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Appendix A-1

Background Monitoring and Barometric Efficiency Calculations

Background Monitoring and Barometric Efficiency Calculations

Pressure transducers were installed in both wells at both sites by April 2, 2008 in order to obtain background ground water level measurements. At the Burdock test site, a transducer was installed in the designated pumping well (DB07-11-11C) in the lower Lakota Formation. At the Dewey test site, a transducer was installed in observation well (DB07-32-4C), screened in the same zone as the pumping well in the lower Fall River Formation.

Figure 3.1 in the text illustrates background measurements before the pumping tests and also the sequence of subsequent test events. The left axis of the figure indicates a narrow range of 1 psi. The background measurements shown on the figure fluctuate over a range of about 0.4 psi.

Converting Pressure Measurements to Head

Pressure transducer psi coverts directly to head [feet of water overlying the transducer] according to the relationship:

$$\begin{aligned} \text{Head } [\text{ft}_{H20}] &= P\,[_{PSI}] \times 144\ \text{in}^2/\text{ft}^2 \div \gamma_{H20}\,[\text{pounds per cubic foot}] \\ &= P\,[_{PSI}] \times 144/62.48 \\ &= P\,[_{PSI}] \times 2.31 \end{aligned}$$

Where γ H_2O [pounds per cubic foot] is the unit weight of water, ignoring temperature effects.

Therefore, a change in transducer pressure (Δpsi) corresponds to a change in water level of about 2.31 [ft_{H20}] x Δpsi with the same sense of increase or decrease. Total variations in background changes in groundwater levels over the one month period of record on Figure 3.1 (in the text) thus correspond to about 0.9 feet of water, which could be significant, although it will be established that such background variations over the time of a pump test do not significantly affect interpretations of the tests.

As indicated on Figure 3.1 (in the text), more than one month of background measurements were obtained from April 8 to May 9, 2008. However, this was also a period when pump installation and testing produced temporary drawdowns where the psi readings dropped below the scale of the figure.

The right hand axis on Figure 3.1 (in the text) illustrates hourly barometric pressure measurements in millibars obtained from the meteorological station installed at the site. The site station is maintained by South Dakota State University (SDSU) at the following URL: "http://climate.sdstate.edu/awdn/edgemont/archive3.asp". Barometric pressure reported by SDSU data is available only in the hourly dataset.

Barometric and Other Water Level Corrections

A period of about two weeks (April 23 to May 8, 2008) after pump installation and initial testing was designated as a period for undisturbed background water level monitoring in order to obtain data for possible barometric corrections. Inspection of Figure 3.1 (in the text) finds the expected inverse relationship between site barometer readings and increases or decreases in ground water levels. There are also smaller order cyclic sinusoidal variations which occur twice daily attributable to lunar tidal cycles.

Two types of barometric and other water level corrections were employed as described separately below.

Manual Barometric Efficiency Corrections

The first correction was manually evaluating the data based on total head (i.e., the transducer psi reading) and correcting the values to the barometric pressure (i.e., barometer millibars converted to psi) trends throughout the test. Kruseman and de Ridder (1991) and Gontheir (2007) state that the barometric efficiency (BE) can be defined as the change in water level in a well versus a change in atmospheric pressure, as follows:

$$BE = \gamma \ H_2O \text{ [pounds per cubic foot]} \times \Delta h_w \div \Delta P_a$$

Where Δh_w is the change in elevation in the well associated with atmospheric pressure change (exclusive of other simultaneous effects that may also induce a change) and ΔP_a is the change in atmospheric pressure at the top of the well and land surface. By convention, the BE is dimensionless and ranges from zero to one.

Measurable water level changes in a well may also be due to a number of other factors in addition to changes induced during a pumping test. These are chiefly long-term seasonal trends and earth tides (Halford, 2006). Gontheir (2007) describes the historical methods of determining barometric efficiency. The methods can generally be said to determine an average response with selective application of corrections depending on the overall trends. The methods employ best fit lines to graphical displays of data and numerical

analysis of the data sequence with sign tests to determine when a change is significant and should be applied.

