Application of the HPT-GWS for Hydrostratigraphy and Water Quality Investigations

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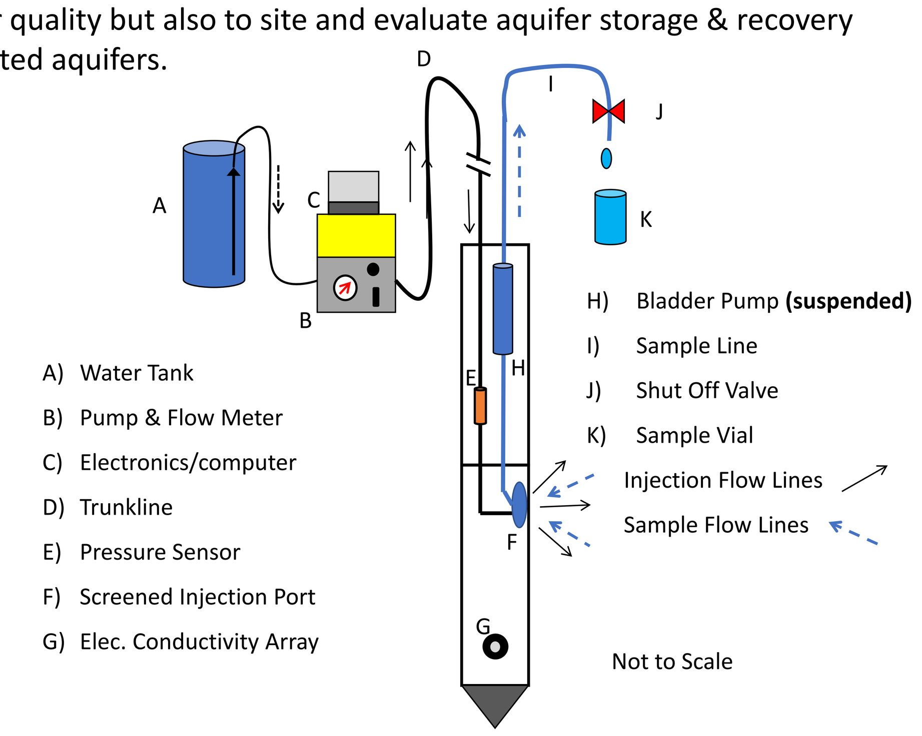
Purging and monitoring water quality before sampling, Location W03, July 2015

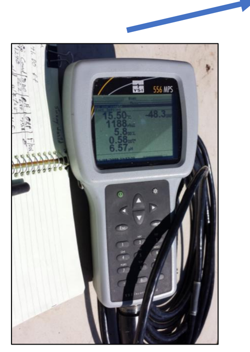
Background/Objectives. Many years of work in site characterization have clearly shown that high resolution information about site hydrostratigraphy and contaminant distribution are critical to the development of an accurate conceptual site model and achieving remediation objectives in a timely manner. Over the past few years the hydraulic profiling tool (HPT) with its injection pressure logs and tandem electrical conductivity (EC) logs has proven to be a valuable technology for detailed characterization of site hydrostratigraphy in unconsolidated formations. A new HPT probe has been designed with multiple injection ports that also may function as sampling ports. This new probe is called the **Hydraulic Profiling Tool-Ground Water Sampler**. Preliminary testing of the HPT-GWS was conducted in an alluvial aquifer in central Kansas at depths approaching 100ft (30m) to evaluate performance of the new tool for defining hydrostratigraphy and groundwater profiling for water quality. Review of EC and Pc logs and water quality data found that the DP EC logs follow Archie's Law. As such The EC logs can be used in contrast with Pc logs to assess formation water quality. Not only can the HPT-GWS be used to assess water quality but also to site and evaluate aquifer storage & recovery systems (ASR) in unconsolidated aquifers.



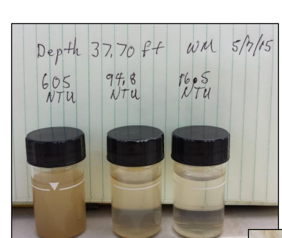
Left: Photo of the HPT-GWS probe with 20 screened injection-sample ports over approximately 4-inches (10cm) vertical length.
Above: Schematic of the HPT-GWS system and operation.

HPT-GWS Sampling in the Field

When the water level is shallow a peristaltic pump may be used to purge and sample. For deeper water levels (>~25ft) a down-hole bladder pump may be used with an electrical actuator (12V).



Water quality may be monitored to stability if desired using conventional meter and flow cell.



