CONCERNS REGARDING THE PLAN FOR AQUIFER PERFORMANCE TESTING OF GEOLOGIC FORMATIONS UNDERLYING GLENN-COLUSA IRRIGATION DISTRICT, ORLAND ARTOIS WATER DISTRICT, AND ORLAND UNIT WATER USERS ASSOCIATION SERVICE AREAS, GLENN COUNTY, CALIFORNIA

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I am currently an associate professor of hydrology and hydrogeology at CSU Chico. I teach classes in Hydrology, Surficial Processes, Watershed Hydrology, and Hydrogeology. Prior to my faculty appointment in January, 2000, I spent 12 1/2 years as a Scientist, Research Scientist, and Senior Research Scientist at the Pacific Northwest National Laboratory in Richland, Washington. My research at PNNL was centered on groundwater flow and associated radioactive contamination in the West Siberian Basin. I have a BA degree in Geology from CSU Chico, an MS degree in Geosciences from the University of Washington, and a Ph.D. degree in Hydrology from The Johns Hopkins University, GWC Whiting School of Engineering. It is my opinion that there is currently insufficient information regarding the affected aquifers to adequately anticipate the consequences of withdrawing large amounts of water over a relatively short period of time, for a number of reasons. These reasons include the lack of detailed hydrostratigraphy, the lack of pump-test data characterizing aquifer transmissivity and storativity, the dearth of knowledge concerning the hydraulic connectivity between successive layers, the lack of recharge data, and inadequate recharge estimations under changing climate conditions.

As far as I know, to date there exists no detailed hydrostratigraphic analysis capable of distinguishing the permeable (water-bearing) units from the less permeable units within the subsurface of the Northern Sacramento Valley. In essence, the thickness and extent of the water-bearing units has not been adequately characterized. Neither the diagram supplied by the Department of Water Resources (DWR) in Technical Memorandum 3 (Davids Engineering, Inc., 2006; Figure 3) nor the description of the stratigraphic layers in Bulletin 118 (DWR, 2003) are sufficient to characterize the geometric complexity of the permeable, water-bearing units or the less permeable, confining units. According to Technical Memorandum 3 (Davids Engineering, Inc., 2006) the upper 50 to 80 feet consists of unconsolidated gravel, sand, silt and clay deposits of the Stony Creek Fan. Beneath these deposits is the Tehama Formation, consisting of moderately compacted silt, clay, and fine silty sand "enclosing lenses of sand and gravel, silt and gravel, and cemented conglomerate." Productive water-bearing zones are found in occasional gravel deposits from ancestral Stony Creek. Interfingering with the Tehama Formation in the Project Area is the Pliocene-age Tuscan Formation, the deposits of which are not described in Technical Memorandum 3. The Lower Tuscan formation, consisting of Tuscan Units A and B, is considered to constitute an important but as yet untapped water-bearing unit in the Project Area.

In our current conceptual model, the Tuscan Formation represents deposition within a volcaniclastic fan apron. Close to the source, believed to be ancestral Mt. Yana located southeast of Lassen Peak, these deposits have the characteristics of a volcanic mudflow (lahar) in which large volcanic boulders are encased in mud. Away from the source, to the west and south, the deposits appear to have be reworked by water, exhibiting successive winnowing of finer material and resulting in the deposition of cobbles and sand; these cobble and sand deposits are conducive to groundwater flow. Successive reworking of mudflow deposits by streams meandering across the fan during non-eruption periods resulted in erosion and re-deposition of the sediments. Ultimately, all the sediments were compacted and cemented into rocks. The result is that in some areas the water-bearing units are confined by less permeable units, such as mudflow and channel overbank deposits, while in other areas the more permeable units are amalgamated into thick sequences, as channels carrying sand sequentially cut down into one another. The water-bearing units shift in location and thickness across the fan due to the distributary nature of the streams reworking the deposits. None of this is described nor depicted in Technical Memorandum 3.

