Report as of FY2008 for 2003MA19G: "A Regional Approach to Conceptualizing Fractured-Rock Aquifer Systems for Groundwater Management"

Publications

- Articles in Refereed Scientific Journals:
  - Manda, A.K; S.B Mabee, D.U. Wise, 2008, Influence of rock fabric on fracture attribute distribution and implications for groundwater flow in the Nashoba Terrane, Eastern Massachusetts, Journal of Structural Geology, (30) 464-477.
  - Diggins, J.P., D.F. Boutt, A.K. Manda and S.B. Mabee, 2006. Estimating bulk permeability of fractured rock aquifers using detailed outcrop data and discrete fracture network modeling. Geological Society of America Annual Meeting, Philadelphia, Abstracts with Programs, v.38, no.7, p.223.
  - Manda, Alex K., Stephen B. Mabee, 2008 (In prep) Contrasting various fracture sampling methods from layered rocks, Submitted to Hydrogeology Journal.
- Conference Proceedings:
  - Manda, A.K, S.B. Mabee and D.F. Boutt, 2006. Characterizing fractured crystalline bedrock aquifers using hydrostructural domains in the Nashoba terrane, eastern Massachusetts. Geological Society of America Annual Meeting, Philadelphia, Abstracts with Programs, v.38, no.7, p.25.
  - Boutt, D.F., A.K. Manda, S.B Mabee, J.P. Diggins, 2006, Characterizing fractured crystalline bedrock aquifers using discrete fracture networks in the Nashoba Terrane, Eastern Massachusetts, Eos Transactions, American Geophysical Union, v. 87, no. 52, Fall Meeting Supplement, Abstract H13D-1429.
  - Manda, A.K., S.B. Mabee and S.A. Hubb,. 2005. Field mapping and fracture characterization techniques predict groundwater preferential flow paths in fractured bedrock aquifers, Nashoba terrane, MA. EOS Transactions, American Geophysical Union, v.86, no. 52, Fall Meeting Supplement, Abstract H23E-1477.
  - Manda, Alex K., Stephen B. Mabee, David F. Boutt, 2007, Discrete fracture network modeling of hydrostructural domains: an example from Eastern Massachusetts, in 2007 US EPA/NGWA Fractured rock Conference: State of the science and measuring success in remediation, September 24-26, 2007, Portland Maine: national Groundwater Association (CD-ROM).

Report Follows

Problem Statement and Research Objectives

The use of fractured-bedrock aquifers to meet private, public and commercial water supply needs is increasing in the New England region. Municipalities and water suppliers are finding it increasingly difficult to locate and develop water supplies in overburden aquifers because of contamination and a lack of suitable sites. In addition, recent droughts in the northeast have forced many communities and homeowners to drill new wells. As a result, water suppliers are going deeper into bedrock aquifers. Yet information on the factors that influence the availability and recharge characteristics of fractured bedrock aquifers in highly deformed crystalline metamorphic rocks is limited.

The availability of water in fractured rock aquifers is particularly critical in New England because growth and development along the coast, major transportation corridors and in rural communities adjacent to large metropolitan areas is rampant. For example, the I-495 corridor in Massachusetts, a circumferential highway 30 miles west of Boston, has become the focus of recent growth. Professional office buildings, research and development parks associated with the computer industry, warehouses and light industry are springing up along this corridor, as are housing and condominium developments. Municipalities and water suppliers are simply unprepared for the onslaught of development and need help in understanding the complex dynamics of the ground water system.

Sustaining and managing ground water resources in fractured bedrock requires an evaluation of 1) the availability of water, 2) the source and vulnerability of recharge to water supply wells and 3) the impact of water withdrawals from the bedrock on streams, wetlands and unconsolidated aquifer systems that overlie the bedrock. These evaluations all require basic information on the physical characteristics of the ground water system.

The objectives of this project are to gather regional bedrock characteristics that relate to the occurrence and movement of ground water in bedrock and use this information to begin constructing regional conceptual models of the fractured-rock aquifers in the Nashoba terrane in Massachusetts. The approach utilizes existing information augmented by the collection of low-cost field data to develop regional conceptual models of the ground water flow system. Water managers can then use these conceptual models as an initial framework for formulating an understanding of bedrock flow behavior and recharge characteristics.

