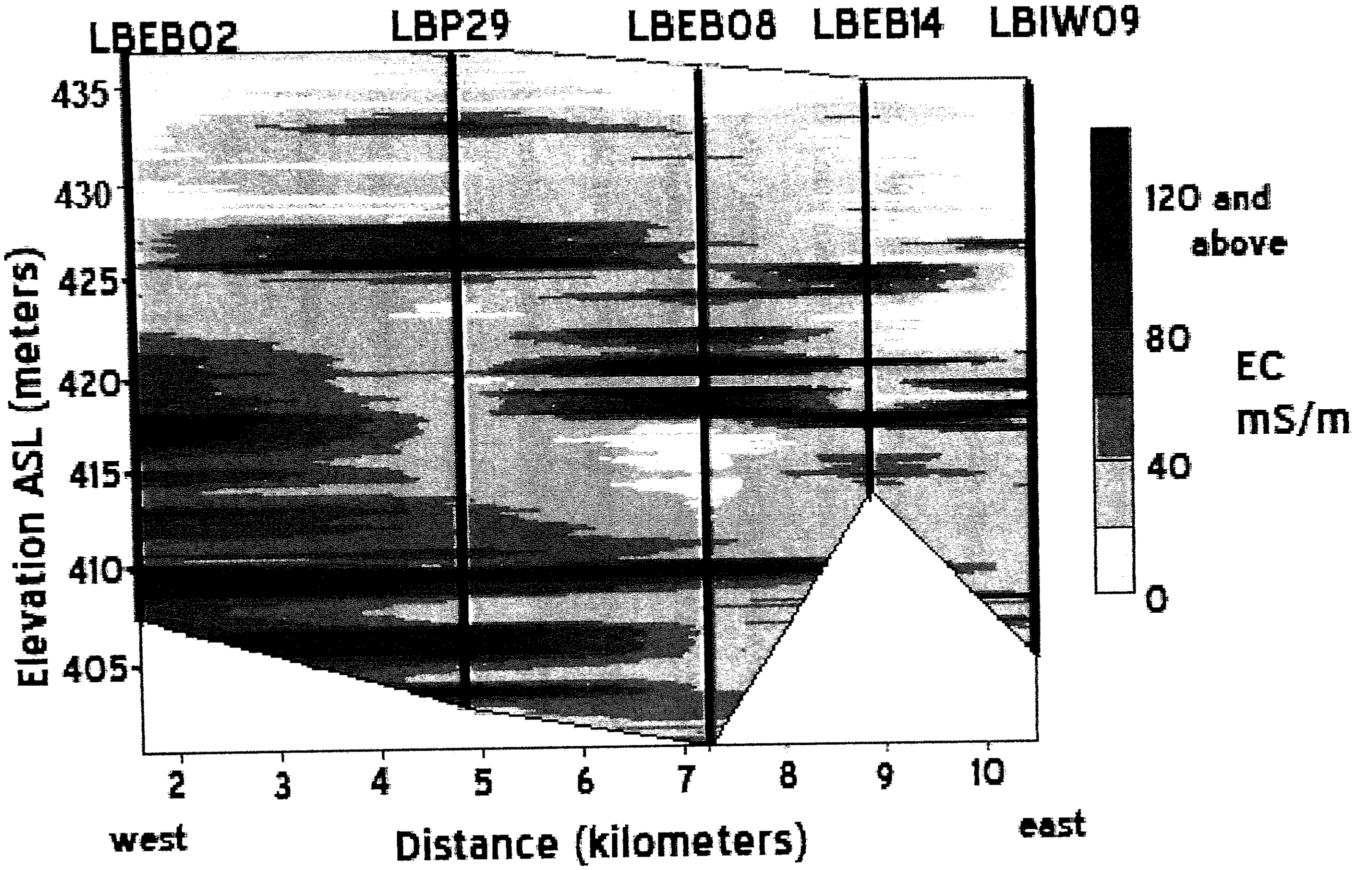


Figure 19. EC based lithologic models of the study transect. Vertical model boundaries include the top of the water table and bottom of EC logs

The lithologic model (Figure 18) was superimposed over the EC model (Figure 19) creating a composite figure for comparison (Figure 20). The lithologic data is represented by blue (clay), green (silty clay), tan (sand with clay), or yellow (sand) transparent crosshatches. Clay identified from the drillers' logs corresponded to the higher EC values. Where sand was indicated in the lithologic logs, lower EC values as indicated by the yellow color were found. In general there was a good visual agreement between the two cross sections. The lithologic cross section indicates thick layers of sand bounded by clay strata. The EC cross section shows much more detail and identified areas of low conductivity in the clay areas describe by the drillers' logs. These low conductivity areas may indicate that the clay strata consists of several clay lens rather than continuous clay layer. These lenses may allow pathways for the chloride contamination to migrate vertically down gradient. The high chloride values have an influence on the EC model. Other discrepancies were identified when correlating the EC and lithologic models, illustrating the ability of the EC model to resolve fine-scale variations in features. The EC indicated high conductivity area, where sand or sand with clay was indicated in the lithologic model. These discrepancies are especially apparent in the EC cross section at depths below 410 m ASL. These higher EC may be clays not described in the drillers' logs or caused by high saline content of the groundwater. This supports the observations that EC values can represent high Cl^- instead of clay. This relationship is explained in the next section.

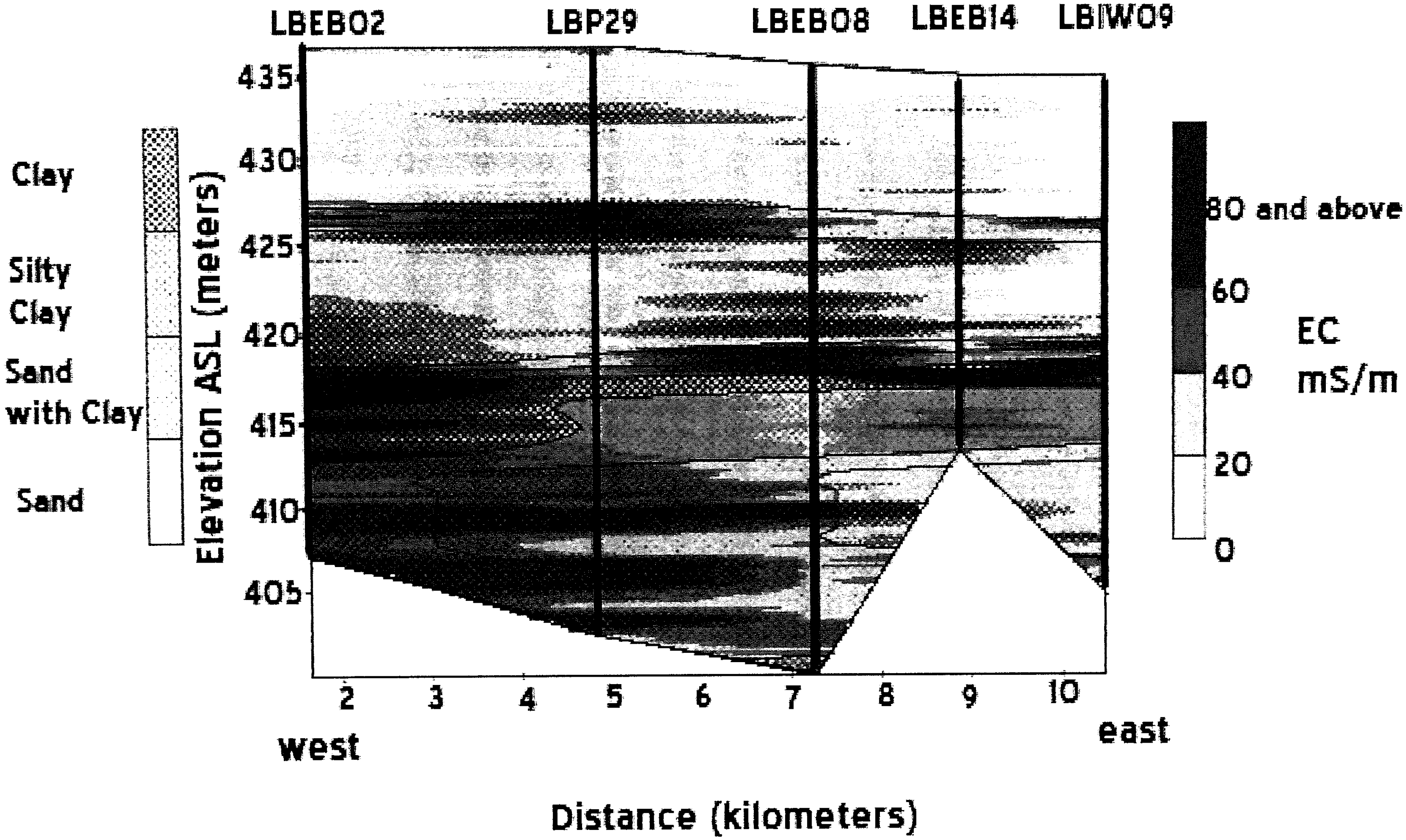


Figure 20. Lithologic model superimposed over EC model. Vertical model boundaries include the top of the water table and bottom of EC logs.

4.4 Modeling the Presence of Clay Based on the EC Logs

A relationship between the specific conductance values of the water samples and the EC values measured in the sediments allows the fluid chemistry's influence on the EC signal to be predicted at depths where no samples were observed. By using SpC as independent variable and EC as the dependent variable, the linear expression $EC=0.12(SpC)-10.21$ was determined in 13 samples. The linear expression had a high coefficient of determination ($R^2 = 0.94$). (Two samples were not used: no EC data obtained due to probe malfunction at LBEB14 depth 101 and sample LBEB08 at depth 55 may have been diluted with deionized water.) This equation was applied to the entire EC data log where no samples were obtained to predict the EC signal that might be attributed to the chloride ions in the groundwater. In some sand layers, the predicted values correspond well to the EC values as at LBIW09 and LBEB14. Areas where the predicted EC values did not match the model (they were lower than expected) indicated higher conductivities that corresponded with the combined clay strata and high chloride content as at LBP29 and LBEB02. The EC logs with predicted EC values for all sites are shown in Figure 21.

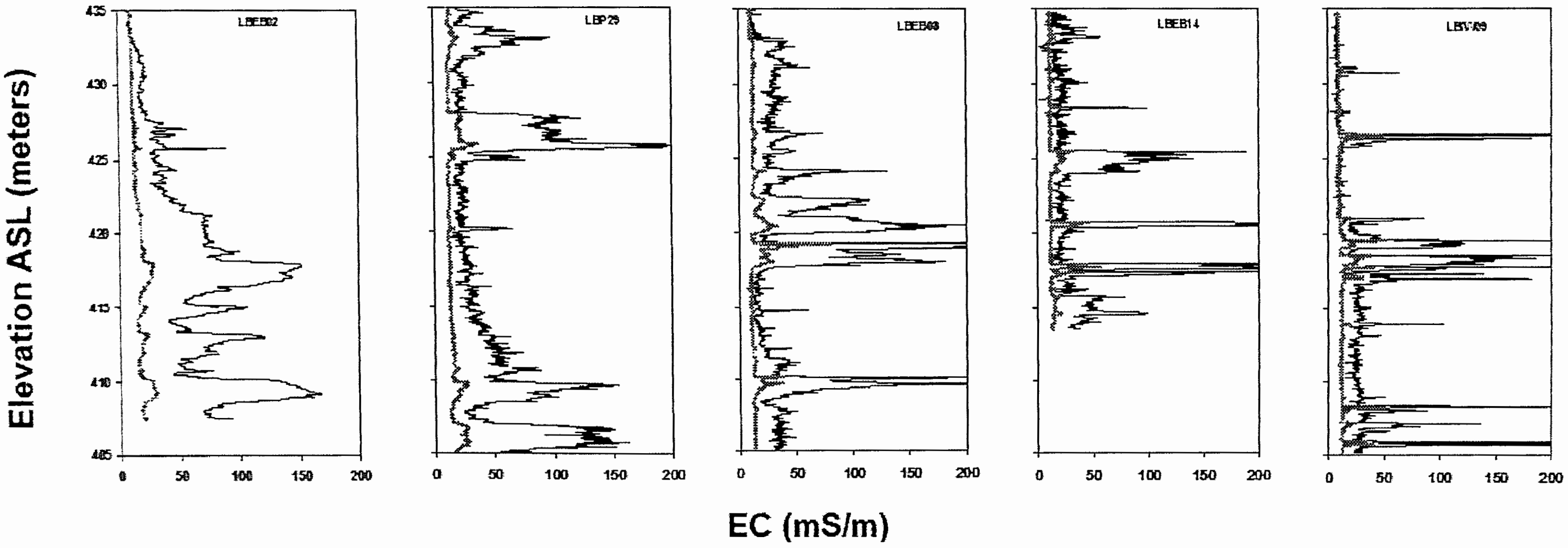


Figure 21. EC logs with EC values predicted by the relationship indicated by the chloride and specific conductance of the geoprofiling samples. A dashed grey line represents the predicted EC values, and solid lines represent the actual EC values. EC logs progress from IBIW09 (least contaminated) to LBEB02 (most contaminated) right to left.