The stratigraphic interpretation depicted in Figure 3 (Technical Memorandum 3), as interpreted by the DWR from electric resistivity logs, well logs, and well cuttings, is open to interpretation. Electric resistivity logs do not constitute primary data when determining lithology. Instead, rock types are inferred from the shapes of the curves generated as the signal passes through the rock materials in a process known as inverse modeling. This requires electric logs to be correlated with actual rock chip samples, such as those generated from drilling wells, or other types of information. The problem with using well cuttings to correlate with kicks in the electric resistivity logs is that the exact depth from which the sample comes cannot be known precisely due to the time it takes for the cuttings to travel to the surface in the drilling mud. A better way to correlate resistivity logs with actual rock types is to take solid cores of the material at the same time the well is drilled, but coring is expensive.

A comparison of recent work by Spangler (2002) and Skartvedt-Forte (2006) provides an example of how two very different interpretations can be generated from similar data. Electric resistivity logs across the Sacramento Valley were correlated by Spangler (2002), in conjunction with the DWR, on the basis of a distinctive, widespread, high-resistivity kick. The kick was inferred to represent a permeable, water-bearing unit within the Tuscan Formation consisting of interbedded coarse volcanic sand, fine gravel, and tuffaceous siltstone. The high resistivity in the kick indicated the presence of water. The Tuscan confining layer, consisting of fine-grained massive volcaniclastic breccia (mudflow-type deposits) and reworked fine volcanic tuff, was assigned extremely low resistivity, probably due to the assumed absence of water. Skartvedt-Forte (2006) interpreted electric resistivity logs for the Tuscan Formation within the vicinity of Chico based on detailed stratigraphic measurements and drilling core. In her interpretation, volcaniclastic breccia displayed a very prominent blocky resistivity signature with an abrupt base and top. Tuff intervals were distinguished on the basis of an extremely high sharp peak. Water-saturated conglomerates and volcaniclastic conglomerates displayed the third highest resistivity, with a signature that extended outward at the base and receded at the top. Water-saturated sandstone and volcaniclastic sandstone exhibited a signature that was not as strong as conglomerate but stronger than siltstone. The lowest, flattest signature on the log represented siltstone or mudstone. If Skartvedt-Forte's (2006) interpretation is correct, then the Tuscan sand and gravel water-bearing unit does not thin to the south and west, nor does the fine-grained Tuscan confining layer become thicker to the west to interfinger with the Tehama Formation, as suggested by Spangler (2002). Instead, it is the fine-grained, impermeable volcanic breccia unit that thins to the south and west, resulting in less confinement, and the water-saturated conglomerates and sandstones that thicken to the west. In essence, the aquifer could behave as one large unconfined aquifer in the vicinity of the Sacramento River.

Another concern is the lack of aquifer-test data characterizing the hydrogeologic properties of individual water-bearing units. To my knowledge, there have been no pump tests performed on individual water-bearing units performed with the goal of quantifying their transmissivity and storativity properties. According to Spangler (2002), some localized aquifer testing has been performed, but the results of the tests are considered "sensitive" and are not available to the general public. It is my opinion that the reason that aquifer pump testing is not more common in the water-bearing units is that the hydrostratigraphy is so poorly characterized that most wells are completed with multiple screens to maximize the chances of obtaining water. The existence of multiple screened intervals precludes the possibility of performing proper aquifer tests, in which both the pumping and observation wells are finished in a single aquifer. Problems stemming from the lack of proper hydrogeologic data cannot be overstated. If the units are less permeable than anticipated, the cone of depression that forms in the potentiometric surface could be deeper and more extensive than anticipated. The depth of the cone depends on the permeability of the aquifer materials, the shape of the cone depends on the storativity, and the extent depends on time since pumping began. Inadequate characterization of the permeability and storativity may result in the formation of an unusually large cone of depression during seasonal pumping. If this occurs, adjacent wells may go dry. Additionally, recharge to the aquifer, especially in the vicinity of the well, may take longer than anticipated due to the low transmissivity of the aquifer material.

