Slide 1

Use of Direct Push Logging & Sampling to Characterize a Groundwater Recharge Zone

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Basic field set up for conducting HPT-GWS logging/sampling near the N. Ohio bridge. “Matt” worked with us as a summer intern. The original purpose of our project was to test the new 20 port HPT-GWS probe and sampling system. During our field testing we learned some unexpected details about the subsurface aquifer in this area.

I would also like to acknowledge the support of Martha Tasker, Director of Utilities and Dan Stack, City Engineer at the City of Salina, KS for their support and permission to access city property to conduct this project.

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Direct Push (DP) Method

The hydraulic hammer, hydraulic slides and vehicle weight are used to advance the tools into unconsolidated materials.

No rotation or cuttings removal.

For those not familiar with DP methods … Percussion from the hammer and static force of the vehicle weight combine to repack the soil particles allowing for advancement of the tools through the unconsolidated soils and sediments. Depending on local soils and geologic conditions tools can be advanced to depths of 50 to 100+ feet. Under very good conditions tools have been advanced over 200ft. If bedrock is at 3ft below grade, you can only go 3ft. Must understand local soils & geology to determine if DP is a good method to use.

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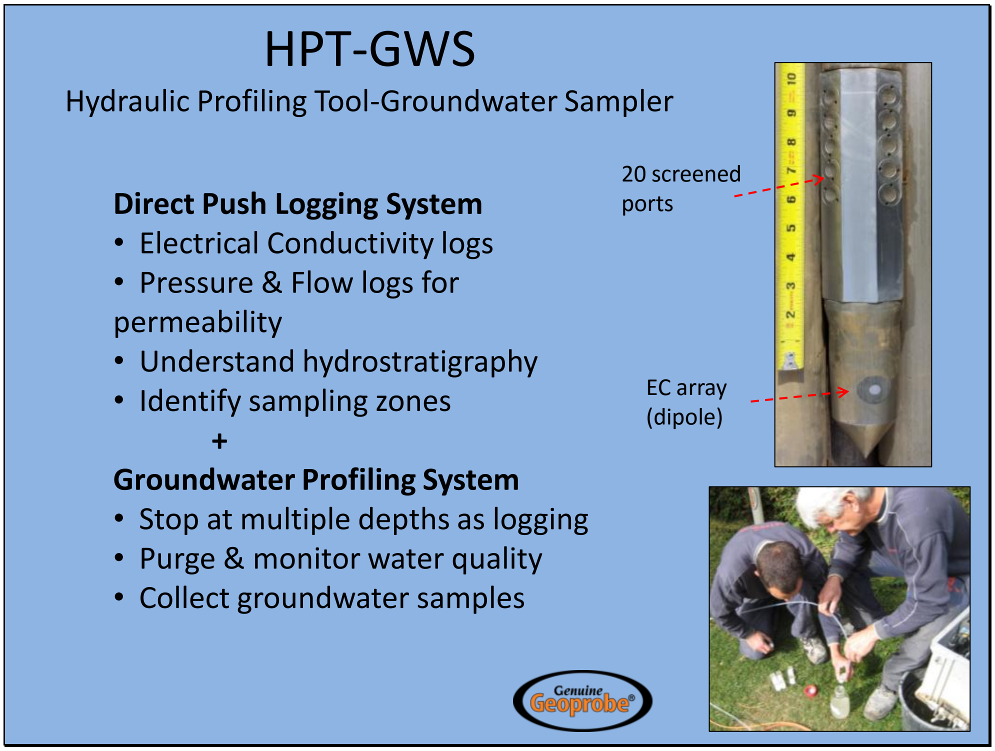

We used the HPT-GWS system to conduct the logging and sampling for this project. This is a DP logging system and a DP groundwater profiling system in one tool. DP tools are for penetration of unconsolidated soils and sediments. These tools will not penetrate consolidated rock.

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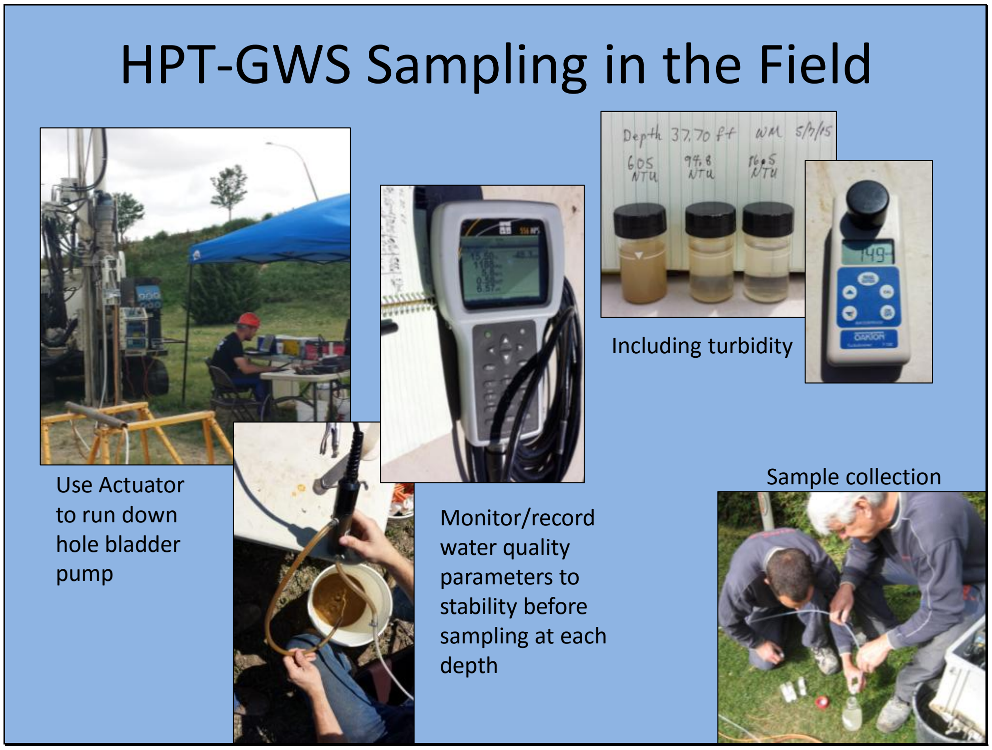

At this site we used the mechanical bladder pump (MB470) to conduct the purging and sampling. Flow from the sample line was directed into a flow cell and water quality parameters, including specific conductance were monitored to stability before samples were collected. At many sampling depths turbidity dropped below 20NTU before sampling was conducted. Samples were collected in appropriately preserved bottles. All samples for major element cation & anion analyses and trace metals were filtered with a 0.45 micron filter as they were collected directly into preserved bottles.

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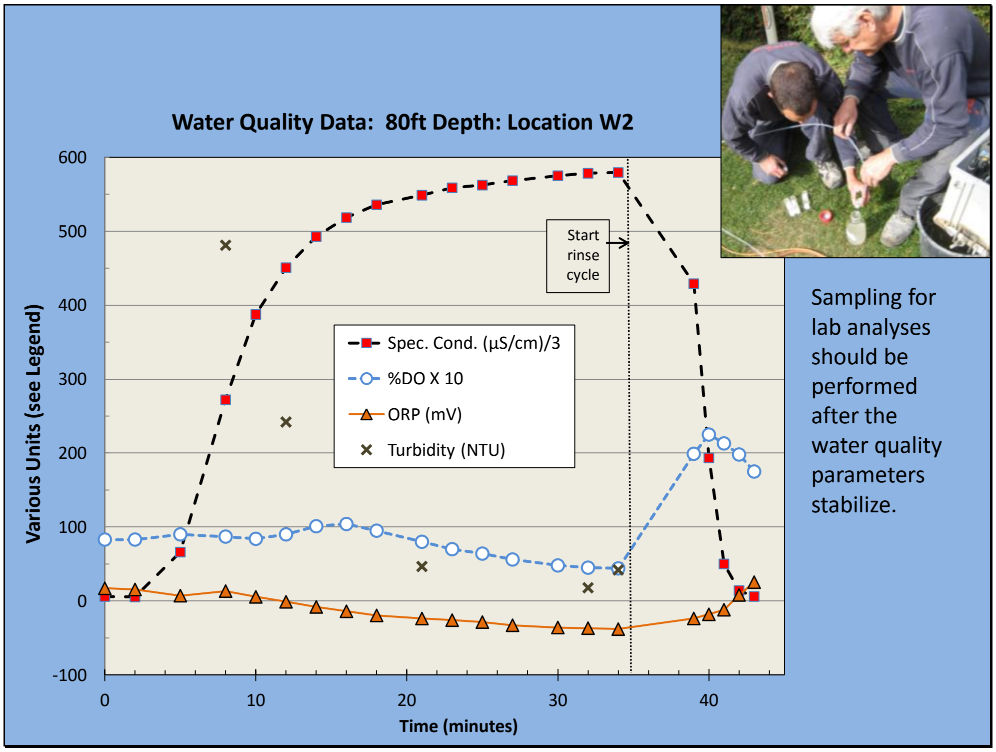

This is a fairly typical water quality stabilization profile for the field site. When measurements are started there is de-ionized water in the flow cell and the sample line. Specific conductance displays a quick rise as formation water reaches the flow cell from the pump down hole. It usually takes longer for dissolved oxygen (DO) and the oxidation-reduction potential (ORP) to stabilize. At many locations/depths we reached stability in 15 to 20 minutes with 5 to 10 minutes required for the “rinse cycle”. The purging/sampling/rinse process takes longer at greater depths due to reduced flow rates. During the rinse cycle the HPT pump is re-started and DI water is pumped down while the bladder pump continues to purge. The water quality parameters clearly show when DI water reaches the flow cell. This process “rinses” the pump and sample line before proceeding to the next depth interval to minimize cross contamination.

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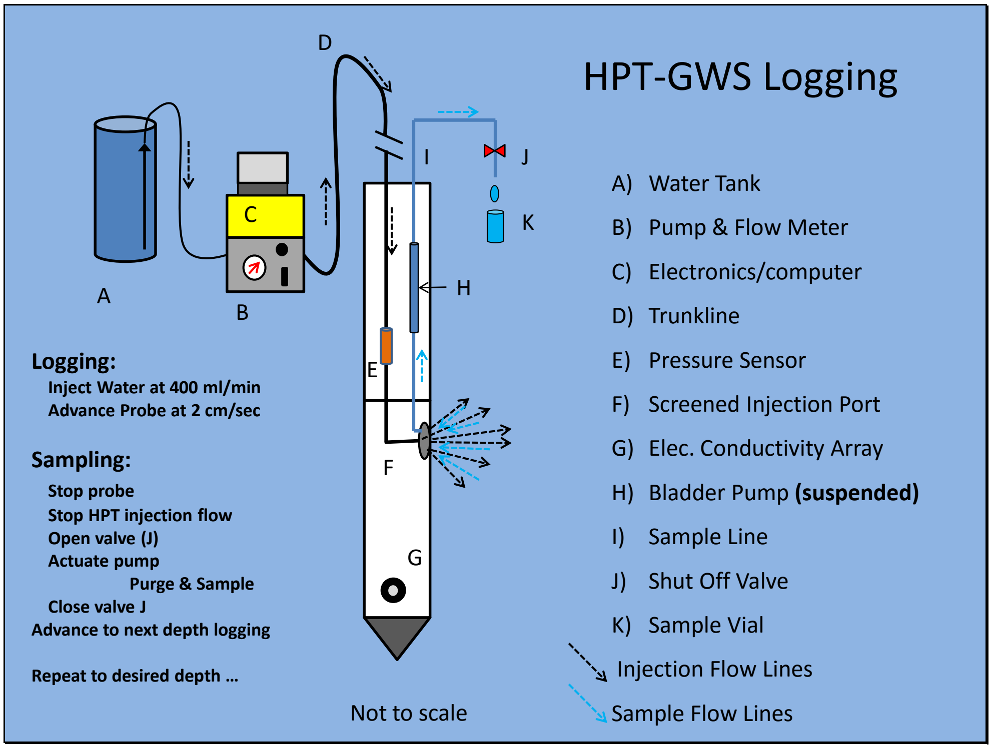

The pump in the HPT flow module (B) draws water from the supply tank (A) and pumps water down the trunkline (D) at a constant flow rate. An inline flow meter (B) measures the flow rate. The downhole pressure sensor (E) monitors the pressure required to inject water into the formation matrix. The HPT-GWS probe includes an electrical conductivity (EC) array (G). The EC, pressure and flow rate are logged every 0.05 ft (~15 mm) and displayed onscreen as the probe is advanced.

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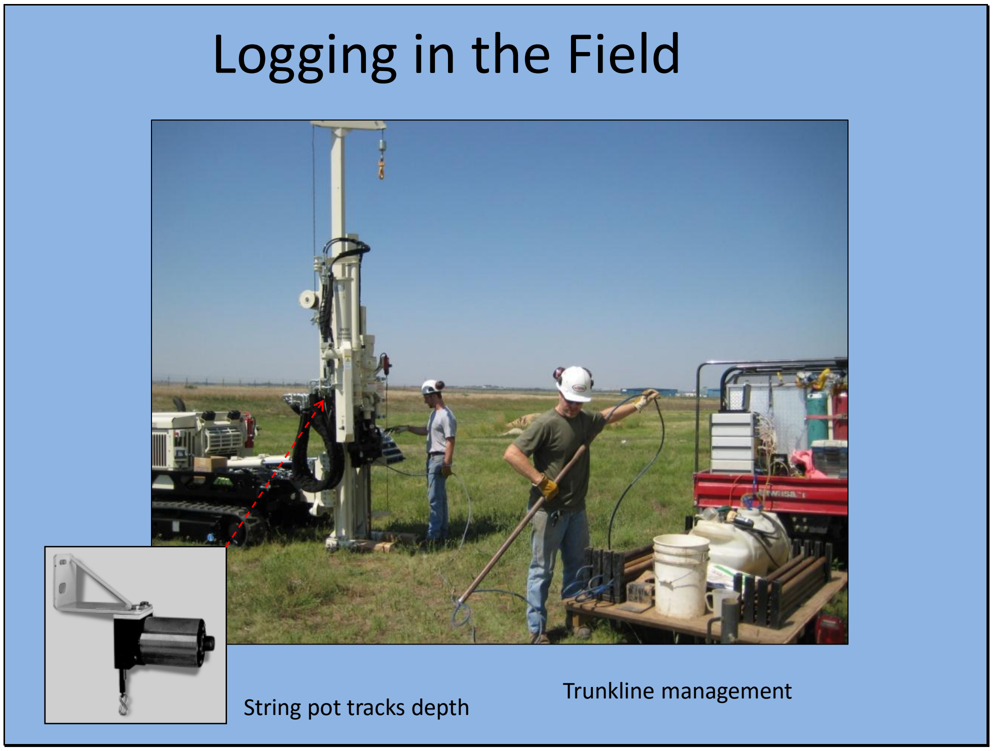

A probe machine advances the tool string into the subsurface while a stringpot tracks depth of the probe. Rod and trunkline management provide your daily workout routine. The trunkline is pre-strung through all of the rods before logging is started to make the process efficient. The trunkline attaches to the up-hole pump and electronics, including a lap top computer to display the log data.

