A Karst Aquifer Map for the United States—Is it possible?

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Abstract

Is it possible to classify karst aquifers? This question is central to any attempt to construct a map of karst aquifers for the United States. To make such a map, one must assign spatial boundaries to karst aquifers that are defined by an encompassing set of classifying criteria. The classification paradigm used to make such a map should permit comparison of studies conducted in different regions of the nation and world, and facilitate knowledge transfer between karst regions. However, even attempting to classify different types of karst terrain presents obstacles (Veni, 2002; Weary, 2005). Criteria for establishing boundaries of karst aquifers may call for compromise in "transitional" areas (Taylor, 2001). For example, does a karst aquifer end at a lithologic contact with less soluble rock? How does the definition of a karst aquifer differ from that of a fractured carbonate aquifer? What role does hypogenic speleogenesis play in regulating flow regimes and storage within a karst aquifer (Klimchouk, 2007)? What techniques does one employ when dye-tracing is not practicable for defining basin boundaries and establishing ground water transit time distribution in karst?

An encompassing classification of karst aquifers is one based upon measurable parameters derived from discharge and chemistry at springs and wells within the context of known geologic controls on aquifer extent and speleogenetic development (White, 2003). Such a paradigm presents two main challenges: (1) establishing a conceptual model of karst aquifer development through construction of the geologic framework and speleogenetic history, and (2) determining quantitative indices of the hydrologic response of an aquifer to recharge events from records of flow and water chemistry, supplemented by targeted water tracing experiments and local well tests. The geologic framework provides the basic information on the physical constraints on water storage and movement in the aquifer, including its boundaries and internal structures that guide permeability development through solution. The geologic framework is built through detailed geologic mapping (1:24,000 scale or larger), supplemented by geophysical investigations (e.g., Orndorff and others, 2001; Kozar and others, 2008). The speleogenetic history provides the information on how the permeability structure has been integrated into a highly conductive flow network. The speleogenetic history is reconstructed through the study of caves throughout the geographic extent of the aquifer, their relations to the geologic framework, and what they reveal of former hydrogeologic regimes experienced by the aquifer (Palmer, 2007). Caves represent the greatest degree of integration of the high-transmissivity conduits within the aquifer flow system, thus the processes which lead to their development help to classify the aquifer. Together, the geologic framework and the speleogenetic history provide the conceptual model for the development of the karst. The broadest categories for karst aquifer classification are therefore determined by the conceptual model of karst development. Examples of such broad categories include epigenic (unconfined) versus hypogenic (confined) karst aquifer formation (Klimchouk, 2007; Ford and Williams, 2007), and eogenetic (diagenetically immature) versus telogenetic (diagenetically mature) rocks which host karst aquifers (Florea and Vacher, 2006).

Spring flow records provide the most vital information for karst aquifer resource assessment. Working backwards from discharge may yield more fruitful and realistic aquifer assessment than attempting to work forward from site-specific porosity/permeability characterization and scaling up to the regional aquifer (Bredehoeft, 2007; Fleury and others, 2007). This is best achieved by determining diagnostic parameters of aquifer response to recharge from hydrograph and chemograph analysis. For example, multiple aquifer flow regimes can be identified through hydrograph recession analysis, and aquifer storage volumes drained by springs can be estimated by integrating across recession curves (Doctor and Alexander, 2005). Hydrograph recession analysis thus provides useful quantitative indices

for karst aquifer classification, such as the base flow recession coefficient, α (day^{-1}), and the ratio of dynamic phreatic storage volume to total annual volume discharged, or the "regulating power" of the aquifer system, *k* (dimensionless) (El-Hakim and Bakalowicz, 2007).

While important for karst aquifer classification, quantitative indices derived from hydrograph recession analysis are insufficient for aquifer mapping. A necessary component is the water balance. The exercise of constructing a balanced water budget may reveal the presence of additional water sources or sinks across previously hypothesized aquifer boundaries, and provides a check on the storage capacity of the aquifer estimated from spring flow recession analysis for a particular basin of interest. A balanced water budget will require that the spatial extent for recharge of a particular ground water basin has been properly delineated, thus enabling a mapped representation of the karst aquifer on the land surface. Boundary refinement is best achieved through well-designed tracing experiments. For example, dye-tracing provides information on groundwater flowpaths and subsurface basin divides. In addition, dye-tracing provides quantitative information on the distribution of travel times within an aquifer. Where dye-tracing is impractical, tracing with natural environmental isotopes and chemistry may provide needed information, particularly in aquifers with a significant artesian component (e.g., Doctor, 2007).

In summary, we suggest a classification paradigm for karst aquifers with two primary components: (1) an initial broad categorization based upon a conceptual model for karst development grounded in geologic and speleogenetic data, and (2) refinement within the initial category based upon quantitative indices of aquifer response to recharge from discharge records obtained at springs. Thus, long-term, high frequency hydrologic data are necessary for determining quantitative parameters for karst aquifer classification. However, karst aquifer classification ought not to be based solely upon the prevailing climatic factors of the broader aquifer region. Although climate is often the driving force for karst development, climate is dynamic and variable over time. Rather, the long-term aquifer response (centennial to millennial) to climatic forcing needs to be assessed independently of the short-term aquifer response (annual to decadal) to hydrologic factors that may be used for aquifer classification. In this way, comparisons among a single aquifer type existing under different climatic regimes may facilitate predictions of aquifer response to future climate change.

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