2 February 2010

Memo to: Scott Slater, Brownstein Hyatt Farber Schreck, LLP

From: John M. Sharp, Jr.

Re: Report on Cadiz wells

Following is my report on the Cadiz wells.

This based primarily on my analysis of the television log of the well, my two visits to the site, well cuttings observed at the site, and comparison with karstic systems elsewhere in the United States.

REPORT ON THE CADIZ WELLS

I was contacted by Scott Slater, Brownstein Hyatt Farber Schreck, LLP with regards to new well drilled by Cadiz Farms. This well (TW-1) penetrated a carbonate system that had not been analyzed heretofore. My charge was to look at the data provided and evaluate the properties of this well and compare it with general characteristics that would be expected in a carbonate aquifer. Specifically, I addressed the question – are this well and the aquifer responding in manner consistent with a karstic carbonate system.

My analysis is based upon the following:

1. A television log of the well (TW-1);
2. Results of the pump test of the well;
3. A visit to the site;
4. A perusal of well cuttings of other wells (TW-2 and TW-3);
5. Knowledge of carbonate systems in other locales (a list of my publications on carbonate aquifers is included).

The findings/inferences are:

1. The television log shows significant secondary porosity and permeability. There are ~300 feet with many vugs, cavities/conduits, terra rosa (?), veins that have been re-opened. The karstic features occur over the reach from 454' to 758'. Some appear to be along relict bedding planes. Some appear to be veins that are nearly normal to these planes. This is indicative of a widespread karstification; it is a regional, not a local phenomenon.

The log indicates a well of approximately 1001 feet of depth. A static water level is at a depth of 329'10" and the bottom of the well screen is at 454'. The materials above the well screen were stated to be alluvial or clastic sediments. From 454' to a depth of approximately 758' there are numerous vugs and dissolution zones. Some of these are appear to be along beds (dipping at ~20-45° - note this dip is very approximate only); others are subvertical or at a high angles from the beds. Some of these features appear to be conduits. There is some sparry calcite and calcite (?) druse in some of the conduits, fractures, and veins

Many of these features are sufficiently large that they will provide very highly transmissive zones. A single fracture with an aperture (opening) of 1/16th of an inch would transmit as much water as a permeable sand layer of a thickness of between 10 to 100 feet. There many such productive secondary porosity features apparent in the well log. See attachment.

There is what may be terra rosa to a depth of nearly 600'. Terra rosa is the residuum of the karstic weathering process. There are also appears to be a similar colored silty material in the screen portion of the well. I do not know if this means there is carbonate in the screened section (above 454') or if this was terra rosa displaced by drilling and washed into the screen. Below 600' depth, this sediment is not as evident. Consequently, if the reddish brown sediment is remnants of the drilling mud, this implies a change of drilling procedures below this depth. I was informed that in this well there was no change in the drilling procedure.

From about 758' to ~900-910', there are still small vugs, but the karstic features are not as prevalent. From 910'-920' to the bottom of the well, there are only few, scattered, small karstic features. I infer that there several formations or formation members that have been penetrated by this well. The upper portion has been identified as the Bonanza King Formation. Some interformational conglomerates appear in the well, which is noted for this formation by Hazzard (1954). From this I infer the lower portions of TW-2 to be in the Cadiz Formation,

2. The pump test data supplied by Mr. Foreman (CH2M-Hill) showed no drawdown in the pumping well and very little drawdown in a nearby monitoring well. This occurs in other highly permeable karstic aquifers, such as the Edwards Aquifer of central Texas (Halihan et al., 1999; 2000). There must be a decrease in hydraulic head to permit water to flow into the production well, but it is too small to be measured accurately. One can estimate a conservative value of the transmissivity by arbitrarily assuming a small drawdown (e.g., 0.5 or 1.0 feet).

The fact the borehole upon pumping is filled with waters at the temperature of the deeper producing units can also mask small drawdowns. In this case, the thermal expansion of the hotter fluid can even create a rise in water levels as was observed in the pumping well.

Both of the above corrections/estimations have been conducted by others on the consulting team (Mr. Foreman and Dr. Williams), I have not seen these calculations, but the discussion of these during the telephone conferences sounded reasonable.

The observation well calculations appear reasonable. I do wish to add, however, that karstic aquifers can be highly anisotropic.

Finally, the results of all the observations discussed above indicate that the approximately 300 feet of karstified carbonate rocks provide a highly productive aquifer, independent of the overlying and adjacent alluvium.

3. Site visit showed carbonate rocks with evidence of karstification, which have been tentatively identified as the Chambless Formation. This underlies the Cadiz Formation so there is a possibility that well TW-1 may have more highly permeable rocks at depths below 1000 feet. There are caverns in these Cambrian carbonate formations to the north.