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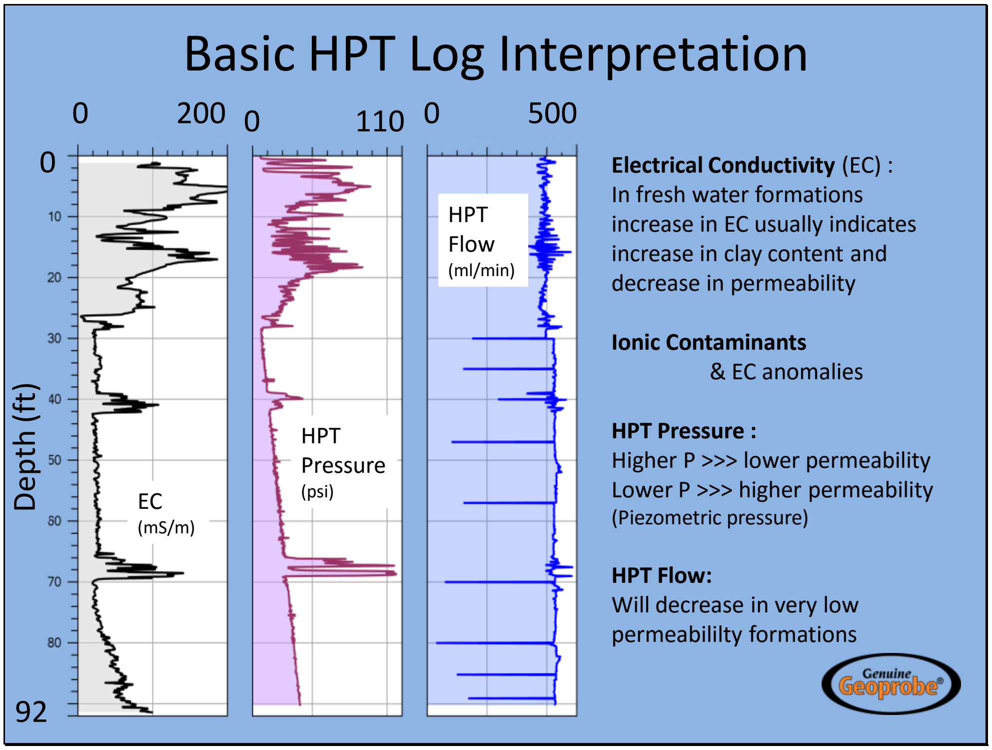

At this location the upper 25+ft is dominated by high EC and elevated HPT pressure, so primarily a lower permeability, finer grained facies.

Below 35ft the Low EC and low HPT pressure indicates higher permeability, coarser grained aquifer materials are predominant. Note the higher EC and HPT pressure peaks around 40 and 68ft, identifying clay layers in the sand/gravel aquifer. The logs are used to guide the selection of permeable zones in the formation where purging and sampling may be done. This is done as the probe is advanced.

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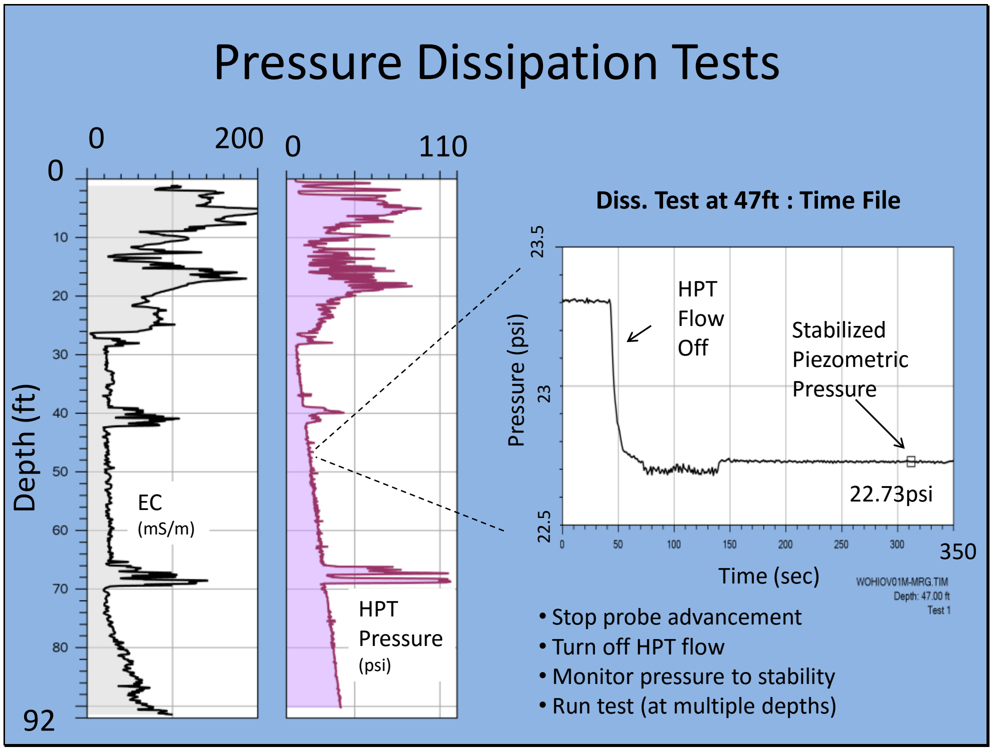

Dissipation tests are usually performed in low EC, Low HPT pressure zones (coarse grained) so that pressure dissipation occurs quickly. If you attempted a pressure dissipation test at 17ft at this location (higher EC and pressure) it may take several hours (even days) for the pressure to dissipate. The dissipation test shown here was run at 47ft in the low EC and low HPT pressure materials. The stabilized pressure here tells us what the piezometric (hydrostatic) pressure is at this depth.

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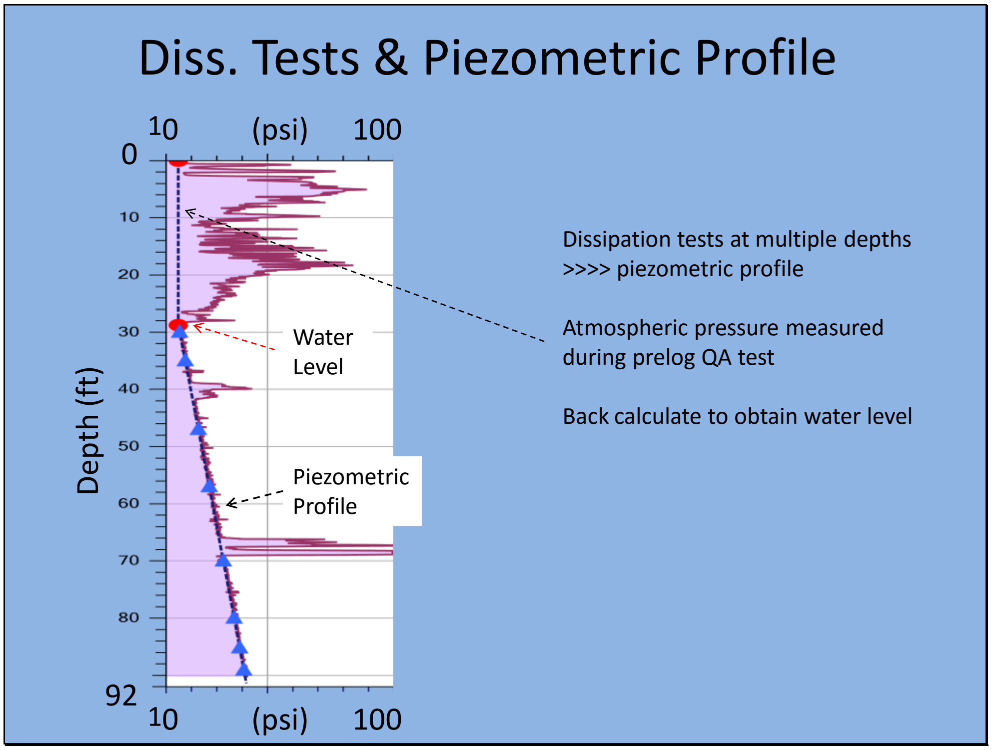

During the pre-log quality assurance test for the pressure sensor we determine what the ambient atmospheric pressure is as measured by the HPT sensor (about 15psi here). Back calculation from a dissipation test depth enables us to define the local water level, here marked with the red circle. Conducting multiple dissipation tests over depth may be useful in looking at vertical gradients in the formation. The blue triangles here mark each depth where we ran a dissipation test and sampled groundwater at this location.

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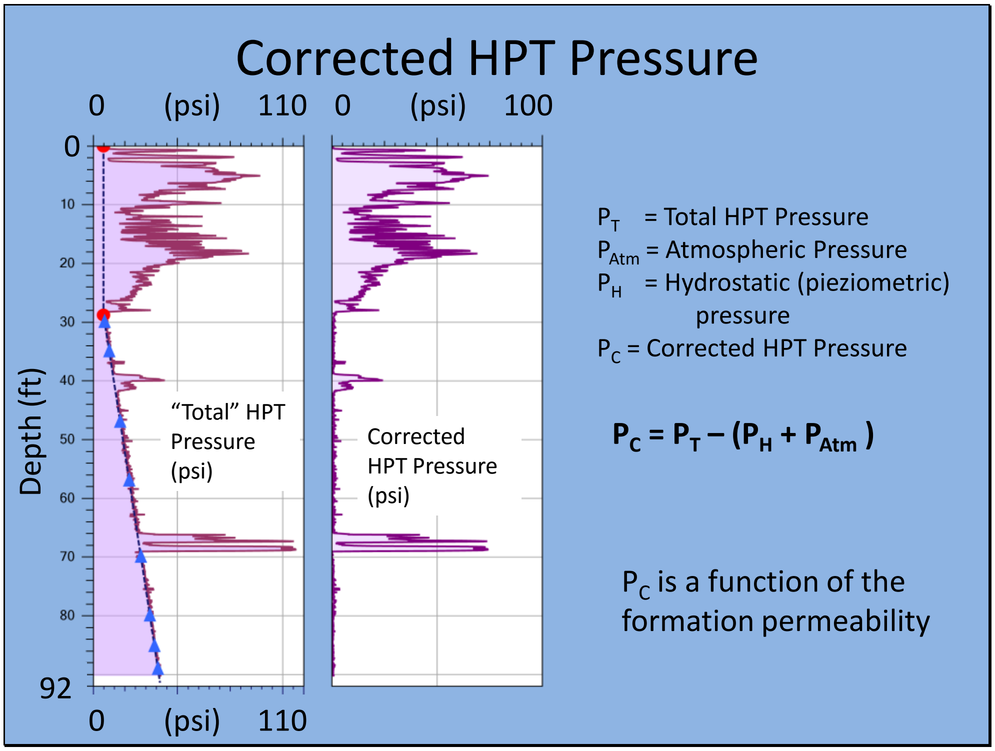

Once we know the atmospheric pressure (P_{atm}) and piezometric pressure (P_H) we can simply subtract these pressures from the "Total" HPT pressure (P_T) measured for each depth increment on the log to get the corrected HPT pressure (P_c). This corrected HPT pressure provides us with a picture of the formation permeability down the log without the piezometric pressure rise. Here we see from about 28ft to 88ft the formation gives very little resistance to injection of the water and so is very permeable, consisting mostly of sand and gravel. Of course the peaks still define the position of the clay layers.

The pressure logs also may be useful for evaluating injection of fluids for remediation.

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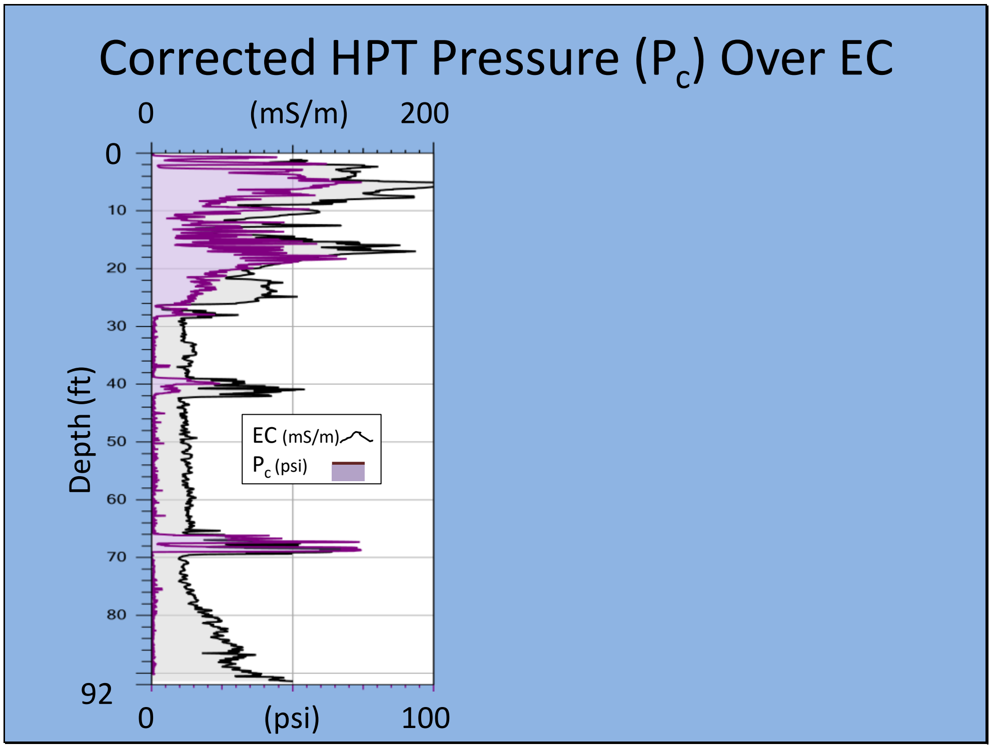

We can plot corrected pressure over the EC log to see how they compare. In the upper 25+ft we have high EC and high pressure = low permeability. Below 30ft Pc and EC are generally low, with both increasing when clay layers are encountered. But what is going on below 75ft?

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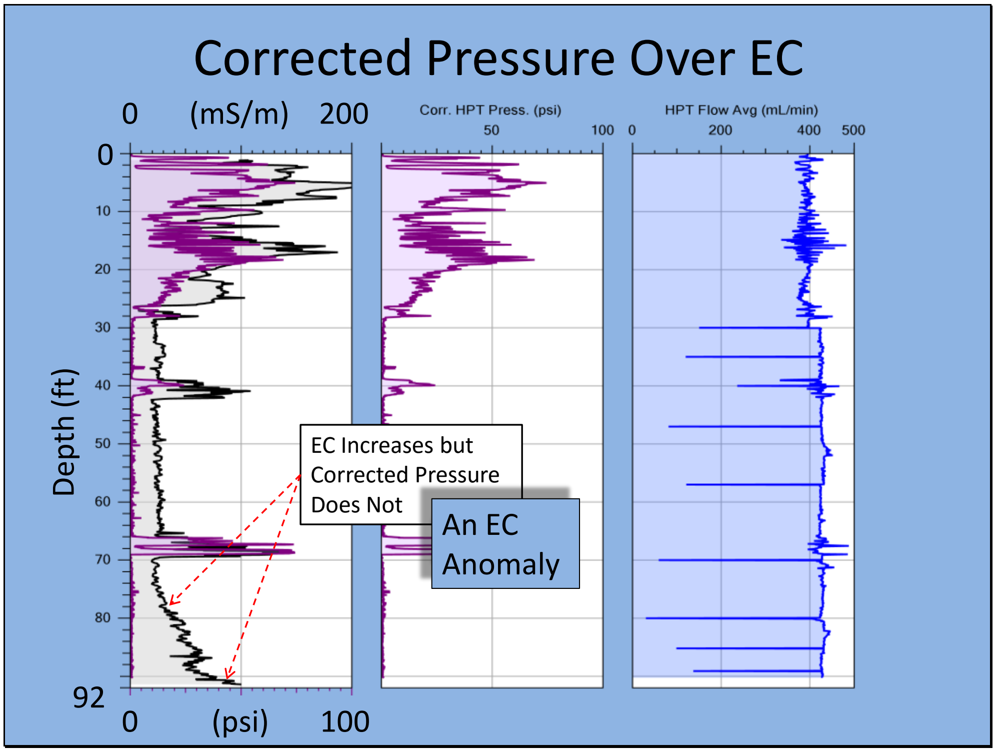

Increasing EC with flat corrected pressure defines an EC anomaly. Without the HPT corrected pressure log we can't be sure that increasing EC is not due to change in formation lithology … increasing clay content. So at this location we can identify an EC anomaly below about 75 ft where the EC increases while the corrected pressure is flat. Of course increasing EC below 75ft here is probably due to increased concentration of ionic species in the groundwater. Let's see if we can confirm this assertion.

