Interesting Field Observations During Development of an Aquifer Monitoring Network Associated with a Mine Decommissioning Project

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ABSTRACT

Recent aquifer characterization studies related to establishing an aquifer monitoring network for an underground mine closure revealed a dynamic and challenging subsurface environment. Five boreholes were advanced to develop baseline hydrogeologic and water quality information prior to controlled flooding of the remaining mine workings. Borehole geophysical, hydrophysical and hydrogeologic (straddle packer) testing methods were applied to assess the structure, geology, hydrostatic elevations, transmissivity and water quality of the identified water bearing intervals. This information was also applied to the selection and construction of a multi-level monitoring system.

This paper will present the methods and summarize the results of the borehole investigation with a focus on the results from one of the five boreholes tested. The borehole investigation was an integral part of a broader network which was established to conduct long-term monitoring of the aquifers. Preliminary observations from the monitoring network will be discussed in a separate paper being presented at this conference (Vernon, et. al. 2018)

INTRODUCTION

The subject site contains two distinct underground mines, one historically developed and undergoing closure/reclamation and the subject of this paper. The second mine is new and was in the process of being developed though has since been put into care and maintenance. Concern regarding the effect from suspending dewatering operations and allowing the mine pool to backfill, required installation of four new, multi-level monitoring wells. Near the historically developed mine, borehole geophysical and flow logging have been conducted since 2008. These data, integrated with high resolution seismic results, have provided a unique understanding of the flow and its relationship to the structure system. With the mine closure and reclamation activities, additional characterization activities were conducted to evaluate subsurface conditions near the mine pool in preparation for design and development of a long-term monitoring network.

(Image Removed at Client's Request)

FIGURE 1. Mine Location and Well Locations

DISSCUSSION

As part of this program, five wellbores were advanced by air-hammer methods to maximum depths ranging from 200 to 300 meters. The locations of these boreholes, relative to the old mine foot print, are shown on the site map above (figure removed at request of client). Traditional drilling parameters were recorded and rock chip samples were collected during drilling. A geologic log was developed and has been included with the borehole geophysical, hydrophysical and straddle packer data montages. A highlighted section of a data montage is shown below.

A comprehensive suite of geophysical, hydrophysical and hydrogeologic methods was conducted to provide extensive characterization of the boreholes and included the following:

1) Natural gamma
2) 3-arm caliper
3) Resistivity (16-64 normal, single point resistance and induction)
4) Gamma-gamma density
5) Full Waveform Sonic
6) Analog Video
7) Optical Televiewer
8) Acoustic Televiewer
9) EM - HPL Flowmeter (HPEMFM)
10) Straddle Packer Testing (pressure monitoring, hydrogeologic evaluation and groundwater sampling)

The sequential order of logging was generally, analog video first, followed by the geophysical logs, imaging logs, flow logs and lastly straddle packer testing. Review of the flow and imaging logs was conducted to provide the principle basis for identifying the specific depths/locations of water bearing intervals and for selecting the straddle packer test intervals. The 3-arm caliper log was instructional in locating specific depths near the identified water bearing intervals where the packer elements could secure a water tight seal.

A highlighted interval of the resulting borehole data sets as collected by these methods is presented below.