A model of the clay strata was created by utilizing the math function (part of the grid option) in the SURFER program. This option allows grids with similar size and node numbers to be subtracted from one another; the difference is contoured. Subtracting the predicted EC grid, which represented the EC values predicted to represent the sand layers and groundwater, from the original EC data grid, created a clay model grid. This clay grid was then contoured, using green to indicate clay-rich areas. This clay model cross section was superimposed upon the original EC cross section (Figure 19) for comparison (Figure 22). The modeled clay cross section agrees well with the original EC cross section. Areas where there is a difference, for example at the LBEB02 location between 418 m – 422 m, may indicate high chloride content in the groundwater. The high chloride content would increase the EC data values. These high EC values would then be modeled as clay instead of sand.

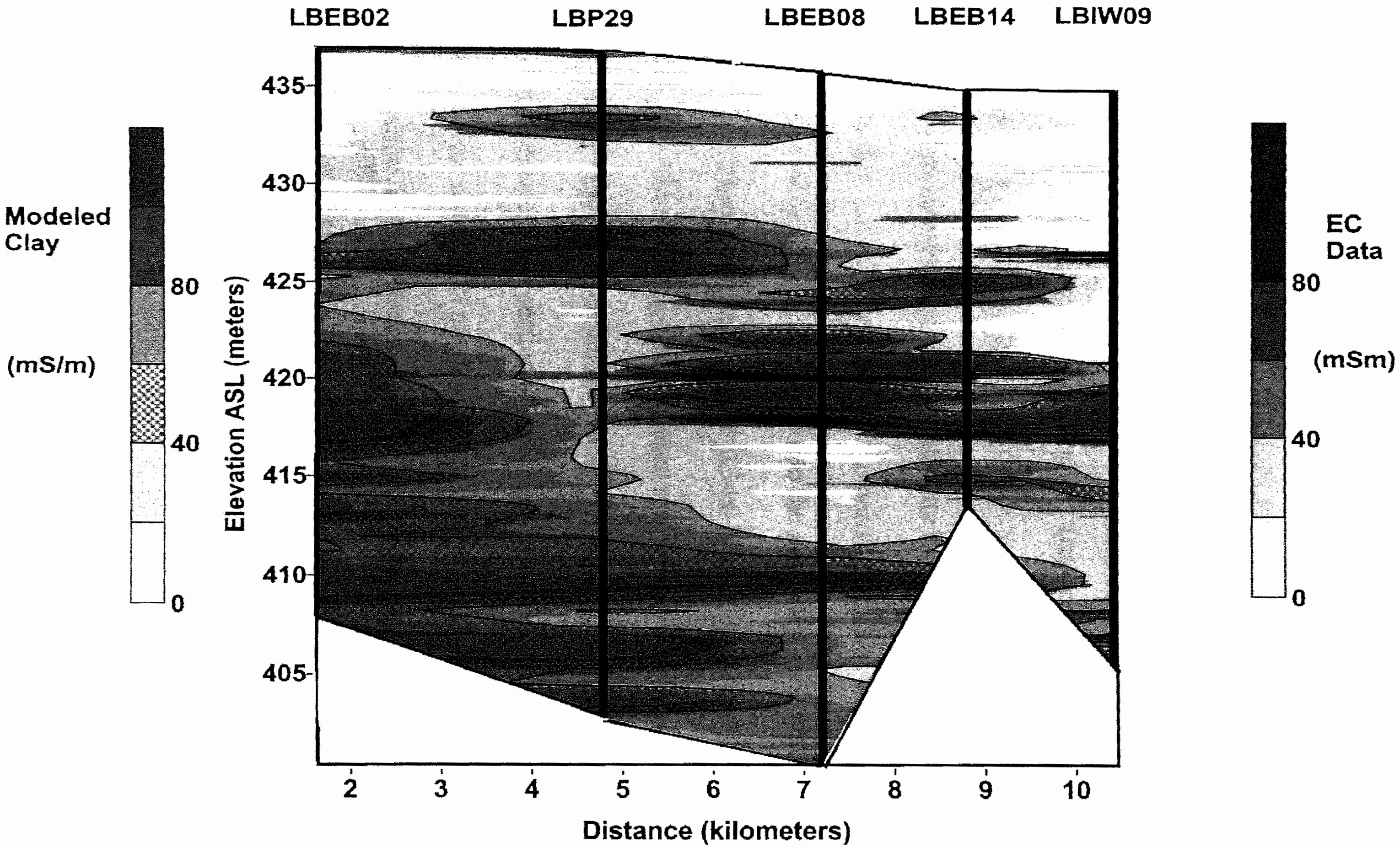


Figure 22. EC minus Predicted EC schema used to model the clay in study area. Vertical boundaries include the top of the water table. Clay and Sand are represented by blue and yellow respectively. Modeled clay is represented by green.

4.5 Chloride Distribution Models

Given the high degree of correlation (R^2= 0.96 for the coefficient of determination) between Cl^- concentrations and SpC in the groundwater at the site, (Figure 15), a numerical relationship based upon the slope intercept of a scatter plot of the Cl^- ion and SpC values was determined. This relationship was used to create a data file of expected chloride levels over the study area. It was assumed at first that the entire EC signal was attributed to high chloride levels in sand. Using the SpC -DP-EC linear expression $y = 8.00x-72.48$, (where y = SpC, x = EC; Figure 16), the EC values from the log were used as inputs into this equation to calculate the expected SpC value. The resulting value was then scaled to account for the porosity (25%) and unit change (mS/m to μS/cm). This new value was used as input into the next numerical relationship that describes the SpC – Chloride relationship, $y = 0.34x-181.63$, (where x= SpC and y = chloride; Figure 15). The resulting data was used to create an input data file for the SURFER contouring software to create the chloride model cross section.

The chloride model cross section suggests high chloride areas located at depth 410 m ASL in the west (LBEB02) migrating east. It also indicates several area of chloride contamination in the eastern portion of the transect approaching the eastern boundary of the transect between 417-420 m ASL.

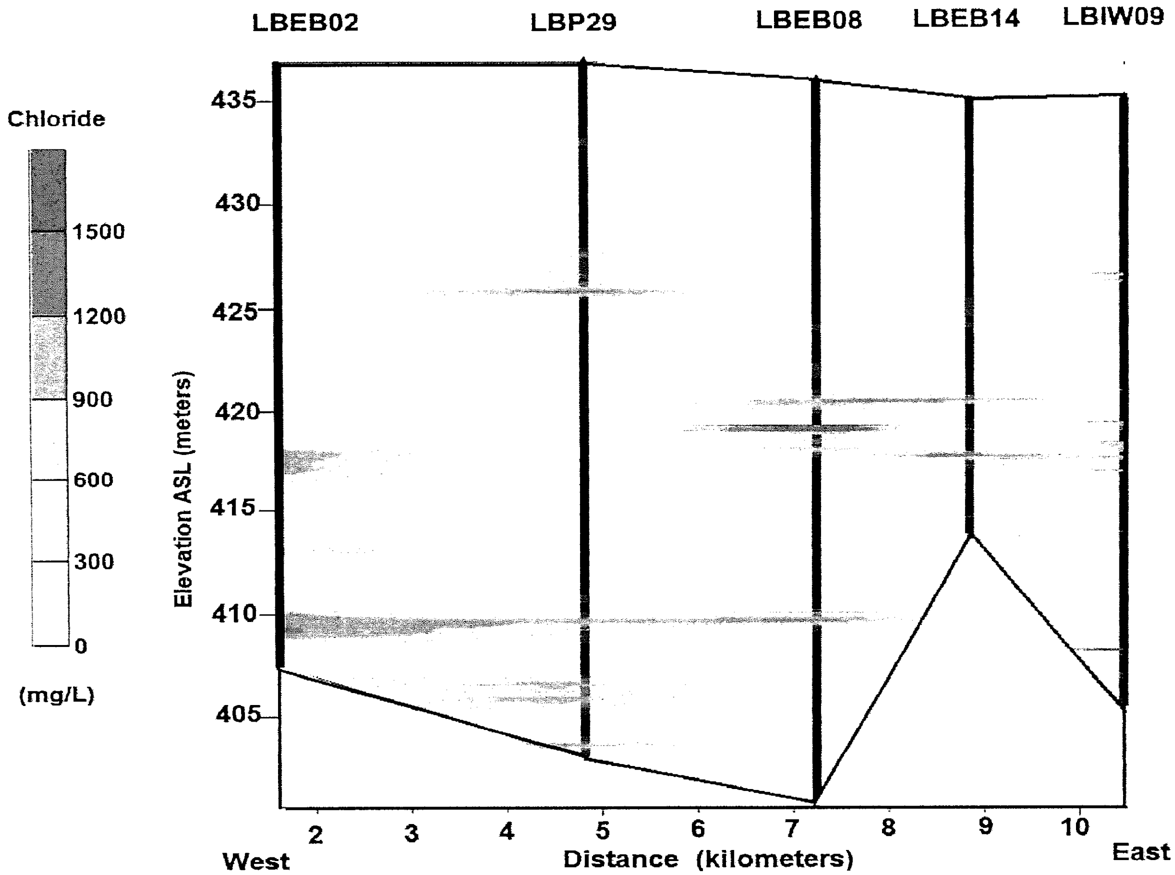


Figure 23. Cross section created for chloride values obtained from SpC vs. EC relationship. Red indicates chloride levels above 1450 mg/L.

The high Cl^- concentrations indicated in the model were confirmed by groundwater samples collected from the probe locations and are in agreement with data from existing Equus Beds monitoring wells. There is some overlapping of the clay and chloride models. That is, neither model could distinguish between high EC values due to chloride content or clay.

The chloride and clay models were superimposed over the EC cross section SURFER file (Figure 24.) to demonstrate the amount of overlap between the two models. Areas that indicated higher chloride content also indicated high clay content. The high EC levels indicate contamination spreading from the existing contamination site. The chloride contamination appears to be migrating eastward, finding a pathway above a clay layer located at a depth of 415 m (ASL) under the LBEB02 and LBP29 well sites, and it extends eastward toward LBEB08. Since high saline fluid would have a higher density, it would be expected to displace the less dense fluid and create a saline-rich lens above the clay layer. The chloride model predicts high chloride level at site LBEB14 at 426 m ASL. The groundwater samples at 432 m ASL did not indicate high chloride contamination (78 mg/L). This area of predicted higher contamination may indicate an area where the chloride is migrating. Chloride contamination (960 mg/L) in the middle levels has since been confirmed in a recent study (Whittemore, 2012). Whittemore believes this contamination is the nose of the plume as it migrates eastward. The model also predicts chloride contamination at IW09, which was not indicated in the recent studies or in the groundwater samples.