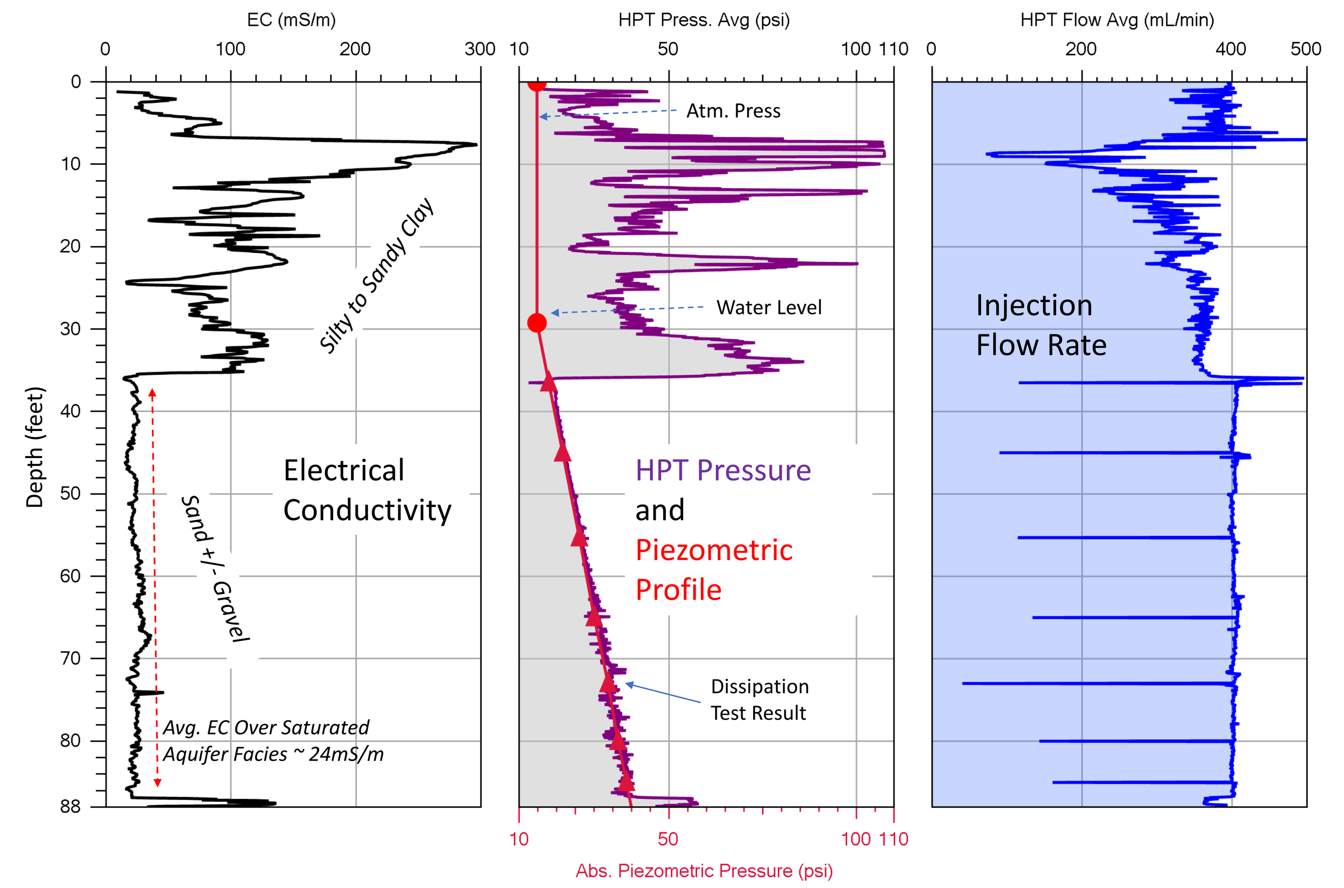
Sample turbidity typically starts out high, but in coarse grained formations may drop below 20 NTU if time for purging is available.

Collect samples as usual

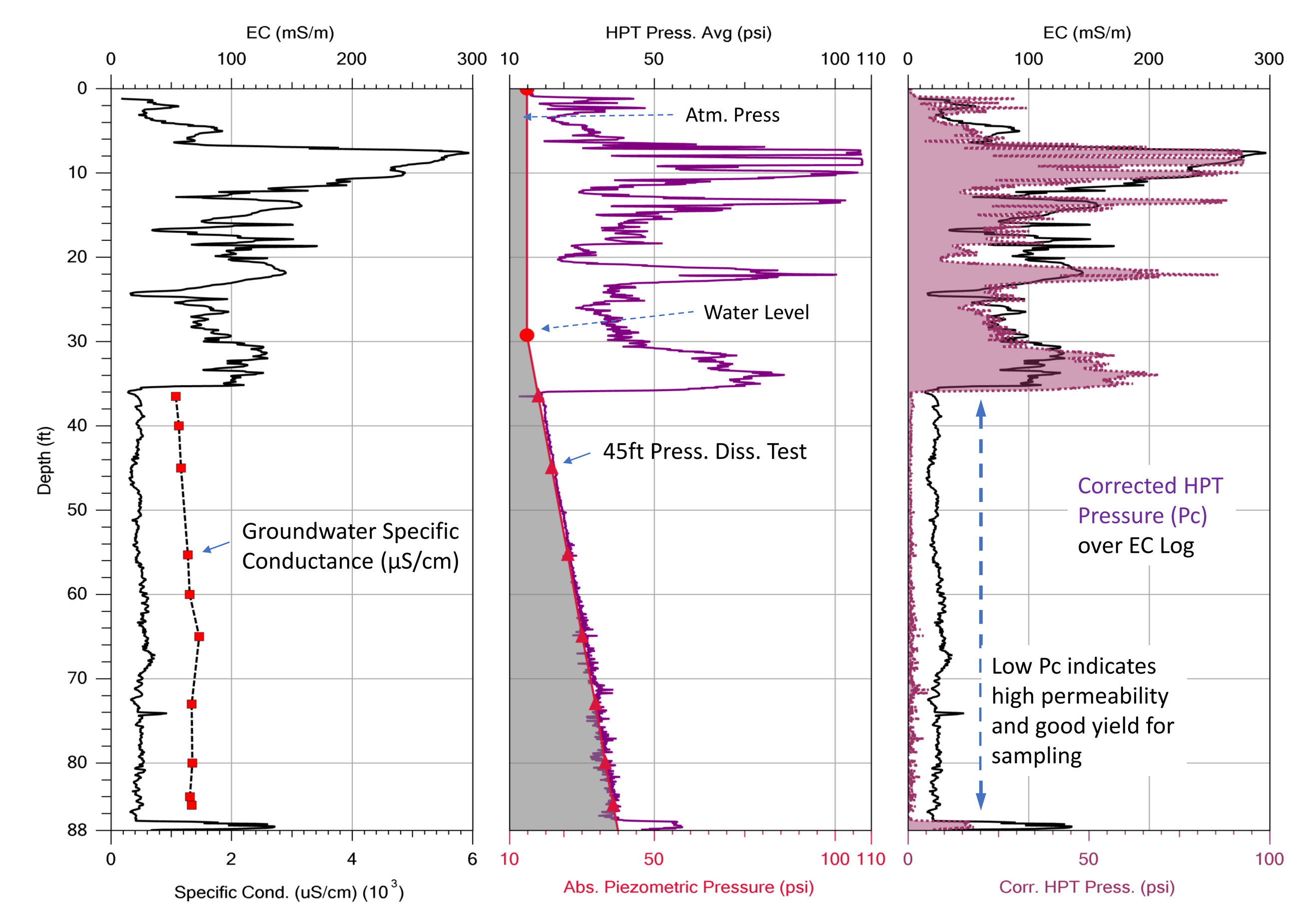
Sample flow rates are controlled primarily by formation permeability but also depth to water and depth of the pump below grade. Flows rates in clean sandy formations typically range from about 100ml/min to as much as 300ml/min under good conditions.