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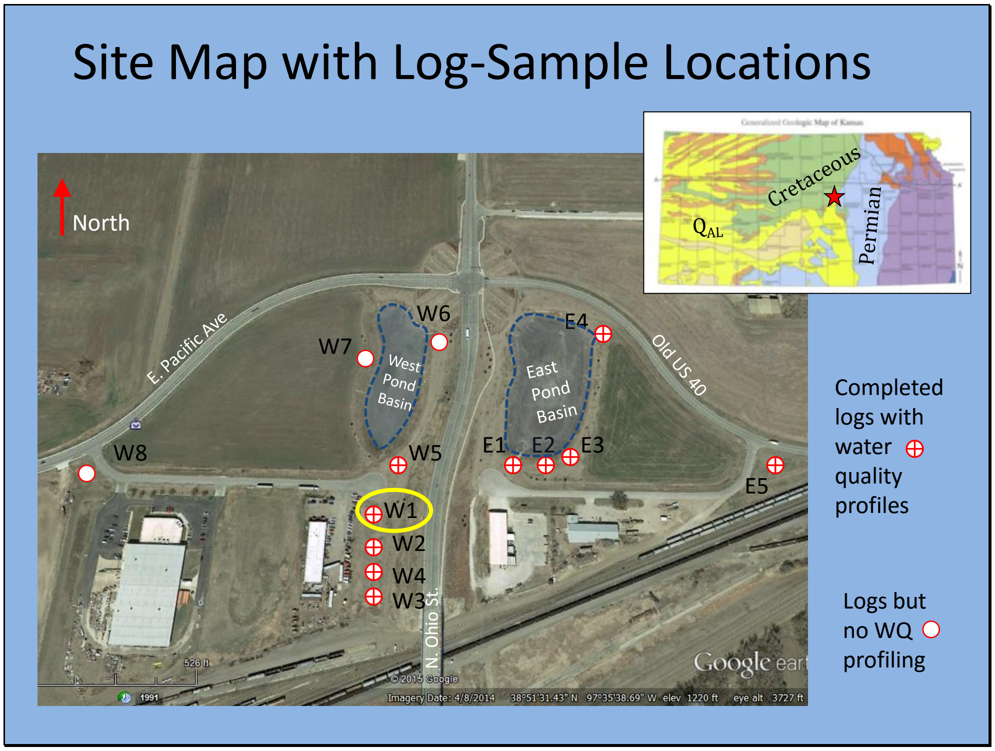

The generalized geologic map for Kansas shows that the field site is located in the Quaternary alluvium and the Permian Age shale underlies the site.

Also the site map displays 10 locations where we have completed logs and groundwater quality profiles and 3 logs without profiles. We have been reviewing log W01 from location W1.

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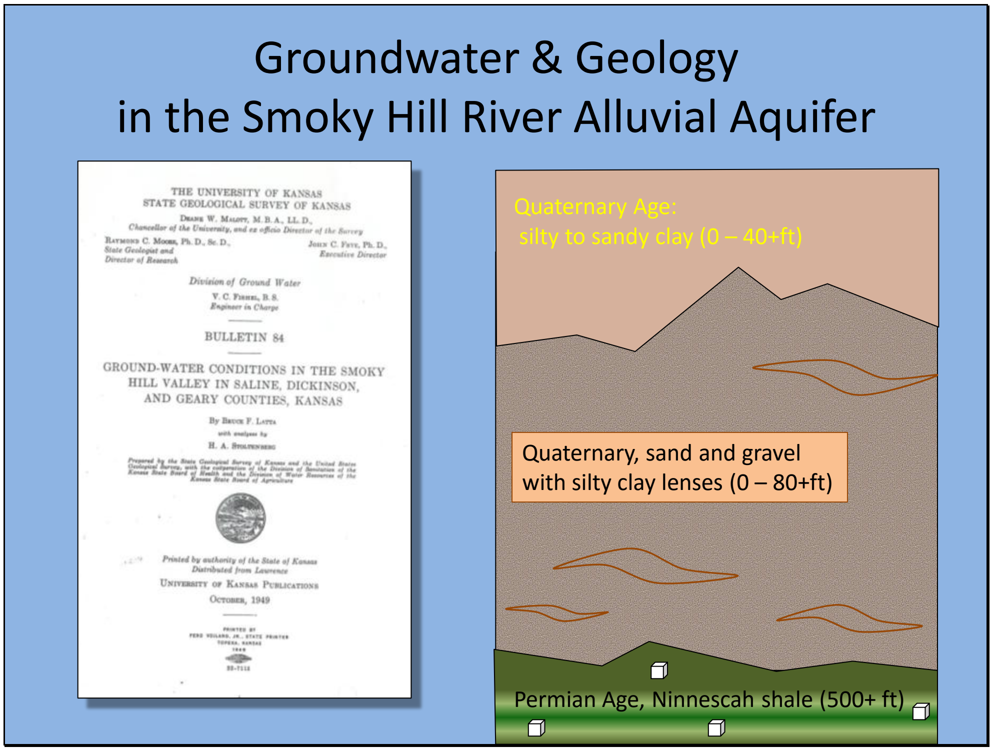

The old state survey geology/groundwater reports are full of good information. Note the salt cubes in the shale. South and west of this area the formation is mined for salt. This site is located in Saline, County, KS, on the north edge of the City of Salina. About 2 miles north of the site the Saline River flows across the flood plain. This stream has high chlorides and could also be a potential source for the EC anomalies observed here. Further research would be required to better constrain the source of the chlorides in the alluvial aquifer.

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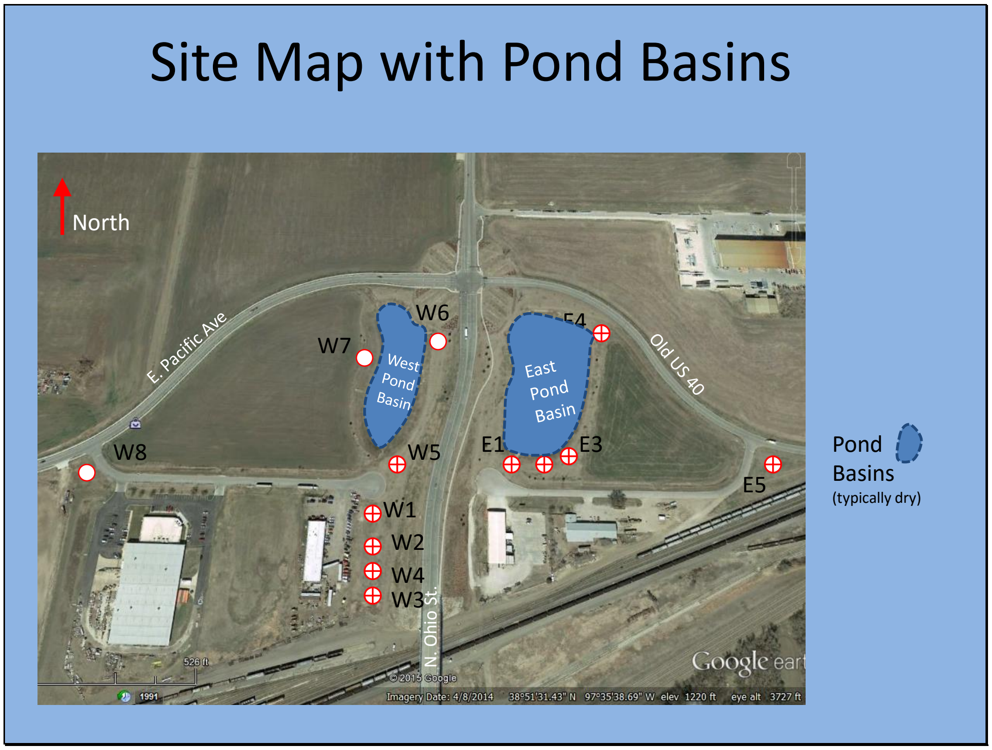

Note the two pond basins here. These were constructed to catch storm water runoff and provide a nice esthetic view along the road into town. Unfortunately the ponds only have a little water in them immediately after a rain storm, otherwise they are dry.

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Site Map with Log-Sample Locations

Now let’s look at the log from the E5 location, our “background” log.

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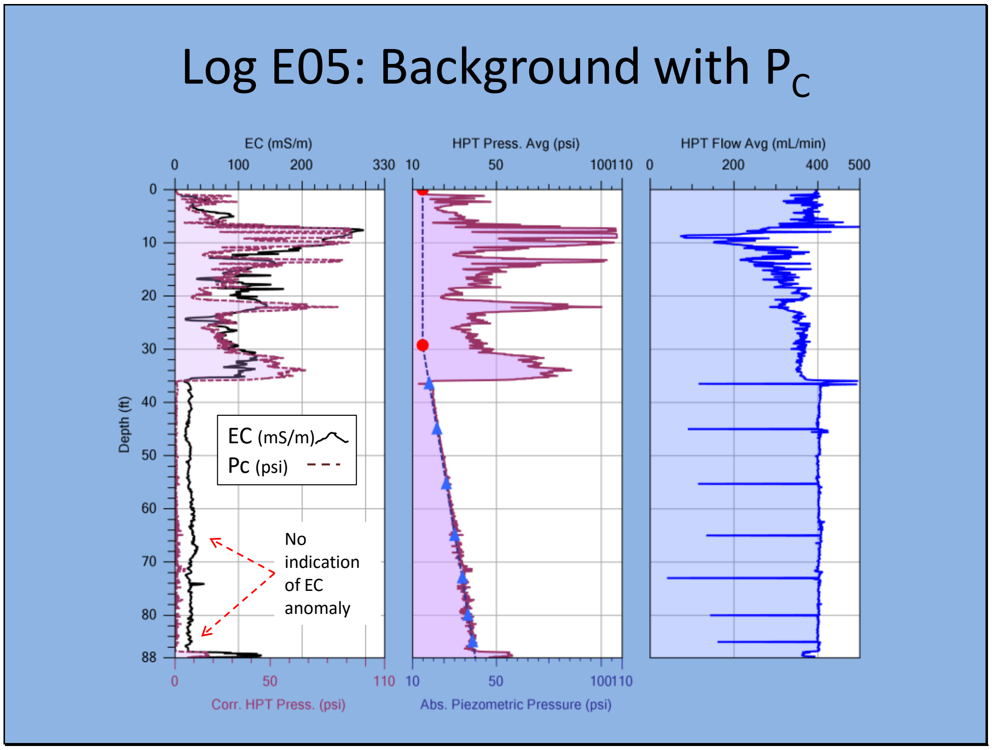

Let's focus on the EC and corrected pressure log here (left panel). Above 35ft we have high EC and pressure, so fine grained facies with varying amounts of silt and sand. Below 35ft both EC and P_c are flat and featureless so no indication of brine impact in the lower part of the formation as seen in the W01 log. Note the EC and Pressure peaks at the top of the shale at ~87ft. Let's look at some water quality data for this location.

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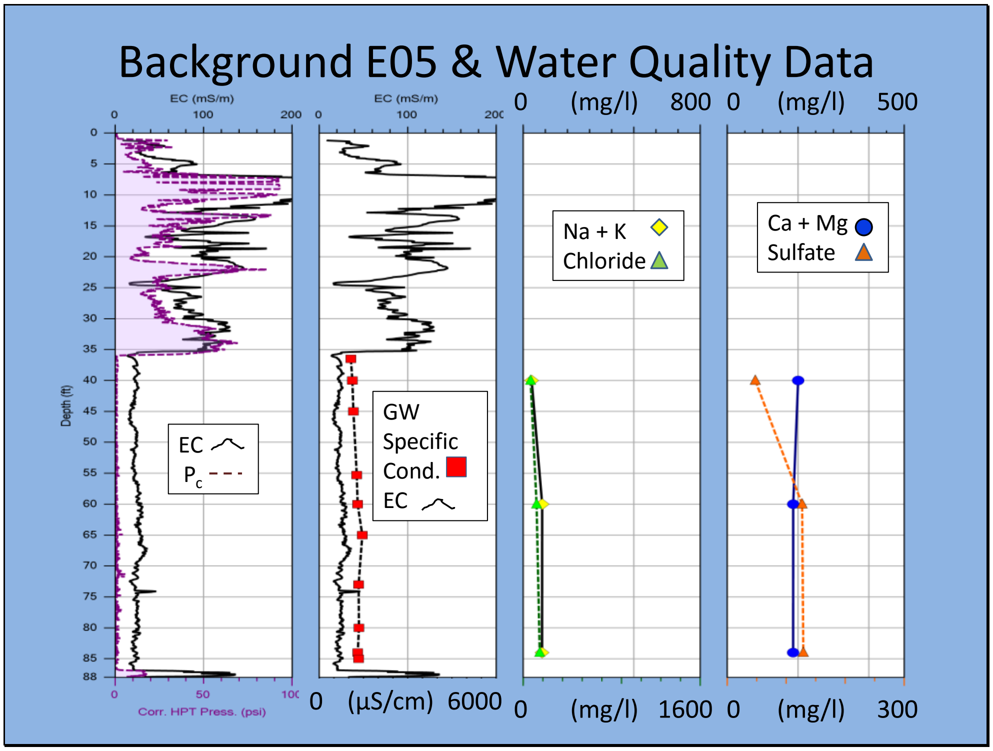

Groundwater specific conductance measured at several depths across the aquifer gives a pretty flat profile, much like the EC log. Also, the cations and anions all give pretty flat concentration profiles across the aquifer at this location, similar to the EC log. Boring …..

(Larger fonts used on some figures/panels to assist with visibility during presentation.)

