Fall, 2015 (only)

**Table 1. Summary of the hydraulic tests done at th Blair Wallis Fractured Rock Hydrology Research Site.**

| # | Test | Purpose | Date | Duration | Results | Comments |
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| 1 | Bailer tests at BW3 and BW5 | Determine relative magnitude of aquifer *near-wellbore* $K_H$ in select boreholes | 9/11/2015 | From 15 min (BW5) to 5 hours (BW3) | BW3: $K_H$ ranges from 2.0E-8 to 1.0E-7 m/s, assuming Re=3Rw to 1000Rw.<br><br>BW5: $K_H$ ranges from 3.6E-7 to 2.3E-6 m/s, assuming Re=3Rw to 1000Rw.<br><br>The estimated $K_H$ is a ***near-wellbore*** parameter, due to the short test duration and the small perturbataion (e.g., basically a variable rate injection test at each borehole). | Slug test sln applied with its accompanying assumptions. The estimated $K_H$ is an equivalent horizontal isotropic conductiivty averaged over the vertical distance of the open borehole. Only an isotropic $K_H$ is obtained, even though $K_H$ could be anisotropic. |
| 2 | Step test at BW4 | Determine a stable discharge rate for a subsequent constant-rate pumping test in BW4, the deepest well with the highest $K_H$ (from drilling observations). Flow rate was stepped from 3 to 6 pgm using a Redi-Pump.<br><br>After this test, the wells were identified as needing development to remove the loose rock and sediments from the borehole. | 10/2/2015 | 207 minutes total:<br><br>121 step test;<br><br>86:monitored WL recovery | BW4: $K_H$ is estimated from the recovery-phase of the drawdown data: 3.7E-6 to 5.7E-6 m/s<br><br>The estimated $K_H$ is a ***near-to-further-away from wellbore*** parameter, as the volume of rock tested is likely greater than that of Bailer tests. $K_H$ is estimated using Cooper-Jacob analytical sln (lateral flow without vertical leakage nor boundary effect).<br><br>Storativity (S) estimate from single-well hydraulic test is not reliable due to the significant effect of wellbore storage on S estimation. Storativity must be estimated from drawdown data collected at an observation well. | We pumped BW4, got 2.8 gpm per foot of drawdown at 3gpm for 100 min. Water became cloudy with red silts after 12 min. At 6 gpm pumping BW4, more sediments came out & pump became plugged at 121 minute. Stopped the step test and entered the recovery phase where WL is monitored until the elapsed time since test started is 207 min. Collected the sediment samples, which are identified by Brad as fine-grained broken granite & powdery rocks from coring.<br><br>No water level response was observed in BW1 for the given rate and duration of the step test – the closest monitoring well approximately 50 m away from BW4. |
| 3 | Airlift Test at BW1 | Clean up BW1, our main observation | 10/20/2015 | 2.4 hours airlift test + 50 min of | BW1: $K_H$ is estimated from the recovery-phase of the drawdown | Water rate (discontinuous at times) is averaged at 1.5 gpm for 2.4 hours; water production did |