The Site barometer readings were interpolated to the 15 minute background water level data using a custom FORTRAN computer method described in Section 1.3, below. A spreadsheet calculation was used to determine BE corrections throughout the background measurement period from April 23 to May 26. The results for the Dewey Site/Fall River aquifer are shown in Figure A.1-1 and the Burdock Site/Lakota aquifer in Figure A.1-2. The empirical method also determines a trend of rising water levels throughout the calibration period. Corrections for earth tides were not employed because these have demonstrably small amplitudes (i.e., 0.05 psi = 0.1 ft) below the limit of transducer accuracy. The figures illustrate that, after correction for the seasonal increase in water levels, BE's of 0.48 and 0.42 are determined for the Dewey and Burdock sites, respectively. It is noted that the barometer data on the right hand side of Figures A.1-1 and A.1-2 are scaled in reverse order to invert the data and allow superimposition of air pressure trends with ground water levels, as presented in Kruseman and de Ridder (1991).

Computer Applications

Two public domain computer applications were used to analyze the barometric and background water level data collected prior to the pumping tests. However, it was determined that use of either method for correction of actual test drawdown data could introduce more error than working with uncorrected data because background water level variations in the same aquifer at the same time as the test (but at great enough distance to be unaffected by the tests) were not available to validate the correction methods.

The first is a spreadsheet developed by the U.S. Geological Survey (USGS – Halford, 2006). The USGS spreadsheet empirically factors the overall water level response into multiple synthetically generated time series with adjustments to both phase and amplitude of each component (Figure A.1-3). The USGS spreadsheet was used to verify that the Dewey background water level data from April 23 to May 8, 2008, could be closely matched as a series of four components: (1) water level increase at a liner rate [i.e., slope], (2) variation in air pressure as measured with the site barometer, (3) two earth tide components (Figure A.1-4).

The second computer method used is BETCO (Sandia Corporation, 2005), which is publically available at "http://www.sandia.gov/betco/". To correct data, water level, time

and barometric pressure are input and BETCO calculates corrected water level values. As described under Section 1.3 "Data Processing" below, the hourly site barometer data were interpolated to the 15 minute water level measurement frequency. Figure A.1-1 compares the BETCO corrected water levels (as equivalent psi) with the manual BE calculations, and the two methods yield equivalent results, generally within about ± 0.01 psi, except that BETCO did not fully correct the water level for the peak (actually a trough with the vertical axis reversed) in barometric pressure at the middle of the calibration period (i.e., about April 30, 2008, Figure A.1-1).

Summary

As shown in Figure A.1-1, the manual BE method was better than the BETCO computer method for the background calibration period examined. Similar to the USGS method, a difficulty with applying BETCO corrections to the Dewey or Burdock tests is that background wells with similar construction to the pumping test wells are not available to validate the corrections. This would have required drilling a well at each site specifically for background measurements. A further difficulty with the available computer methods is that they do not easily accommodate variable measurement times as input data.

To examine the possible importance of BE corrections, the drawdown phase of the Dewey test (10:30 AM, May 15, 2008 through 12:30 PM May 18, 2008, see Figure 3.1 in the text) was selected for manual correction with a BE of 0.48 relative to the Site barometer over the test period. The corrections were applied after Site barometer data were interpolated to the logarithmically-space time-drawdown data using a custom FORTRAN computer program as described in Section 1.3, below. The maximum effect of the BE correction was to add about 0.2 ft to the water levels at the end of the drawdown phase due to an overall barometric pressure decline of about 15 millibars (i.e., from about 1,030 to 1,015 millibars).