HPT-GWS Log Interpretation and Selection of Groundwater Sampling Intervals

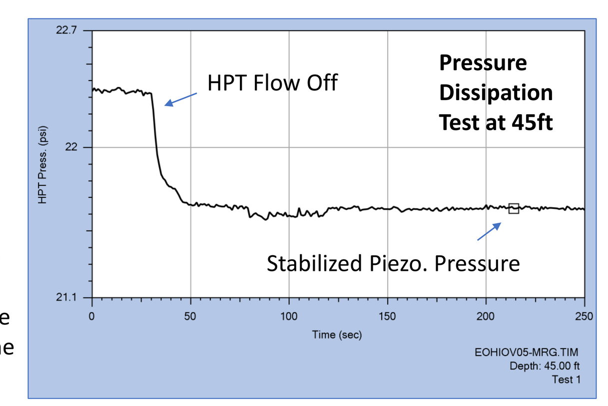
NOTE: Several figures and diagrams in this document are modified or after McCall et al. 2017: GWMR Vol. 37 no. 1, pages 78-91.



Background Log: Many (but not all) clays exhibit high electrical conductivity and so clay content will often control the bulk EC of fresh water formations. This is the case at the background location at this site where high EC readings indicate high percentages of clay in the bulk formation (confirmed with samples). Conversely low EC indicates a dominantly coarse-grained formation. Of coarse fine grained formations have lower permeability and so result in higher injection pressures for the HPT log while coarse grained formations require lower injection pressures. However, as the probe advances below the water table the observed HPT pressure increases as hydrostatic pressure increases. Probe advancement may be halted at desired depths to perform a pressure dissipation test. This gives a measurement of the hydrostatic pressure at that depth.

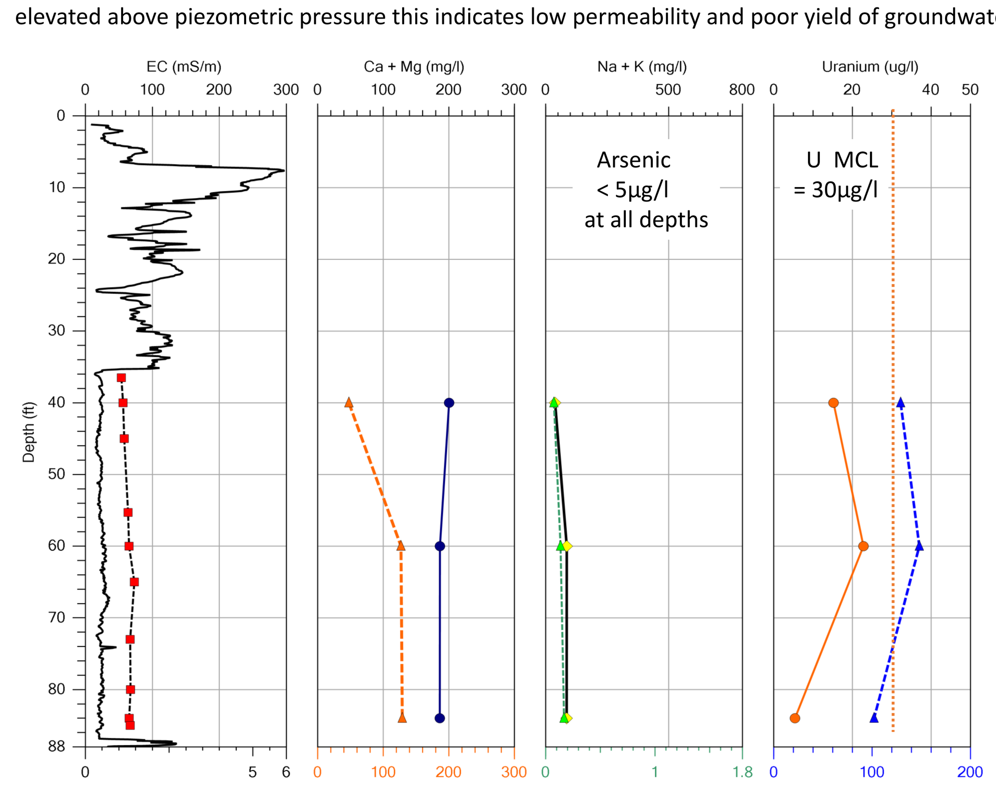


Stabilized groundwater specific conductance was measured at multiple depths where dissipation tests were obtained. Here we see the groundwater specific conductance is relatively low and flat and mimics the trend of the EC log in the saturated coarse-grained facies.