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| | | well for BW4. | | monitored WL recovery. | data: 4.2E-7 m/s.<br><br>The estimated $K_H$ is a ***near-to-further-away from wellbore*** parameter, estiamed with the Cooper-Jacob sln. | not appear to decline with time; At the end of air-lift test, the water had cleared up considerably with only a trace of very fine brown sediment. Water levels did not change at observation wells BW-4, BW-2, and BW-5 during air-lift at BW-1; |
| 4 | Airlift test at BW4 | BW4 is envisioned to be a future pumping well. | 10/21/2015 | 3 hours airlift test + 53 min of monitored WL recovery | BW4: $K_H$=2.2E-6 m/s<br><br>The estimated $K_H$ is a ***near-to-further-away from wellbore*** parameter, estiamed with the Cooper-Jacob sln.<br><br>This is consistent with the earlier estimate from the first step test on this well. | Water rate was continuous at an average rate of 12.5 gpm for 3 hours; recovery data also obtained; At the end of air-lift test, the water had cleared up considerably with only a trace of red-brown sand and occasional granite rock fragments. During the airlift test, water level at nearby observation well BW-1 rose 0.02 feet and was unchanged at far field well BW-2. The rise was attributed to either barometric effect (*later, this was determined unlikely*) or due to aquifer poroelastic response to pumping stress. The airlift test also appears to have changed the hydraulics of BW4 slightly, as a new head equilibrium is achieved after WL recovery. |
| 5 | Airlift test at BW5 | BW5 was envisioned to be both a monitoring well for future pumping test at BW4, and a possible pumping well itself. | 10/21/2015 | 2 hours of airlift +232 min of monitored WL recovery | BW5: $K_H$=1.57E-7 m/s<br><br>The estimated $K_H$ is a ***near-to-further-away from wellbore*** parameter, estiamed with the Cooper-Jacob sln.<br><br>This is consistent with the earlier estimate made from the Bailer test assuming a small radius of pressure perturbation. | Water rate is around 2~3 gpm for 2 hours; water rate is continuous and gradually declined with time from an initial 3 gpm to a final 2.2 gpm. At the end of air-lift test, water had cleared up considerably with only a trace of light gray silt (bentonite?) and occasional coarse granite rock fragments. By the end of air-lift test at BW-5, water levels at observation wells BW-2, BW-1 and BW-4 had risen 0.01 to 0.02 feet. This is likely due to aquifer poroelastic response.<br><br>***Detailed discussion of the airlift tests was sent to the group in late November, 2015.*** |
| 6 | Step test at BW4 | Determine a stable discharge rate for a subsequent constant-rate pumping test in BW4. Flow rate was | 11/16/2015 | 260 minutes total test duration;<br><br>Snow storm | Parameter is not estimated as W L recovery data were not downloaded. We wish not to disturb the transduers before the subsequent pumping test at the same well. | The well efficiency is of interest, as significant turbulence can develop in the pumpoing well when well rate is too high. The turbulent head loss is computed as 17% of the total drawdown at 20 gpm discharge rate; the turbulent head |

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| | | stepped from 10, to 20, to 32 gpm using a 3-inch submersible pump with a maximum capacity of 32 gpm. Note that the pump diameter (and capacity) is limited by the borehole diameter, which is around 3.8 inches in the open interval. | | during most of the test. | During the step test, negnlible WL response was observed in BW1 and all other wells. No WL response observed in the Blair Creek staff gauge insalled by Ye. | loss is computed at 69% at 32 gpm discharge rate. The design discharge rate is determined to be 23 pgm for the subsequent pumping test at BW4. Note that any possible drawdown in BW1 during a long-term pumping test at BW4 is proporational to the discharge rate. Thus, if discharge rate is too small, drawdown in BW1 will likely be difficult to see; however, if discharge rate is too large |
| 7 | Pumping test at BW4 | Determine aquifer parameter and interwell hydraulic connectiivty between BW4 and other wells | 11/18/2015 ~ 11/19/2015 | 28 hours;<br><br>Snow storm during Day 1 of the test.<br><br>A constant pumping rate was not maintained; later a tub test by the drillers determined that the pump was defective.<br><br>The pump was sent back to the manufacturer; we expect a resolution by mid January. | Parameter estimation is largely unsuccessful because the discharge rate was not constant. Although $K_H$ heterogeneity is inferred from the drawdown data in BW4 (see Comments).<br><br>WL rise was observed in BW-1, which is intepreested as aquifer poroelastic repsonse. Any possible drawdown at BW-1 may have been masked by this WL rise, thus drawdown reaonse in BW1 (*i.e., hyraulic connection bewteen BW1 and BW4*) cannot be confirmed given the data we have (Figure 1).<br><br>No WL response observed in the Blair Creek staff gauge insalled by Ye. The creek bed is about 6 m lower from the top of BW4, while the static WL in this and other wells is around 12 m. The saturated zone appears to be 6 m deeper than the creek, suggesting that potentially | There are 2 straight-line slopes identified from the semi-log time-drawdown data of BW4: Slope 1 from 40 to 400 minutes during which the pump rate declined from 23 to 18 gpm. A later test by drillers determined that the pump was detective.<br><br>The inferred $K_H$ will reflect near well fracture network. Slope 2 from 400 min to end of the test, where pump rate declined from 18 to 14 gpm but time-drawdown slope **steepens**. In the absence of T variation, hydraulic boundaries, or fracture closure, slope should have flattened in response to declining Q. Simple explanation is that cone of depression encountered a low K network, thus, as the cone expands, transition from relative high T to relative low T may have been observed. Possible "bottleneck" effect at regional scale, per personal communication with Allen Shapiro at USGS.<br><br>Note that barometric data were also collected: based on both water pressure and air pressure data, the barometric effect at the boreholes was determined to be negligible. This is likely because the wells are quite shallow. Thus, the observed WL rise is likely due to aquifer poroelastic response to pumping.<br><br>***Detailed discussion of the step and pumping*** |

