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Technical Commentary/

Aquifer System Response Time and Groundwater Supply Management

by William C. Walton

The purpose of this Technical Commentary is to stimulate further interest in aquifer system response time and to encourage its consideration in future groundwater supply management investigations. Aquifer system response time is herein defined as the time that it takes for water level and storage changes throughout the aquifer system to become negligible after an increase or decrease in supply withdrawal. Response time is termed as the time to full capture by Bredehoeft and Durbin (2009) and is controlled by basic hydraulic principles of groundwater movement and storage described by Meinzer (1931) and Theis (1940) among many others.

Available literature indicates that response time can range from days to centuries or more (Bredehoeft et al. 1982; Sophocleous 2000; Alley et al. 2002; Bredehoeft and Kendy 2008). Response time depends on many factors including aquifer system dimensions, aquifer transmissivity, aquifer storativity, confining layer storage, confining layer leakance, aquifer system boundary types and locations, and well location and penetration. The factors controlling response time in a semi-infinite one-layer aquifer system with a recharge boundary are described by Wallace et al. (1990). For multidimensional aquifer systems, long response times occur with large systems, high specific storage, and low conductivity (Kooi and Groen 2003).

Constant discharge time-drawdown graphs for a production well and an observation well in an infinite one-layer unconfined aquifer system have three segments coinciding with the three stages of release of water from aquifer system storage (Neuman 1972). Constant discharge time-drawdown graphs for a partially penetrating production well and a partially penetrating observation well in an infinite multilayer aquifer system can have several segments coinciding with the stages of release of water from aquifer and confining layer storage and confining layer leakage (Neuman and Witherspoon 1969).

Estimating Aquifer System Response Times

Response time can be based on water level and budget data for a production well with constant discharge generated by a numerical model such as MODFLOW (Harbaugh 2005) and an idealized conceptual model with uniform aquifer system properties and boundaries, multiple stress periods, and usually a 10-, 100-, or 1000-year simulation time. Response time can be further defined as the elapsed time after a discharge increase or decrease when time-drawdown graph slopes throughout the aquifer system are within an acceptable stated deviation from absolute zero. Conceptual models can be systematically modified to determine the impacts of individual and collective factors controlling response time.

Unsound estimates of response time can occur if the water table layer or groundwater divides are incorrectly modeled. For example, the water table in a multilayer aquifer system is sometimes modeled as an infinite source of water. Groundwater level declines in a multilayer aquifer system are underestimated as a consequence of this modeling technique (Moltz 1978). The response time is also underestimated because the water table is not allowed to decline until the upper layer recharge and discharge is captured by supply wells.

Sound estimates of response time occur when specific yield is specified only for the uppermost portion of the aquifer system within which the water table is expected to fluctuate (Reilly and Harbaugh 2004) and special care is taken in modeling the water table (Niswonger et al. 2006). Sound estimates of response time occur when model grids extend beyond existing groundwater divides in all layers so that possible divide movement can be simulated.

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Groundwater Supply Management

Groundwater supply management is often based on water level declines estimated with models and threshold or prescribed constraint statements such as water levels in production wells should not decline below the top of the most productive layer of an aquifer system, stream flow should not be reduced below a specified amount as a result of future discharges, and/or the water table should not decline to the extent that undesirable flora and fauna changes occur.

Supply management planning time frames are usually constrained to 50 years or less partly because of the difficulty and uncertainty surrounding the projection of future development. However, response time may exceed 50 years especially if the aquifer system is multilayered. Impacts of supply withdrawals can be underestimated with models based on management planning time frames and final stress period lengths shorter than response times. In addition, full capture of supply availability with partially penetrating production wells may not be possible because aquifer system layer's vertical hydraulic properties and dimensions are bounded, and large decreases in saturated thickness of aquifer system layers result in serious declines in production well yields.

Probable future water level declines in aquifer systems during supply management times are commonly estimated with models. However, optionally generated budget data for each aquifer system layer, particularly the layer containing the water table, frequently receive secondary attention. This is unfortunate because an accounting of inflows, storage changes, and outflows in all layers is necessary in assessing supply withdrawal impacts.

Supply management is best when it is based on periodic accountings of discharge from, recharge to, and storage changes for each layer of an aquifer system during both planning and response times, when it is based on recharge and discharge capture limitations, and when it considers potential loss of wetland and riparian ecosystems, land subsidence, salt water intrusion, changes in groundwater quality, and social problems (Grantham 1996; Winter et al. 1998; Alley et al. 1999; Glennon 2002). There is need for a review of the definition of sustainable yield in light of bounded supply and aquifer system response time.

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