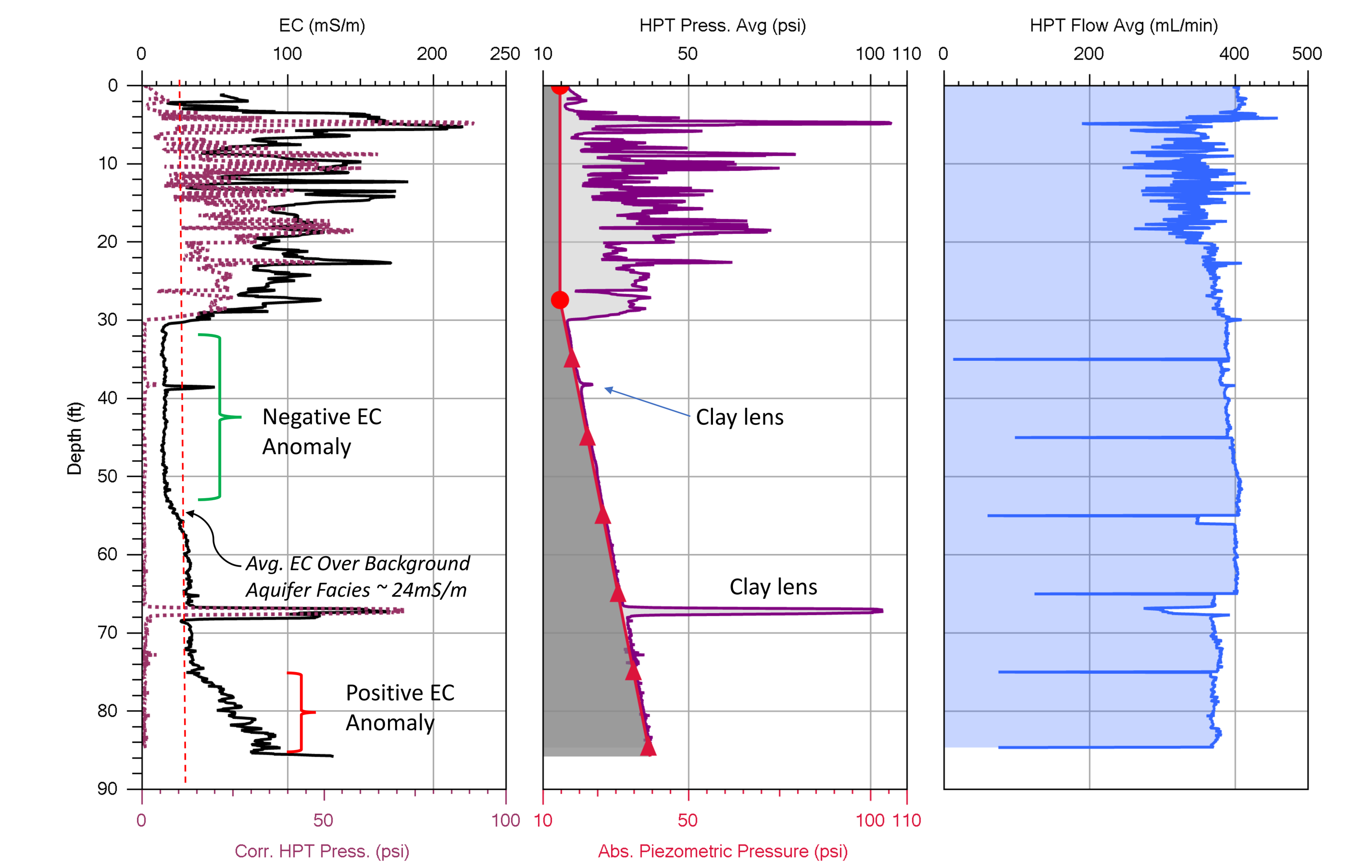
Dissipation tests run at multiple depths were used to plot the piezometric profile. The DI Viewer software allows you to back calculate the water level from the dissipation test data. The software also can subtract the atmospheric + piezometric pressure from the total HPT pressure at each depth to obtain the corrected HPT Pressure (Pc). We see in the coarse-grained facies that Pc is low and flat like the EC log and groundwater specific conductance at the background log.

Where can I sample groundwater? When the total HPT pressure is at or near the piezometric pressure profile in the saturated zone the permeability is high and sampling can be performed (about 37 to 86ft zone here). However, if the HPT pressure is elevated above piezometric pressure this indicates low permeability and poor yield of groundwater (about 30 to 37ft here).