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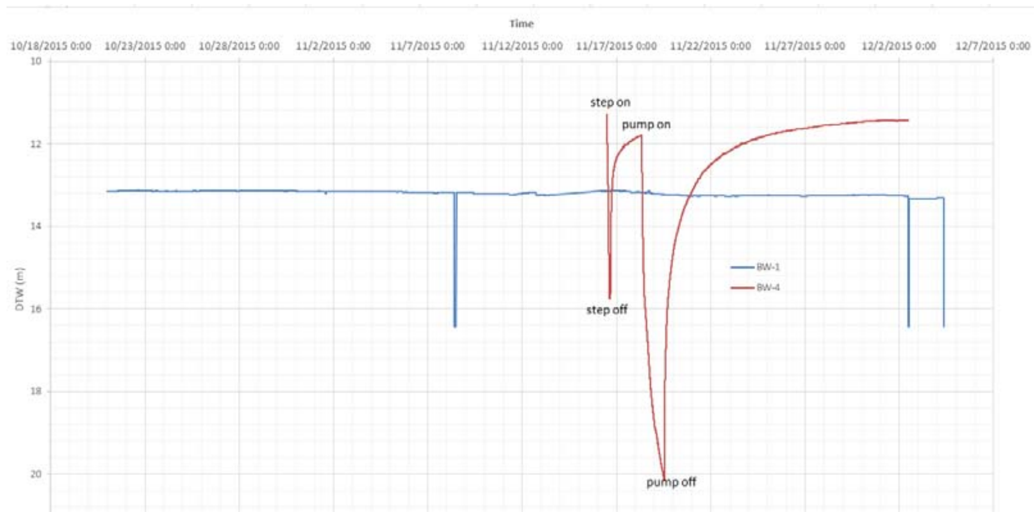
| | | | | | there is either a hydraulic separation or limited hydraulic communication bewteen groundwater and surface water. | ***test was sent to the group around Dec 2, 2015.*** |

*WL is water level, T is transmissiblity, and $K_H$ is an average horizontal hydraulic conductivity. "#" denotes the sequeqnce of tests done. The bold texts indicate the scale of the aquifer investigated by the different tests. With the exception of the Bailer test, water chemistry (pH, conductvivity) and suspended sediment content were also meauserd, though they are not reported here.*



