PROJECT SUMMARY

Title: What Happens When The Confined Cambrian-Ordovician Aquifer In Southeastern Wisconsin Begins To Be "Dewatered"?

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Background/Need: The Cambrian-Ordovician aquifer has long been an important source of municipal water supply in Wisconsin, and recent trends are of some concern for future supply. Pumping has drawn down the potentiometric surface (hydrostatic pressure) of this deep aquifer system by over 400 ft during the 20th century. Wisconsin state observation wells show that head in the deep aquifer system continues to decline at a rate of 7 ft/yr and will eventually dip into the top of the St. Peter sandstone, causing dewatering as air enters the pore space. Computer simulations cannot account for reduction in hydraulic conductivity caused by progressively developing unsaturated conditions near the well bore, which forms the principal avenue for air to reach the aquifer. It is not clear exactly what happens under these conditions in the real world because few observations have been made of this phenomenon in deep aquifers where field data are rarely available.

Objectives: The goal of the research reported here was to investigate possible dewatering phenomena in the Cambrian-Ordovician aquifer system in southeastern Wisconsin. The specific objectives were **1)** to investigate how unsaturated conditions might develop in a physical sand-tank model, **2)** to attempt to verify the development of such hydrogeologic conditions in the field, and **3)** to predict the long-term impact on water supply and quality by observing the evolution of head in the vicinity of model pumping wells.

Methods: The sand-tank model was based on a design developed by Dr. James O. Peterson and Ronald Hennings, now in widespread use across the United States. It consists of vertical Plexiglas plates mounted one inch apart containing saturated sands and clays arranged to represent generic subsurface formations in profile. Sediments used were carefully analyzed for grain size and uniformity to be able to estimate resulting hydraulic conductivity when packed. The model was customized with double-curved manometer tubes and scaled graduations on either face of the model, that enabled head to be measured as the colored water levels fell below the elevation of the piezometer openings in the model aquifer. In response to pumping of wells centered in the sediment, head data over time was recorded on video camcorders. Model runs were made with a laboratory pump connected to both well discharge tubes, with wellhead valves in closed and open positions. Head in the pumping wells was drawn down below the top of the confined aquifer, drawdown was observed in the manometer water levels around each pumping well, and resulting cones of depression quickly merged. Data were compiled by viewing the resulting videotape and transcribing the head values, read as the water levels in each manometer passed the graduated lines on the model faces. These data were plotted in the form of graphs of head change over time. They were also plotted as contour maps of the head field in the plane of the model at successive times. A field component of this project consisted of converting and instrumenting an open borehole at a site west of Milwaukee to a monitoring well with a short screen in the Sinnipee Group dolomite below the Maquoketa Formation.

Results and Discussion: Basic drawdown data shows that heads at the monitoring points responded rapidly to the pumping well drawdown, and that there are significant variations in head with depth. Head data at the monitoring points after pumping water level stabilization indicates fluctuations over time. Close examination of these fluctuations show that they are out of sequence with changes in pumping water level, a complexity in the head field in a near-uniform model aquifer that is rarely, if ever, observed in actual monitoring wells. The effective pumping rate was uncontrolled, but monitored. As the pumping water level dropped, the instantaneous pumping rate peaked and then was reduced to stabilize at about 66% of maximum capacity. The coincidence of maximum pumping rate with drawdown stabilization suggests that the pumping reached some equilibrium where it was balanced by steady-state flow from the lateral constant-head boundaries. In the confined model aquifer, the hydraulic head was used to infer less than saturated conditions when the measured head fell below the elevation of the monitoring points. Resulting hydraulic pressure at the monitoring points decreases below atmospheric pressure, at which time air enters the pore space, and pore water drains out forming a seepage face. The data show that this desaturation phenomenon occurs relatively rapidly. Head decreased to the elevation of the top of the aquifer first near one well then the other, followed by a merging of the desaturating fronts, which advanced quickly to approximately halfway down the thickness of the aquifer. Water level measurements at the field site indicate that hydraulic head in the Sinnipee Group dolomite is just above the elevation of the monitoring screen at that location.

Conclusions/Implications/Recommendations: After onset, the spread of desaturating conditions is relatively rapid at first, but then slows. Simulated lateral spread from wells is also rapid, leading to a merging of zones of desaturation near the top of the aquifer, before spreading to greater depths, in contrast to expected vertical development near well bores. As pumping well head decreases level off when flow from the boundaries equals the rate of well pumpage, head at monitoring points at elevations near the pumping water level continue to fluctuate over time frames that are difficult to explain solely by pumping water level fluctuations. Pumping rates decrease as pumping water levels fall below the top of the aquifer and saturated thickness diminishes.

Without airflow down the well bore, pumping rates are much lower and head drawdown much less rapid. Measurement of hydraulic head at the field site suggests that regional drawdown in the underlying Cambrian-Ordovician aquifer is now sufficient to cause development of desaturated zones in the Sinnipee Group dolomite around open wells.

Desaturation of pore space causes decreases in hydraulic conductivity that affect flow through the desaturating zone to the well, shown by the asynchronous fluctuations in head. Such dynamics would be more complex in a fully three-dimensional system, and flow to an overpumped well may be the integration of sequential flows from different sectors around the well depending on the relative saturation of the surrounding pore space. The practical consequences could increased oxidation reactions and deterioration of water quality depending on the mineralogy of the aquifer material. These dynamics of desaturation may also seriously reduce municipal well yields for given rates of drawdown. Once such desaturation is widespread, it may be impossible for well yields to recover, even with cessation of pumping, because air becomes indefinitely trapped in the pore space.

Related Publications: Eaton, T.T., 2004. Desaturation and flow dynamics beneath an aquitard near excessively pumped wells. Geological Society of America *Abstracts with Programs*, Vol. 36, No. 5.

Key Words: confined aquifer, aquitard, desaturation, flow dynamics