SNL Hydrology Review and Recommendations Regarding I&W Brine Cavity

Kristopher L. Kuhlman and Bwalya Malama
Sandia National Laboratories
4100 National Parks Highway
Carlsbad, NM

Appendix I review comments

While we agree with the general conclusions drawn from analysis presented in sections I.4.1 and I.4.2 regarding scenarios 1 and 2; we have comments regarding details in the relationship given between the solution cavity and the overlying freshwater.

First, as we observe herein, and likely under previous operating conditions, the fluid in the solution cavity is artesian (> 30 feet artesian during Eugenie #1 re-entry). The brine cavity is also filled with water, presumably at saturation with halite, which corresponds to a specific gravity of approximately 1.2, and a freshwater head >36 feet above the land surface. The monitoring wells in the shallow alluvium and Rustler formation are presumably much fresher water than the brine and are not artesian. The alluvium aquifer is known to be unconfined, while the deeper saturated formation in the Rustler formation is confined. Under these conditions, hydraulic heads would be driving flow away from the brine cavity, not into it. Freshwater in formations above the cavity would have both pressure and salinity gradients tending to prevent freshwater from mixing with the brine in the cavity. Brine mixing with freshwater would be driven more by halite concentration gradients (molecular diffusion) and brine outflow from (not freshwater flow into) the cavity. That this is the more plausible scenario is supported by the fact that the brine production operation required freshwater to be forced into the solution cavity under pressure to create the current cavity.

After a potential collapse event, the artesian pressure in the brine cavity would no longer be contained, reducing the head to that of the highest unit which would be hydraulically connected and capable of flowing to the sinkhole. Depending on the relative freshwater heads in the alluvial and Rustler formations, water may flow from the alluvium into formations with lower head, such as the Rustler. The collapsed brine cavity would likely be a dead-end to flow, filling up with sediment and brine. In order for flow to pass through the cavity and dissolve more salt, a permeable formation of lower potential must exist, and be accessible to water at the bottom of the sinkhole. A highly pressurized, relatively fresh water source from stratigraphically below the salt would do this (e.g., the San Simon sink located where the reef underlies the Salado formation), but is not known to exist at the I&W site. It is our opinion here that post-collapse, and after equilibration of brine cavity hydraulic heads with those of the alluvium and Rustler formation, brine mixing with freshwater would be driven primarily by concentration gradients.

The analysis presented in section I.5 "Dewatering Analysis" is based largely upon the State Engineer's Office (SEO) groundwater model, created in 2004 by INTERA (Barroll et al., 2004). This model is a two-layer MODFLOW model of the area surrounding Carlsbad, including a portion of the Capitan Reef, and the shallow alluvium associated with irrigation in the Carlsbad area. The model was primarily designed to investigate water-budget questions and for planning scenarios related to future use of groundwater.

The addition of the Rustler Formation to the SEO model, in the manner indicated in the report, is likely of limited use in making predictions. The "Rustler Aquifer" was assigned a thickness of 25 ft and a hydraulic conductivity value of 0.3 ft/day. The thickness value is not justified by any references or lithologic log data. East of the Pecos River, the Rustler over 400 feet thick, with the two most permeable units (the Magenta and Culebra dolomites) each being approximately 20 feet thick. No mention is made of the storage coefficient used for the Rustler, and it is indicated that "no boundary conditions were assigned to the Rustler Aquifer" during the simulations. The only source of water for the Rustler is where it abuts the reef, receiving no recharge from or discharge to the overlying alluvial aquifer.

The dewatering study, using this modified SEO model, seems impractical in its recommendation for pumping such large amounts of water from the alluvial aquifer. Although the SEO model has been "history matched" to observed historical water levels, no changes of the magnitude proposed in this dewatering study have ever been observed. Predictions made with a groundwater model that is essentially extrapolating from observed condition, rather than interpolating, has great potential to be very incorrect. A similarly useful, but much more simplistic analysis could be carried out using a superposition of analytic solutions (e.g., confined Theis solution or unconfined Neuman solution, depending on the formation).