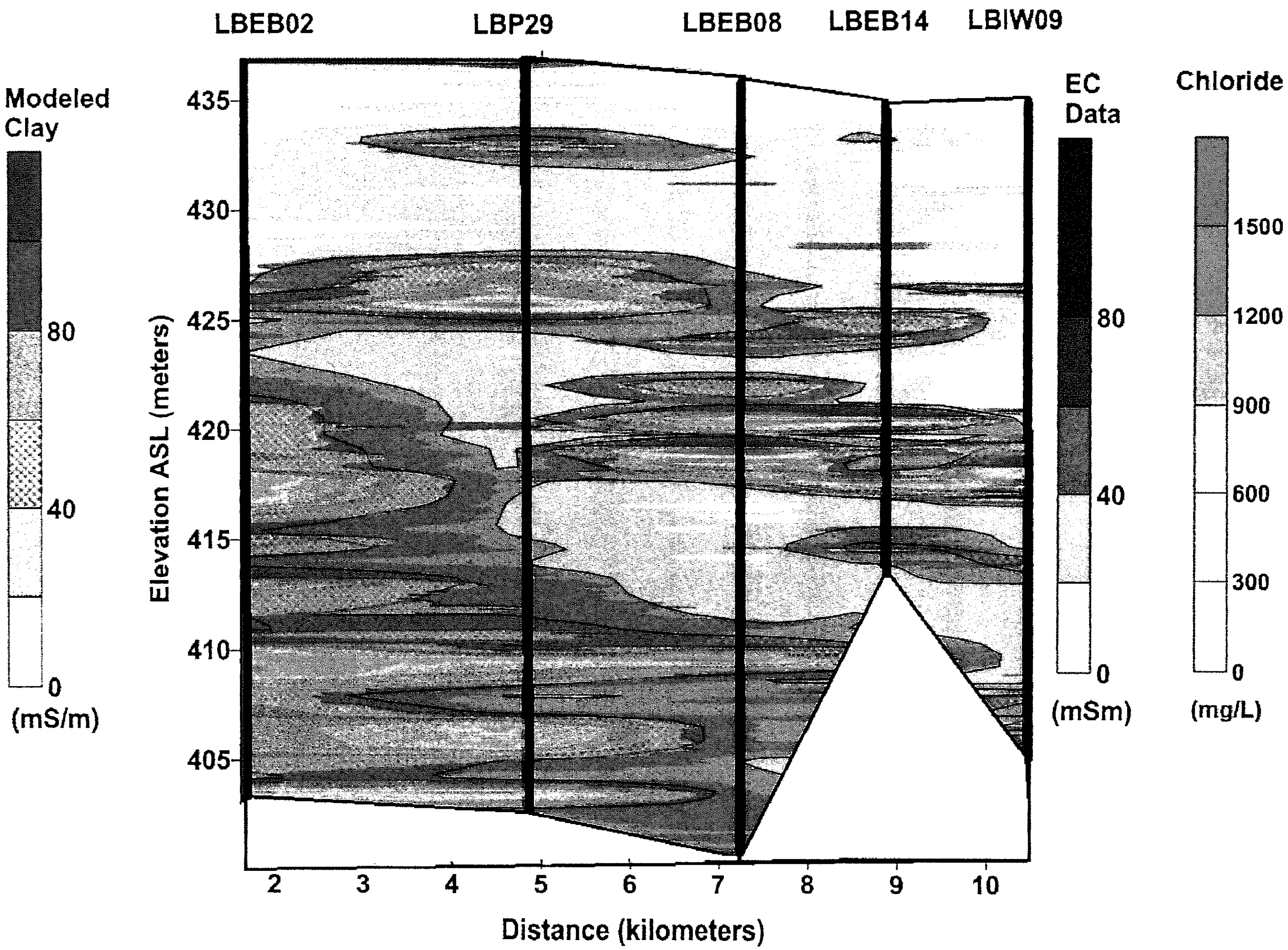


Figure 24. Chloride and Clay model superimposed over EC cross section. The vertical boundaries include the water table and the bottom of the EC logs. Thin red areas indicate suspected chloride migration through fine pathways.

Because the porosity of the aquifer varies, possible high and low porosity values were considered in the models to account for the range of porosities and their effect of the EC values. Using Cl^- concentration values measured in the groundwater samples, the EC data was modeled using two porosities of 15% and 25%. These values were chosen because they represent the effective porosities typically found in the Equus Beds aquifer (Ziegler et al., 2010). The EC data were first compared to the expected clay model, if the EC exceed the clay value; it was then modeled with the higher porosity equation. Figure 25 represents an attempt to model the chloride with this two-porosity approach. While this two-tier model better represents the clay and high chloride zones, there is still a great deal of overlap, especially in the highly contaminated zones. This two-tier model did resolve the high clay zones in LBEB14 and LBEB08 at about 420 ASL that were depicted as chloride in the first approach (Figure 23). It did continue to predict higher chloride levels in the mid-level (420 and 422 m ASL) at EB14, which correspond to recent studies (Whittemore, 2012).

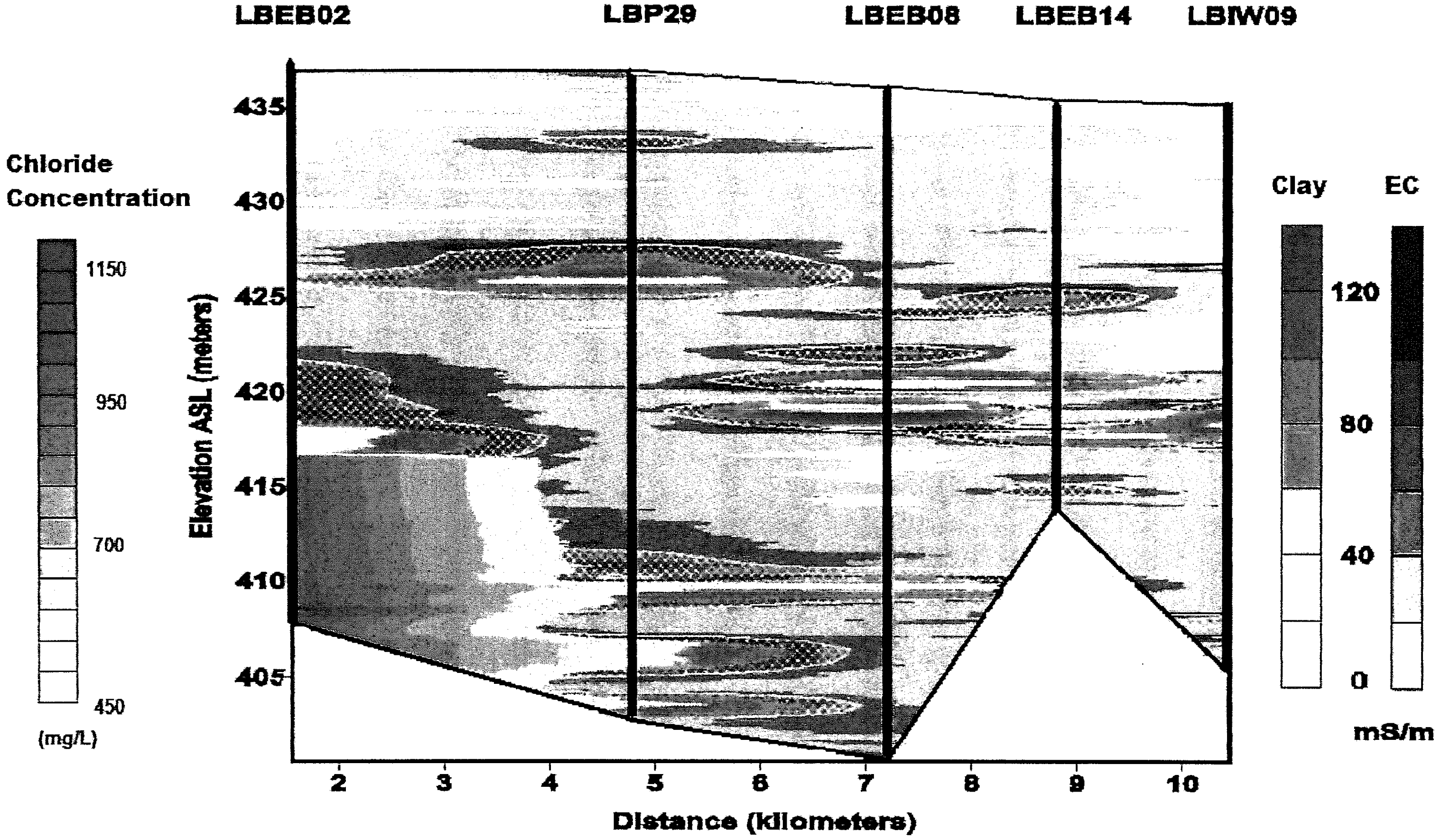


Figure 25. Two tier modeling approach for the chloride superimposed over the clay model.

CHAPTER 5

CONCLUSIONS

In this study, EC logs confirmed the existence of thick clay layers indicated in associated drillers' logs. The EC logs also reveal thin clay lenses that were not apparent in the descriptive well logs. These fine clay lenses are often overlooked with conventional driller logs as has been seen in other studies, (Schulmeister et al, 2003). More importantly, EC logs reveal thin areas of low conductivity within clay sediments themselves. These areas can allow chloride migration vertically through less permeable zone and then laterally through areas of high permeability (sand). This stair-stepping chloride migration (Whittemore, 2012) within the thin zones presents an atypical contaminant model, which may be overlooked in conventional plume modeling. EC log can reveal the stratification of both the sediments and the chloride plume, resulting in area of high chloride concentrations within the plume.

Because chloride ions are electrically charged, EC logs are influenced by the presence of chloride contamination. When concentrations are high enough, zones of high chloride could be interpreted as clay. To discern between chloride and clay, groundwater samples must be collected and chloride concentrations must be determined before interpreting EC logs for lithologic features. Because these fine pathways create areas of high chloride concentrations, these areas may be misinterpreted as clay layer (typically < 90 mS/m. At even higher concentrations (> 500 mg/L), the chloride can overwhelm any EC signal from clay.

The research demonstrates that chloride concentrations can be modeled if representative field samples are obtained, providing the rationale for EC interpretations.

If the chloride concentrations are excessive, they can overwhelm the DP-EC signal. To effectively model the chloride plume, a limiting scheme must be employed to filter out the high EC associated with clays. This can be achieved by using the same scheme initially utilized, but by adding an upper limit to screen out the values associated with clays and high chloride values (> 90 mS/m). The assumption is that the leading edge of the chloride plume would not be as concentrated and would fall somewhere below 90 mS/m. By comparing the chloride contour to the lithologic contour and current plume models, the irregular plume margins can be more fully delineated.

The EC data provides a means of obtaining current, cost-effective and accurate data of the hydrostratigraphic conditions that exist at Equus Beds aquifer. The areas of lower electrical conductivity may provide pathways for contaminant migration into the less contaminated areas. EC data can then be correlated to the groundwater samples to track the probable pathways of chloride migration. Tracking contaminant migration is important because the contaminant concentrations in the Equus Beds Aquifer are changing. The aquifer is the primary groundwater source for a major population center and a substantial investment has been made by the City of Wichita, USGS and Equus Beds GMD#2 to prevent further encroachment of the saltwater into the aquifer. A rapid, accurate and efficient means of characterizing the local subsurface and groundwater geochemistry is vital to ensure the remediation efforts are the most effective at mitigating the harmful effects of the contamination.

The combination of the DP-EC logging and geochemical sampling may be used to track other inorganic changes that may occur in the Equus Beds Aquifer. Changes to redox chemistry are commonly associated with the injection of recharge water into the ground via the recharge basin and injection wells. The approach may be useful to track toxic metals such as arsenic and chromium that may be introduced into the aquifer as such redox changes occur.

Aquifers are commonly impacted by natural recharge mechanisms such as recharge via precipitation and the exchanged of river water and groundwater. Variations in each of these processes may alter that chemical composition of the shallow or near-stream aquifer and cause short-lived or dynamic geochemical conditions that are difficult to monitor. The cost effectiveness and ease of obtaining direct-push EC data provides a new approach to monitoring large scale processes such as these. The coupled approach described in this paper may be valuable wherever ever-changing conditions affect vital water resources.