4. During the site visit, I stopped at a second well (TW-2) and have been informed that this well was drilled to nearly 1000 feet, but did not penetrate the carbonates. The well cuttings that I observed were well-sorted medium-to-coarse sand. I predict its transmissivity would be high, but not as great as the well discussed above. I have not seen well logs or pumping test data for this well. A second site visit at well TW-3, indicated that bedrock had not been reached at a depth of 1360'. The hydraulic conductivity of the TW-2 was reported by CH2M-Hill for be approximately 600 feet/day. TW-3 should also have a high transmissivity.

5. The above observations, analyses, and the general nature of karstic aquifers indicate that these strata will provide a superb aquifer. I conclude that the well and the aquifer will be highly productive.

The area of interest is highly faulted, and there has been some intrusive activity in the region. The intrusive activity may cause some contact (local) metamorphism and could also have caused the development of additional secondary porosity and permeability (by volcanogenic karstification, see Gary and Sharp, 2006 and 2009). The faulting commonly leads to more intense karstification and the development of preferential flow paths that tend to align in the direction of the faulting. This is observed in New Mexico, Texas (Sharp, 1998 and 2001; Mayer and Sharp, 1998), and elsewhere.

These aquifer materials are similar to those observed in the Edwards aquifer of Central Texas and many other highly productive karstic aquifers that are documented elsewhere (e.g., Missouri, Florida, and in the carbonate units of the Great Basin).

Synopsis

I conclude that this well and the aquifer are responding in manner consistent with a productive karstic carbonate system.

Note #1 - The inverse modeling proposed by CH2M-Hill is a logical exercise and should be compared with simpler cross-sectional flow models using estimated cross-sectional areas, the measured hydraulic gradients, and hydraulic conductivities measured or inferred from pumping tests.

Note #2 - In considering the water budget for this system, it is difficult to do this from the recharge estimates alone, because of variations in precipitation and recharge rates as functions of elevation, lithology, and evapotranspiration. In addition, it has been shown for karstic carbonate rocks in arid and semi-arid zones that the contributing area may differ from that of the surface water catchments. Longer flow systems are common in such settings. However, a water budget can be calculated from discharge estimates as calculated in Note #1.

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Sand K [m/s]	b [m]	Fracture aperture b [mm]	b [inches]	fluid density [kg/m**3]	visosity [kg/m/sec]	Equivalent sand thickness H [m]	H [ft]
1.0E-04	0.000794	0.79375	1/32"	1000	0.001	4.1E+00	1.2E+00
1.0E-04	0.001588	1.5875	1/16"	1000	0.001	3.3E+01	1.0E+01
1.0E-04	0.003175	3.175	1/8"	1000	0.001	2.6E+02	8.0E+01
1.0E-04	0.00635	6.35	1/4"	1000	0.001	2.1E+03	6.4E+02
1.0E-04	0.0127	12.7	1/2"	1000	0.001	1.7E+04	5.1E+03
1.0E-04	0.0254	25.4	1"	1000	0.001	1.3E+05	4.1E+04
1.0E-04	0.00001	0.01		1000	0.001	8.2E-06	2.5E-06
1.0E-04	0.0001	0.1		1000	0.001	8.2E-03	2.5E-03
1.0E-04	0.001	1		1000	0.001	8.2E+00	2.5E+00
1.0E-04	0.002	2		1000	0.001	6.5E+01	2.0E+01
1.0E-04	0.005	5		1000	0.001	1.0E+03	3.1E+02
1.0E-04	0.01	10		1000	0.001	8.2E+03	2.5E+03
1.0E-05	0.000794	0.79375	1/32"	1000	0.001	4.1E+01	1.2E+01
1.0E-05	0.001588	1.5875	1/16"	1000	0.001	3.3E+02	1.0E+02
1.0E-05	0.003175	3.175	1/8"	1000	0.001	2.6E+03	8.0E+02
1.0E-05	0.00635	6.35	1/4"	1000	0.001	2.1E+04	6.4E+03
1.0E-05	0.0127	12.7	1/2"	1000	0.001	1.7E+05	5.1E+04
1.0E-05	0.0254	25.4	1"	1000	0.001	1.3E+06	4.1E+05
1.0E-05	0.00001	0.01		1000	0.001	8.2E-05	2.5E-05
1.0E-05	0.0001	0.1		1000	0.001	8.2E-02	2.5E-02
1.0E-05	0.001	1		1000	0.001	8.2E+01	2.5E+01
1.0E-05	0.002	2		1000	0.001	6.5E+02	2.0E+02
1.0E-05	0.005	5		1000	0.001	1.0E+04	3.1E+03
1.0E-05	0.01	10		1000	0.001	8.2E+04	2.5E+04

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