The alluvial aquifer at the I&W site is quite permeable and contains good quality water. Simply pumping this aquifer dry would be quite difficult and wasteful to the point that it could even create legal problems with other water users in the basin. Dewatering might be more efficient, if coupled with some sort of deep soil mixing, cutoff wall, or slurry trench at the periphery of the I&W property or at least near the canal (e.g., see the handbook by Powers et al. (2007), Chapter 21). Lining the canal in the vicinity of I&W might also be a simple way to reduce fresh recharge at the site. Additionally, dewatering the formation while there is still a significant pressure in the brine cavity might lead to upward expansion of the cavity, due to removal of overburden pressure.

Is there currently any perched water at the I&W site? Dewatering the shallow aquifer might create some disconnected perched zones if lower-permeability layers exist in the alluvium (something not included in or predicted by the MODFLOW model that simulates the alluvium as a vertically homogeneous layer). The shallow water encountered in the 60-ft borehole is likely not perched, based on comparison to water levels on published maps, but the existence of perched water near the canal does occur and is mentioned in several references (Hendrickson & Jones (1952) p. 42; Bjorklund & Motts (1959) pp. 205-207; Barroll et al. (2004) §2.2.2).

The Rustler formation is not a likely source of large amounts of fresh water. It is likely not even worth the effort or expense of trying to dewater the formation.

Review of hydrologic data available from the I&W site.

The 32-ounce slug that was added to the 220-ft monitoring well on July 20, 2010 was analyzed (see figure 1 below). Although there is an obvious undulating background trend observable before and after the test (due to the low signal-to-noise ratio), a few hours of response data indicate that the hydraulic conductivity of the screened interval is low (on the order of 0.2 feet per day), see Aqtesolv output in Figure 1. This compares well with the value used for the Rustler in the dewatering model (0.3 feet per day), assuming the well is actually screened across the entire productive thickness of the Rustler. The specific storage estimated from the slug is approximately 0.025 1/ft (reflecting wellbore storage). Both these estimated values are associated with a large amount of uncertainty. The Rustler is known to be quite vertically heterogeneous, and the Culebra or Magenta dolomitic members of the Rustler formation typically have much more permeability than the rest of the formation. The slug in the alluvial aquifer (60-ft well) was too small to create a response for interpretation; this indicates the 60-ft well is screened across more permeable formation than the 220-ft well.

The water levels reported in the Atlas system, for the two monitoring wells, were plotted along with canal flow rates on the USGS WaterWatch website from near the Avalon dam (USGS 08403500 Carlsbad Main Canal at Head), and weather reported at the Carlsbad airport (approximately 4 miles away); see Figure 2. In this period of available data, several things can be observed. The dashed vertical lines indicate the first day of each month, minor ticks indicate days. The water level in the 220-ft well has been adjusted to remove the large jump, due to moving the instrument.