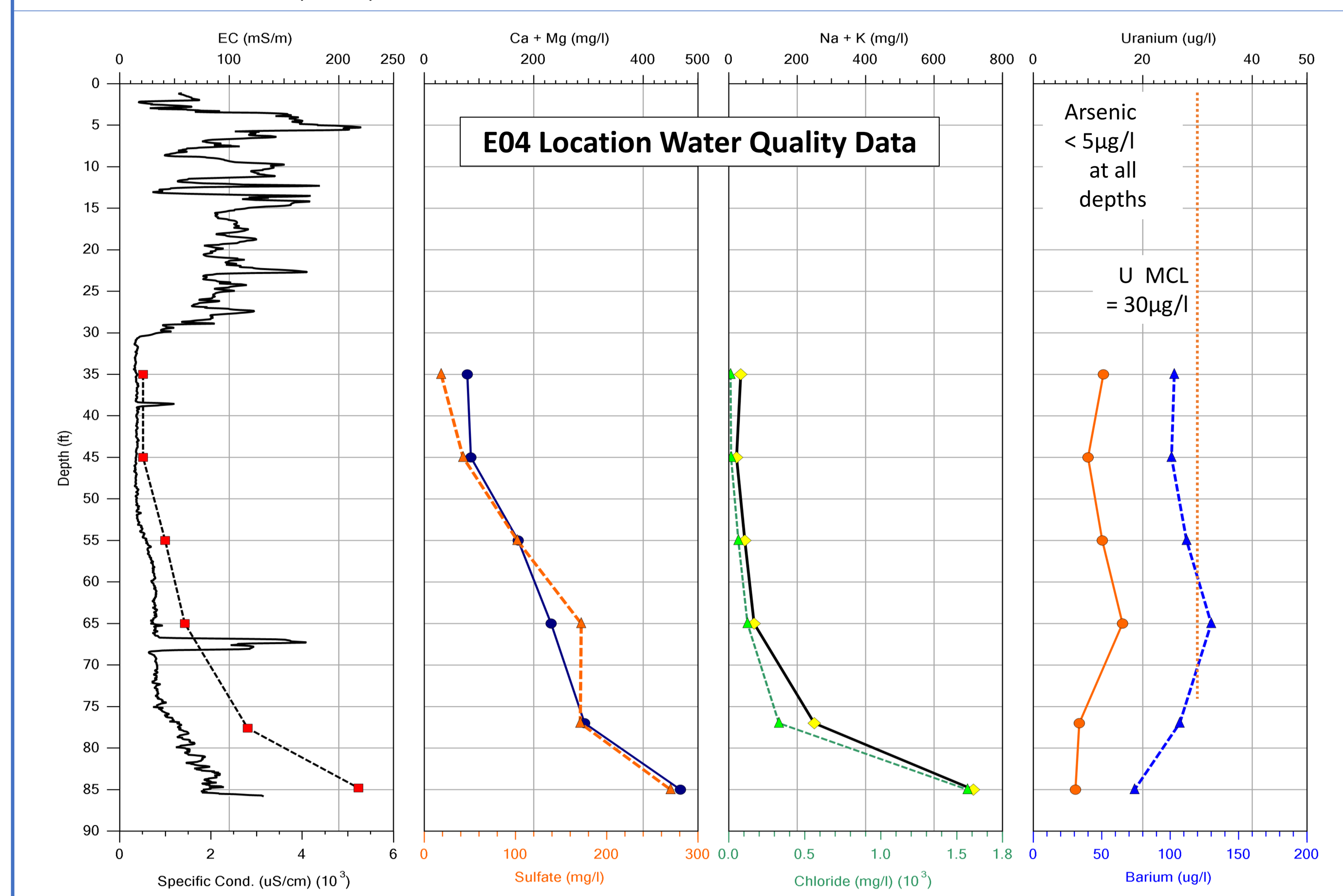


Background water quality samples were collected at 3 depths in the coarse-grained facies after water quality parameters had stabilized. The divalent cations (calcium + magnesium) and anion (sulfate) and the monovalent cations (sodium + potassium) and anion (chloride) exhibit relatively low concentrations at the background location. They exhibit flat profiles which is consistent with both the groundwater specific conductance and EC log profiles. Arsenic = ND and uranium was below its maximum contaminant level at all depths and Barium was < 200µg/l.

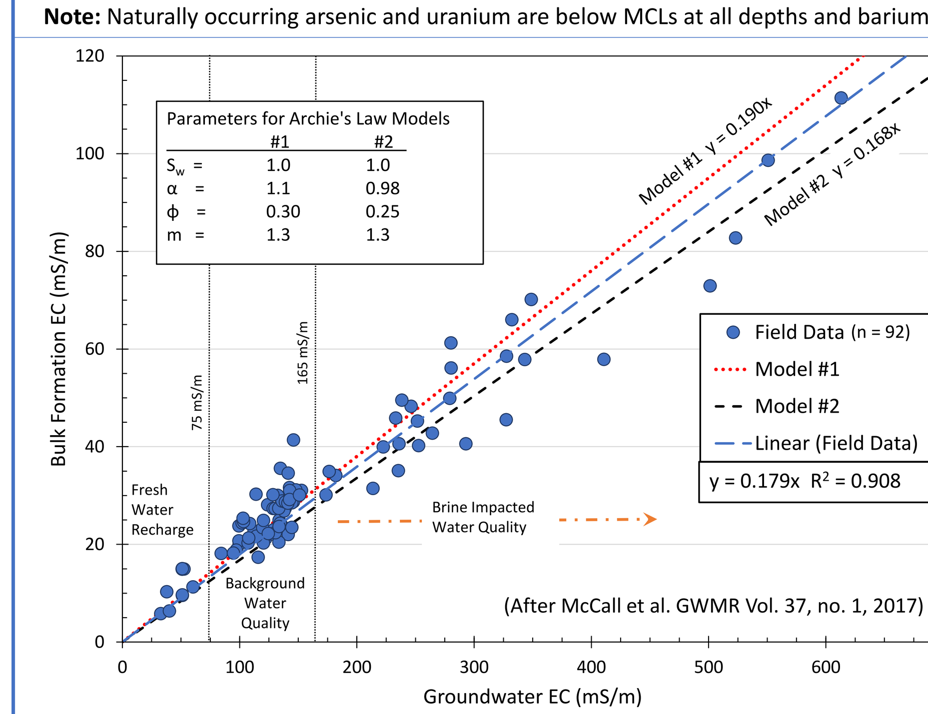
Assessing Water Quality Impacts by Comparing & Contrasting Direct Push Electrical Conductivity (EC) and HPT Corrected Pressure (Pc) Logs



Log Location E04: The HPT pressure log is similar to the background location displaying higher pressure in the silty-sandy clays above 30ft and HPT pressure following the piezometric pressure in the deeper sands and gravels, with the exception of a couple of clay lenses. The HPT corrected pressure (Pc) log is again flat in the saturated sand & gravel (aquifer) facies, with the exception of the 2 clay lenses. However the EC log displays some different results. Between approximately 30 to 55ft depth the EC is below that observed at the background log. Conversely, between about 75 to 88ft depth the EC is higher than the level observed at the background location. Looking at the Pc log we see it is low and flat across the entire 30-87ft interval, with the exception of the 2 clay lenses. The low/flat Pc log indicates high permeability sand and gravel with no significant fines present over this interval. This means that the variation in the EC over the saturated aquifer facies is not due to changes in the amount of clay in the formation. This condition defines an EC anomaly. Comparing this EC log to the average EC over the saturated facies at the background location (red dashed line) indicates we have both a positive and a negative EC anomaly at this location. Let's see if the water quality data from this location can help us explain the EC anomalies we have observed.