Methodology

Specific tasks of this project involve: 1) Fracture Characterization and Domain Analysis - collection and synthesis of fracture characterization data over the region and mapping of the spatial distribution (domain analysis) of fracture sets and their characteristics, 2) Compilation and Analysis of Existing Well Data - compilation and statistical analysis, including variography, of available well data to link spatial continuity of well yields to characteristics of the fractured rock system, 3) Borehole Geophysics - collection of optical and acoustic televiewer data from selected boreholes to verify sheeting joints, 4) Compilation of Regional Litho-Group Map - development of a mapping classification system that uses the notion of “litho groups” to characterize bedrock units in terms of their fracture characteristics, physical properties and geologic setting (eg., overburden type and thickness) and 5) Conceptual Model - preparation of a qualitative conceptual model of ground water flow behavior in each litho group category.

Principal Findings and Significance

A new method has been developed to quantitatively assess the hydraulic properties of fractured rocks that is independent of geology. This approach uses easily obtained fracture data to prescribe hydraulic properties of discrete fracture networks (DFNs) to rocks with negligible matrix porosity. The properties that are required to provide a hydraulic property estimate are fracture intensity, size, intersection angle of fractures, and number of fracture sets in a fracture network. The ratio (R) of the permeability of a fracture network to the permeability of a single fracture within an identical model domain is used to quantify the hydraulic character of DFNs with fracture sets that comprise persistently parallel fractures. Results reveal that R is consistently most sensitive to the angle of intersection of fractures in a network and least sensitive to the fracture intensity. The analyses also show that there is a predictable relation between R and the above mentioned parameters. Thus, a methodology for developing type curves through numerical simulations is also provided. These type curves are a series of graphs, which provide R estimates that are based on unique combinations of fracture properties and configurations collected in the field. Estimates of R from the type curves can then be used to compute the first-order approximations of fracture network permeability or hydraulic aperture at a cost far less than that associated with performing aquifer tests.

Publications and Conference Presentations

a. Articles in Refereed Scientific Journals

Manda, Alex K., Stephen B. Mabee, Donald U. Wise. 2008. Influence of rock fabric on fracture attribute distribution and implications for groundwater flow in the Nashoba Terrane, eastern Massachusetts. Journal of Structural Geology, v.30, pp.464-477.

Manda, Alex K., Stephen B. Mabee, David F. Boutt. (In Review). Effects of fracture configurations and properties on the hydraulic properties of three-dimensional networks. Submitted to Water Resources Research.

Manda, Alex K., Stephen B. Mabee (In Review). Comparison of three fracture sampling methods in layered rocks. Submitted to International Journal of Rock Mechanics and Mining Science.

b. Dissertations

Manda, Alex K. 2009. Development and validation of conceptual models to characterize the fractured bedrock aquifer of the Nashoba Terrane, Massachusetts. Ph.D. Dissertation, Geosciences Department, University of Massachusetts, Amherst, Massachusetts, 159p.

c. Conference Proceedings

Manda, Alex K., Stephen B. Mabee, David F. Boutt. 2007. Discrete Fracture Network Modeling of Hydrostructural Domains: An Example from Eastern Massachusetts, *in* U.S. EPA/NGWA Fractured Rock Conference: State of the Science and Measuring Success in Remediation, September 24-26, 2007. Portland, Maine, pp.480-488.

d. Published Abstracts

Manda, Alex K, Stephen B. Mabee, David F. Boutt. 2006. Characterizing fractured crystalline bedrock aquifers using hydrostructural domains in the Nashoba terrane, eastern Massachusetts. Geological Society of America Annual Meeting, Philadelphia, Abstracts with Programs, v.38, no.7, p.25.

Diggins, John P., David F. Boutt, Alex K. Manda, Stephen B. Mabee. 2006. Estimating bulk permeability of fractured rock aquifers using detailed outcrop data and discrete fracture network modeling. Geological Society of America Annual Meeting, Philadelphia, Abstracts with Programs, v.38, no.7, p.223.

Manda, Alex K., Stephen B. Mabee, Steven A. Hubbs. 2005. Field mapping and fracture characterization techniques predict groundwater preferential flow paths in fractured bedrock aquifers, Nashoba terrane, MA. EOS Transactions, American Geophysical Union, v.86, no. 52, Fall Meeting Supplement, Abstract H23E-1477.

Manda, Alex K. 2005. Characterizing the fractured bedrock aquifer of the Nashoba Terrane, Massachusetts. Massachusetts Water Resources Research Center/UMass Extension 3rd Annual Conference, Research to Practice: Science for Sustainable Water Resources, Amherst (Poster).