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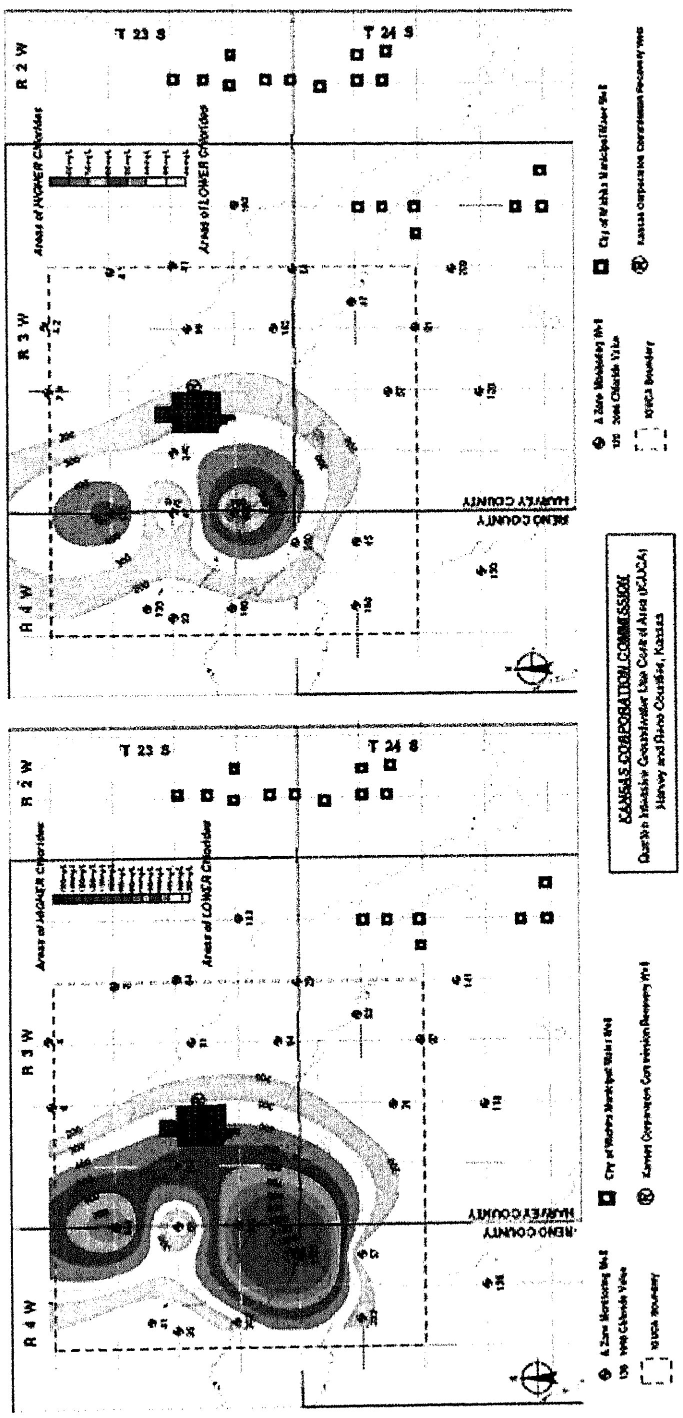
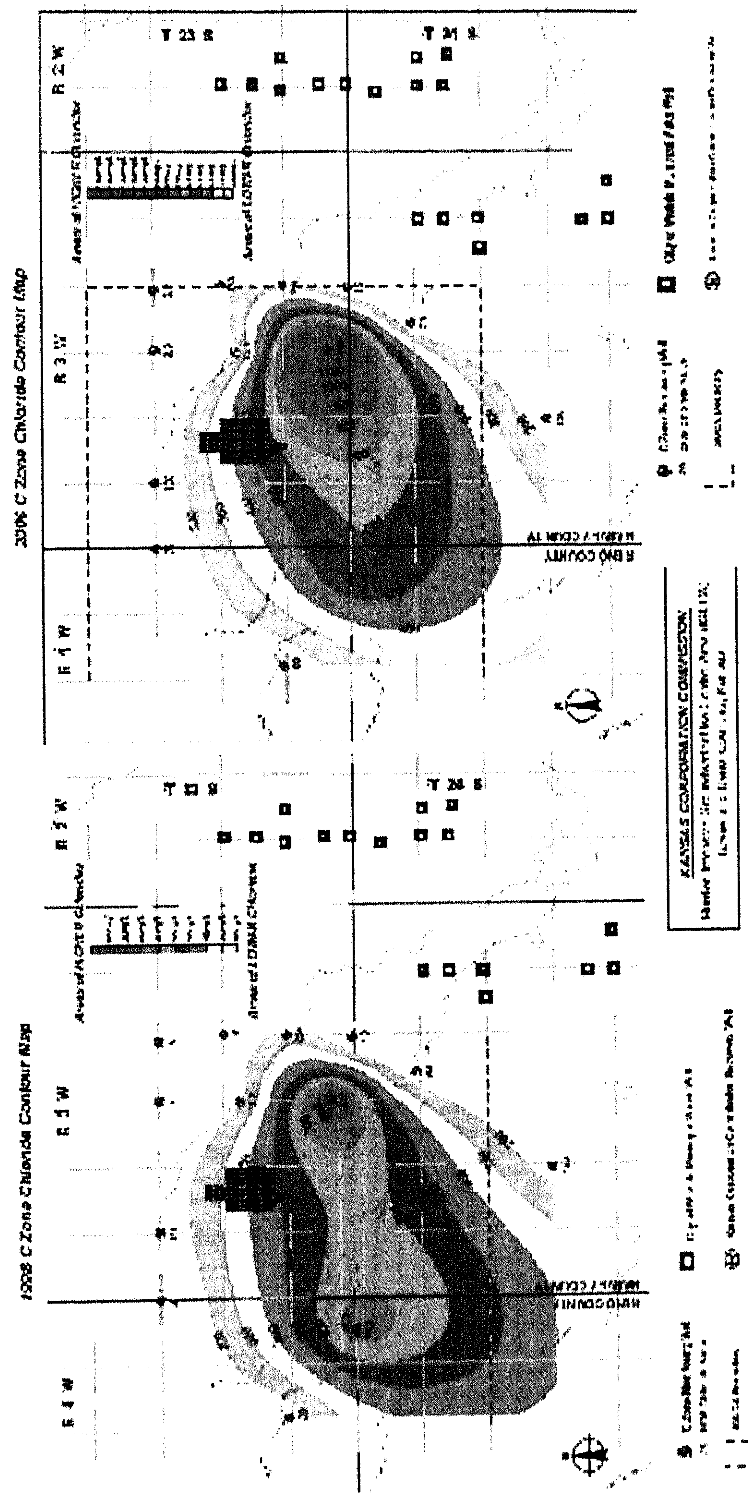
APPENDIX A: KANSAS CORPORATION MAPS

A.1 Zone A Chloride Concentration Map (Shallow)

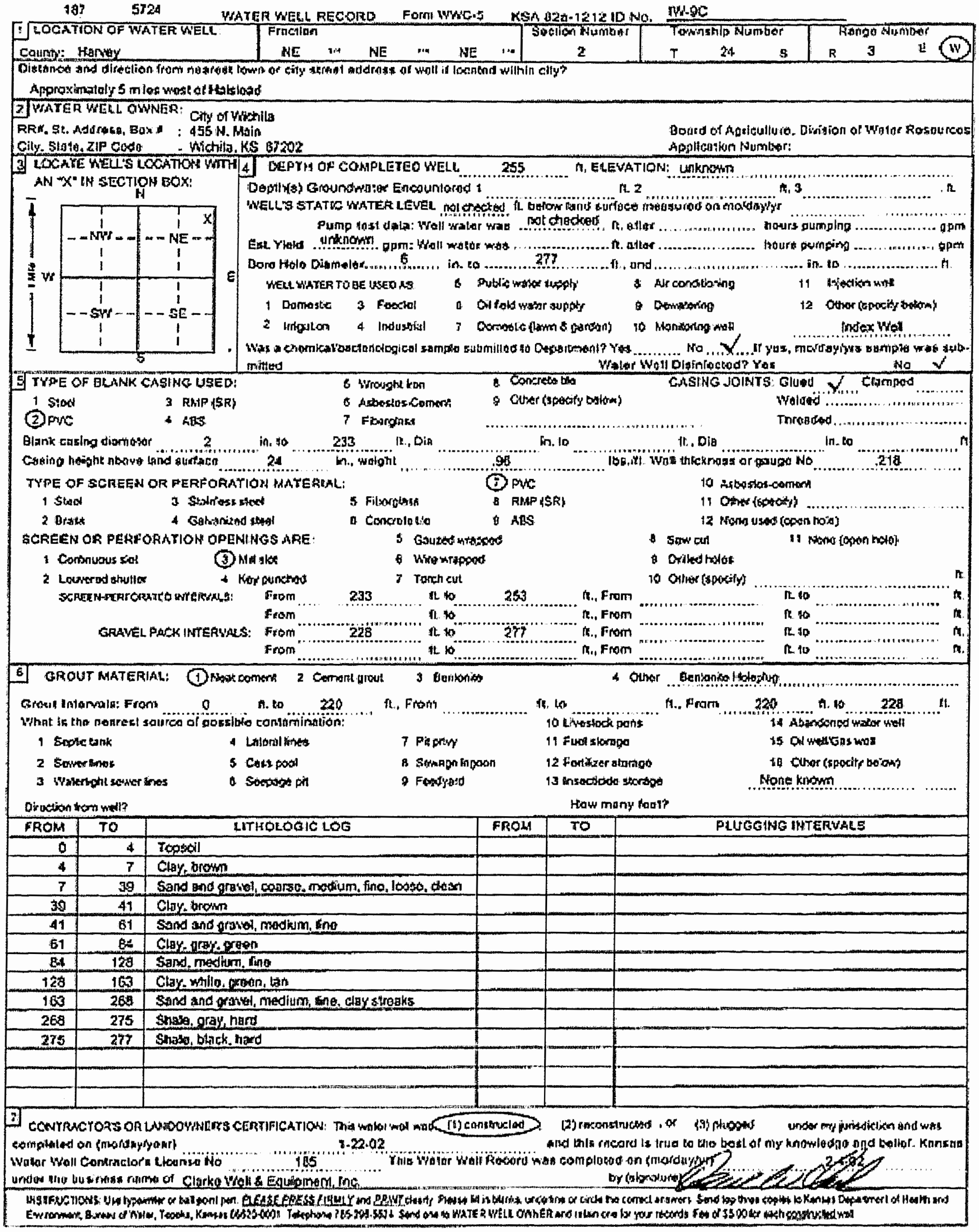


A.2 Zone C Chloride Concentration Map (Deep)



APPENDIX B: WELL COMPLETION RECORDS

B.1 Well Completion Record for IW09



187 5724 WATER WELL RECORD Form WWC-5 KSA 82a-1212 ID No. IW-9C

1 LOCATION OF WATER WELL:
County: Harvey
Fraction: NE 1/4 NE 1/4 NE 1/4
Section Number: 2
Township Number: T 24 S
Range Number: R 3 E [✓ W]

Distance and direction from nearest town or city street address of well if located within city?
Approximately 5 miles west of Halstead

2 WATER WELL OWNER: City of Wichita
RR#, St. Address, Box # : 455 N. Main
City, State, ZIP Code : Wichita, KS 67202
Board of Agriculture, Division of Water Resources
Application Number:

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:

4 DEPTH OF COMPLETED WELL 255 ft. ELEVATION: unknown
Depth(s) Groundwater Encountered 1 .... ft. 2 .... ft. 3 .... ft.
WELL'S STATIC WATER LEVEL not checked ft. below land surface measured on mo/day/yr ....
Pump test data: Well water was not checked ft. after .... hours pumping .... gpm
Est. Yield unknown gpm: Well water was .... ft. after .... hours pumping .... gpm
Bore Hole Diameter 6 in. to 277 ft., and .... in. to .... ft.

WELL WATER TO BE USED AS:
1 Domestic
2 Irrigation
3 Feedlot
4 Industrial
5 Public water supply
6 Oil field water supply
7 Domestic (lawn & garden)
8 Air conditioning
9 Dewatering
10 Monitoring well
11 Injection well
12 Other (specify below) Index Well

Was a chemical/bacteriological sample submitted to Department? Yes .... No ✓ If yes, mo/day/yr sample was submitted
Water Well Disinfected? Yes No ✓

5 TYPE OF BLANK CASING USED:
1 Steel
[✓ 2 PVC]
3 RMP (SR)
4 ABS
5 Wrought iron
6 Asbestos-Cement
7 Fiberglass
8 Concrete tile
9 Other (specify below)

CASING JOINTS: Glued ✓ Clamped ....
Welded ....
Threaded ....

Blank casing diameter 2 in. to 233 ft., Dia .... in. to .... ft., Dia .... in. to .... ft.
Casing height above land surface 24 in., weight .96 lbs./ft. Wall thickness or gauge No .218

TYPE OF SCREEN OR PERFORATION MATERIAL:
1 Steel
2 Brass
3 Stainless steel
4 Galvanized steel
5 Fiberglass
6 Concrete tile
[✓ 7 PVC]
8 RMP (SR)
9 ABS
10 Asbestos-cement
11 Other (specify) ....
12 None used (open hole)

SCREEN OR PERFORATION OPENINGS ARE:
1 Continuous slot
2 Louvered shutter
[✓ 3 Mill slot]
4 Key punched
5 Gauzed wrapped
6 Wire wrapped
7 Torch cut
8 Saw cut
9 Drilled holes
10 Other (specify) ....
11 None (open hole)

SCREEN-PERFORATED INTERVALS: From 233 ft. to 253 ft., From .... ft. to .... ft.
From .... ft. to .... ft., From .... ft. to .... ft.
GRAVEL PACK INTERVALS: From 228 ft. to 277 ft., From .... ft. to .... ft.
From .... ft. to .... ft., From .... ft. to .... ft.