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Site Map with Log-Sample Locations

We will look at data from the E4 location next …

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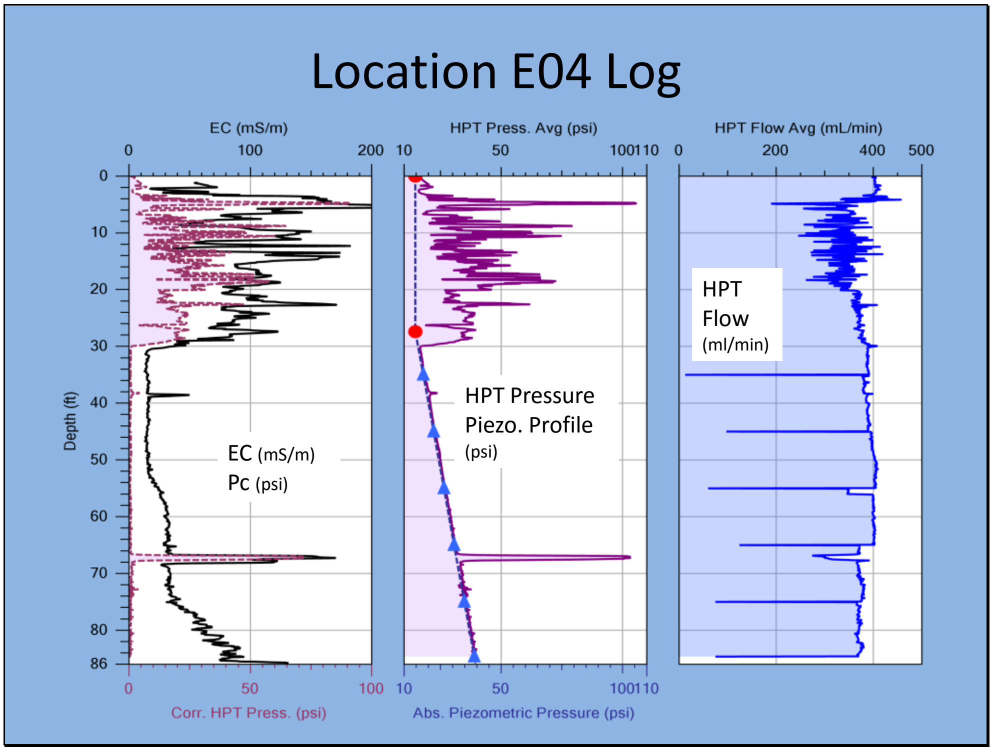

Again focusing on EC & corrected pressure / left panel … Above 30ft the corrected Pressure and EC logs are relatively high indicating the formation is dominated by fine grained materials. Below 30ft the corrected HPT pressure is flat with peaks indicating 2 clay layers at about 38 & 67ft. Below 30ft on the EC log are some distinct variations in EC with depth (beside the two clay layers), much different than the flat background log. Let's look at the EC and corrected pressure plot more closely to evaluate this.

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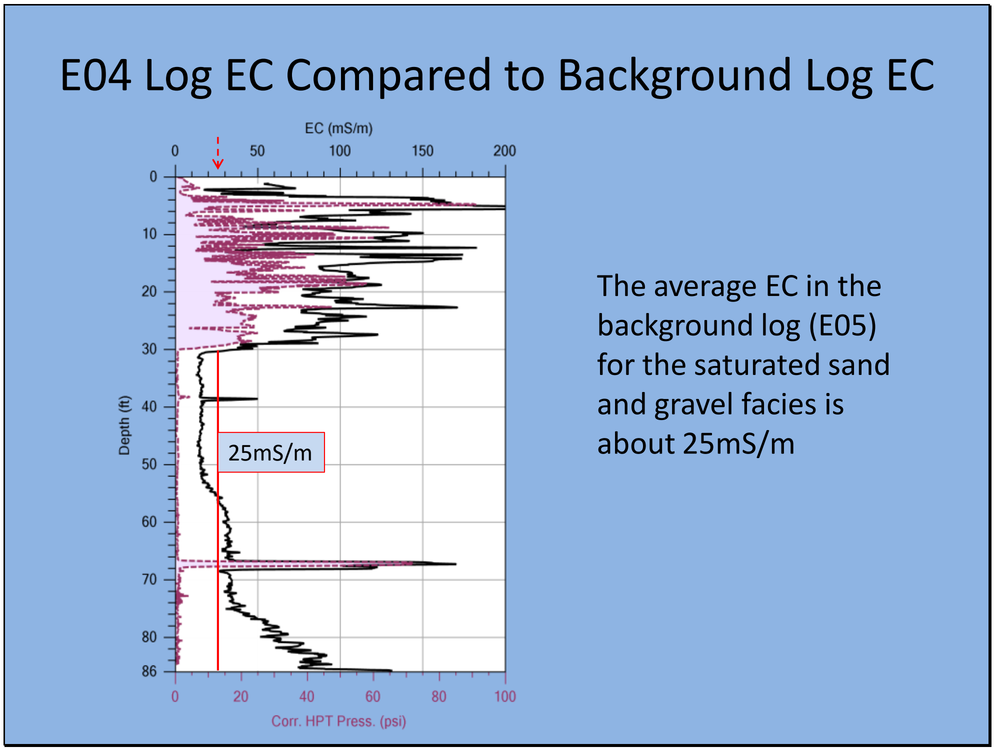

The average bulk formation EC was calculated for the saturated sand and gravel facies at the background location. The average bulk formation EC was about 25mS/m. Plotting this over the EC log as a bold red line allows us see that the bulk formation EC between ~30 to 52 feet is below the background average. Then between ~55 to 75ft the EC is similar to the background level and below 75ft it is clearly above background and climbing … our EC anomaly. Now let's look at some water quality data for this location. (Log not so boring !)

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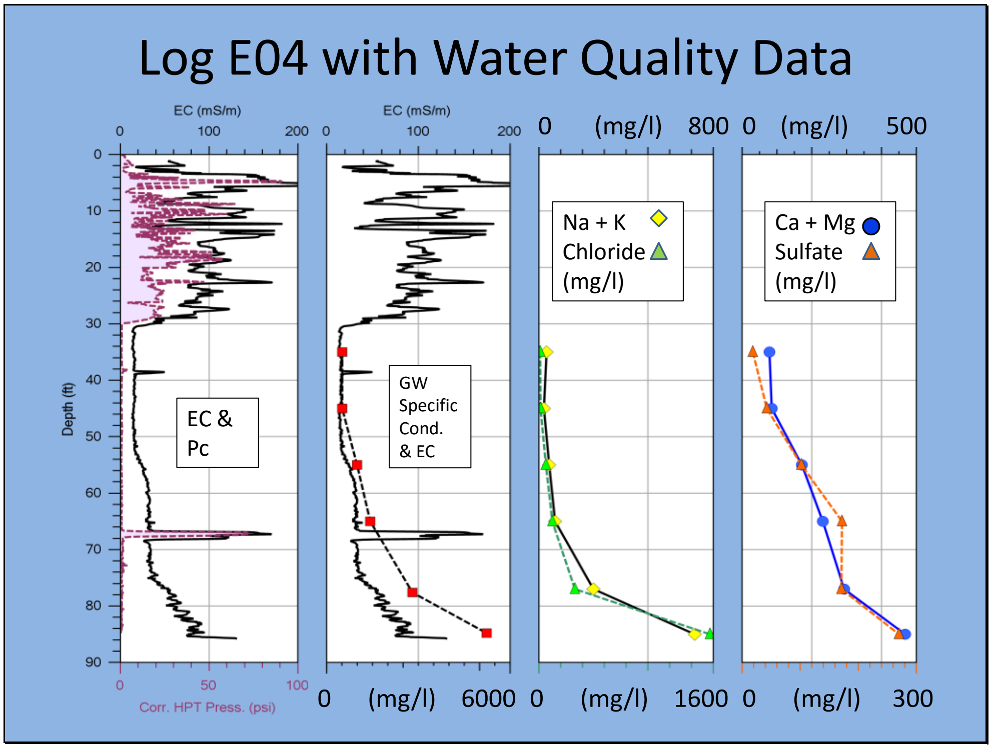

Much as we expected the Groundwater specific conductance, cation and anion concentrations are low in the upper part of the aquifer and increase some near the middle and are noticeably higher below 75ft where we observe the positive EC anomaly. So we see that the dissolved ion concentrations are controlling the groundwater specific conductance.

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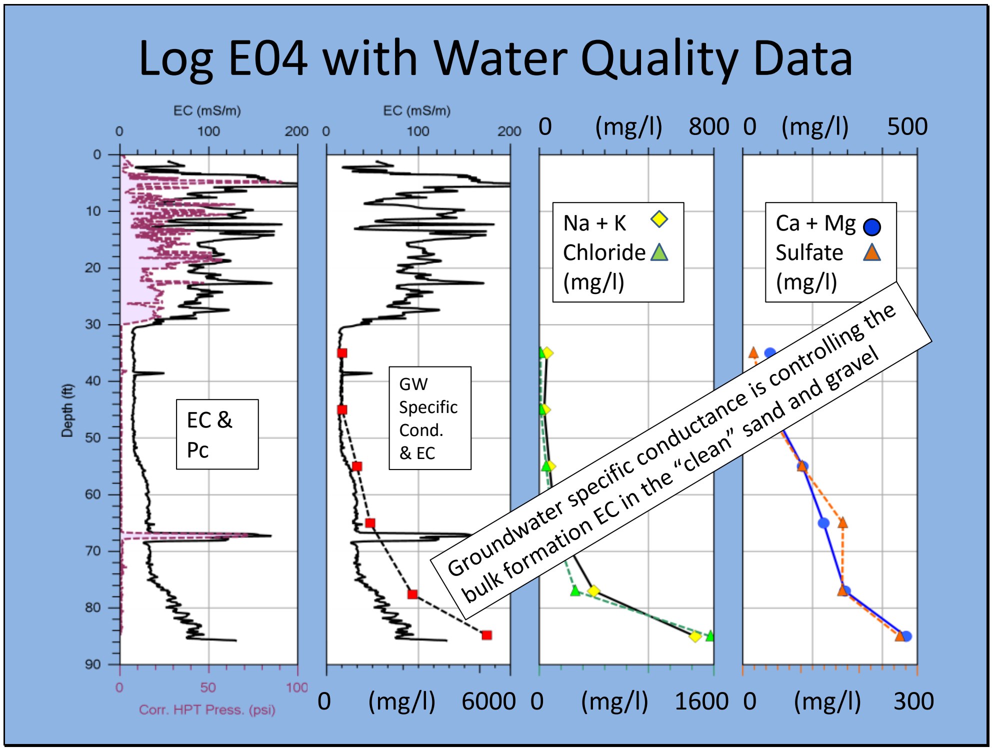

And the groundwater specific conductance is controlling the bulk formation EC in the saturated, clean sand and gravel facies. (Excluding clay-rich lenses and layers.)

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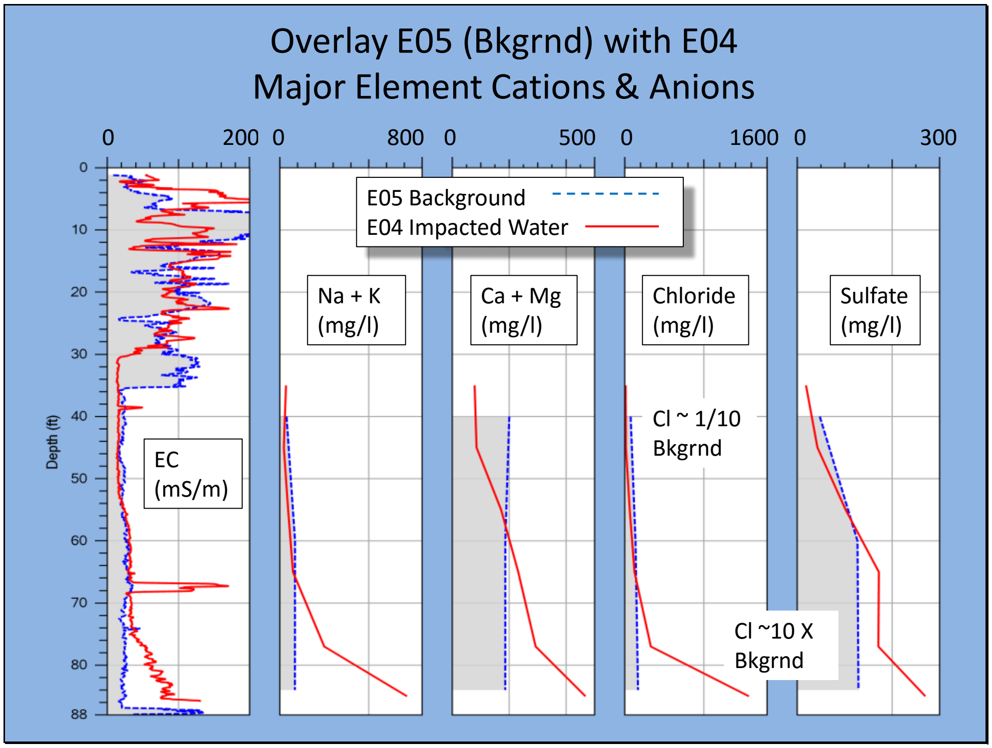

To further emphasize the difference between the cation and anion concentrations at the background location and the E04 location … For each parameter you can see it is lower across the 35-50ft zone for E4 as compared to background E05, and then clearly higher for E04 as compared to background E05 below 70ft. The scale on the chloride graph makes it difficult to see but in the shallow part of the aquifer at E04 the chloride is about one tenth the concentration observed at the background location. Similar trend for Na+K in the shallow and deep zones. The Ca+Mg and SO_4 concentrations also display a similar increasing trend with depth.

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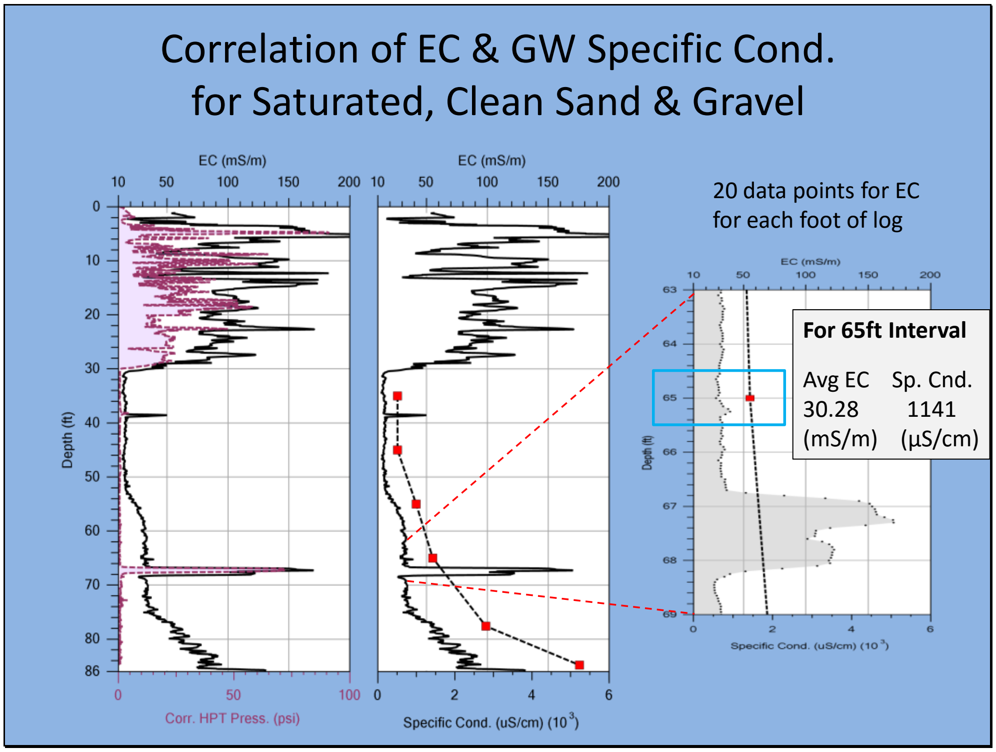

Can we quantify the relationship between the bulk formation EC and the groundwater specific conductance for the saturated "clean" sand & gravel facies of the formation? What we did was to average the bulk formation EC for a one-foot interval centered around each depth where groundwater specific conductance was measured. If the Specific cond. measurement was made right beside a clay layer the interval location was adjusted so that high EC from the clay did not bias the result for the saturated sand/gravel formation. This was done for each depth and location where we had collected groundwater specific conductance data.