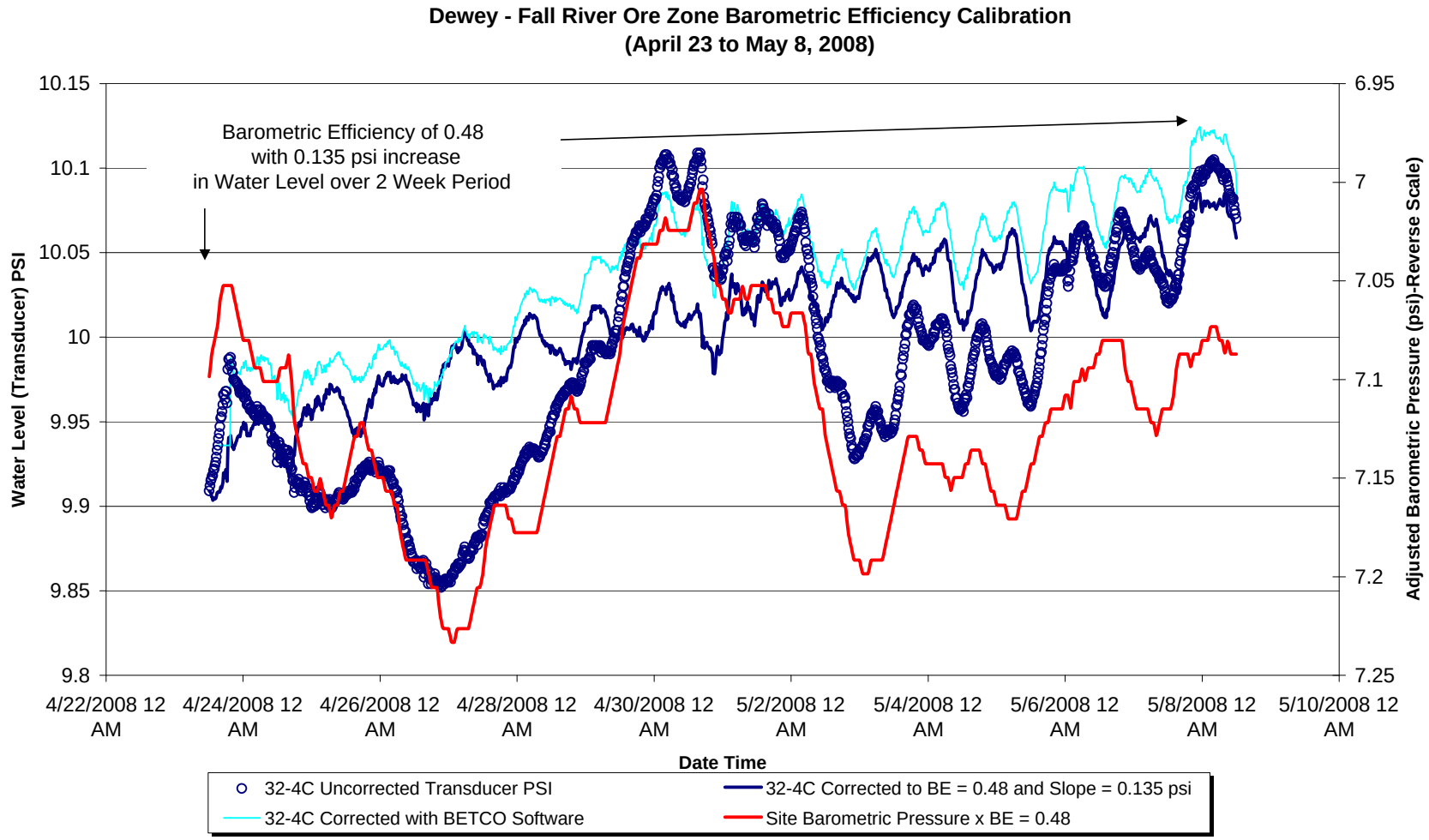
Test interpretations (Theis drawdown, Section 4 in the text) were made with and without the BE corrections for the data at all wells screened in the Fall River aquifer for the Dewey test, and the corrections were found to have no discernable effect on the visual fits to type curves. Because the changes in barometric pressure during the three day constant rate tests at Burdock and Dewey were similar (Figure 3.1 in the text), the above analysis indicates the magnitude of the BE corrections would be no greater for the Burdock test compared to the Dewey test. Therefore, corrections to water level data were not further performed and the test interpretations rely on uncorrected time-drawdown data.