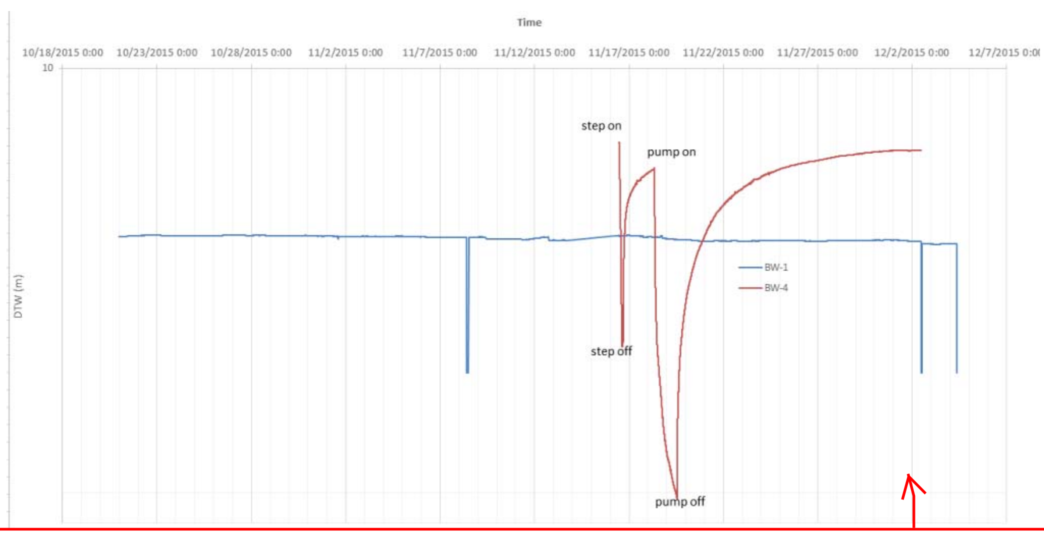
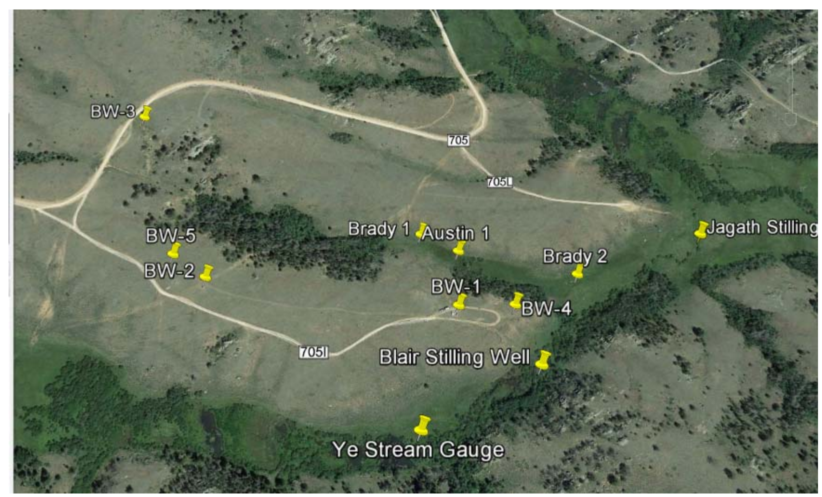




**Figure 1. WL observations in BW4 and BW1 during the step test and long-term (28 hour) pumping test from Nov 16 to Nov 19.** Note the slight water level rise in BW-1 in response to pumping in BW4. DTW: depth to water, which is plotted in linear (top) and log scale (bottom). At the Blair site, the aquifer is significantly shallow and connected to the atmosphere thus barometric influences on the measured WL is negligible. Thus, this WL rise is interpreted to be a poroelastic response. Similar poroelastic response is also observed during the earlier, shorter duration airlift tests at the site.




At Blair Wallis, bulk (matrix+fracture) k from small-scale well tests ranges from 1.0E-14 (BW3) to 5.0E-13 (BW4) m^2. In comparison, Gimmi et al. [1997] estimated a permeability of $10^{-18}$ m^2 for a crystalline rock that lacks fractures at the investigation scale. Using packer tests, Snow [1979] reported bulk permeability at $10^{-14}$ m^2 for most of the fractured crystalline rocks he considered. Caine et al. [2003] similarly estimated a bulk permeability of $10^{-13}$ to $10^{-14}$ $m^2$ for intensively fractured crystalline rock in the Turkey Creek Watershed of the Front Range of Colorado.