Water Quality Data E04 Location: This data displays some notable differences as compared to the background location. The groundwater specific conductance is below background levels (~1000µg/l) over the 35-45ft zone, similar to background in the 55-65ft zone and well above background below 75ft. Looking at the major element cation and anion data we see these dissolved solids are controlling the groundwater specific conductance and also appear to be controlling the bulk formation EC in the saturated sand & gravel (aquifer facies) of the formation. This behavior is similar to that observed by Archie (1942) for brine saturated sandstones in petroleum reservoirs. Lets look at log and water quality data from across the site to evaluate this relationship.
Note: Naturally occurring arsenic and uranium are below MCLs at all depths and barium is less than 200µg/l.



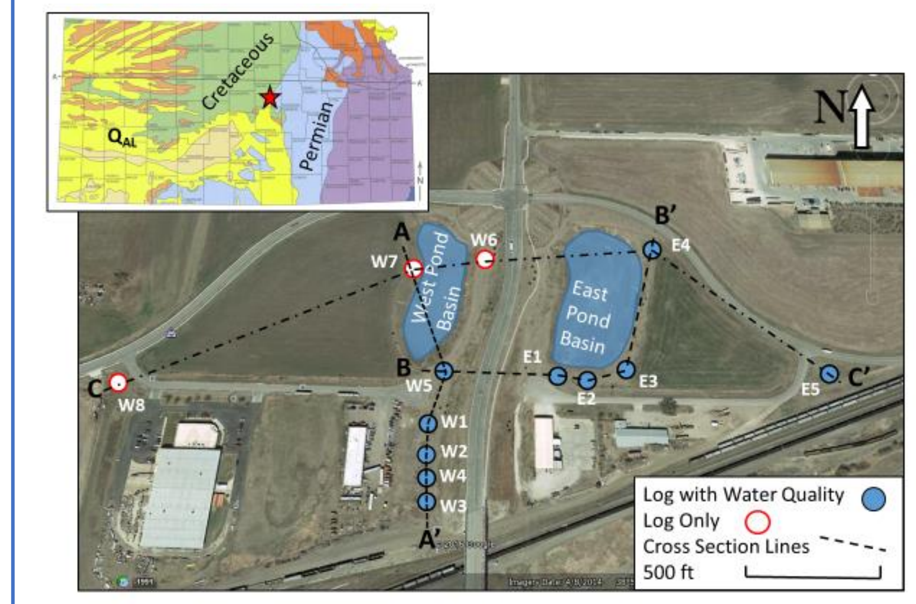
Archie's Law (Archie 1942) defined for electrical conductivity :

$$C_B = (1/\alpha)\, C_w\, \varphi^m\, S_w^{\,n}$$

C_B = EC of the fluid saturated bulk formation
C_w = EC of the brine (groundwater in this case)
S_w = brine saturation of the fm
n = saturation exponent
α = tortuosity factor (typically between 0.5 and 1.5)
φ = porosity
m = cementation exponent (typically 1.3 for unconsolidated sands)

Archie's Law & Relationship between Bulk Formation EC and Groundwater EC: Archie's Law was developed for brine saturated sandstones where sodium chloride was in the range of ≥20,000mg/l (Archie 1942, Hallenberg 1998). HPT-GWS logs with water quality profiles were obtained at 10 locations at this site (see map). Groundwater specific conductance is converted from microSiemens/cm to milliSiemens/m (EC units) simply by multiplication of ten (10X 1µS/cm = 1mS/m) for the above plot. We averaged bulk formation EC for 1ft (30cm) intervals centered on each sample depth to develop the above plot. Archie's Law assumes EC ≡ 0 for formation solids. This yields an R2 = 0.908 for the field data. Using the measured groundwater EC data we substituted in two sets of appropriate values for porosity and tortuosity with groundwater saturation = 1.0 and cementation factor = 1.3 (Archie 1942) to calculate the bulk formation EC. These two models effectively bracket the field data indicating that Archie's Law applies in this geological setting. This relationship allows us to use variations in EC (contrasted with Pc) in saturated sands & gravels to identify changes in water quality due to changes in concentrations of major element dissolved solids.

Cross Sections with HPT-GWS Log and Water Quality Profiles to Define Aquifer Recharge and Brine Impact on the Aquifer Facies