A third concern is the unknown nature of the hydraulic connectivity between units, both vertically and laterally. This concern is voiced numerous times in Technical Memorandum 3 (Davids Engineering, Inc., 2006) and basically results from the use of multiple screens in finished wells in the area; it is not known from which water-bearing unit the water being pumped is supplied. There are at least two problems associated with this lack of knowledge. If the aquifer acts as an unconfined aquifer in the Project Area, as suggested by a re-interpretation of the electric resistivity logs, the cone of depression that forms during pumping could extend to intersect either a recharge or a discharge area. Normally, the Sacramento River serves as a discharge area for the unconfined aquifer (Technical Memorandum 3, 2006). Should the cone of depression intersect the Sacramento River, the hydraulic gradient would reverse and Sacramento River water would be drawn into the aquifer at a rate dictated by the hydraulic conductivity and slope of the hydraulic gradient. If the aquifer in the Project Area is imperfectly confined (and there are no perfectly confining layers in nature), then, when the hydraulic head difference between the confined and unconfined aquifers was of sufficient magnitude, it would induce vertical downward flow through the imperfect "confining" layer. The end result would be the same as in the unconfined case, and Sacramento River water could potentially be withdrawn into the aquifer and ultimately into the wells.

A fourth concern is the fact that no compressibility testing, to my knowledge, has been conducted with respect to the water-bearing units. Generally, compressibility tests are performed to define the water level below which water is not withdrawn to prevent aquifer ruin. The drawdown of the water level in a well essentially represents a lowering of the hydraulic head, which reduces the fluid pressure in an aquifer. This lowering of the fluid pressure in the aquifer requires that the solid aquifer skeleton bear more the of weight of the overlying solid material and water. If too much water is withdrawn, the aquifer skeleton could collapse under the weight of the overlying material. The collapse takes place in the form of grain rearrangement and packing, effectively reducing the aquifer's water-holding capacity. Rocks are not elastic; they will not bounce back when water is re-supplied to the system. If too much water is withdrawn, the existing solid portion will collapse to the point where it can no longer contain water. If the water-bearing layers in the aquifer are thin enough, collapse of the units may yield imperceptible subsidence at the surface, and the extent of the damage to the aquifer system cannot be assessed through traditional surface subsidence surveys.

My fifth concern is the lack of adequate recharge data for the aquifer. Although regional measured groundwater levels are purported to "recover" during the winter months (Technical Memorandum 3), data from Spangler (2002) indicate that recovery levels are somewhat less than levels of drawdown, suggesting that, in general, water levels are declining. The use of multiple screens in monitoring wells precludes the identification of which aquifers are actually being recharged. Recent age dating of water from the Lower Tuscan aquifer performed by Jean Moran of the Lawrence Livermore National Laboratory indicates that water from this unit could be extremely old, on the order of tens of thousands of years. This implies that there is currently no active recharge to the Lower Tuscan aquifer system (M.D. Sullivan, personal communication, 2004). If this is the case, then water in the Lower Tuscan system may constitute fossil water with no known modern recharge mechanism, and, once it is extracted, it is gone as a resource.

Finally, I am concerned that mechanisms of recharge to the aquifer under changing climate conditions have been inadequately defined and quantified. If the primary source of aquifer recharge is precipitation, either through diffuse or localized mechanisms, then aquifer performance recorded from the years 1970 to 1999 may not be representative of what can be expected over the next 30 or so years. Scientists at the Jet Propulsion Laboratory affiliated with NASA have found evidence that we have just entered a "cool" phase with respect to sea surface temperatures in the eastern Pacific (the Pacific Decadal Oscillation). The cool phase is characterized by a cool wedge of lower than normal sea surface temperatures in the eastern Pacific and a warm horseshoe pattern of higher than normal sea surface temperatures connecting the northern, western and southern Pacific. Other cool periods included the years 1890 to 1924 and 1947 to 1976. Prior to entering this cool phase we were in a warm phase, characterized by a wedge of warm water in the eastern Pacific and cooler water in the west. This warm phase had been in existence since 1977: a previous warm phase occurred between 1925 and 1946. During a warm phase, sea surface temperatures off the North American coast are higher than usual, resulting in greater precipitation during the winter months. During the current cool phase, expected to last over the next 20 to 30 years, we are likely to have lower rainfall than we have had since the late 1970's. "We will still have winter rains, but the number of wet years is likely to decrease" (http://topex-www.jpl.nasa.gov).

In conclusion, the testing plan proposed for the geologic formations underlying the Glenn-Colusa Irrigation District has been formulated with inadequate knowledge concerning aquifer characteristics. I recommend that the plan be suspended until sufficient characterization data, with which to adequately anticipate the response of the aquifer system to such perturbation, is in place.

References

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