REPORT - PERMEABILITY OF THE CARBONATE AQUIFER AT CADIZ
John M. Sharp - May, 2010

The telephone conversation of 29 April 2010 raised a question on the value of hydraulic conductivity of the carbonate aquifer as inferred from the TW-1 pumping tests. One participant stated that a value of 183 ft/day and 170 ft/day (essentially that of a well-sorted fine to medium sand) for the alluvium and carbonate aquifer, respectively, at TW-1 were obtained based upon the pumping test as reported in CH2MHill (2010). I have not seen the analysis that provided these values. Consequently, I do not comment directly on this analysis. Well TW-1 penetrated a carbonate system that had not been analyzed heretofore. It is assumed that these data reflect the properties of the Bonanza King Formation

My charge has been to examine 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 primarily upon the following:

1. Well logs and, in particular, the television log;
2. Reported results of the pump test of the well; and
3. Knowledge of carbonate systems in other locales.

The findings/inferences of my previous memo included:

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

The log indicates a well of approximately 1001 feet of depth. A static water level is at a depth of ~330' and the bottom of the well screen is at 454'. The materials above the screened interval are logged as alluvial sediments. From 454' to a depth of approximately 758' there are numerous vugs and dissolution zones. Some of these appear to be along beds (dipping at ~20-45°; note this is approximate); others are subvertical. Many of these appear to be conduits capable of transmitting water very efficiently. There is some sparry calcite and calcite (?) druse in some of the conduits, fractures, and veins

Many of these features are sufficiently large to provide very highly transmissive zones. A single fracture with an aperture (opening) of $1/16^{th}$ of an inch would transmit as much water as a permeable sand layer of a thickness of between 10 to 100 feet. Just a few of these secondary features can provide a very high transmissivity and there are many such potentially productive features apparent in the well log.

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 fewer, scattered, small karstic features

2. The pump test data are included in the reports of CH2MHill (2010) and GSS (Geoscience Support Services) (2010) showed little drawdown in both the pumping well TW-1 and the monitoring well (MW-7). The standard analytical procedures can be utilized in the monitoring well, but it must be noted that we are making inferences on very small drawdowns. These are such that it is reasonable to treat the aquifer mathematically as confined as the drawdown (~0.5 feet or less) is much less than the saturated thickness (whether using 403 feet in the GSS, 300 feet of intensely karstified section, or ~650 feet of total saturated thickness). The general rule is that confined test analyses yield accurate results where the ratio of drawdown to saturated thickness is small as is the case here. The accepted practice in such situations is to "correct" the drawdowns using

$$s_a = s_{wt} - \frac{s_{wt}^2}{2m}$$

Where s_a and s_{wt} are, respectively, the drawdowns that would occur in an artesian aquifer and the observed drawdown in the water table aquifer; m is the initial saturated thickness of the aquifer. In this case, for s_{wt} = 1.0 foot and m = 400 foot, s_a is almost exactly 1.0 foot (0.999 feet).

Carbonate aquifers are highly anisotropic and heterogeneous so extrapolation of one pumping or piezometric test to an entire aquifer must be done with caution. However, the results indicate the TW-1 and MW-7 are well connected. With this mind, consider the results of a Cooper-Jacob time drawdown analysis at MW-7 and TW-1.

2.1. MW-7. The GSS analysis (Fig. 18) is generally correct and a hydraulic conductivity (K) of ~1000 ft/day is indicated. Deviations beginning at t=100 minutes are consistent with boundary conditions. The first straight line portion using the Cooper-Jacob method is the best direct measure of hydraulic conductivity for this unit that we have. The GSS estimates for time up to 10^2 minutes are reasonable. I did use the time drawdown analysis for time between 10^2 and 10^3 minutes; this yields K= ~340 ft/day and S=~0.001. Even this K, which is reflecting boundary conditions, is twice the suggested rate of 170 ft/day. The analyses indicate that for the time of the pump test the aquifer is semi-confined. CH2MHill estimates K = ~1100 ft/day and S = ~10^3.

2.2. TW-1. Because of carbonate aquifer variability, the response at the pumping well gives the best test of aquifer properties. However drawdown was minimal and a draw-up actually occurred because of thermal changes. Storativity cannot be determined by analysis of the pumping well. However, using specific capacity we can estimate a T if we assume s. Using Q = 1168 gpm = 2.25×10^5 ft^3/day; t = 1 day, aquifer thickness of 400 ft, well radius = 0.4 ft, and a well efficiency of 100%, we get for an assumed

S= 10^{-3} and s = 0.5, that K = ~870 ft/day
S= 10^{-3} and s = 1.0, that K = ~420 ft/day
S= 0.012 and s = 0.5, that K = ~770 ft/day

There are, of course, and infinite number of such hypothetical scenarios that can be utilized. CH2Mhill estimates K = ~1100 ft/day. However, all the above results indicate that K = 600 ft/day for the carbonates is reasonable and probably conservative.

2.3 Comparison with TW-2 results. CH2MHill estimates K between 304 and 980 ft/day and S = ~10^{-3} with a saturated thickness of 478 ft. GSS estimates K = ~ 654 ft/day and S = 0.002. These are consistent. Strata thicknesses – 403-548 at TW-1 and 439-478 at TW-2 - and pumping rates – 1168 at TW-1 and 1130 at TW-2 - are similar. The fact that during the pumping tests the total drawdown at TW-2 was 6.6 feet after 72 hours and the total drawdown at TW-1 was less than 0.5 feet after 66 hours indicates that the transmissivity and hydraulic conductivity of the carbonate aquifer must be greater than in the alluvial aquifer.

Based upon the above observations, the existing data and analyses at TW-1 and TW-2, and the general nature of karstic aquifers lead me to conclude that:

1. These strata have superb aquifer characteristics and
2. 600 feet/day is a reasonable and probably conservative estimate of the carbonate aquifer's hydraulic conductivity.