Time-drawdown and Barometer Data Processing

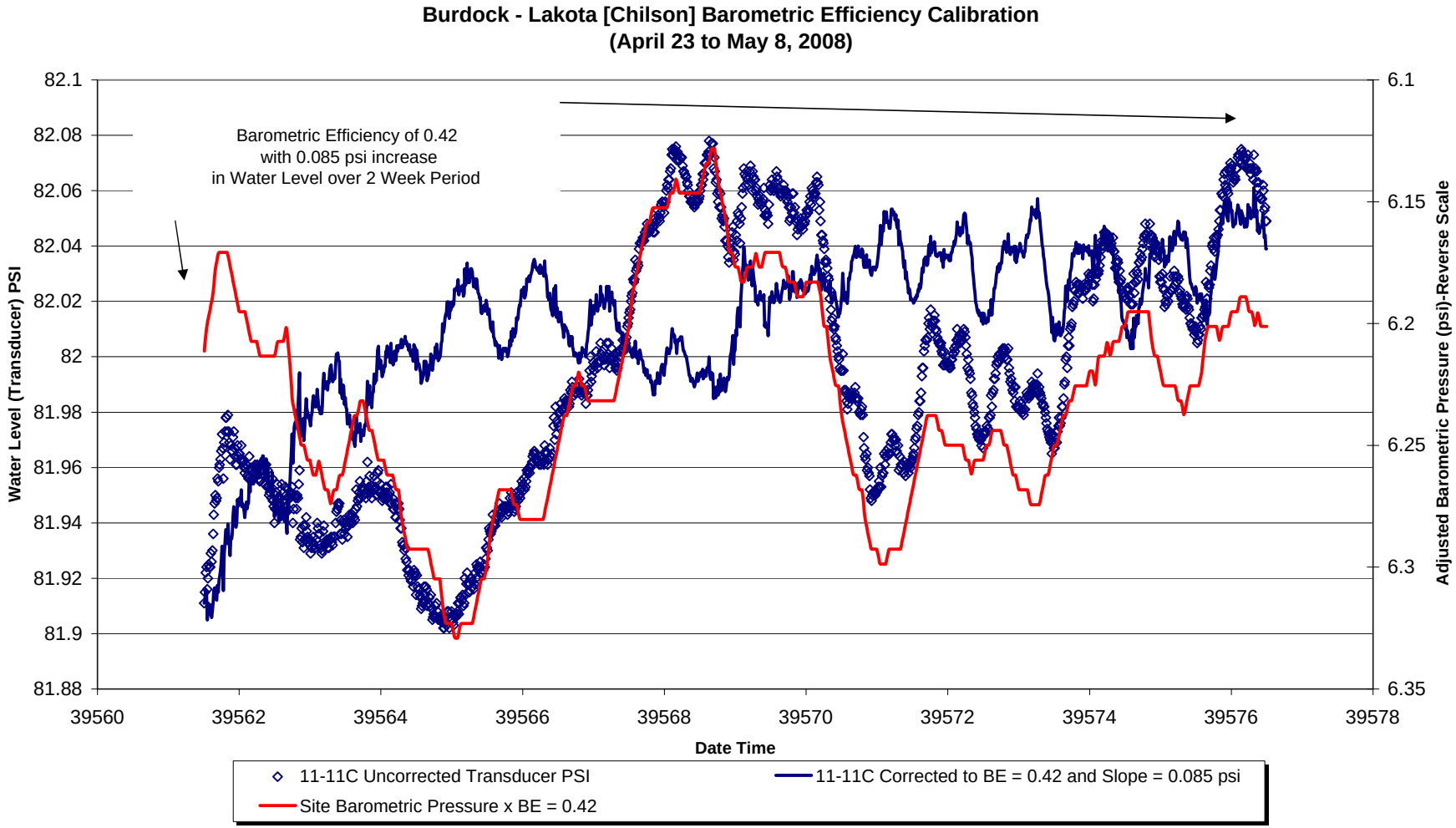
The time-drawdown data from the data loggers consisted of two hours of data at one second intervals followed by 72 or 74 hours of data collected at 10-second intervals, with the sequence repeated for the recovery phase. The WinSitu™ software exported transducer data logger records to ".csv" files with approximately 60,000 to 70,000 records for each well. The time-drawdown data were processed using a custom FORTRAN program employing a template file specifying which date-time records would be written to an output file. The program cycled through the raw data input file and wrote data records to the output file. The template file was prepared to produce logarithmically spaced data with about 30 records per log cycle (in seconds). Due to slight variations in transducer output and the precision of the Microsoft Excel date-time format, there are some ± 1 second variations in the sequences of records from well to well.

The FORTRAN program for drawdown data also converted transducer psi to drawdown in feet using formulas presented in Section 1.1. The reference value for zero drawdown was set to be the average of all psi readings from the start of the data log to the time just prior to test startup.