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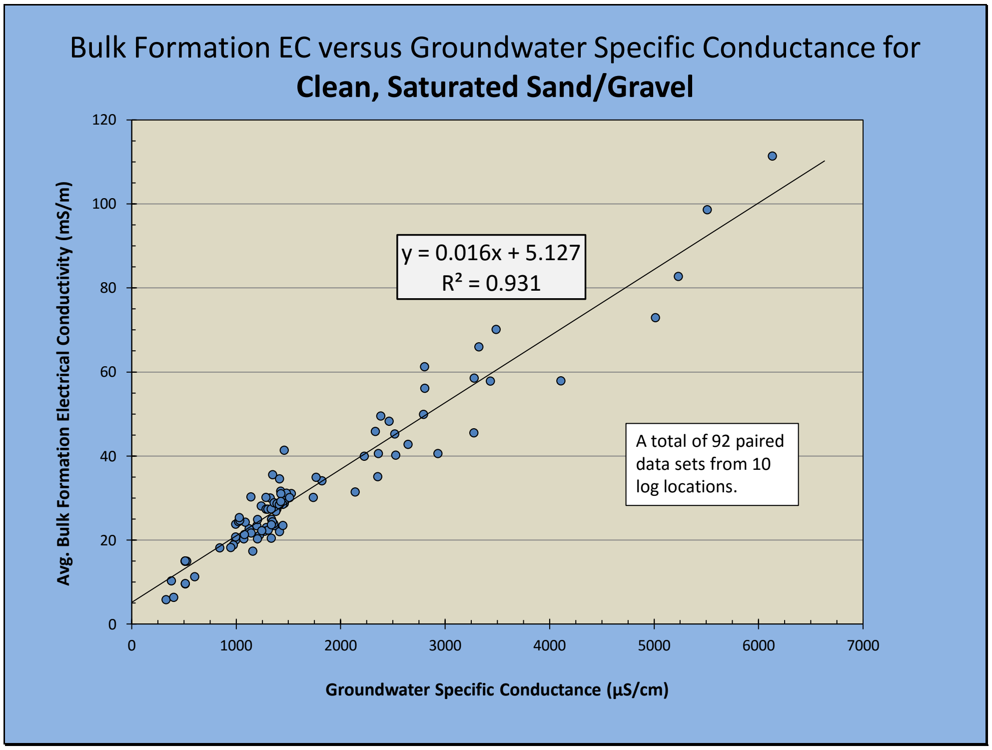

With a little spread sheet work we see that there is a strong correlation between groundwater specific conductance and bulk formation EC for the clean, saturated sands/gravels. So this gives us a site specific model to help identify EC anomalies at this site. This model may have some potential for use as a general model for sites with similar conditions but more data would be needed to confirm that. At sites with very concentrated brines a different model would probably be required.

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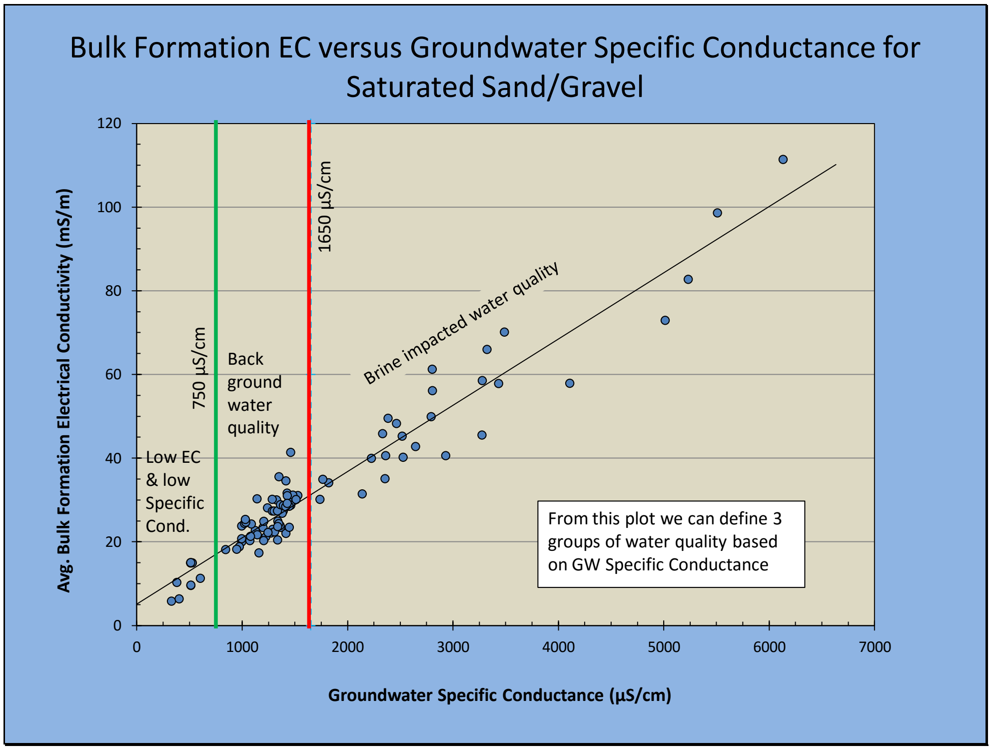

With a little closer inspection we see what appears to be 3 groups or zones of water quality based on groundwater specific conductance. The large grouping between about 750 & 1650 µS/cm are in the range of the background water quality. Above 1650 µS/cm the water is impacted by the brine. Below 750 µS/cm there is a small group of low EC and low specific conductance data. Can we identify these "zones" in the EC logs? What do they tell us? Where/what is this low EC/low specific conductance zone?

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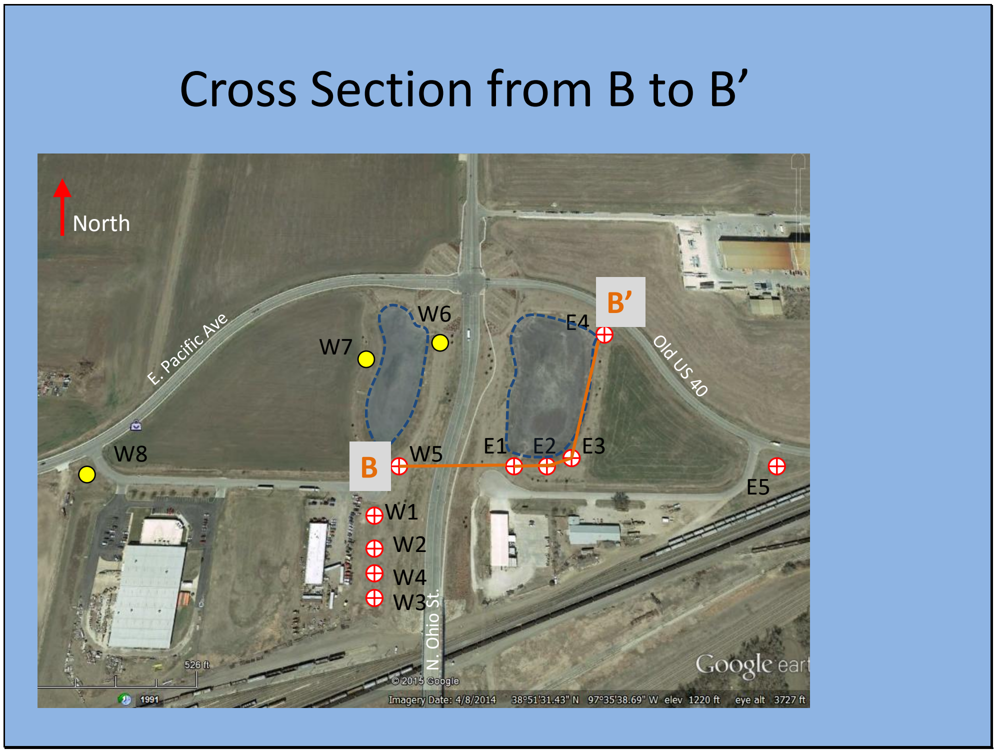

Let’s look at a cross section from B (at W5) to B’ (at E4) to evaluate the 3 zones of water quality. Note lateral spacing between the logs is not equal here but the logs in the following cross sections are presented with equal spacing, so not to scale laterally, but very useful for identifying water quality zones.

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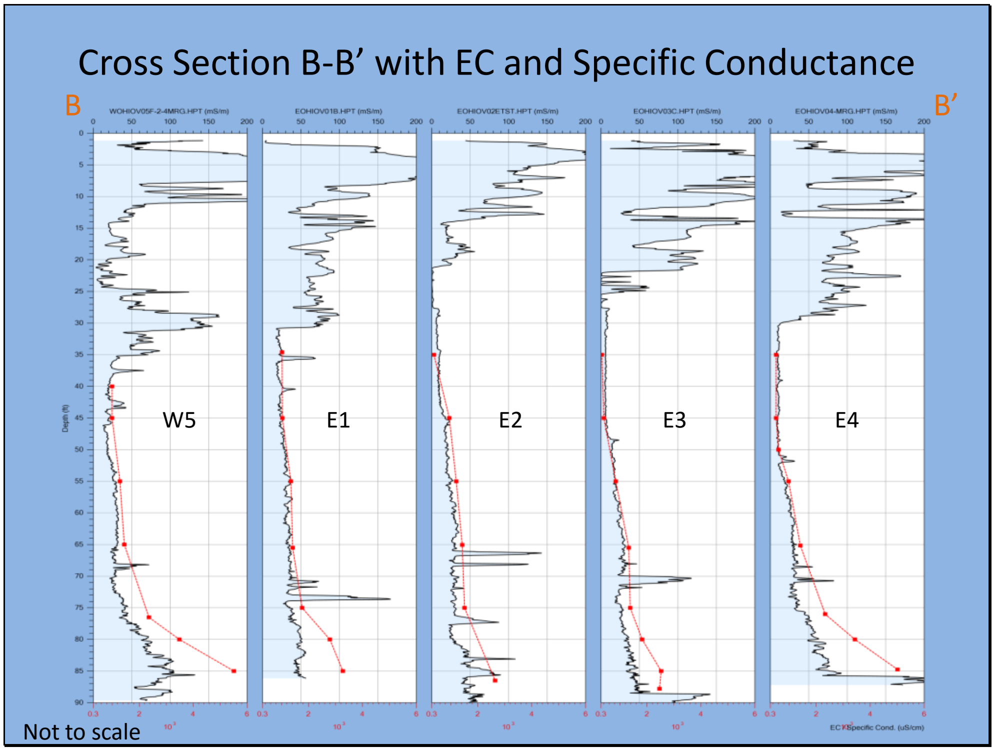

Here is the cross section of logs with EC shaded blue and groundwater specific conductance in red line with red square. First … As we have seen the upper facies of the formation is comprised of high EC fines (clay) with varying amounts of silt and sand. The thickness of this fine grained facies varies across the site.

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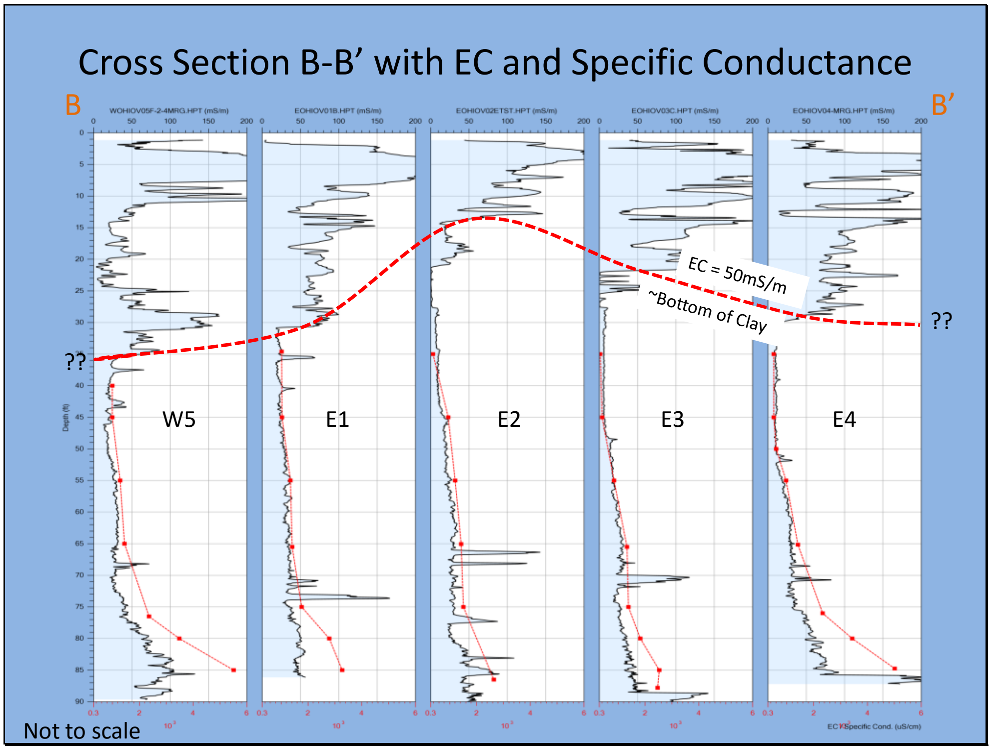

Here a red dashed line indicates the base of the clay rich facies based on EC dropping to 50 mS/m. It is apparent that the clay rich facies is thinnest at the E2 log location.
Below the upper facies and above 75ft the formation is mostly lower EC sand & gravel with a few clay layers, often in the 65-75ft zone. Then down around 75ft we see increases in EC due to our EC anomaly (elevated specific conductance) that we already observed in other logs at the site.