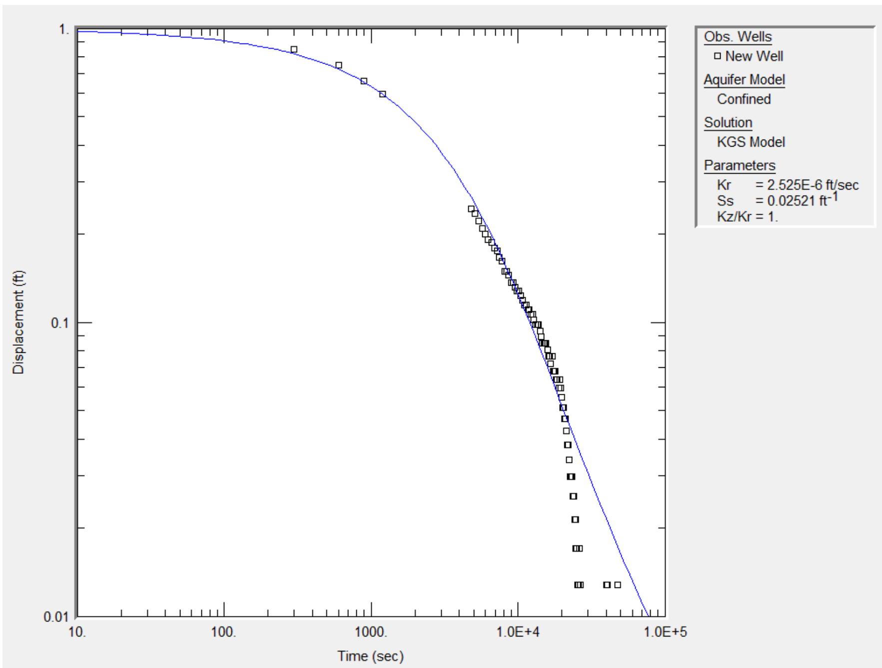

Figure 1: Results of slug test analysis with AQTESOLV.

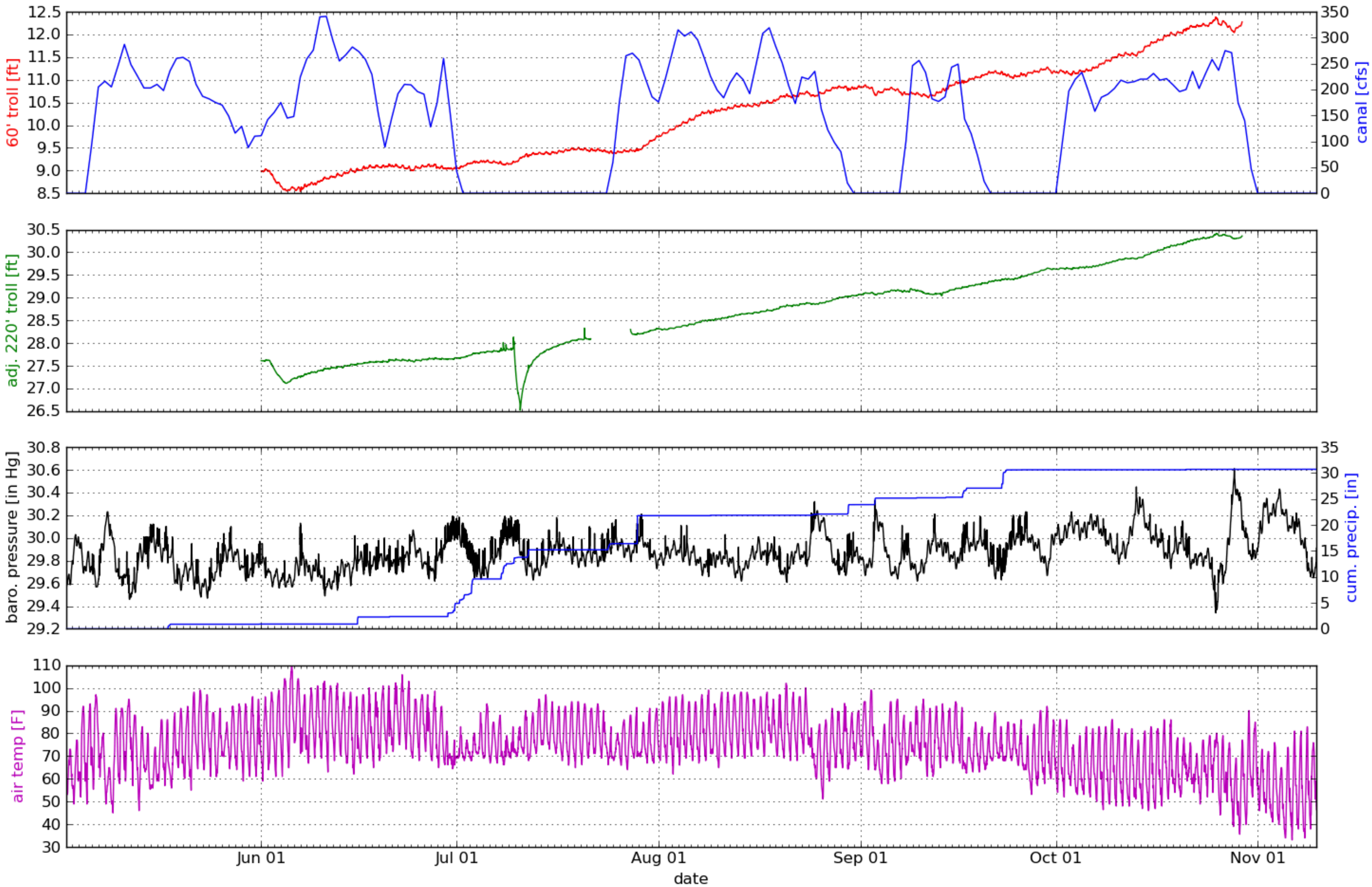

Figure 2: Monitoring well water levels, canal flow, and site weather for summer and fall 2010.