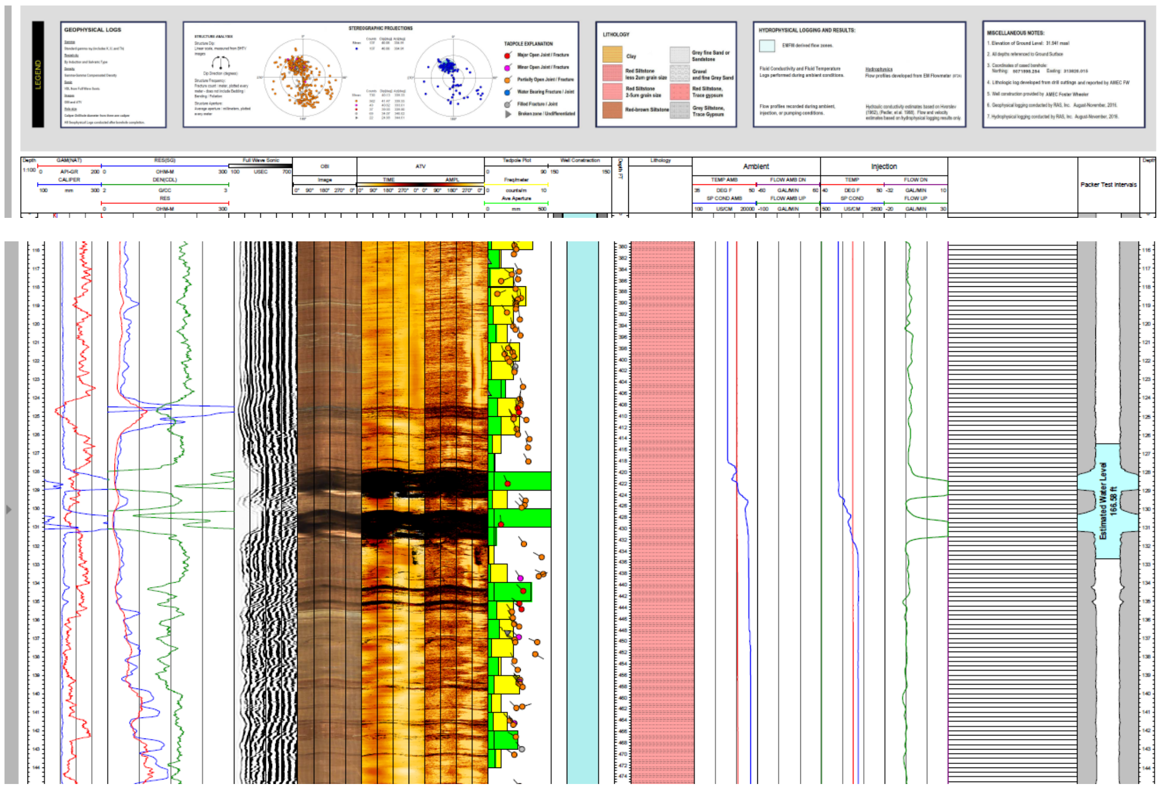

FIGURE 2 Geophysical, hydrophysical and hydrogeologic data montage, Well 16-117. Highlighted interval of interest.

This borehole investigative approach led to a challenging, but very successful straddle packer testing program which was implemented to acquire interval specific groundwater samples and evaluate formation hydrogeologic properties. Based on the dynamic and potentially unstable borehole conditions, the packer assembly and testing approach were slightly modified for this testing. These modifications included; dedicated pressure transducers enshrouded in the packer units (no exposed cables), a larger diameter flush joint stand pipe (~8-cm diameter) was used to convey the packer (helped maintain borehole stability), and a wireline-operated, pressure sonde was developed. The pressure sonde was employed to confirm target depth and record pressure response of the isolated interval during initial packer inflation. This larger diameter stand pipe allowed the electric submersible pump to be lowered down separately after confirmation of target conductive interval. The signature of this pressure response was indicative of isolation of the targeted conductive interval. The data set and results from well 16-117 are presented as they illustrate some of the most challenging flow and pressure conditions observed during the overall program. Specifically, these observations included, extreme vertical hydraulic gradient, extreme downflow, large fracture apertures, and other characteristics.

Straddle Packer Interval No.	Depth of Straddle Packer Interval (m)	Estimated Hydraulic Conductivity (m/day)	Average Flow Rate During Sampling (Lpm)	Maximum Drawdown During Sampling (m)	Interval Salinity (µS/cm)	Estimated Depth to Ambient Water Level (mbgs)
1	70.71-76.81	*	13.2	*	900	*
2	126.5-132.6	1.67	20.4	3.2	6,000	50.77
3	158.5-164.6	1.52	24.2	4.2	1,200	59.79
4	183.5-189.6	6.01E-02	16.3	71.8	1,300	56.97
5	197.2-203.3	1.23	20.8	4.5	1,600	62.10
6	204.2-210.3	3.36E-01	18.9	14.9	2,200	66.55
7	215.2-221.3	8.78E-01	20.4	6.1	14,000	64.73
8	240.2-246.3	4.85E-02	15.1	82.7	86,000	133.50

*Note: * – Insufficient data with which to make a calculation.*

Table 1. This table presents a summary of the estimated Hydraulic Conductivities, Pumping Flow Rates, Drawdown, Salinity and Estimated Depth to Ambient Water Level observed during Straddle Packer Testing and Sampling. Well 16-117.