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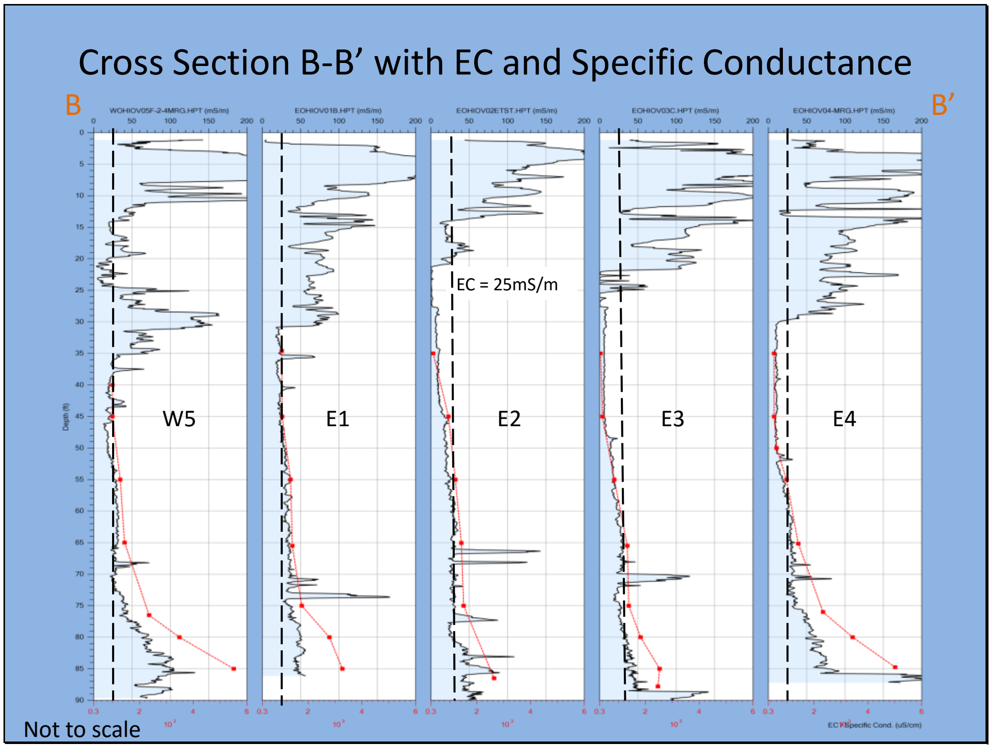

Here a black dashed line representing the average EC of the saturated sand & gravel from the background log (25mS/m) is plotted over each log. This helps to see where the bulk formation EC is high or low relative to the background log. At logs E2, E3 and E4 we see that EC is below background levels from the top of the aquifer (~30ft) down to about 50ft. We can see that the specific conductance is low over these same zones and we saw that the cations and anions at the E4 location were relatively low over this interval.

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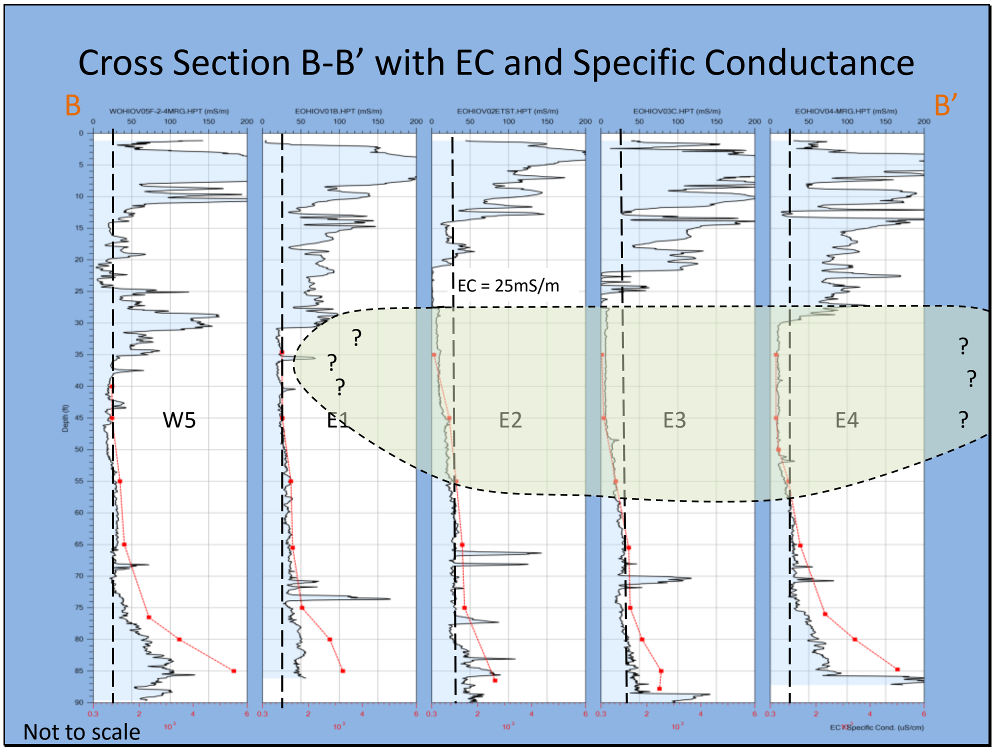

To help see this area of lower EC and lower groundwater specific conductance shading has been added to outline this zone. Based on the EC log data, the groundwater specific conductance data, and the cation and anion data we have, it appears that fresh surface water (rain water runoff) from the pond is locally recharging the alluvial aquifer. And the recharge appears to be extending to depths of 50ft and possibly greater. When compared to locations W5 and E4 The lower bulk formation EC and lower specific conductance of the groundwater down to depths of over 75ft at locations E1, E2 and E3 suggest recharge may be having an impact fairly deep in the alluvial aquifer.

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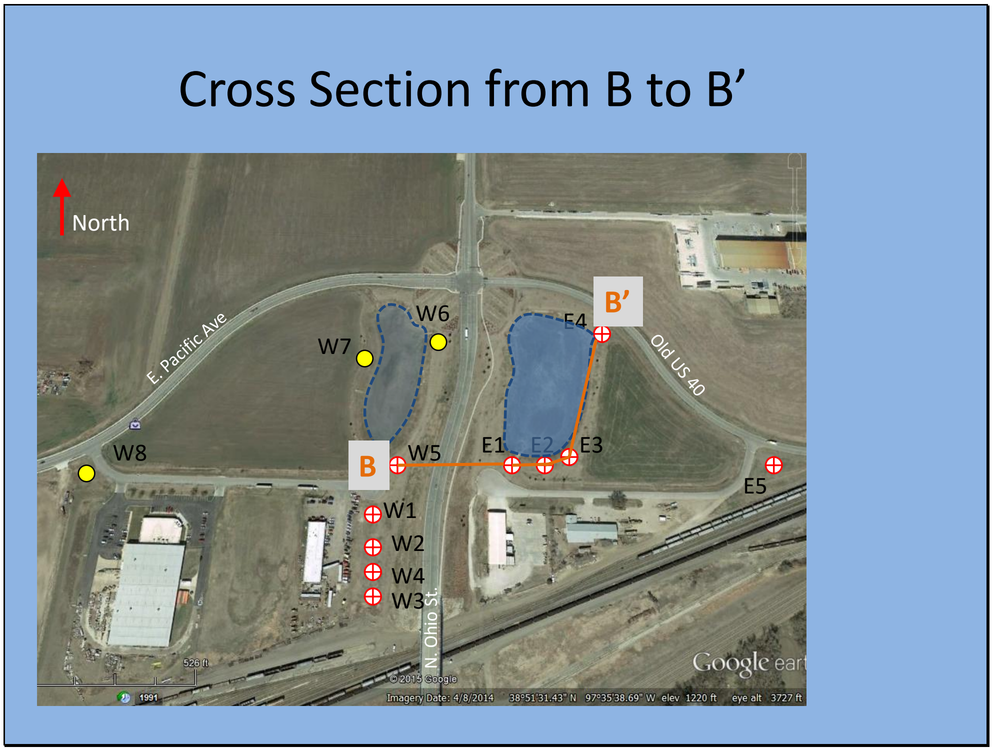

Now, looking at the map again we see that the E1, E2 and E3 logs are around the south side of the east pond basin.

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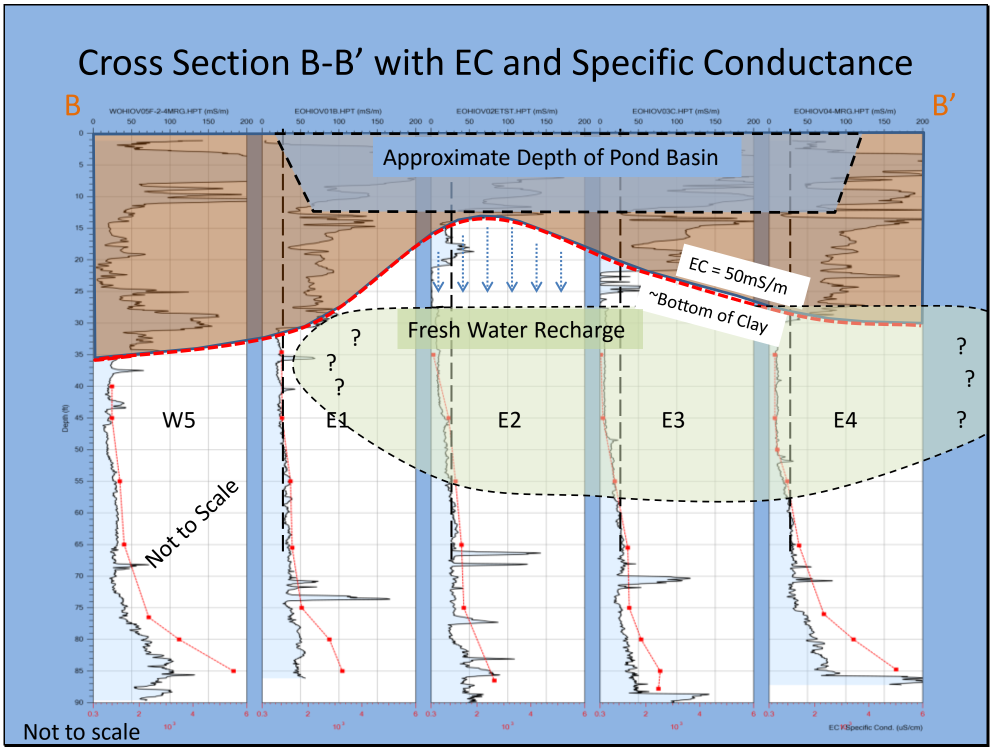


Here the clay-rich facies is shaded brown and a blue shaded block is added to show the approximate depth of the pond basin over the area. Now we see that especially at location E2 the thickness of the overlying clay-rich facies is relatively thin and the base of the pond lies over the top of the aquifer with little to retard downward infiltration of surface water filling up the pond after storm/rain events. If this "thin clay feature" extends north under the pond basin recharge would probably be relatively quick and efficient … unfortunately for the desired scenic "duck ponds" feature. However, the pond basins do appear to be providing a very effective "aquifer recharge" system. Additionally the aquifer recharge appears to be reducing the impact of the brine plume as it migrates south toward the existing municipal well field.

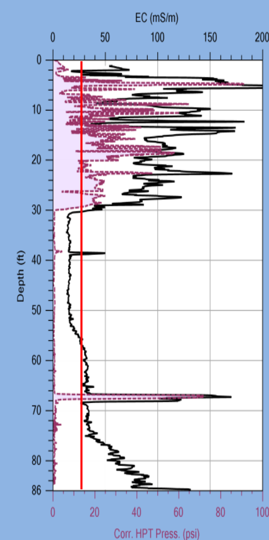
Slide 36

Summary / Conclusions

HPT corrected pressure (P_c) logs are critical for accurately identifying EC anomalies

An EC anomaly is identified when HPT P_c remains flat but EC increases (or decreases) in a clean saturated sand/gravel

Major element cation & anion concentrations increase for positive EC anomalies at this site and vice versa



The results presented here reveal that the combined HPT pressure and EC logs can provide a very useful tool for use in selecting locations for construction of aquifer recharge basins in unconsolidated formations.

Additionally, after a recharge basin is constructed the HPT-GWS system may be useful in defining the vertical and lateral extent of the recharge plume given that there is a water quality parameter (e.g. groundwater specific conductance or bulk formation EC as demonstrated here) that provides a contrast between “background” water and infiltrating recharge water. Other parameters also may be effective for defining the recharge plume.

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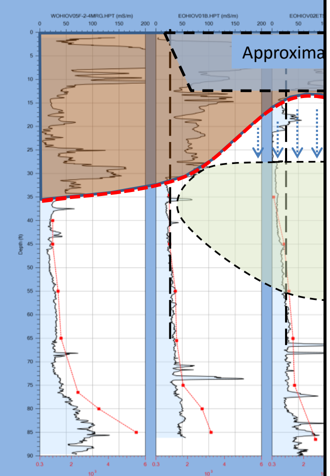
Summary / Conclusions

For clean saturated sand & gravel there is a strong correlation between bulk formation EC and groundwater specific conductance ... Site model ?

At this site low bulk fm EC was able to locate and identify fresh water recharge from an overlying "leaky" pond (recharge basin !)

Groundwater specific conductance measurements and limited cation/anion data support the fresh water recharge model



Obviously, using the contrast between the bulk formation EC logs and HPT corrected pressure logs can be very useful in locating and tracking brine plumes in unconsolidated formations. This technique also could be applied in appropriate geological settings to evaluate sea water encroachment into coastal aquifers. Additional log review, cross sections and "plume" maps below provide more information on this topic.

Furthermore, The HPT-GWS system can be used for contaminant plume mapping for environmental contaminants such as chlorinated VOCs (e.g. TCE, PCE, DCE, etc.), aromatic contaminants (Benzene, etc.) semi-volatiles, pesticides and heavy metals (Pb, As, U, Cr^{+6}, Cd, etc.) in appropriate geologic settings. Emerging contaminants such as PFOS/PFOA and 1,4-Dioxane could be investigated with this system.

For additional information about Geoprobe equipment, tools and methods please go to www.geoprobe.com . For more information about this specific project, tools and methods used, please contact Wesley McCall at mccallw@geoprobe.com or 785-404-1147.

Additional slides not presented at the NGWA Southwest meeting are provided below. They provide information about the extent of the brine plume impact and further information about the extent of the fresh water recharge zone.