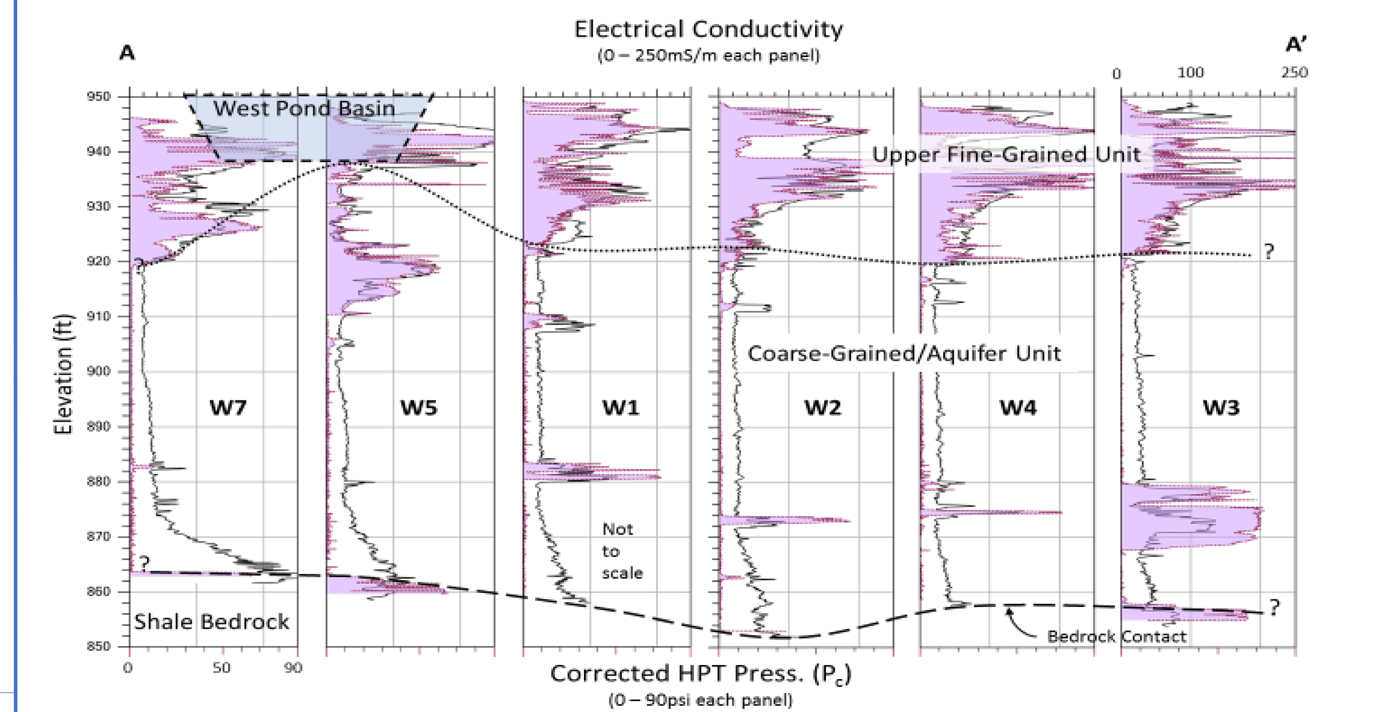
Site Map & Background

Red star shows site located in the Quaternary Age alluvial deposits in Saline Co., KS which unconformably overly the Permian Age Ninnescah shale. The Permian fm is mined for salt south & east of this area.

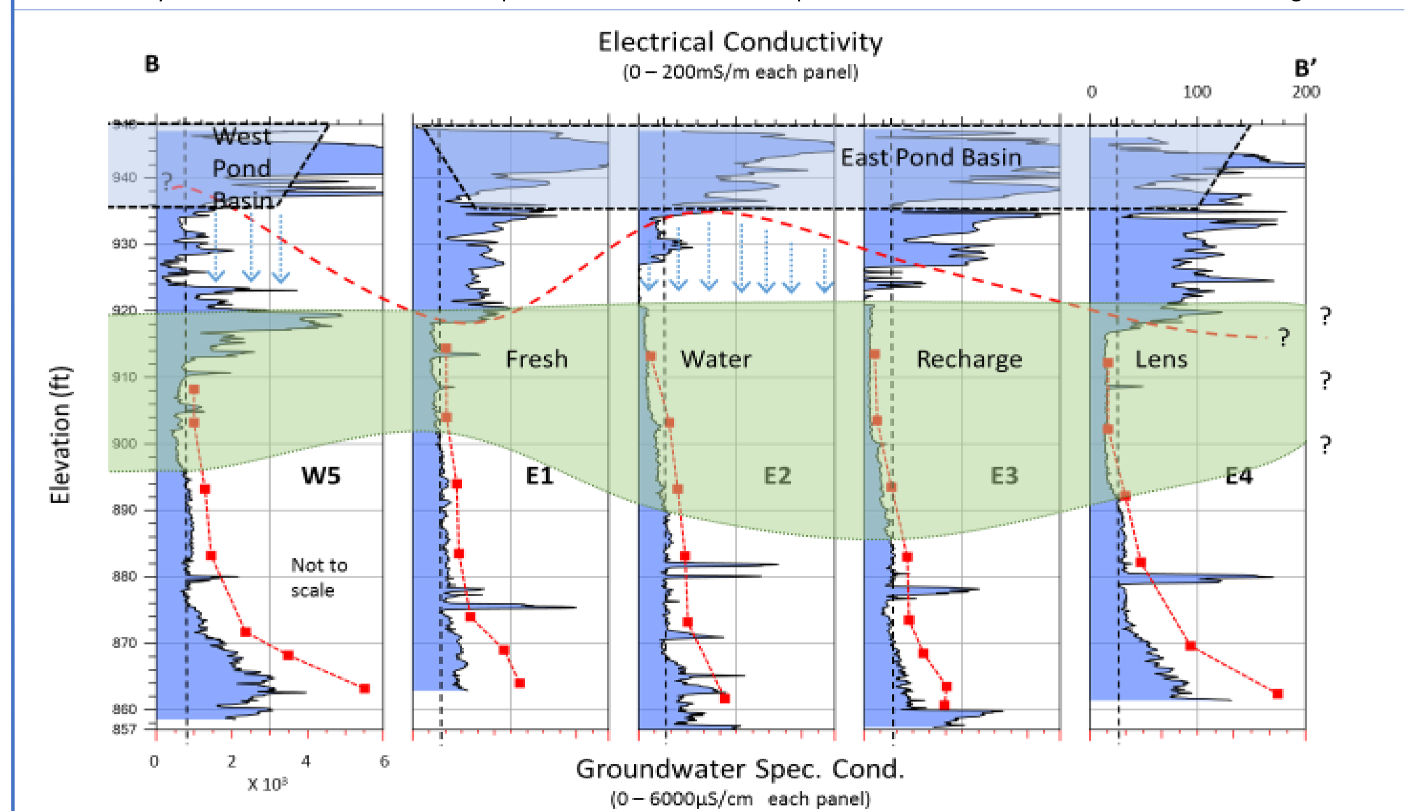
The City of Salina installed storm water retention basins when the new viaduct was built over the railroad.