After review of the analog video from well 16-117 and subsequent geophysical, imaging and flow logs, the dramatic cascading water from exposed hydraulically conductive intervals (conductors) suggested an extreme vertical gradient and complex hydrogeological subsurface environment were present near the mine pool. Visually dramatic inflow from the “perched” conductors was estimated at 30 liters per minute (lpm). Downflow, measured using the HPEM flowmeter, was recorded at over 100 lpm and was observed exiting near the bottom of the wellbore. A temporary packer was installed above the primary thieving (outflowing) interval, which caused the water level to rise approximately 30 metres and dramatically decrease vertical flow. The temporary, single packer was instrumented with two digitally recording pressure transducers to record pressure history during its placement. One of the most interesting observations from review of the resulting data was that the hydrostatic pressure for the interval below the packer, the bottommost interval, decreased dramatically and approached near atmospheric pressure conditions (instead of reflecting the anticipated hydrostatic pressure being close to ~400 psi). Straddle packer testing was also conducted and the results are summarized in Table 1.

This table summarizes the straddle packer results from well 16-117 and presents several noteworthy observations:

1) Eight (8) conductive intervals were identified from the geophysical and flow logging results. These intervals accounted for less than 20% of the saturated interval. Focusing the packer testing only on the known conductive intervals reduced the amount of packer testing by 88%, resulting in considerable time and cost savings.
2) Based on review of the geophysical and flow logging results, all of the conductive intervals could be tested with the same sample length (the interval between packers) of 6.1 meters. This saved time and expense as the packers did not need to be re-configured for each test interval. Packer testing in the subject well took two, 10- hour shifts to complete.
3) Hydraulic conductivity estimates were made using the packer system flow and pressure data, in conjunction with the actual length of the conductive interval as identified from the geophysical and flow results. Calculated "K" values ranged over three orders of magnitude (6.0E-02 to 1.7 m/day).
4) There was a dramatic increase in salinity with depth. Interval specific salinity ranged from 900 to 86,000 µS/cm. The deepest, most saline interval also displayed the lowest interval-specific, hydrostatic pressure.
5) Interval-specific, hydrostatic pressure dramatically decreased with depth.

SUMMARY

The integration and interpretation of the borehole data and mine pool suggest the following relationships:

1) **Geology and structure/fractures** - Fractures were distributed among all the geologic units penetrated by the subject wells. Fracture density varied among the boreholes, but no single geologic unit had a greater propensity for fractures than the others
2) **Structure and groundwater relationships** – Review of flow rate, permeability, water quality, and hydraulic gradient showed 22.8 % of all fractures identified in well 16-117 were water-bearing. A direct relationship between apparent aperture versus hydraulic conductivity was observed. No direct relationship between depth versus hydraulic conductivity was observed.
3) **Mine pool and structure/fractures** – The data suggest that mining activity probably enhanced the conductive properties of the natural fractures near, and to a significant distance away, the mine pool. Boreholes with greater conductive fracture density were, in general, closer to the mine footprint.

4) **Groundwater and Mine Pool** – Evaluation of flow, interval specific hydrostatic pressure, hydraulic gradient, water quality and mine pool fracture analysis suggested these wells display collapsed structure features and associated fracture dilation. This fracture dilation mostly likely enhanced flow properties. Wells further away from the mine pool were highly fractured but typically did not contain fractures with large apertures and displayed much fewer flow features.

CONCLUSIONS

The integrated approach of borehole geophysical, hydrophysical and hydrogeologic testing conducted at this site provided a safe, rigorous and technically sound means to evaluate a very challenging environment. The data collected from these methods provided initial characterization of the subsurface conditions and critical information for the selection, design and installation of a multi-level monitoring system. Given the long-term requirements of this monitoring system, proper design and construction are paramount for collecting legally defensible data for this site. The borehole characterization methods described in this paper provided this critical information in a valid, robust and cost-effective manner.