1. Water levels in the 60-ft and 220-ft intervals both have small-scale fluctuations on the order of days.
2. Water levels in the 60-ft well seem to rise suddenly around the end of July, middle of September, and less so in the beginning of October. The rise around the end of July follows the beginning of a period with water flowing in the canal, and the very wet month of July, when more than 12 inches of precipitation fell at the airport.
3. Weather data are reported at the Carlsbad airport hourly. If more frequent data were available near the I&W site, more detailed analysis of water level fluctuations would be possible, with respect to barometric fluctuations. A spectral analysis indicates that the natures of the fluctuations in the shallow and deeper wells are possibly different. Hsieh, Bredehoeft, and Farr (1987), and Cutillo and Bredehoeft (2010) show that barometric fluctuations are characterized by only two main frequency components (12-hour and 24-hours, indicated by vertical dashed lines on Figure 3). Earth-tide fluctuations are characterized by five discernible frequencies, also clustered around 12- and 24-hours frequencies.
4. The re-entry to Eugenie #1 is clearly evident in the 220-ft monitoring well in mid-July. No discernible effects are seen in the 60-ft monitoring well. While this is likely an indicator that vertical hydraulic communication between the 60- and 220-ft intervals is very weak, this does not necessarily indicate the connection between the brine cavity and the 220-ft interval is hydraulic. The response observed in the 220-ft monitoring point may be entirely due to mechanical movement and deformation of the brine cavity overburden during the flow of water from the brine cavity during re-entry. The difference in response of the two intervals might be due to the difference in the mechanical properties of the formations.