6 GROUT MATERIAL: [✓ 1 Neat cement] 2 Cement grout 3 Bentonite 4 Other Bentonite Holeplug
Grout Intervals: From 0 ft. to 220 ft., From .... ft. to .... ft., From 220 ft. to 228 ft.

What is the nearest source of possible contamination:
1 Septic tank
2 Sewer lines
3 Watertight sewer lines
4 Lateral lines
5 Cess pool
6 Seepage pit
7 Pit privy
8 Sewage lagoon
9 Feedyard
10 Livestock pens
11 Fuel storage
12 Fertilizer storage
13 Insecticide storage
14 Abandoned water well
15 Oil well/Gas well
16 Other (specify below) None known

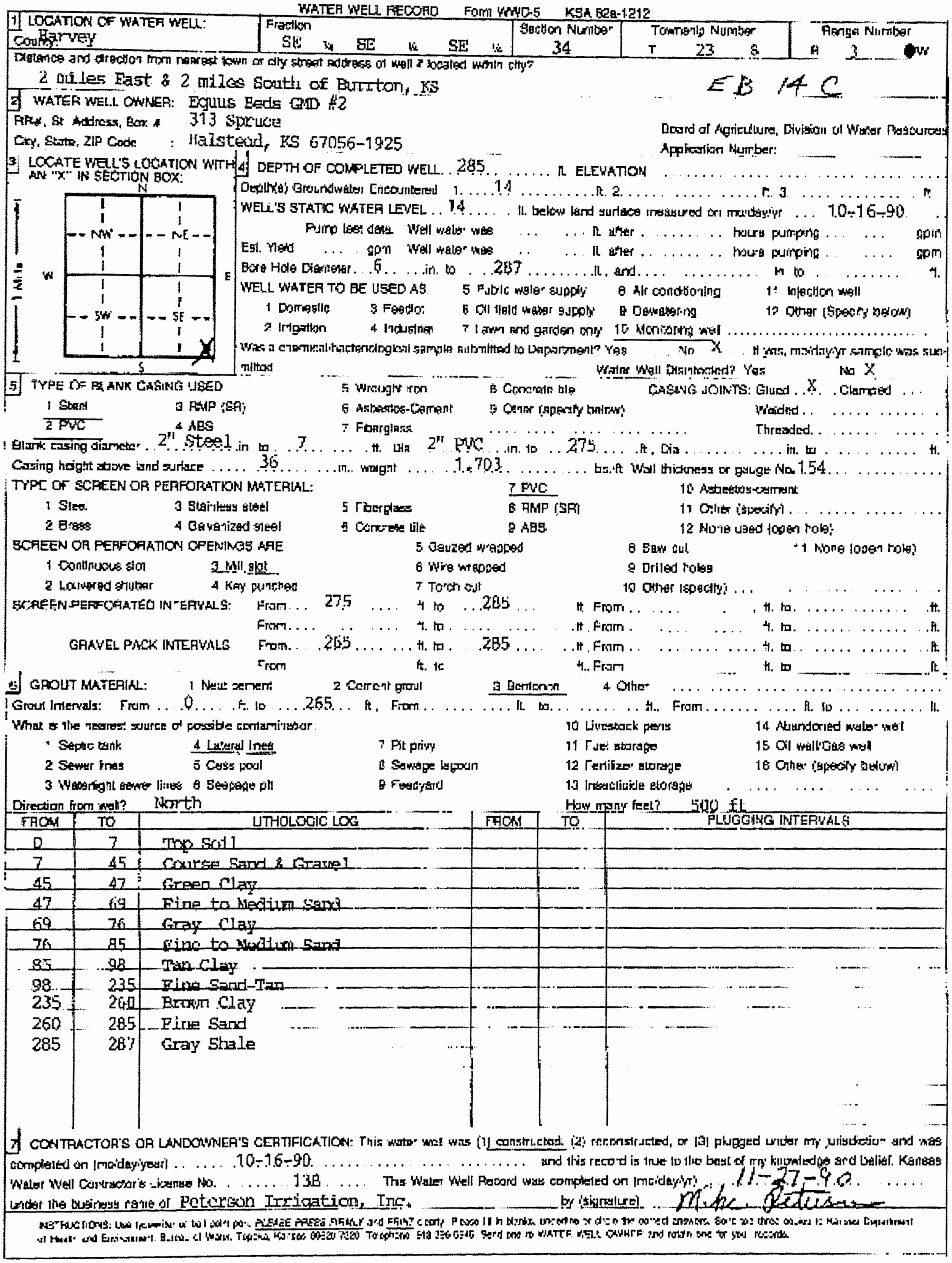
Direction from well?
How many feet?

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
0	4	Topsoil			
4	7	Clay, brown			
7	39	Sand and gravel, coarse, medium, fine, loose, clean			
39	41	Clay, brown			
41	61	Sand and gravel, medium, fine			
61	84	Clay, gray, green			
84	128	Sand, medium, fine			
128	163	Clay, white, green, tan			
163	268	Sand and gravel, medium, fine, clay streaks			
268	275	Shale, gray, hard			
275	277	Shale, black, hard			

7 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was [✓ (1) constructed] (2) reconstructed, or (3) plugged under my jurisdiction and was completed on (mo/day/year) 1-22-02 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No 185 This Water Well Record was completed on (mo/day/yr) 2-4-02 under the business name of Clarke Well & Equipment, Inc. by (signature)

INSTRUCTIONS: Use typewriter or ball point pen. PLEASE PRESS FIRMLY and PRINT clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Topeka, Kansas 66620-0001. Telephone 785-296-5514. Send one to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well.

B.2 Well Completion Record EB14



WATER WELL RECORD Form WWC-5 KSA 82a-1212

1 LOCATION OF WATER WELL: County: Harvey
Fraction SE ¼ SE ¼ SE ¼
Section Number 34
Township Number T 23 S
Range Number R 3 ●W
Distance and direction from nearest town or city street address of well if located within city?
2 miles East & 2 miles South of Burrton, KS

EB 14 C

2 WATER WELL OWNER: Equus Beds GMD #2
RR#, St. Address, Box # 313 Spruce
City, State, ZIP Code : Halstead, KS 67056-1925
Board of Agriculture, Division of Water Resources
Application Number:

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:
N
NW NE
W E
SW SE X
S
1 Mile

4 DEPTH OF COMPLETED WELL 285 ft. ELEVATION
Depth(s) Groundwater Encountered 1. 14 ft. 2. ft. 3. ft.
WELL'S STATIC WATER LEVEL 14 ft. below land surface measured on mo/day/yr 10-16-90
Pump test data: Well water was ft. after hours pumping gpm
Est. Yield gpm: Well water was ft. after hours pumping gpm
Bore Hole Diameter 6 in. to 287 ft., and in. to ft.
WELL WATER TO BE USED AS: 1 Domestic 2 Irrigation 3 Feedlot 4 Industrial 5 Public water supply 6 Oil field water supply 7 Lawn and garden only 8 Air conditioning 9 Dewatering 10 Monitoring well 11 Injection well 12 Other (Specify below)
Was a chemical/bacteriological sample submitted to Department? Yes No X ; If yes, mo/day/yr sample was submitted
Water Well Disinfected? Yes No X

5 TYPE OF BLANK CASING USED: 1 Steel 2 PVC 3 RMP (SR) 4 ABS 5 Wrought iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below)
CASING JOINTS: Glued X Clamped Welded Threaded
Blank casing diameter 2" Steel in. to 7 ft., Dia 2" PVC in. to 275 ft., Dia in. to ft.
Casing height above land surface 36 in., weight 1.703 lbs./ft. Wall thickness or gauge No. 1.54
TYPE OF SCREEN OR PERFORATION MATERIAL: 1 Steel 2 Brass 3 Stainless steel 4 Galvanized steel 5 Fiberglass 6 Concrete tile 7 PVC 8 RMP (SR) 9 ABS 10 Asbestos-cement 11 Other (specify) 12 None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE: 1 Continuous slot 2 Louvered shutter 3 Mill slot 4 Key punched 5 Gauzed wrapped 6 Wire wrapped 7 Torch cut 8 Saw cut 9 Drilled holes 10 Other (specify) 11 None (open hole)
SCREEN-PERFORATED INTERVALS: From 275 ft. to 285 ft., From ft. to ft.
From ft. to ft., From ft. to ft.
GRAVEL PACK INTERVALS: From 265 ft. to 285 ft., From ft. to ft.
From ft. to ft., From ft. to ft.

6 GROUT MATERIAL: 1 Neat cement 2 Cement grout 3 Bentonite 4 Other
Grout Intervals: From 0 ft. to 265 ft., From ft. to ft., From ft. to ft.
What is the nearest source of possible contamination: 1 Septic tank 2 Sewer lines 3 Watertight sewer lines 4 Lateral lines 5 Cess pool 6 Seepage pit 7 Pit privy 8 Sewage lagoon 9 Feedyard 10 Livestock pens 11 Fuel storage 12 Fertilizer storage 13 Insecticide storage 14 Abandoned water well 15 Oil well/Gas well 16 Other (specify below)
Direction from well? North
How many feet? 500 ft.

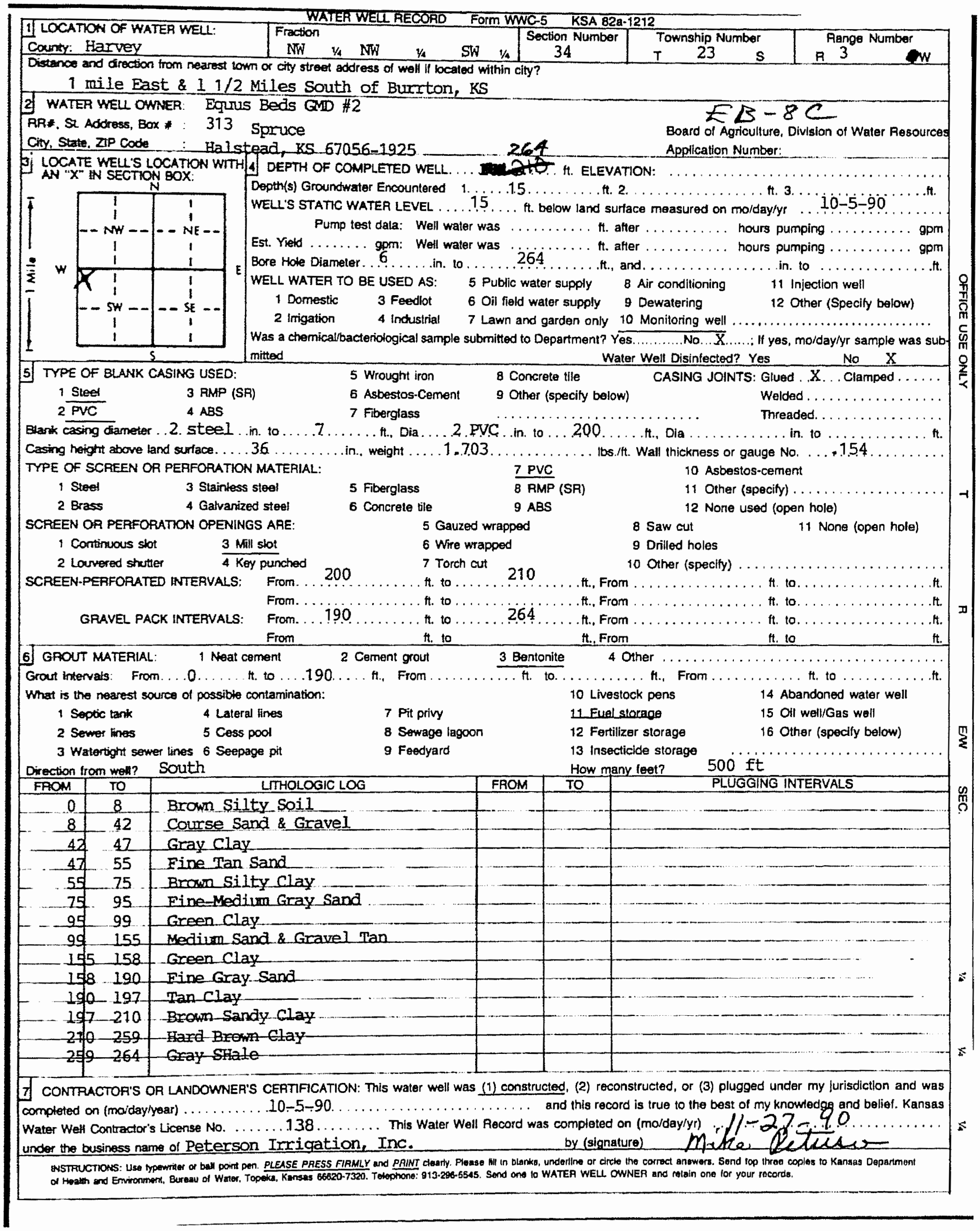
FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
0	7	Top Soil			
7	45	Course Sand & Gravel			
45	47	Green Clay			
47	69	Fine to Medium Sand			
69	76	Gray Clay			
76	85	Fine to Medium Sand			
85	98	Tan Clay			
98	235	Fine Sand-Tan			
235	260	Brown Clay			
260	285	Fine Sand			
285	287	Gray Shale			

7 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) constructed, (2) reconstructed, or (3) plugged under my jurisdiction and was completed on (mo/day/year) 10-16-90 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 138. This Water Well Record was completed on (mo/day/yr) 11-27-90 under the business name of Peterson Irrigation, Inc. by (signature) Mike Peterson

INSTRUCTIONS: Use typewriter or ball point pen. PLEASE PRESS FIRMLY and PRINT clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Topeka, Kansas 66620-7320. Telephone: 913-296-5545. Send one to WATER WELL OWNER and retain one for your records.