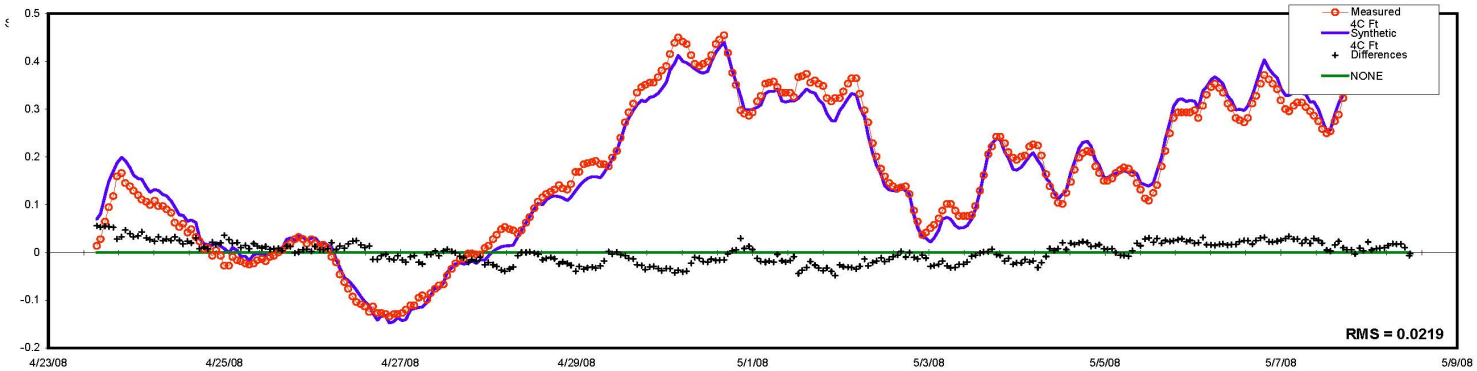
Two custom FORTRAN programs were also used to interpolate hourly site barometer readings to (1) the evenly spaced background transducer measurements described in Section 1.2.2 and (2) the logarithmically spaced drawdown data described in Section 1.2.3.



Client	Project	Title	
Knight Piésold CONSULTING	DEWEY-BURDOCK HYDROGEOLOGIC TESTING REPORT	Background Water Level and Site Barometer Readings Dewey/Fall River Barometric Efficiency Calculations (April 23 to May 8 2008)	
	Project No: DV10200279.01	Date: 10/14/08	Appendix A, Figure A.1-1



Client	Project	Title	
Knight Piésold CONSULTING	DEWEY-BURDOCK HYDROGEOLOGIC TESTING REPORT	Background Water Level and Site Barometer Readings Burdock/Lakota Barometric Efficiency Calculations (April 23 to May 8 2008)	
	Project No: DV10200279.01	Date: 10/14/08	Appendix A, Figure A.1-2