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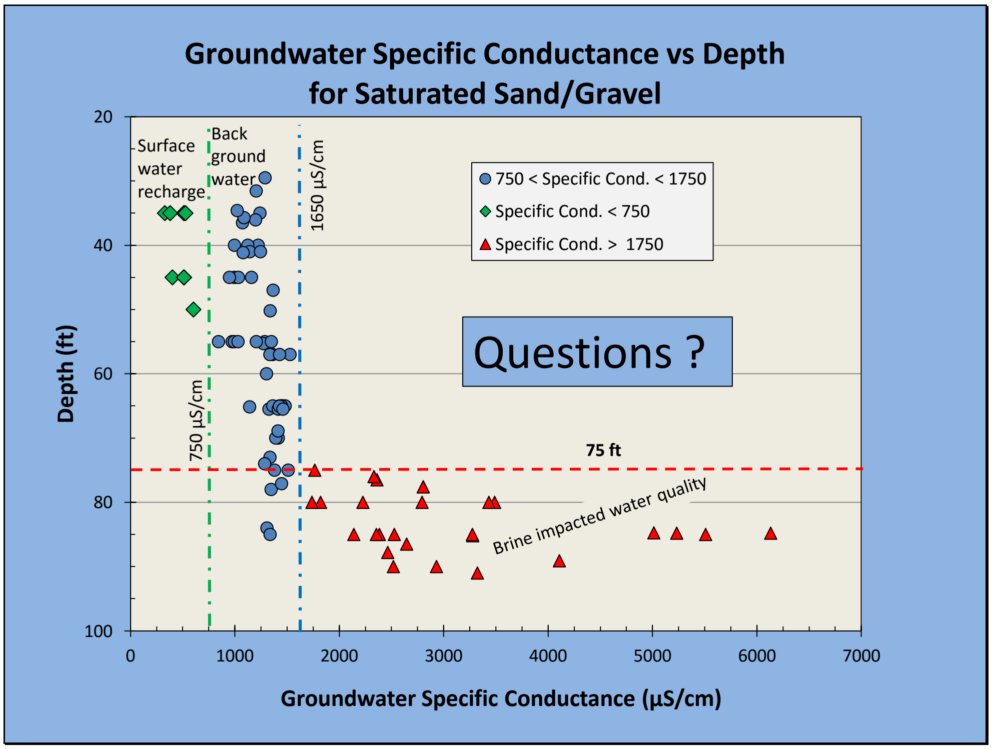
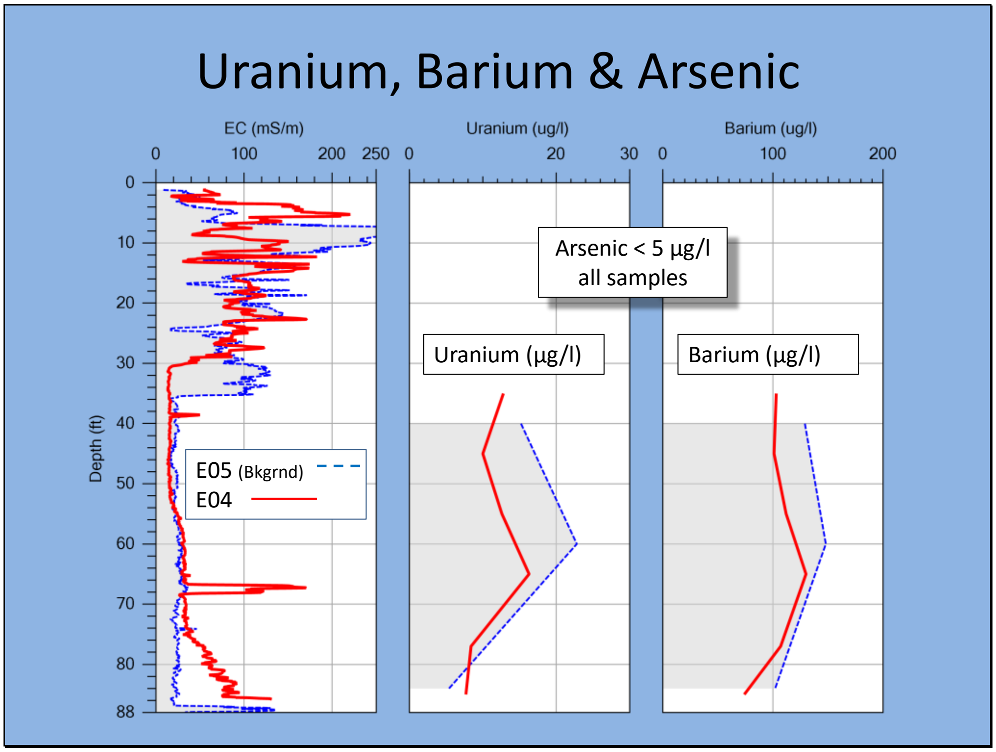


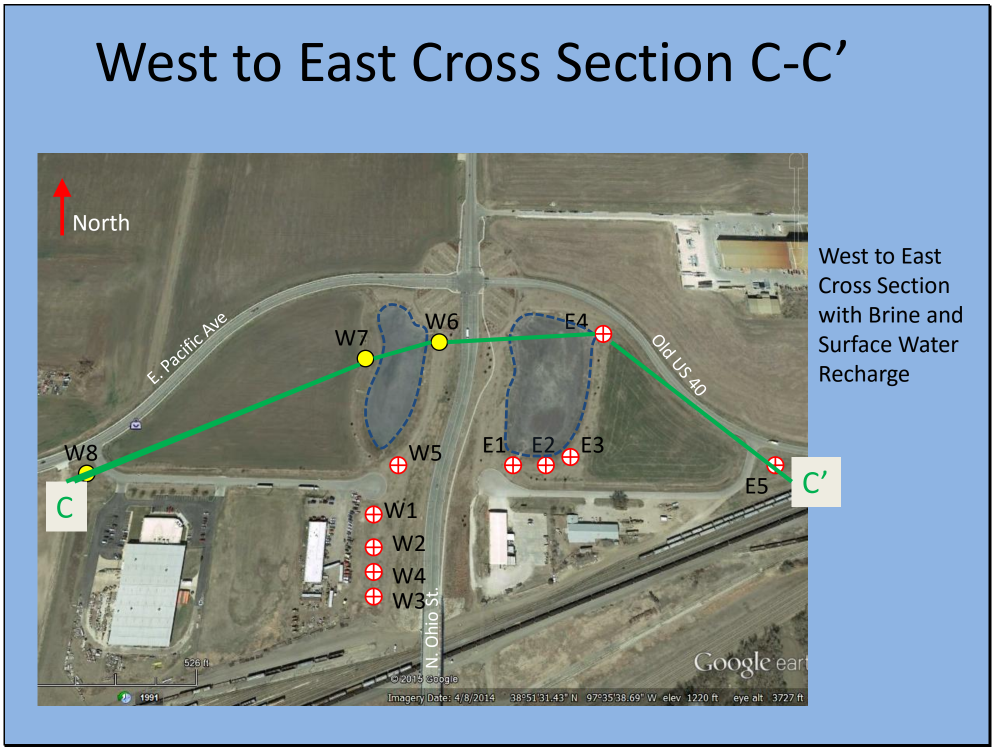
This plot of groundwater specific conductance versus depth also helps us to see the three zones of water quality defined earlier based on the bulk formation EC vs Specific Cond. plot. We are able to see that brine impact to the aquifer has occurred primarily below 75ft in the area studied (red triangles). Conversely we see that fresh water recharge around the east pond has occurred mostly in the upper part of the aquifer, above 50ft (green diamonds). Water that is not effected by the brine or fresh water recharge falls in a zone mostly between 750-1650 µS/cm, basically background quality water at this site (blue circles). Note, the 4 data points which fall below the 75ft line and left of the 1650 µS/cm line were collected at the background location, outside of the brine plume.

Slide 39



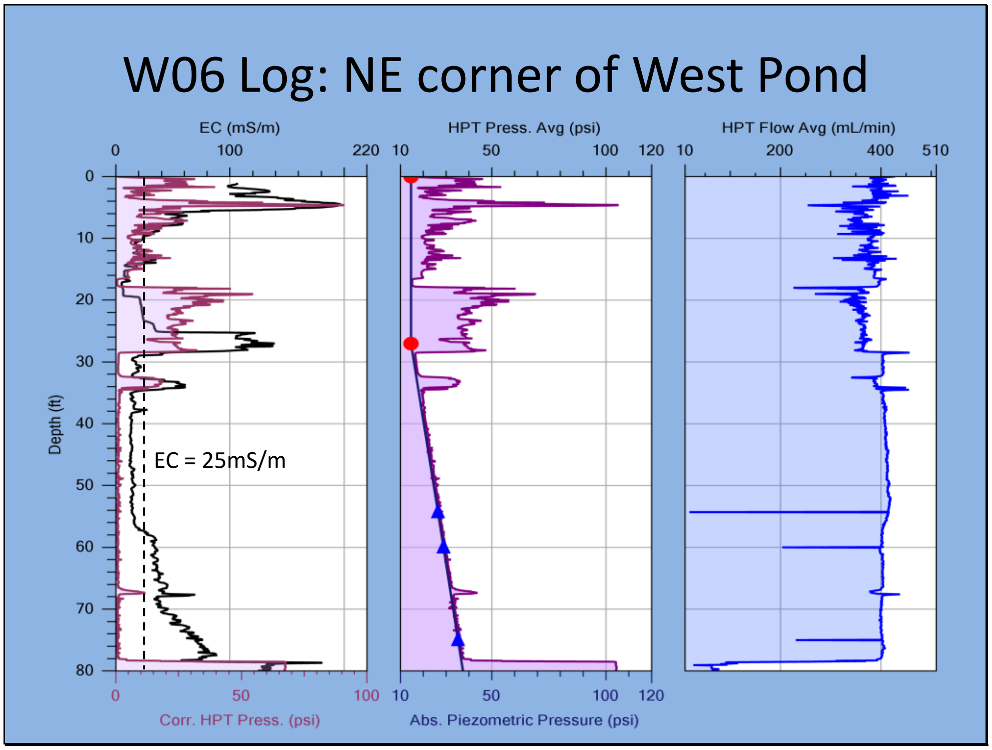
Samples for uranium, barium and arsenic were collected at the background location (E05) and the E04 location. This was done to determine if the brine or fresh water recharge was impacting the levels of these naturally occurring elements that are of concern for human health impact. Interestingly, the highest uranium and barium concentrations occur at the background location. It appears that the fresh water infiltration may be lowering both U and Ba where significant recharge is occurring (30-60ft in the aquifer). Arsenic was below the laboratory reporting limit of 5 µg/l for all samples. So it appears that the surface water recharge is not mobilizing these naturally occurring elements of concern from the aquifer solids at the sampled location (E04).

Slide 40



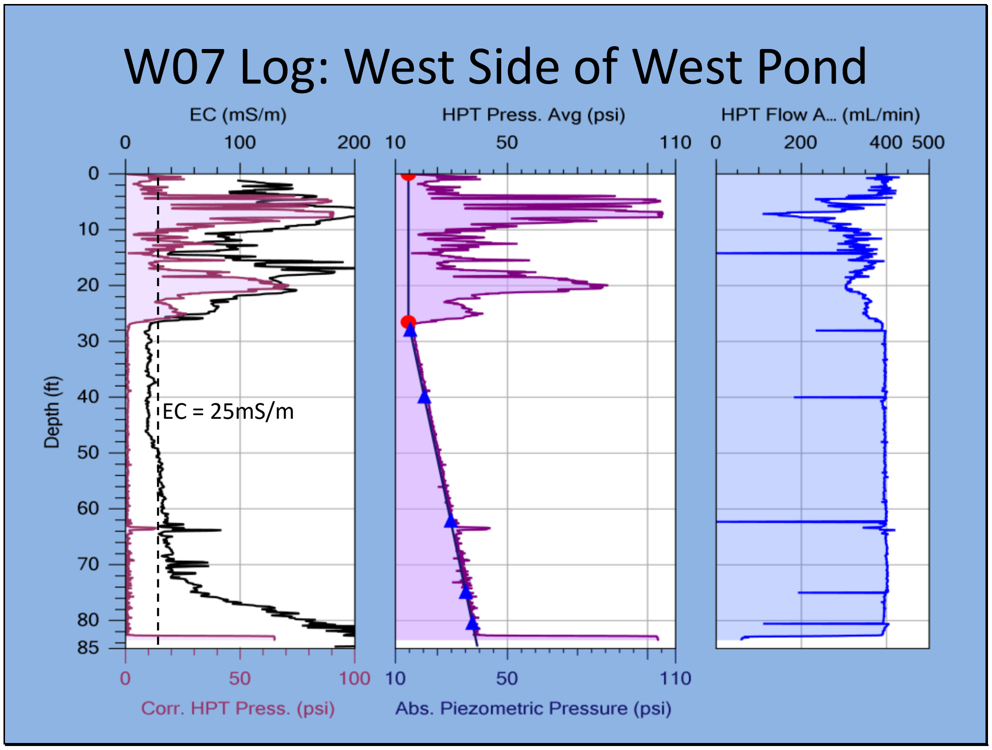
Let’s look at a west-to-east cross section (C to C’) of the EC logs to assess the extent of fresh water recharge and the brine plume in the study area.   First, let’s review logs W6 and W7 to evaluate the EC relative to corrected HPT pressure.

Slide 41



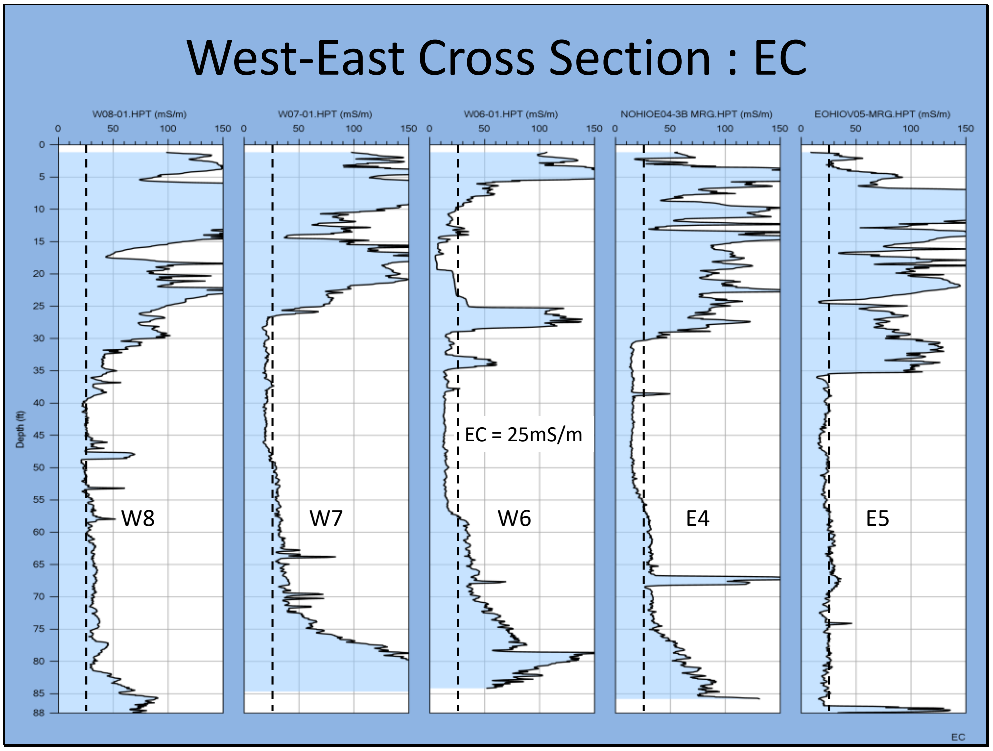
At this location the corrected pressure (left panel) below 28ft indicates the formation is mostly high permeability sand and gravel with a clay layer between 32-34ft and a clay lens at about 67ft. Pressure and EC increases at 78ft defines the top of the shale bedrock at this location. Bulk formation EC from 29-~56ft is below the background average, indicating freshwater recharge. Below ~70ft the EC trends up indicating brine impact.