OFFICE USE ONLY
EW
SEC.

B.3 Well Completion Record for EB08



WATER WELL RECORD Form WWC-5 KSA 82a-1212

1 LOCATION OF WATER WELL: County: Harvey	Fraction NW ¼ NW ¼ SW ¼	Section Number 34	Township Number T 23 S	Range Number R 3 W

Distance and direction from nearest town or city street address of well if located within city?
1 mile East & 1 1/2 Miles South of Burrton, KS

2 WATER WELL OWNER: Equus Beds GMD #2
RR#, St. Address, Box # : 313 Spruce
City, State, ZIP Code : Halstead, KS 67056-1925

EB-8C

Board of Agriculture, Division of Water Resources
Application Number:

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:

4 DEPTH OF COMPLETED WELL ~~210~~ 264 ft. ELEVATION:
Depth(s) Groundwater Encountered 1. 15 ft. 2. ft. 3. ft.
WELL'S STATIC WATER LEVEL 15 ft. below land surface measured on mo/day/yr 10-5-90
Pump test data: Well water was ft. after hours pumping gpm
Est. Yield gpm: Well water was ft. after hours pumping gpm
Bore Hole Diameter 6 in. to 264 ft., and in. to ft.
WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well
1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering 12 Other (Specify below)
2 Irrigation 4 Industrial 7 Lawn and garden only [✓ 10 Monitoring well]
Was a chemical/bacteriological sample submitted to Department? Yes ..... No X ; If yes, mo/day/yr sample was submitted
Water Well Disinfected? Yes No X

5 TYPE OF BLANK CASING USED: 5 Wrought iron 8 Concrete tile CASING JOINTS: Glued X Clamped
[✓ 1 Steel] 3 RMP (SR) 6 Asbestos-Cement 9 Other (specify below) Welded
[✓ 2 PVC] 4 ABS 7 Fiberglass Threaded
Blank casing diameter 2 steel in. to 7 ft., Dia 2 PVC in. to 200 ft., Dia in. to ft.
Casing height above land surface 36 in., weight 1.703 lbs./ft. Wall thickness or gauge No. .154
TYPE OF SCREEN OR PERFORATION MATERIAL: [✓ 7 PVC] 10 Asbestos-cement
1 Steel 3 Stainless steel 5 Fiberglass 8 RMP (SR) 11 Other (specify)
2 Brass 4 Galvanized steel 6 Concrete tile 9 ABS 12 None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE: 5 Gauzed wrapped 8 Saw cut 11 None (open hole)
1 Continuous slot [✓ 3 Mill slot] 6 Wire wrapped 9 Drilled holes
2 Louvered shutter 4 Key punched 7 Torch cut 10 Other (specify)
SCREEN-PERFORATED INTERVALS: From 200 ft. to 210 ft., From ft. to ft.
From ft. to ft., From ft. to ft.
GRAVEL PACK INTERVALS: From 190 ft. to 264 ft., From ft. to ft.
From ft. to ft., From ft. to ft.

6 GROUT MATERIAL: 1 Neat cement 2 Cement grout [✓ 3 Bentonite] 4 Other
Grout Intervals: From 0 ft. to 190 ft., From ft. to ft., From ft. to ft.
What is the nearest source of possible contamination: 10 Livestock pens 14 Abandoned water well
1 Septic tank 4 Lateral lines 7 Pit privy [✓ 11 Fuel storage] 15 Oil well/Gas well
2 Sewer lines 5 Cess pool 8 Sewage lagoon 12 Fertilizer storage 16 Other (specify below)
3 Watertight sewer lines 6 Seepage pit 9 Feedyard 13 Insecticide storage
Direction from well? South How many feet? 500 ft

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
0	8	Brown Silty Soil			
8	42	Course Sand & Gravel			
42	47	Gray Clay			
47	55	Fine Tan Sand			
55	75	Brown Silty Clay			
75	95	Fine-Medium Gray Sand			
95	99	Green Clay			
99	155	Medium Sand & Gravel Tan			
155	158	Green Clay			
158	190	Fine Gray Sand			
190	197	Tan Clay			
197	210	Brown Sandy Clay			
210	259	Hard Brown Clay			
259	264	Gray SHale			

7 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was [✓ (1) constructed], (2) reconstructed, or (3) plugged under my jurisdiction and was completed on (mo/day/year) 10-5-90 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 138 This Water Well Record was completed on (mo/day/yr) 11-27-90
under the business name of Peterson Irrigation, Inc. by (signature) Mike Peterson

INSTRUCTIONS: Use typewriter or ball point pen. *PLEASE PRESS FIRMLY* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Topeka, Kansas 66620-7320. Telephone: 913-296-5545. Send one to WATER WELL OWNER and retain one for your records.

OFFICE USE ONLY
T
R
E/W
SEC.
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¼
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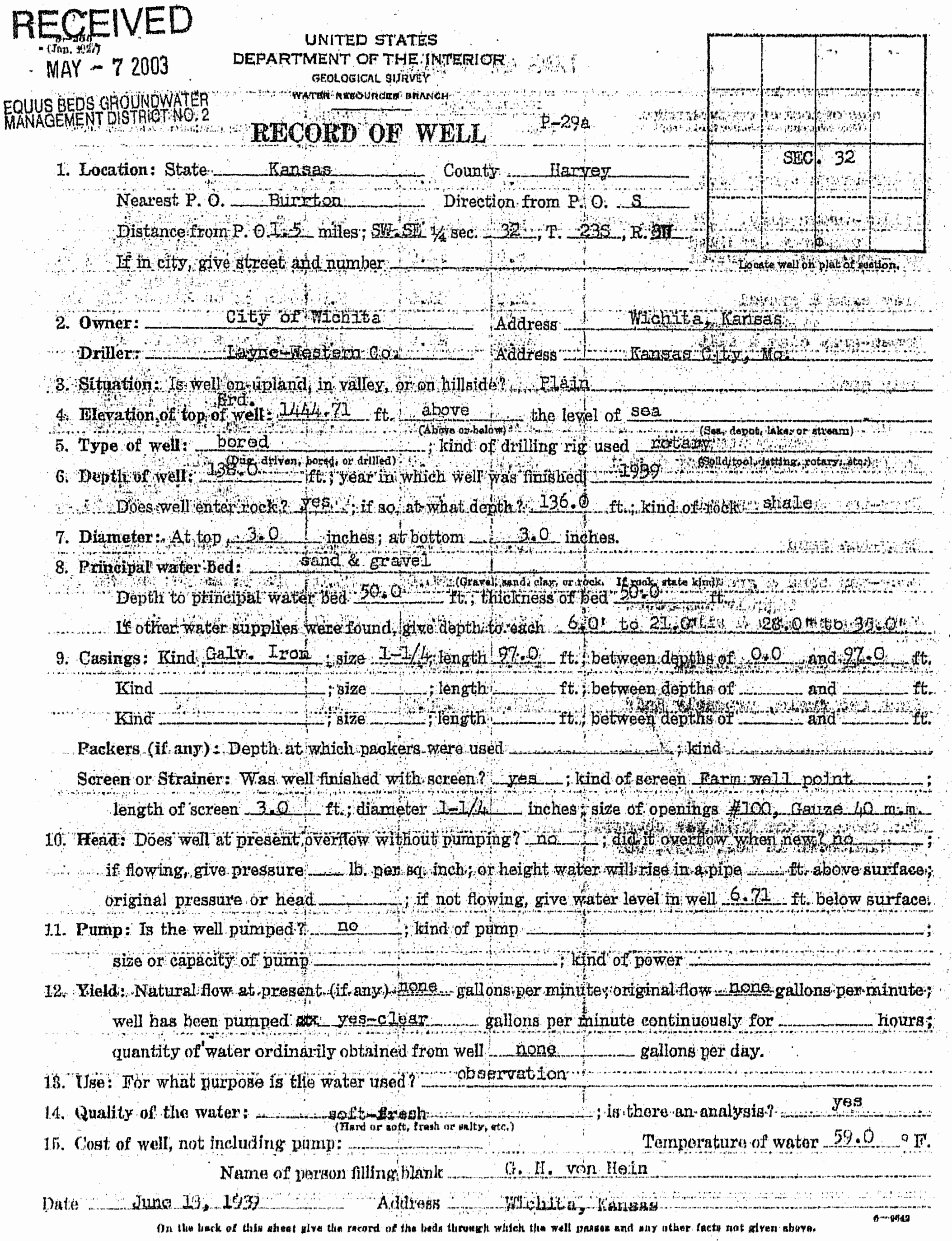
B.4 Well Completion Record for P29

Note: P29 Record received from T. Boese of Equus Beds Groundwater Management District in poor condition. It was not available from the WWC database.



RECEIVED
MAY - 7 2003
EQUUS BEDS GROUNDWATER
MANAGEMENT DISTRICT NO. 2

(Jan. 1927)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES BRANCH

P-29a

RECORD OF WELL

SEC. 32
Locate well on plat of section.

1. **Location:** State Kansas County Harvey
Nearest P. O. Burrton Direction from P. O. S
Distance from P. O. 1.5 miles; SW.SE ¼ sec. 32, T. 23S, R. 3W
If in city, give street and number

2. **Owner:** City of Wichita Address Wichita, Kansas
Driller: Layne-Western Co. Address Kansas City, Mo.

3. **Situation:** Is well on upland, in valley, or on hillside? Plain

4. **Elevation of top of well:** Grd. 1444.71 ft. above (Above or below) the level of sea (Sea, depot, lake, or stream)

5. **Type of well:** bored (Dug, driven, bored, or drilled); kind of drilling rig used rotary (Solid tool, jetting, rotary, etc.)

6. **Depth of well:** 138.0 ft.; year in which well was finished 1939
Does well enter rock? yes; if so, at what depth? 136.0 ft.; kind of rock shale

7. **Diameter:** At top 3.0 inches; at bottom 3.0 inches.

8. **Principal water bed:** sand & gravel (Gravel, sand, clay, or rock. If rock, state kind)
Depth to principal water bed 50.0 ft.; thickness of bed 50.0 ft.
If other water supplies were found, give depth to each 6.0' to 21.0' & 28.0' to 35.0'

9. **Casings:** Kind Galv. Iron; size 1-1/4; length 97.0 ft.; between depths of 0.0 and 97.0 ft.
Kind ; size ; length ft.; between depths of and ft.
Kind ; size ; length ft.; between depths of and ft.
Packers (if any): Depth at which packers were used ; kind
Screen or Strainer: Was well finished with screen? yes; kind of screen Farm well point;
length of screen 3.0 ft.; diameter 1-1/4 inches; size of openings #100, Gauze 40 m.m.

10. **Head:** Does well at present overflow without pumping? no; did it overflow when new? no;
if flowing, give pressure lb. per sq. inch; or height water will rise in a pipe ft. above surface;
original pressure or head ; if not flowing, give water level in well 6.71 ft. below surface.

