Reply to comment by T. N. Narasimhan on "A method to estimate groundwater depletion from confining layers"

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[1] We thank T. N. Narasimhan for his comment on our paper [*Konikow and Neuzil*, 2007] and for extending the discussion with a historical perspective, additional examples, and some considerations we did not discuss, including implications for water management. We support and agree with the thrust of his comments.

[2] It is sobering to realize that storage depletion in confining layers supplies so much of the water our civilization depends upon because, by its nature, storage depletion is transient and ultimately unsustainable. In some confined aquifers, such as the Dakota, initially rapid rates of head decline have slowed considerably, giving the impression that conditions are close to a new and seemingly stable steady state wherein extraction is offset by increased recharge and decreased discharge. Analyses that include confining layer storage, however, suggest that this is not true because production has been largely offset by storage losses in the adjoining confining layers. For effective resource management, one must attempt to predict how flow transients that are sustained by storage decreases will evolve and to plan for the decreasing groundwater yields that must eventually follow.

[3] Regarding resource management, *Narasimhan* [2008, p. XXX] considers when ''water management in the future will not allow any further decline in hydraulic heads through controlled withdrawals.'' This may be an overly optimistic scenario because groundwater resources are usually managed locally and with a relatively short-term focus. There are, of course, areas where management proactively strives to limit or even reverse water level declines, but there are many other areas where aquifer management is still so limited and practices are so unregulated that further declines in head and storage can be anticipated for the foreseeable future. Indeed, the only regulation one can anticipate in some cases is economic, when pumping costs become too great or water quality degrades to the point that treatment becomes too costly.

[4] Narasimhan concludes his comment with interesting observations on the geochemical implications of mixing confining layer water with aquifer water. Geochemical changes one might anticipate are delayed by the fact that confining layer water generally becomes more like the aquifer water as the contact with the aquifer is approached. This results from diffusive and advective solute transport between the aquifer and confining layer prior to development. When aquifer geochemistry is eventually affected by flow from the confining layers, we note that the effects will also include changes in the apparent groundwater age. This is expected in developed aquifers in which withdrawals induce leakage from and depletion of storage in adjoining confining layers; the effects should be detectable even at some distance from pumped wells where aquifer drawdowns are modest [e.g., see *Zinn and Konikow*, 2007].

References

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