Simply-structured groundwater model analysis for informing management of transboundary aquifers: Examples from Bengal Aquifer System (Bangladesh, India) and Nubian Sandstone Aquifer System (Chad, Egypt, Libya, Sudan)

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ABSTRACT

Important information for management of transboundary aquifers can be obtained via a parsimonious approach to groundwater modeling. This approach requires (1) development of groundwater models with very simple hydrogeologic structures, and, (2) basic application of these models to answer fundamental questions about the natural functioning of the aquifer system and its responses to human and other external forces. A 'parsimonious' approach implies active avoidance of overly-complex features when constructing models and model-based analyses. 'How simple' and 'how complex' should a particular model analysis be? The answer must rely on hydrologic expertise and experience, and on open scientific discussion.

The need for effective simple modeling is pertinent to large transboundary aquifer systems that do not have informative and extensive hydrogeologic databases. Effective simple models and insightful approaches to analysis account for the limitations of both the modeling approaches and knowledge of aquifer system structure. Simple models can provide clear and robust answers to pertinent questions about transboundary aquifers. This approach was applied for study of two very large transboundary aquifer systems, the Bengal Aquifer System (BAS) of Bangladesh and India, and, the Nubian Sandstone Aquifer System (NSAS) of Chad, Egypt, Libya and Sudan. For BAS, where dissolved arsenic is the noxious substance of the world's largest contamination problem, parsimonious modeling allowed identification of a management approach that could supply a sustainable arsenic-free groundwater supply. For NSAS, development of a parsimonious model is a key step in providing a technical basis for international discussion concerning management. Initial application of the model shows that development of this non-renewable water resource will require effective management of primarily local impacts, as transboundary impacts are of lesser magnitude.

Keywords: Groundwater modeling, Management, Transboundary Impacts, Bengal Aquifer System, Nubian Sandstone Aquifer System.

1. PARSIMONIOUS GROUNDWATER MODELING

Effective simple models include only salient features of the aquifer system that control primary aquifer behaviors of interest regarding understanding and management. A 'parsimonious' model has only enough features to represent key data and processes needed to answer questions at hand. Effective analyses evaluate impact of alternative model structures and features on questions being answered. Complex models often include all available data just because some data details are available, but the practical value of adding model complexities that do not impact results of interest is questionable. Moreover, the processes of developing complex models and using them for analyses are more difficult and time-consuming than for simple models. Potential advantages of complex models are ultimately limited because of inherent uncertainty in knowledge of aquifers. Aquifers can rarely be measured and characterized at spatial-temporal scales required for complete characterization and effective complex modeling, but sparse characterization and parsimonious modeling often allow well-posed questions to be answered. Mere addition of all available hydrogeologic details should thus not be the model-development objective; rather, the central model-development objective is identification of hydrogeologic and other factors that allow questions at hand to be answered.

2. BENGAL AQUIFER SYSTEM

In the Bengal Aquifer System (BAS) of Bangladesh and India, access to groundwater is generally not a problem. Indeed, groundwater is the primary domestic water source for tens of millions of inhabitants. However, shallow groundwater being used has very high levels of dissolved arsenic. This is adversely impacting public health. Deeper groundwater in BAS is currently arsenic-free (meaning: As < 10 μg/L), but any wide-scale program to deepen wells to tap this As-free resource may cause shallow arsenic to migrate downwards, permanently spoiling this sole-source transboundary aquifer. Alternatives are being sought that will provide a sustainable arsenic-free water supply. Parsimonious model-based analysis of the entire BAS (Michael and Voss, 2008, 2009a, 2009b; Burgess *et al*., 2010) has allowed evaluation of key controls on regional groundwater flow. The robust result of this analysis is that, by deepening only domestic wells in the impacted areas while keeping irrigation wells pumping from the shallow part of the aquifer, a sustainable arsenic-free groundwater supply is provided for most of the impacted region. Regarding implementation, it is important to note that this is a low-tech solution that employs socially-functional and passive technology, deepening the common tube wells already preferred by the population. However, it is important that deepening of shallow domestic wells is accompanied by close monitoring and is undertaken with great care and precautions to prevent creation of preferential and rapid pathways for As-laden water to reach the deeper aquifer.

3. NUBIAN SANDSTONE AQUIFER SYSTEM

In the Nubian Sandstone Aquifer System (NSAS) of Chad, Egypt, Libya and Sudan (*http://water.cedare.int/cedare.int/files15%5CFile2813.pdf*), water availability is a key problem and there are concerns about transboundary impacts of water use. Reserves are extensive, particularly in areas where NSAS is thick (Libya and northern Egypt), but there is no modern recharge in most areas. Thus, this resource has limited volume, particularly in areas where NSAS is thin (southern Egypt and Sudan). Transboundary concerns include excessive depletion of groundwater reserves by individual countries and the spread of water-table drawdown across borders, causing shallow wells to dry and oases to disappear. There are also local concerns, including excessive local drawdown within pumping centers, local contamination by untreated waste recharge, and disappearance of oases where most pumping centers are co-located. Simply-structured model analyses, undertaken as part of an IAEA/UNDP/GEF project (*http://www-naweb.iaea.org/napc/ih/IHS_projects_nubian.html*), have shown that transboundary issues should not be an obstacle to practical management of NSAS water resources. Although the foremost transboundary impact of development was indeed found to be drawdown crossing national boundaries, the large scale of the NSAS and its plausible ranges of aquifer parameter values make the magnitude and extent of such transboundary drawdown small and likely not an issue of practical significance in the next century. On the contrary, parsimonious modeling forecasts large local drawdown, potentially impacting the existence of oases in pumping centers. Thus, primary NSAS management concerns should be focused at the local scale. Indeed, new management and engineering approaches may be required to maintain both economical production of groundwater in the face of drawdown and environmental stability in the face of spring flow reduction.

REFERENCES

Michael, H.A., and Voss, C.I. (2008): Evaluation of the sustainability of deep groundwater as an arsenic-safe resource in the Bengal Basin: Proceedings of the National Academy of Sciences of the United States of America, 105(25): 8531-8536.

Michael, H.A., and Voss, C.I. (2009a): Estimation of regional-scale groundwater flow properties in the Bengal Basin of India and Bangladesh, Hydrogeology Journal, 17(6): 1329-1346.

Michael, H.A., and Voss, C.I.(2009b): Controls on groundwater flow in the Bengal Basin of India and Bangladesh: Regional modeling analysis, Hydrogeology Journal, 17(7): 1561-1577.

Burgess, W.G. , Hoque, M.A. , Michael, H.A. , Voss, C.I. , Breit, G.N., and Ahmed, K.M.(2010): Vulnerability of deep groundwater in the Bengal Aquifer System to contamination by arsenic, Nature Geoscience, 3(2): 83-87.