11. **Pump:** Is the well pumped? no; kind of pump ;
size or capacity of pump ; kind of power

12. **Yield:** Natural flow at present (if any) none gallons per minute; original flow none gallons per minute;
well has been pumped ~~xx~~ yes-clear gallons per minute continuously for hours;
quantity of water ordinarily obtained from well none gallons per day.

13. **Use:** For what purpose is the water used? observation

14. **Quality of the water:** soft-fresh (Hard or soft, fresh or salty, etc.); is there an analysis? yes

15. **Cost of well, not including pump:** Temperature of water 59.0 °F.

Name of person filling blank G. H. von Hein
Date June 13, 1939 Address Wichita, Kansas

6—9642

On the back of this sheet give the record of the beds through which the well passes and any other facts not given above.

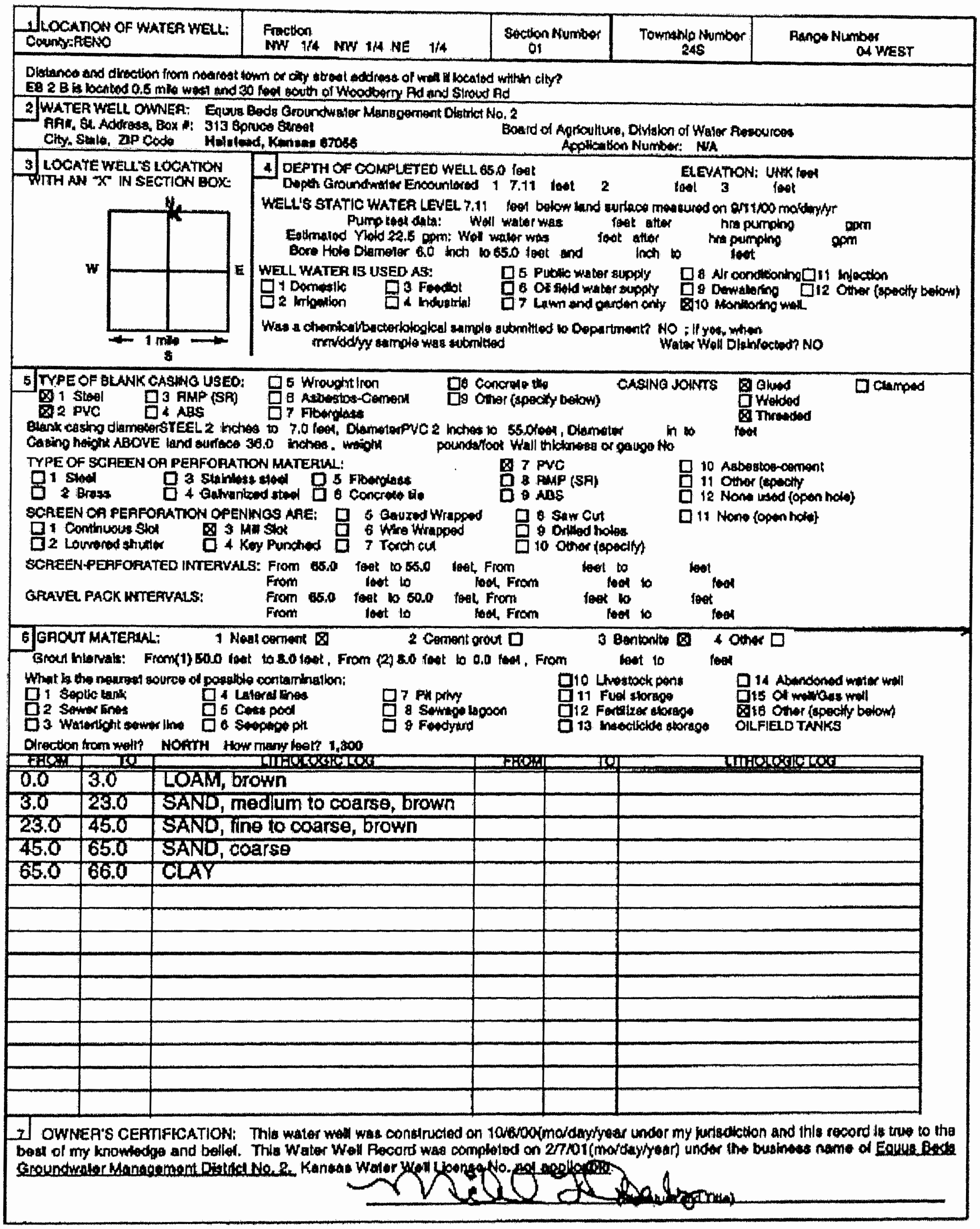
LOG OF WELL

KIND OF ROCK OR OTHER MATERIAL (Give color and tell whether hard or soft)	DEPTH, IN FEET		THICKNESS, IN FEET	REMARKS (Especially information as to water found)
	From—	To—		
Black-brown sandy loam	0.0	2.0	2.0	soil
Yellow-brown clay, silt & f. sand	2.0	6.0	4.0	c 5; s 70; fs 25
somewhat oxidized Red-brown sand & gravel	6.0	12.0	6.0	mg 10; cg 10 fs 10; ms 15; cs 35; fg 20
Gray sand & gravel	12.0	21.0	9.0	mg 10; cg 30 fs 5; ms 20; cs 15; fg 20
tightly compacted Green-gray clay & silt	21.0	28.0	7.0	c 25; s 65; fs 10
Gray sand	28.0	35.0	7.0	fg 5 s 5; fs 20; ms 40; cs 30;
do	35.0	41.0	6.0	mg 10; cg 25 fs 15, ms 20; cs 25; fg 5
tightly compacted Yellow & gray-green clay & silt	41.0	50.0	9.0	c 20; silt 80
Gray-tan sand & gravel	50.0	73.0	23.0	mg 10; cg 10 fs 15; ms 30; cs 15; fg 20
Gray-tan sand	73.0	75.0	2.0	fs 35; ms 60; cs 5
Gray-tan sand & gravel	75.0	100.0	25.0	mg 20; cg 15 fs 5; ms 30; cs 25; fg 5
tightly compacted Yellow-rose clay & silt	100.0	136.0	36.0	c 15; s 80; fs 5
Rose-red clay & silt, do	136.0	137.0	1.0	do
Dark red shale, probably Enid	137.0	138.0	1.0	100

The name of the Enid was changed to Ninnescah in Dec. 1939, JCF

U. S. GOVERNMENT PRINTING OFFICE 8—6542

B.5 Well Completion Record for EB02



1 LOCATION OF WATER WELL: County:RENO	Fraction NW 1/4 NW 1/4 NE 1/4	Section Number 01	Township Number 24S	Range Number 04 WEST

Distance and direction from nearest town or city street address of well if located within city?
EB 2 B is located 0.5 mile west and 30 feet south of Woodberry Rd and Stroud Rd

2 WATER WELL OWNER: Equus Beds Groundwater Management District No. 2
RR#, St. Address, Box #: 313 Spruce Street
City, State, ZIP Code Halstead, Kansas 67056
Board of Agriculture, Division of Water Resources
Application Number: N/A

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:

4 DEPTH OF COMPLETED WELL 65.0 feet ELEVATION: UNK feet
Depth Groundwater Encountered 1 7.11 feet 2 feet 3 feet
WELL'S STATIC WATER LEVEL 7.11 feet below land surface measured on 9/11/00 mo/day/yr
Pump test data: Well water was feet after hrs pumping gpm
Estimated Yield 22.5 gpm: Well water was feet after hrs pumping gpm
Bore Hole Diameter 6.0 inch to 65.0 feet and inch to feet

WELL WATER IS USED AS:
☐ 1 Domestic ☐ 3 Feedlot ☐ 5 Public water supply ☐ 8 Air conditioning ☐ 11 Injection
☐ 2 Irrigation ☐ 4 Industrial ☐ 6 Oil field water supply ☐ 9 Dewatering ☐ 12 Other (specify below)
☐ 7 Lawn and garden only ☒ 10 Monitoring well.

Was a chemical/bacteriological sample submitted to Department? NO ; If yes, when mm/dd/yy sample was submitted
Water Well Disinfected? NO

5 TYPE OF BLANK CASING USED: ☐ 5 Wrought Iron ☐ 8 Concrete tile CASING JOINTS ☒ Glued ☐ Clamped
☒ 1 Steel ☐ 3 RMP (SR) ☐ 6 Asbestos-Cement ☐ 9 Other (specify below) ☐ Welded
☒ 2 PVC ☐ 4 ABS ☐ 7 Fiberglass ☒ Threaded
Blank casing diameterSTEEL 2 inches to 7.0 feet, DiameterPVC 2 inches to 55.0feet , Diameter in to feet
Casing height ABOVE land surface 36.0 inches , weight pounds/foot Wall thickness or gauge No

TYPE OF SCREEN OR PERFORATION MATERIAL:
☐ 1 Steel ☐ 3 Stainless steel ☐ 5 Fiberglass ☒ 7 PVC ☐ 10 Asbestos-cement
☐ 2 Brass ☐ 4 Galvanized steel ☐ 6 Concrete tile ☐ 8 RMP (SR) ☐ 11 Other (specify
☐ 9 ABS ☐ 12 None used (open hole)

SCREEN OR PERFORATION OPENINGS ARE: ☐ 5 Gauzed Wrapped ☐ 8 Saw Cut ☐ 11 None (open hole)
☐ 1 Continuous Slot ☒ 3 Mill Slot ☐ 6 Wire Wrapped ☐ 9 Drilled holes
☐ 2 Louvered shutter ☐ 4 Key Punched ☐ 7 Torch cut ☐ 10 Other (specify)

SCREEN-PERFORATED INTERVALS: From 65.0 feet to 55.0 feet, From feet to feet
From feet to feet, From feet to feet
GRAVEL PACK INTERVALS: From 65.0 feet to 50.0 feet, From feet to feet
From feet to feet, From feet to feet

6 GROUT MATERIAL: 1 Neat cement ☒ 2 Cement grout ☐ 3 Bentonite ☒ 4 Other ☐
Grout Intervals: From(1) 50.0 feet to 8.0 feet , From (2) 8.0 feet to 0.0 feet , From feet to feet

What is the nearest source of possible contamination:
☐ 1 Septic tank ☐ 4 Lateral lines ☐ 7 Pit privy ☐ 10 Livestock pens ☐ 14 Abandoned water well
☐ 2 Sewer lines ☐ 5 Cess pool ☐ 8 Sewage lagoon ☐ 11 Fuel storage ☐ 15 Oil well/Gas well
☐ 3 Watertight sewer line ☐ 6 Seepage pit ☐ 9 Feedyard ☐ 12 Fertilizer storage ☒ 16 Other (specify below)
☐ 13 Insecticide storage OILFIELD TANKS
Direction from well? NORTH How many feet? 1,300

FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHOLOGIC LOG
0.0	3.0	LOAM, brown			
3.0	23.0	SAND, medium to coarse, brown			
23.0	45.0	SAND, fine to coarse, brown			
45.0	65.0	SAND, coarse			
65.0	66.0	CLAY			

7 OWNER'S CERTIFICATION: This water well was constructed on 10/6/00(mo/day/year under my jurisdiction and this record is true to the best of my knowledge and belief. This Water Well Record was completed on 2/7/01(mo/day/year) under the business name of Equus Beds Groundwater Management District No. 2. Kansas Water Well License No. not applicable.

(Signature and Title)

APPENDIX C: EC LOG LOCATIONS

The following Table B.1 contains the locations where the EC logs were obtained, the depths reached, and any difficulties encountered obtaining the logs. The data logs are available on a CD. The depths are reported in feet in the original EC logs.

Table C.1 EC Log Location and Depth

Owner	WELL	Latitude	Longitude	EC Log	Depth (ft)	DP Tool	Notes
Wichita	IW09	37.9986	-97.6112	LBIW09	26	HPT	String Pot broke
				LBIW09B	3.85	HPT	
				LBIW09C	108.8	HPT	Good Log
GMD#2	EB14	38.00539	-97.6295	LBEB14A	12.5	HPT	Noisy log
				LBEB14B	0	HPT	
				LBEB14B2	108.75	HPT	Noisy Log
				LBEB14EC2	81.45	EC	Good Log
GMD#2	EB08	38.00416	-97.6456	LBEB08a	126.05	HPT	Lost Probe
Wichita	P29			LBP29	124	HPT	Good Log WBurmac6-25
GMD#2	EB02	37.99865	-97.7097	LBEB02a	101.15	HPT	
				LBEB02E	101.15	EC	Good Log

Field Notes:

Two EC log were obtained at LBEB14 location. The values obtained during the first logging attempt were erratic, and it was determined that the EC probe was damaged during the pushing. A second probe was installed and a new EC log was obtained to a depth of 413 meters ASL.

