Title:
Groundwater recharge through a thick sequence of fine-grained sediment in the Fox River valley, east-central Wisconsin

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Background/Need:
Groundwater in the Fox River valley, Wisconsin has been of significant interest for the past several decades due to concerns about groundwater availability in rapidly growing metropolitan areas such as Green Bay, Appleton, Menasha, and Oshkosh. The water used by many municipalities, industries, and private residents in the Fox River valley is pumped from carbonate and sandstone rocks known as the Cambrian–Ordovician aquifer system. These rocks lie on top of relatively impermeable Precambrian crystalline bedrock and dip eastward toward the Lake Michigan basin. Shale of the Maquoketa Formation, dolomite of the Sinnipee Group, and/or fine-grained glacial sediment cap the Cambrian–Ordovician aquifer system. Where present along the eastern margin of the Fox River valley, the Maquoketa shale and the Sinnipee dolomite act as aquitards, confining the aquifers below. Recharge to these aquifers is traditionally understood to occur west of the Maquoketa shale and Sinnipee dolomite subcrop. However, a thick sequence of fine-grained glacial sediment covers large parts of this area and may act as an additional regional aquitard. The presence of this unit might shift the areas of recharge farther to the west than is currently assumed.

Objectives:
Given the importance of groundwater reserves in the Fox River valley, this study was aimed at understanding vertical groundwater flow through the fine-grained glacial deposits to deeper bedrock aquifers.

Methods:
To characterize the sediment sequence, two boreholes were drilled to collect continuous core and install multilevel wells. Representative samples of the core were used to determine physical properties of the sediment, including hydraulic conductivity. To evaluate vertical groundwater flow across the sediment sequence, multilevel wells were installed in each borehole to determine the distribution of hydraulic head. Pore water was also extracted from core subsamples to evaluate its relative age using stable isotope of oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$).

Results and Discussion:
Two boreholes, RS-17 and RS-18, were drilled in Outagamie County to a total depth of approximately 300 ft. Consolidation testing conducted on selected sections of core yielded hydraulic conductivity values that ranged from 1×10^{-8} ms^{-1} to 1×10^{-11} ms^{-1}. Multilevel wells installed in each borehole were used to monitor water levels and collect samples for isotope analyses. The water level data from the seven wells at RS-18 indicated an upward hydraulic head difference of about 10 ft over the entire section. In RS-17, a slight downward hydraulic head of approximately 1 ft over 80 ft was observed, but unfortunately four of the seven ports were compromised during well installation, making data interpretation difficult. Using these gradients and the average hydraulic conductivity from the consolidation experiments, the vertical flux is 4.4×10^{-12} ms^{-1} and 1.3×10^{-11} ms^{-1} for RS-17 and RS-18, respectively. Such a low rate of advection

indicates that diffusion may be the primary mechanism for movement of water through the sediment. This low rate of advection is reflected in oxygen isotope analyses of pore water extracted from core samples. The data show modern values near the surface (-9 ‰) gradually decreasing with depth (-16 ‰ to -18 ‰) before increasing toward the bedrock surface (-11 ‰ to -12 ‰). Analyses of the water samples collected from the multilevel wells verify the pore-water analyses. The lighter $\delta^{18}O$ results indicate relatively old water, potentially dating to the most recent glaciation. The bow-shaped isotopic curves are typical of chemical diffusion with limited advection driven by differences in hydraulic head. The large difference between the depleted $\delta^{18}O$ values at depth in the aquitard and those at the ground surface suggests that little displacement of the sediment pore water has occurred, which is consistent with the low value of hydraulic conductivity determined from the consolidation data.

Although there are lighter $\delta^{18}O$ values near the middle of the sediment sequence, the heavier values close to the bedrock surface are difficult to explain, especially because the values reflect modern-day precipitation. These results are surprising, in that several investigations into the stable isotopes of groundwater in the northern Midwest showed that the geochemistry of the Cambrian–Ordovician aquifer system was modified during the Pleistocene by a large-scale emplacement of glacial meltwater, and that groundwater in this part of the aquifer system could be hundreds of thousands of years old. If this is the case for the bedrock aquifer system in the Fox River valley, then lighter $\delta^{18}O$ values would be expected in the bottom part of the sediment sequence. However, this is not the situation indicating that groundwater recharge must be occurring elsewhere.

Conclusions/Implications/Recommendations:

The fine-grained glacial deposits in the Fox River valley greatly limit surface-water infiltration and groundwater recharge to the bedrock aquifers, particularly west of the Fox River where the Maquoketa shale and Sinnipee Group subcrop. The nature of the sediment is a critical variable in understanding flow patterns and recharge to the underlying aquifers. The thick sequences of fine-grained sediment prevent downward migration of modern precipitation to the bedrock underneath. However, groundwater flow is still uncertain in the areas over bedrock uplands, where the sediment is much thinner. We are currently planning to collect hydrologic data and investigate these areas to define local conditions and improve our understanding of the regional groundwater flow system. Where the glacial sediment may only be 15 to 30 ft thick, the bedrock aquifers are much closer to the surface and might be susceptible to local groundwater recharge. We will continue monitoring our existing deep wells and install shallow wells in areas where the sediment is significantly thinner and potentially fractured. We expect these shallow wells to yield information regarding the flux of groundwater to the bedrock aquifer so that distribution of recharge to the deep aquifer can be determined. Because large parts of the Cambrian–Ordovician aquifer lie beneath fine-grained till and lake sediment, understanding the spatial distribution of recharge in this region is crucial for planning the future management of groundwater quality and quantity.

Related Publications (abstract):

Moeller, C.A., Hooyer, T.S., Hart, D.J., Batten, W.G., and Mickelson, D.M., 2007. Investigating recharge to the Cambrian-Ordovician aquifer through fine-grained glacial deposits in east-central Wisconsin. American Water Resources Association Conference, Wisconsin Chapter, Wisconsin Dells, WI.

Hooyer, T.S., Hart, D.J., Cherry, J.A., Parker, B.L., and Moeller, C.A., 2006. Groundwater recharge through a thick sequence of fine-grained sediment in the Fox River valley, east-central Wisconsin. American Water Resources Association–Wisconsin, Elkhart Lake, Wisconsin.

Key Words:

Aquitard, groundwater recharge, hydraulic conductivity, and oxygen isotopes.

Funding: *Wisconsin Department of Natural Resources*

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.