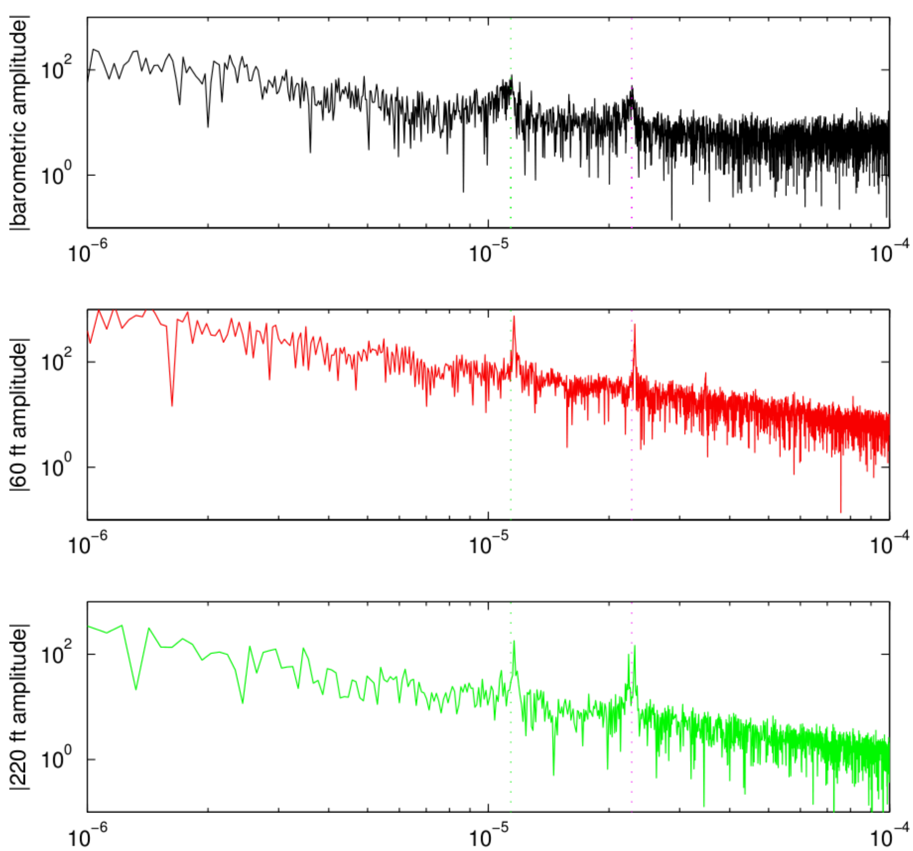

Figure 3: Spectral analysis of barometric and well head fluctuations at the I&W site. Vertical dashed lines indicate 12-hour and 24-hour periods (*x*-axis labeled in Hz).

Recommendations

1) We recommend placing at least one pressure transducer in the brine cavity, to monitor both large- and small-scale fluctuations. The most sensitive pressure transducer possible should be used; within the realm of practicality and given the pressure ranges expected in the brine cavity. Large-scale fluctuations that are potentially related to the dissipation of pressure from the brine cavity are important from the point of view of an early-warning system. If the water pressure in the cavity is supporting the roof, an unexpected loss of pressure (even slowly) related to the slow loss of water would be critical. Small-scale natural fluctuations – due to Earth tides and barometric fluctuations – can potentially be used to estimate the volume or other characteristics of the open cavity (Bredehoeft, 1967; Cutillo and Bredehoeft, 2010). Barometric and Earth-tide fluctuations are observed in the monitoring well water levels.

2) A geophysical survey or video log of the monitoring wells would be useful, if it were able to determine the geologic contact information or even simply depths and screened intervals of the two observation wells. This would be especially important if any pumping tests were to be performed in the wells.

3) A small-scale pumping test in the existing monitoring wells at the I&W site might shed more light on the local hydrology. Monitoring should be continued in the shallow alluvial aquifer, the deeper Rustler formation, and the brine cavity. Despite their small diameter casing (2 inch), a flow rate of a few gallons per minute might be maintainable for up to 72 hours. The permeability, storativity, and potentially specific yield of the upper alluvium can be estimated, which may prove useful in design of any dewatering systems. Although analysis of the 32-ounce slug has already provided a rough estimate of formation permeability and specific storage, a pumping test would additionally provide information on the confined-ness and potentially leakiness of the screened Rustler interval. Monitoring the upper alluvial and lower brine cavity during a pumping test of the Rustler would also potentially indicate a connectivity, or lack of connection.

4) Water quality sampling, to determine general mineral and physical properties (including specific gravity), would be simple to perform in conjunction with a pumping test, and might shed some light on the similarities or differences in waters between the formations and the brine cavity.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

References

Barroll, P., D. Jordan, and G. Ruskauff, 2004. *The Carlsbad Area Groundwater Flow Model*, New Mexico Office of the State Engineer and INTERA Incorporated.

Bjorklund, L.J. and W.S. Motts, 1959. *Geology and Water Resources of the Carlsbad Area, Eddy County, New Mexico,* United States Geological Survey, Open-File Report 59-9.

Bredehoeft, J.D., 1967. Response of well-aquifer systems to Earth tides, *Journal of Geophysical Research*, 72(12), 3075-3087.

Cutillo, P.A. and J.D. Bredehoeft, 2010. Estimating Aquifer Properties from the Water Level Response to Earth Tides, *Ground Water*, doi: 10.1111/j.1745-6584.2010.00778.x

Hendrickson, G.E. and R.S. Jones, 1952. *Geology and Ground-Water Resources of Eddy County, New Mexico*, New Mexico Bureau of Mines & Mineral Resources, Ground-Water Report 3.

Hsieh, P.A., J.D. Bredehoeft, and J.M. Farr, 1987. Determination of aquifer transmissivity from Earth tide analysis, *Water Resources Research*, 23(10), 1824-1832.

Powers, J.P., A.B. Corwin, P.C. Schmall, and W.E. Kaeck, 2007. *Construction Dewatering and Groundwater Control: New Methods and Applications,* third edition. John Wiley & Sons.