Title: *Mechanisms of Groundwater Flow across the Maquoketa Formation*

Project I.D.: *WDNR Groundwater Research Program 144-NP30*

Investigators: ***David Hart*** *(PI), Associate Professor, Wisconsin Geological and Natural History Survey, University of Wisconsin-Extension*
Kenneth Bradbury *(Co-PI), Professor, Wisconsin Geological and Natural History Survey, University of Wisconsin-Extension*
Daniel Feinstein *(Co-PI), Hydrogeologist, United States Geological Survey-Wisconsin District*
Basil Tikoff *(Co-PI), Associate Professor, Department of Geology and Geophysics, University of Wisconsin-Madison.*
Suzanne Braschayko *(Project Assistant), Wisconsin Geological and Natural History Survey, University of Wisconsin-Extension*
Jeff Wilcox *(Project Assistant), Department of Geology and Geophysics, University of Wisconsin-Madison*

Period of Contract: May 1, 2005 to June 30, 2006

Background/Need: Groundwater use in southeastern Wisconsin has resulted in more than 400 feet of drawdown in the deep sandstone aquifer since pumping begin in the 1860's. Because of this drawdown, the area was designated as a critical groundwater management area in the 2003 Groundwater Protection Act 310. The deep sandstone aquifer is confined by a regional aquitard, the Maquoketa Formation, over much of southeastern Wisconsin. This aquitard is important because it controls how much water can enter the deep sandstone aquifer. Currently pumping from the deep sandstone aquifer is 33 million gallons per day. Of this amount, around 8 mgd is estimated to flow downward across the Maquoketa Formation through poorly understood pathways.

Objectives: We sought to understand how groundwater is flowing across the Maquoketa Formation, whether through multiaquifer wells or the Waukesha fault.

Methods: We conducted two simultaneous investigations to determine whether significant flow can occur through multaquifer wells or the Waukesha fault. Our hypotheses and approach to testing them are below.

Possibility 1: Significant flow moves downward through cross-connecting multiaquifer wells. Our approach to explore this possibility included: 1) A records search to identify the number and location of multiaquifer wells in southeastern Wisconsin. 2) A review of well abandonment history to determine how many of these wells still exist. 3) Simulation of the wells using a numerical flow model. 4) A sensitivity analysis to determine the potential importance of the existing wells to the regional flow system.

Possibility 2: Significant flow moves downward along the Waukesha fault. Our approach to explore this possibility included: 1) A literature review of the Waukesha fault and the tectonic setting of the Michigan Basin. 2) A field visit to a quarry exposure of the Waukesha fault and other joints and fractures. 3) Incorporation of the Waukesha fault into a regional groundwater flow model. 4) Sensitivity analysis to determine the potential importance of the fault to the regional flow system. 5) Rehabilitation of borehole WK-1376 to allow study of the horizontal fractures through the Maquoketa Formation.

Results and Discussion:

We found there are more than 100 multiaquifer wells in southeastern Wisconsin. The simulated flow through these multiaquifer wells is currently estimated to be 4.4 mgd. Model calibration at higher flows is not possible without adjusting hydrologic parameters outside of reasonable bounds. Simulated flows through the multiaquifer wells are not evenly distributed. Few high flow wells contribute the majority of flow. Increased drawdown due to abandonment of the multiaquifer wells will be small because the flow rate of 4.4 mgd is only 15 percent of the total pumped from the deep sandstone aquifer and because many of the wells may never be located for abandonment.

Flow through the Waukesha fault system was investigated. If low estimates of the fault hydraulic conductivity of 5.6×10^{-3} ft/day are used, then the Waukesha fault plays a relatively unimportant role in the larger flow system. If the fault hydraulic conductivity is closer to an upper estimate of 0.28 ft/day, the flow through the Waukesha fault of around 4 mgd is similar in magnitude to that through the multiaquifer wells. As was the case with the multiaquifer wells, model calibration at higher flows is not possible without adjusting hydrologic parameters outside of their reasonable bounds. While the flow value of 4 mgd is significant, it does not represent the majority of flow across the Maquoketa Formation. We suspect that many smaller unmapped faults, fractures and joints contribute to flow across the Maquoketa Formation.

Conclusions/ Implications/ Recommendations:

Multiaquifer wells and the Waukesha fault may transmit significant flow through the Maquoketa Formation but they do not dominate the flow system. Rather we suspect many distributed joints and fractures transmit most of the flow through the Maquoketa Formation. The Waukesha fault might contribute significant flow if the hydraulic conductivity in the fault is dominated by fractures in a damaged zone through the Maquoketa Formation. Otherwise, the flow through the Waukesha fault likely is not significant and it is merely one of many fractures and joints that transmit water across the Maquoketa Formation.

We recommend the following:

- Continue abandonment of the multiaquifer wells to limit contamination to the deep sandstone aquifer.
- Additional observation wells should be placed in the deep sandstone aquifer. The calibration effort was hampered by a lack of water level observations at depth and areally across southeastern Wisconsin.
- Collect groundwater use data for high capacity active wells. Only 69 of the 172 multiaquifer wells had pumping records available.
- Continue tracking the status of the high capacity wells. Unreported and unabandoned wells may present unknown pathways for contaminants to enter the deep sandstone aquifer.

Related Publications:

Braschayko, Suzanne (2005) The Waukesha Fault and Its Relationship to the Michigan Basin: A Literature Compilation. Wisconsin Open File Report 2005-05, Wisconsin Geological and Natural History Survey, Madison, WI. pp 62.

Key Words: *Multiaquifer wells, Maquoketa Formation, aquitards, Waukesha fault,*

Funding: WDNR Groundwater Monitoring and Research Program Grant Number 144-NP30.

Final Report: A final report containing more detailed information on this project is available for loan at the Water Resources Institute Library, University of Wisconsin - Madison, 1975 Willow Drive, Madison, Wisconsin 53706 (608) 262-3069.