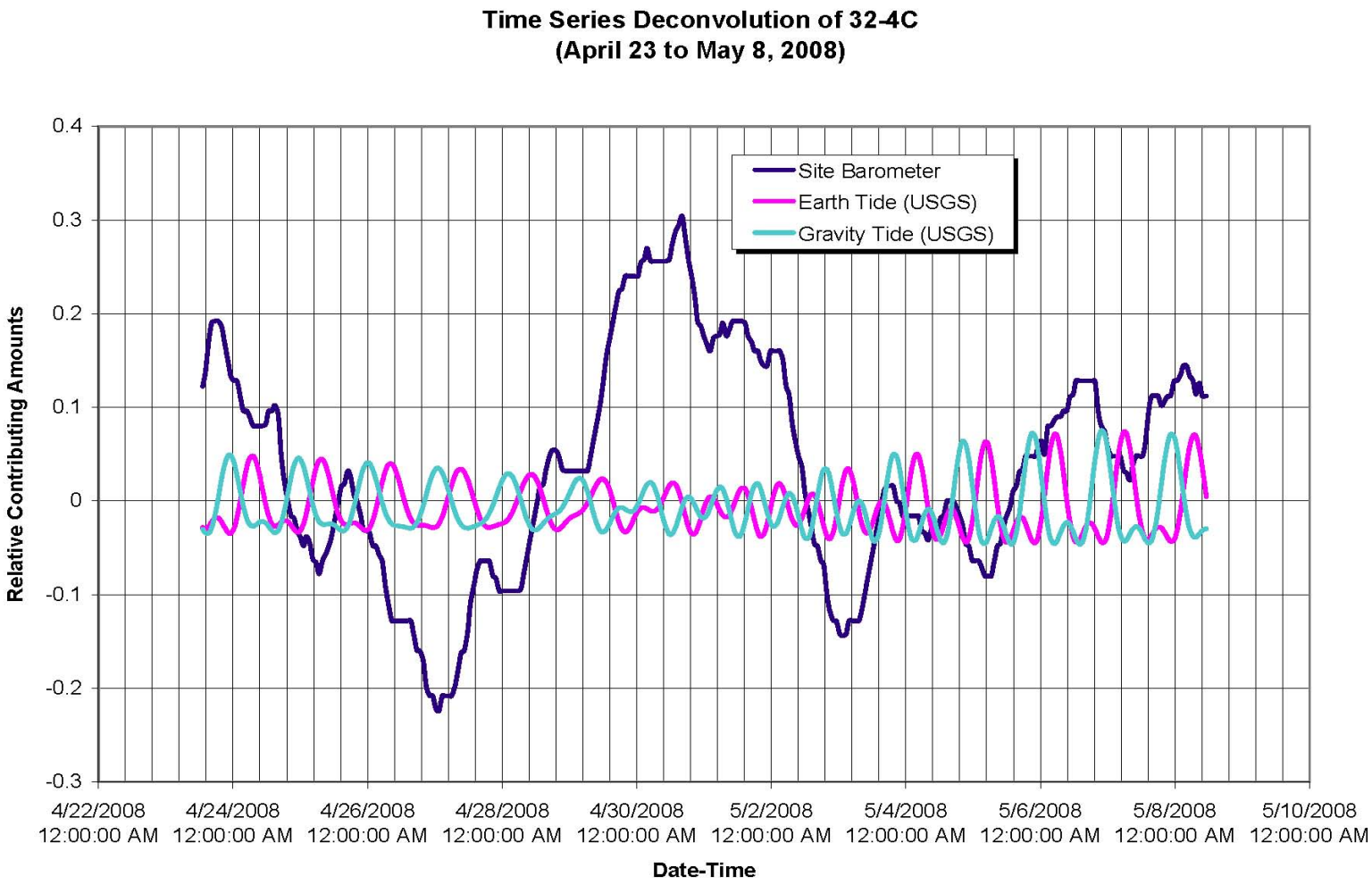
Series Comparison

Time Overview

Phase Increment:	50	AVERAGE = 0.000	LOAD	FITTING	ESTIMATION	FEEL GOOD
Phase Limit:	48:00	RMS = 0.022	Begin:	04/23/2008 12:25	04/23/2008 12:25	04/23/2008 12:25
Moving Average:	24:00	Save Solutions on Estimation	End :	05/08/2008 11:55	05/08/2008 11:55	05/08/2008 11:55
		Initialize parameters on LOAD	Interval:	01:00	01:00	01:00
NEW			Samples:	359	359	359
Result:	TIME SERIES	Offset: 0.0054	Phase Shift:	0.0191	-0.1390	0.1979
Analyze:	4C Ft	FIT Slope: 0.0193	Multiplier:	-0.0160	0.0013	-0.0005

DATE-time	Measured 4C Ft	Synthetic 4C Ft	Differences	NONE	Baro2{ Raw}	EarthTide	GravityTide	NONE
04/23/2008 13:10:45	0.014	0.070	0.056	0	0.12	-0.028283855	-0.030282086	
04/23/2008 14:10:45	0.028	0.081	0.053	0	0.14	-0.030098538	-0.034381662	
04/23/2008 15:25:45	0.065	0.119	0.055	0	0.17	-0.02676559	-0.034150371	

Client	Project	Title	
Knight Piésold CONSULTING	DEWEY-BURDOCK HYDROGEOLOGIC TESTING REPORT	Time-series from USGS Spreadsheet Method (Halford, 2006) for Dewey Observation Well 32-4C Background Measurements and Site Barometer Readings (April 23 to May 8 2008)	
	Project No: DV10200279.01	Date: 10/14/08	Appendix A, Figure A.1-3



Client	Project	Title	
Knight Piésold CONSULTING	DEWEY-BURDOCK HYDROGEOLOGIC TESTING REPORT	Plotted Time-series Output for Dewey Observation Well 32-4C Background Measurements and Site Barometer Readings (April 23 to May 8 2008)	
	Project No: DV10200279.01	Date: 11/12/08	Appendix A, Figure A.1-4