Cross sections A-A', B-B' and C-C' are identified on the map along with log locations.

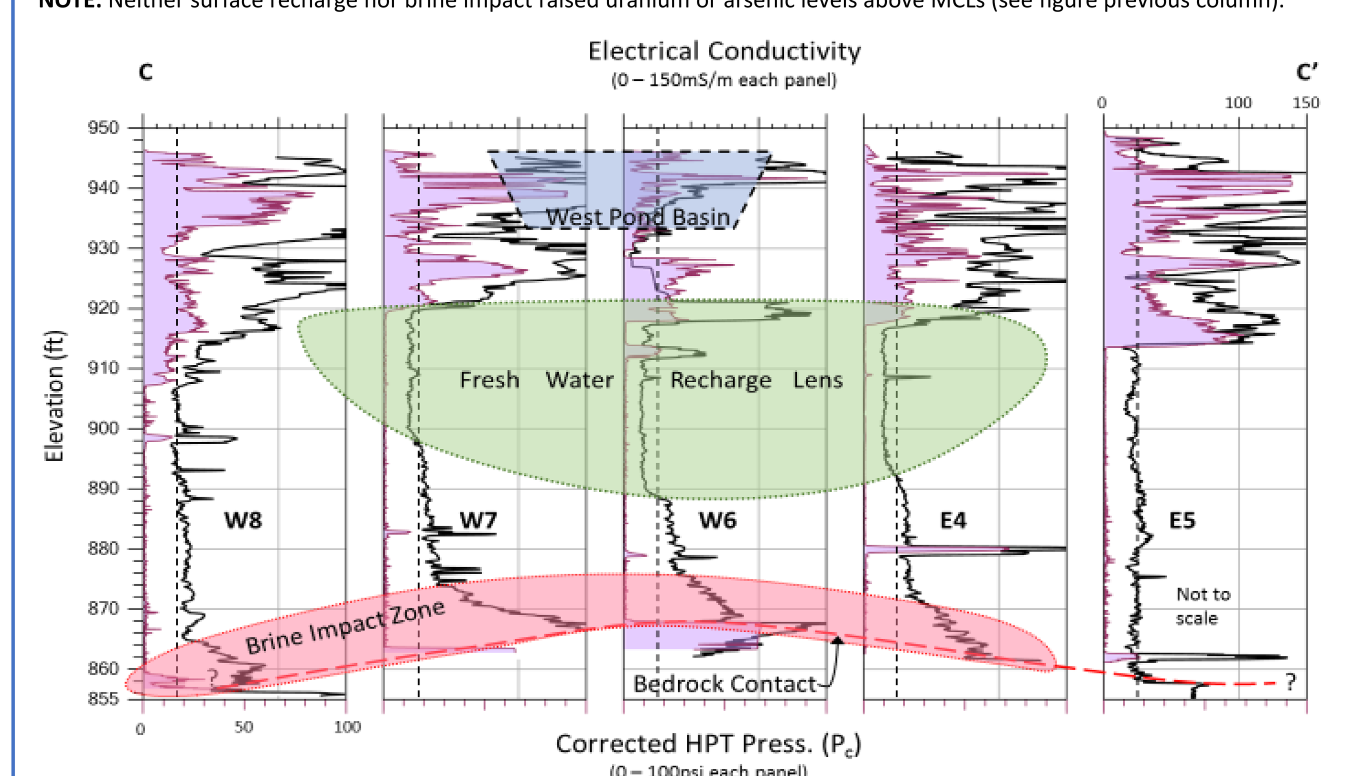
Generalized Kansas Geologic map after KGS 2000.



Site Hydrostratigraphy Based on HPT-GWS Logs: Elevated pressure (Pc) and high EC in the upper part of the formation identify the Upper Fine-Grained facies consisting of silty-sandy clays. Increase in Pc and EC and reduced speed define contact with the underlying shale bedrock. Low Pc defines the coarse-grained aquifer facies at the site. Clay lenses in the aquifer facies are identified by increased Pc and EC values. Deeper in the formation brine impact form the shale renders EC useless for lithologic ID.



Mapping Water Quality: Black dashed vertical line on each log shows background EC of aquifer facies (~24mS/m) and allows us to identify both positive and negative EC anomalies relative to background water quality. ABOVE: Negative anomalies define rain water recharge to aquifer from storm water basins. Specific conductance of groundwater & major element dissolved ions from samples verify log interpretation. BELOW: Contrasting Pc with the EC logs provides confirmation of EC anomalies due to fresh water recharge or brine impact at base of aquifer.
NOTE: Neither surface recharge nor brine impact raised uranium or arsenic levels above MCLs (see figure previous column).



Summary: 1) HPT-GWS allows for EC and Pc logging with simultaneous water quality profiling and sampling at the µg/l level. 2) The logs may be used for high resolution hydrostratigraphic interpretation. 3) DP EC logs follow Archie's Law in saturated, coarse-grained aquifer facies. 4) Contrasting EC to Pc logs helps to identify EC anomalies. 5)Stabilized water quality data and targeted sampling confirms EC anomalies and contaminant distribution. 6) This technology also may be used to site and study aquifer storage and recovery (ASR) systems in unconsolidated aquifers.