APPENDIX D: EC VALUES FOR GEOCHEMCIAL PROFILES

Appendix C contains the calculated EC values for geochemical profiling samples. After the depth of the sample screen was determined, the DP-EC longs were examined. Summing the EC values over the screen length and dividing by the number of readings obtained the average value. The readings were recorded in mS/m.

Table D.1 Electrical Conductivity Data Averaged over the screen length

Sample (EClog–depth)	Average EC (mS/m)	Screen Depth (feet)
LBIW09-31	10.58	30-31
LBIW09-50	10.09	50-51
LBIW09-96	28.09	96-95
LBEB14-24	19.61	23-24
LBEB14-56	21.51	56-55
LBEB08-33	37.12	33-32
LBEB08-93	36.81	93-92
LBEB08-55	48.32	55-52
LBP29-35	26.13	34-35
LBP29-60	23.08	60-59
LBP29-95	53.16	95-94
LBEB02-40	39.65	40-41
LBEB02-54	53.28	55-54
LBEB02-83	98.27	83-84

APPENDIX E. CHLORIDE CONCENTRATIONS

Table D.1 includes the chloride concentrations associated with the samples taken from sampling locations: LBIW09, LBEB14, LBEB0, LBP29, and LBEB02. If there was enough fluid volume, the sample was filtered with 0.45µM cellulose nitrate membrane (Sanders, 1998). The sample was obtained with a polyethylene bottle, which was triple-rinsed with the fluid sample and sealed (Sanders, 198). The 25 mL of the fluid sample was poured into a beaker triple-rinsed with sample fluid and field-tested with the Chloride QuanTab® Test Strip. 30-600 mg/L (Hach, 2009). Once the mg/L range was determined, the sample was tested with a Chemetrics field titrette sampler with the appropriate measuring range, according to the manufacturers instructions (Chemetrics, 2009). The Chemetrics Kits information included below:

Kit	Range	Lot Number	Expiration Date
Chloride K-2002	2-20 mg/L	73790/73795/12	Dec. 2011
Chloride K-2020	20-200 mg/L	72241/2	April 2011
Chloride K-2050	50-500 mg/L	71040/12	2011

The chloride concentrations in several samples exceeded the range of the Chemetrics kit. In these cases (LBEB08, LBP29, and LBEB02), the sample was diluted by ratio 1:1, 1:2 and 1:4 using a triple-rinsed glass 250 mL graduated cylinder and deionized water until the concentration was in a range measurable by the Chemetrics titrette.

Table E.1 Chloride Field Concentrations Week 2 - 7/7-7/8/2009

Well Sample	Screen Depth (feet)	Cl- strip (mg/L)	Diluted	Cl- titrets (mg/L)	Diluted	Filtered
LBEB02-40F-1	40-41	580				Y
LBEB02-40FD1:9	40-41	750	75	700	70	Y
LBEB02-54F-1	54-55	<608				Y
LBEB02-54FD1:3	54-55	1132	282	1200	300	Y
LBEB02-83U	83-84	164		175		N

Indicates calculated value determined from diluted solution.

Table E.2 Chloride Field Concentrations Week 1 6/23 –6/26/2009

Well Sample	Screen Depth (feet)	Cl- strip (ppm)	Average Diluation (ppm)	Cl- titrets (ppm)	Diluted	Filtered
LBIW09-31-1	31-30	<31		6		n
LBIW09-31-2	31-30	<31		6		n
LBIW09-50-1	50-49	<31		6.2		n
LBIW09-96F-1	96-95	193		175		f
LBIW09-96F-2		178		200		f
LBEB14-24F-1	24-23	75		70		y
LBEB14-24F-2	24-23	84		75		y
LBEB56-56F-1	56-55	84		82		y
LBEB14-56F-2	56-55	75		75		y
LBEB14-101F-1	*101-100*	*<490*		*<500*		*y*
LBEB14-101aFD1:1-1	101-100	544	272	520	260	y
LBEB14-101aFD1:1-2	101-100					y
LBEB14-101bFD1:1-1	*101-100*	*470*	*235*	*500*	*250*	*y*
LBEB14-101bFD1:1-2	101-100	564	282	600	300	y
LBEB08-33F-1	33-32	226		225		y
LBEB08-33F-2	33-32	226		225		y
LBEB08-55U-1	*55-52*	*<31*		*17*		*n*
LBEB08-55U-2	*55-52*	*<31*		*14*		*n*
LBEB08-55F-1	*55-52*	*<31*		*11*		*y*
LBEB08-55F-2	*55-52*	*<31*		*10*		*y*
LBEB08-93F-1	*93-92*	*>608*		*>500*		*y*
LBEB08-93FD1:1-1	93-92	488	244	500	250	y
LBEB08-93FD1:1-2	93-92	524	262	520	260	y
LBP29-35F-1	35-34	226		230		y
LBP29-35F-2	35-34	226		230		y
LBP29-60F-1	60-59	200		205		y
LBP29-60F-2	60-59	200		205		y
LBP29-95F-1	*95-94*	*>608*		*>500*		*y*
LBP29-95F-2	*95-94*	*>608*		*>500*		*y*
LBP29-95FD1:1-1	*95-94*	*1130*	*565*	*>500*	*>500*	*y*
LBP29-95FD1:3-A-1	95-94	1160	290	1200	300	y
LBP29-95FD1:3-B-1	95-94	1128	282	1100	275	y
LBP29-95FD1:3-B-2	95-94	1088	272	1120	280	y

indicates calculated value determined from diluted solution by multiplying the dilution ppm by the magnitude of dilution.

The suffixes on the samples include: F-filtered, D-diluted, 1:3 one part sample to three parts dionized water, A,B,C,D –alpha notation that distinguishes different dilution solutions sampled. Italics indicate invalid sample due to improper technique.

APPENDIX F: SPECIFIC CONDUCTANCE FIELD MEASUREMENTS

Table E.1 determines the specific conductance of the samples obtained from all sampling depths. After the sample was filtered, approximately 50 ml of the sample was placed in a triple-rinsed polyethylene beaker and tested with a Hanna EC/TDS/and Temperature meter (H198311) (Hanna, 2009). The meter was placed in the sample and agitated. The reading was recorded once the timer indicated the testing was complete. If dilution was necessary, the sample was diluted using a glass 250 mL graduated cylinder and deionized water, and the sample was retested. Readings were given in mg/L and degrees centigrade. All containers were tripled rinsed with the fluid that was being tested.

Table F.1 Specific Conductance Field Data Week 2 7/7-7/9/2009

Well Sample	Screen Depth (feet)	Specific Conductance (mg/L)	Filtered
LBEB02-40F-1	40-41	2355	y
LBEB02-40FD1:9	40-41	2840	y
LBEB02-54F-1	54-55	3793	y
LBEB02-54FD1:3	54-55	4172	y
LBEB02-83U	83-84	1184	n

Italics - invalid - improper technique or bad analysis

Indicates calculated value determined from diluted solution.

Table F.2 Specific Conductance Data Week 1 - 6/23-6/26/2009

Well Sample	Screen Depth (feet)	Specific Conductance (ppm)	Filtered
LBIW09-31-1	31-30	167	n
LBIW09-31-2	31-30	166	n
LBIW09-50-1	50-49	190	n
LBIW09-96F-1	96-95	555	Y
LBIW09-96F-2		556	Y
LBEB14-24F-1	24-23	513	Y
LBEB14-24F-2	24-23	525	Y
LBEB14-56F-1	56-55	341	Y
LBEB14-56F-2	56-55	346	Y
LBEB14-101F-1	*101-100*	*1070*	*Y*
LBEB14-101aFD1:1-1	101-100	1154	Y
LBEB14-101aFD1:1-2	101-100		Y
LBEB14-101bFD1:1-1	*101-100*	*1188*	*Y*
LBEB14-101bFD1:1-2	101-100	1196	Y
LBEB08-33F-1	33-32	913	Y
LBEB08-33F-2	33-32	913	Y
LBEB08-55U-1	*55-52*	*281*	*N*
LBEB08-55U-2	*55-52*	*271*	*N*
LBEB08-55F-1	*55-52*	*270*	*Y*
LBEB08-55F-2	*55-52*	*269*	*Y*
LBEB08-93F-1	*93-92*	*915*	*Y*
LBEB08-93FD1:1-1	93-92	1064	Y
LBEB08-93FD1:1-2	93-92	1062	Y
LBP29-35F-1	35-34	658	Y
LBP29-35F-2	35-34	660	Y
LBP29-60F-1	60-59	578	Y
LBP29-60F-2	60-59	589	Y
LBP29-95F-1	*95-94*	*1917*	*Y*
LBP29-95F-2	*95-94*	*1917*	*Y*
LBP29-95FD1:1-1	*95-94*	*2078*	*Y*
LBP29-95FD1:3-A-1	95-94	2184	Y
LBP29-95FD1:3-B-1	95-94	2116	Y
LBP29-95FD1:3-B-2	95-94		Y

Suffix F indicates a filtered sample. D is a diluted sample. The ratio indicated the proportions of deionized water to the sample. Alpha and numeric suffixes indicate the diluted sample. Italics – invalid data due to improper technique.

APPENDIX G: SPECIFIC CONDUCTANCE LAB MEASUREMENTS

Goal: To determine the specific conductance of samples obtained from several locations with a recalibrated field ED/TDS and Temperature meter and determine the range of the EC/TDS Meter. This was done to validate the measurements obtained in the field.

Method: Approximately 50 ml of the sample was placed in a triple-rinsed polyethylene beaker and tested with a Hanna EC/TDS/and Temperature meter (H198311) (Hanna, 2009). The reader was placed in the sample and agitated after the red button was pressed. The reading was recorded once the timer indicated the testing was complete. If dilution was necessary, the sample was diluted using a glass 250 ml graduated cylinder and deionized water, and the sample was retested. Readings were recorded in mg/L and degrees centigrade. All containers were tripled-rinsed with the fluid that was being tested prior to using the beaker.

Stock Solutions: Meter was calibrated using solution created using a 745.6 mg KCl (anhydrous KCl) mixed with 1000 ml diluted H_2O. Calibration was set at 1412 µS/cm at 23.7 degrees centigrade.

Table G.1 Specific Conductance Lab May 2010

Well Sample	Summer (2009) (uS/cm)	May 5/2010 (uS/cm)	Diluted May13/2010 (uS/cm)
LBIW09-31	343	343	
LBIW09-50	388	392	
LBIW09-96	1121	1121	
LBEB14-24	1022	1038	
LBEB14-56	661	668	
LBEB14-101	2104	**2112**	2240
LBEB08-33	1784	1790	1952
LBEB08-55	542	526	
LBEB08-93	1890	1889	2000
LBP29-35	1305	1327	1406
LBP29-60	1186	1208	
LBP29-95	3929	3878	4148
LBEB02-40	2355	2370	2470
LBEB02-54	3794	3847	4118
LBEB02-83	1184	1042	

APPENDIX H: SAMPLES SENT TO OUTSIDE LAB

Table H.1 Samples Sent to Outside Lab

Sample Name	Date Collected	Bottle Size	Sample Size (ml)	Serv-Tech Value Mg/L
LBIW09-31-1	6/22/2009	500 ml	300	10
LBIW09-50-1	6/22/2009	500 ml	250	9.8
LBIW09-96F-1	6/26/2009	250 ml	200	170
LBEB14-24F-2	6/23/2009	250 ml	250	64
LBEB14-56F-2	6/23/2009	250 ml	250	69
LBEB14-101F-1	6/24/2009		250	490
LBEB08-33F-1	6/24/2009	250 ml	240	190
LBEB08-55F-1	6/24/2009	250 ml	200	16
LBEB08-93F-1	6/24/2009	250 ml	150	420
LBP29-35F-2	6/25/2009	250 ml	200	210
LBP29-60F-2	6/25/2009	250 ml	200	200
LBP29-95F-1	6/25/2009	250 ml	200	*1000*
LBEB2-41	7/7/2009			520
LBEB2-54	7/7/2009			970
LBEB2-83	7/8/2009			160

Italics denote improper sampling technique

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Date

"An Assessment of Direct-push Electrical Conductivity for Identifying Chloride Migration Pathways in the Equus Beds Aquifer"

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