PhD Dissertation Defense

Understanding Fen Hydrology – A Hierarchical, Multi-scale Groundwater Modeling Approach

by

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ABSTRACT

Fens are groundwater-fed wetlands that support a large variety of biodiversity. The hydrologic system that supports the existence of these fens is much larger, more complex and inter-connected than expected. Even though fens occur in varied hydro-geologic and topographic settings, they share a common source of water, namely regional groundwater mounds. Traditional approaches of understanding fen hydrology have simplified the hydrologic system that supports the fens, such as using one scale of model to represent multi-scale variability, or using a vertical profile model to represent the 3-dimensional variability in topography and geology. I argue that fens are a product of complexity in topography, geology and hydrology, and therefore, simplified models cannot capture such systems. In this research I use hierarchical, multi-scale groundwater modeling at three fen sites in southern Michigan to understand the hydrologic processes and mechanisms that sustain these unique ecosystems. The methodology adopted in this research takes advantage of the detailed and extensive hydrologic data that is made available by the GIS and IT revolution in recent decades.
The first application of this approach is for modeling the hydrology of two fen sites that occur close to each other, i.e. MacCready Fen and Skiff Lake Fen in Southern Michigan. I built a hierarchy of nested steady-state models to capture the groundwater flow system at spatial scales ranging from the regional ground-watershed to the local fen sites. Three-dimensional particle tracking was used to predict the sources of water to the fens and the corresponding delivery mechanisms. I use vertical profile models, created from the 3-dimensional models, in order to illustrate the inability of simpler models to predict the complexity of the fens’ hydrologic system.

The second application is for the geographically-isolated Ives Road Fen in south-eastern Michigan. Although the overall methodology adopted was similar to the one used for MacCready and Skiff Lake Fens, this site was characterized by very complex 3-dimensional geologic variability that had to be accurately characterized. To accomplish this, a Transition Probability approach was used to create a 3-D geologic model, which was then incorporated into the groundwater flow model.

Results from the multi-scale simulations illustrate the complex, inter-connected nature of the hydrologic system that supports these fens. The water in MacCready and Skiff Lake fens can be traced back to a network of sources, including lakes and wetlands at different elevations, which are connected to the regional Hillsdale groundwater mound through a “cascade delivery mechanism.” Simplified models, such as a vertical profile model, are unable to replicate the complex, 3-D geology and topography that creates the conditions favorable for the fen to survive. In the case of the Ives Road Fen, water from the Hillsdale mound moved through a “pipeline,” consisting of a confined aquifer beneath a thick clay layer, to deliver water to the fen through a break in the clay layer. Thus, a geographically-isolated fen far away from other fens is hydrologically connected to the same regional mound that provides water to a fen that is part of a geographic cluster of fens. The regional mound also acts as a “master recharge area,” since it is the ultimate source of water not only to fens, but also for many rivers, lakes, wetlands and aquifers. The implication of these findings is that rather than protecting individual fens and their immediate surroundings, fens must be managed as part of a much larger, inter-connected groundwater system. The current approach to managing fens and other ecosystems must be reassessed and should move away from localized, short-term fixes to system-based, long term solutions.