Slide 42



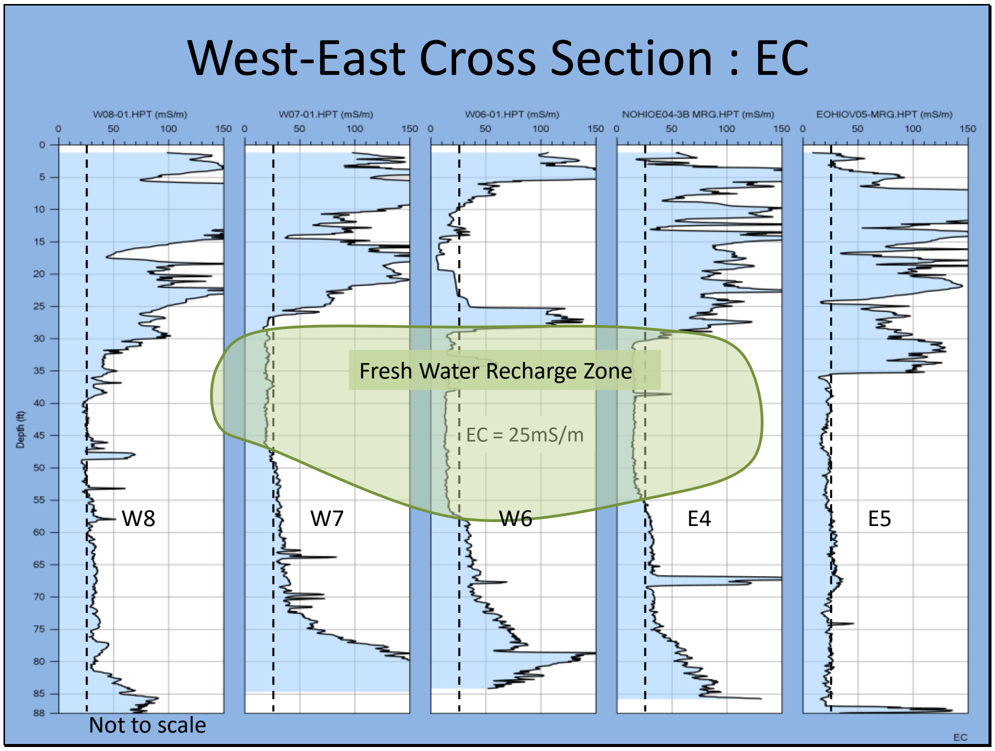
Results here are similar to the W06 location just discussed, but the low EC area does not go as deep nor as low as in the W06 log. Conversely the EC readings at depth (below 70ft) due to the brine are higher. HPT pressure defines top of shale at just below 82ft here.

Slide 43



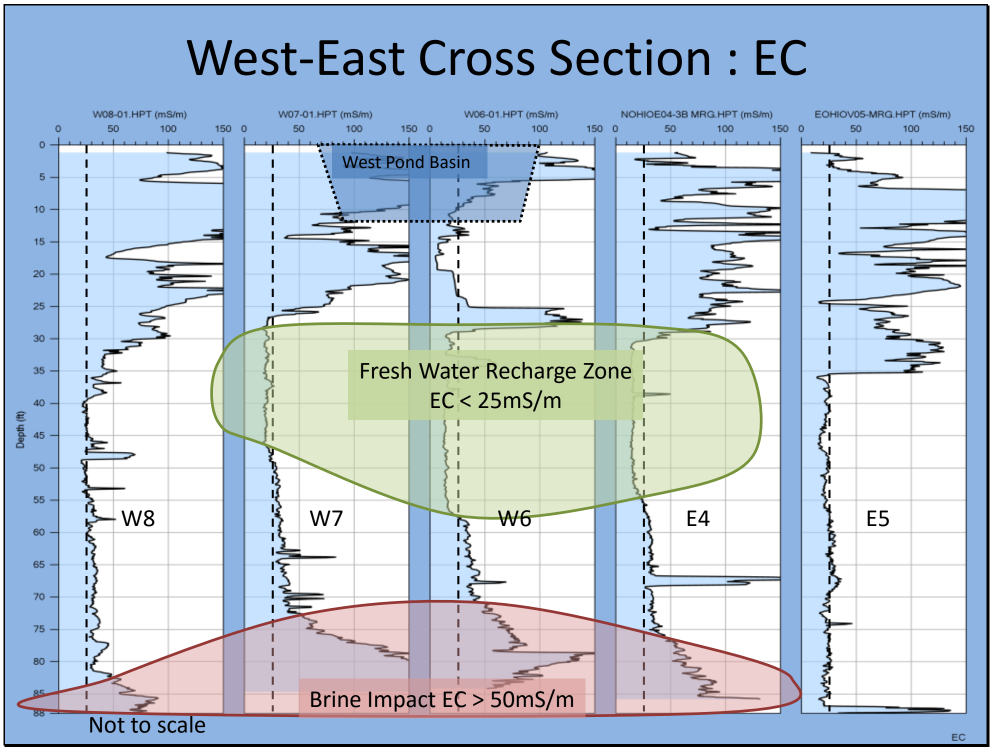
Now on the cross section (not to scale), plotting the average background EC for the saturated sand/gravel facies over the logs again allows you to see where the bulk formation EC is low (fresh water recharge) and the bulk formation EC is high (brine impact) for all of these logs.

Slide 44



Shading is applied here to help visualize the fresh water recharge zone in the upper part of the sand/gravel facies (the aquifer). Again, defined as the zone in the saturated sand and gravel where bulk formation EC is below 25mS/m.

Slide 45



Now, shading (pink) is added to outline the brine impact in the sand/gravel facies across the bottom of the aquifer.

It is also interesting to look at the pond basin relative to the EC log at W6. It is evident that the bottom of the pond at the W6 location is into a sandy zone (low bulk formation EC). While there is a clay layer over 25-28ft it does not appear to be continuous over to the W7 location (below the pond), so a migration pathway for water to infiltrate to the aquifer. Of course more logs would help to fill in the detail.

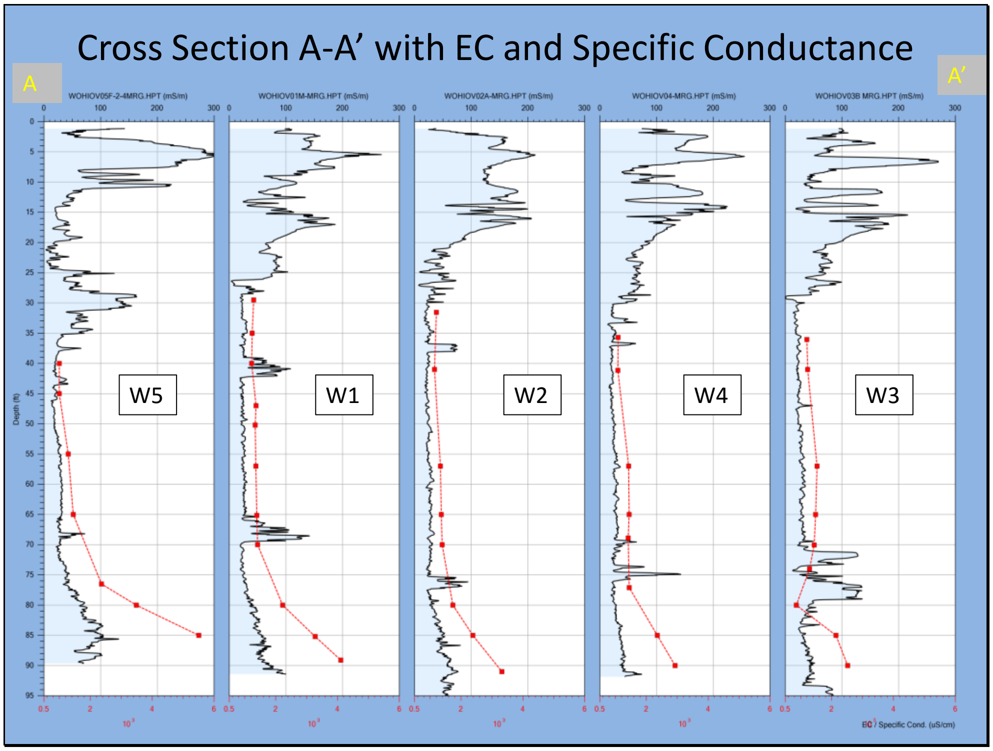
Slide 46

Cross Section A-A’ : Brine Plume Trend

North to South Trend of Brine Impact

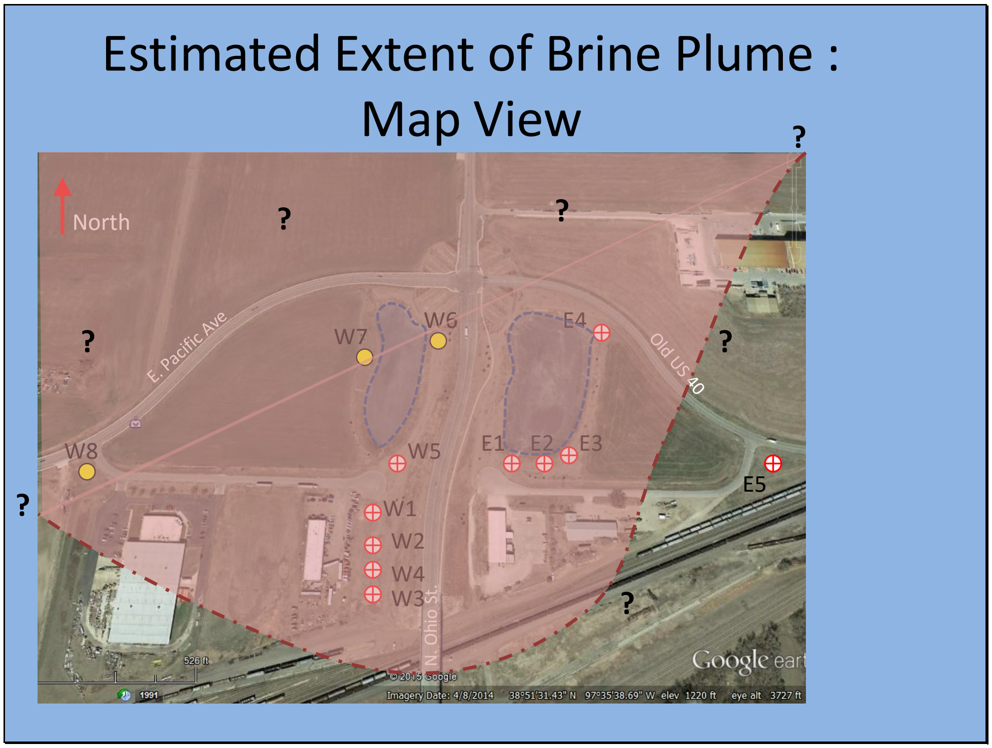
Let’s look at a cross section (A-A’) of the EC logs together with the groundwater specific conductance data to asses the concentration trend ~north-to-south across part of the brine plume.

Slide 47



The logs all show EC increasing below 70-75 feet but as we go south (to the right toward A') the increase in EC below 75 feet diminishes. A similar trend is displayed by the specific conductance of the groundwater samples. This indicates that the brine source is probably north of the study area and the impact of the brine is generally decreasing to the south in this area. Of course additional logs and water quality data would help to substantiate this data and interpretation.

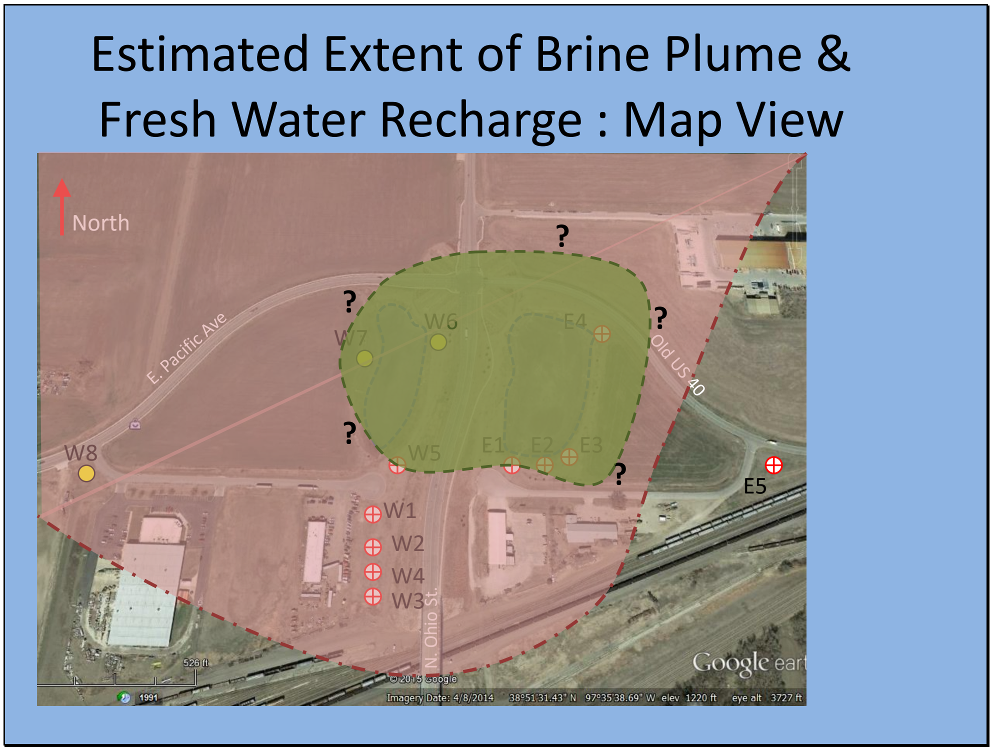
Slide 48



Based on the limited data from the EC logs versus HPT Pc logs this gives an estimate of the extent of the brine plume around the area studied at this time. The closest municipal supply wells are about 1.5 miles south of this area. More logs would be required to further constrain the extent of the brine plume.

The Saline River, another possible source for the brine plume, flows across the river flood plain about 2.5 miles north of this area. It is possible that as the Saline River meandered across the flood plain that saline river water recharged the aquifer leaving this brine in the aquifer. Further work would be required to confirm if the brine source was from the underlying Permian shale or the meandering Saline River.

Slide 49

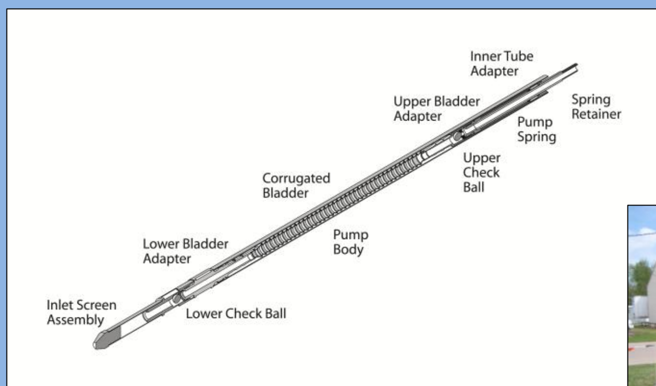


Here the green shading (over the pink) is used to estimate the aerial extent of the fresh water recharge in the upper part of the aquifer. The south edge appears to be close to the W5 and E1 logs based on the bulk formation EC at those locations. Alternately, the north side of the recharge plume may extend further north, more logging data would be required to accurately define the full extent of the fresh water plume.

If additional fresh water could be routinely added to the “recharge basins” the size and extent of the recharge plume could be enlarged. This might slow the advance of the brine plume southward toward the municipal well field. **If** water from the local waste water treatment plant were treated to an acceptable quality it could possibly be used to increase the recharge volume and area and reduce the advancement of the brine plume south. Additional work would be required to evaluate this option.

Slide 50

Sampling: Mechnical Bladder Pump



12 V actuator for down hole pump

For sampling with the HPT-GWS system the inlet screen is replaced with a barbed inlet that attaches to the sample line a few feet above the probe.

A 12V electric actuator mounts on top of the 2.25” tool string and the sample line is attached to the slider block. The up and down motion of the actuator opens & closes the bladder in the pump, pumping water to the surface. Depending on depth and formation permeability flow rates range between 50ml/min and 300ml/min. Low permeability formations (high EC and high HPT pressure) will not yield water for sampling. For more information about the pump go to www.geoprobe.com