Development of Regional-Scale Conceptual Models of Ground Water Flow in the Fractured Crystalline Bedrock Aquifers of the Nashoba Terrane Using Borehole Geophysical Techniques and Outcrop Data

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Abstract

In New England, ground water has traditionally been drawn from surficial aquifer systems, composed primarily of glacial sediments, to meet private, commercial and industrial water needs. Development of new, productive wells in this overburden is constrained by the lack of extensive sand and gravel deposits as well as by the high vulnerability of these units to contamination. Rapid development throughout the region has exacerbated this problem, and the need for better water resource management is great. The surficial aquifers (if present) can no longer support the water needs of this growing population and regional climate predictions suggest that the timing and extent of precipitation will change in the future. Increasingly, municipalities are drawing from deep metamorphic and igneous bedrock units.

The goal of this project is to collect reliable, consistent, and informative data set of the regional hydrogeologic properties of the fractured crystalline bedrock aquifer of the Nashoba Terrane of Eastern Massachusetts. To accomplish this goal a borehole geophysical investigation of the Nashoba Terrane is undertaken, using previously drilled commercial and residential wells. Statistical data from the study is used to characterize the depth and nature of flow systems in the Nashoba Terrane. It is often assumed that fracture density in bedrock decreases with depth. If this assumption is valid then the presence of water-producing fractures should decrease at a similar rate. This paper examines the depth relationship of fracture density in the Nashoba Terrane.

Study Area

The Nashoba Terrane is a fault bounded, northeast-trending bedrock unit that lies in the I-495 corridor of eastern Massachusetts (Figure 1). The primary composition of the Nashoba is igneous and highly metamorphosed rocks, overlain by thin glacial sediments. In general, fractured crystalline bedrock systems are not productive aquifers due to their low porosity and conductivity; additionally, there is no matrix storage in these aquifers further limiting the availability of water. There are several ductile faults in the terrane, and how these faults affect the flow in the subsurface is not known.

Figure 1. Map of the study area in Eastern Massachusetts. Red dots denote well locations.
These faults could act as barriers to flow or as conduits. Manda, et al. (2007) have completed an extensive fracture mapping study of the Nashoba in an attempt to link the surface expression of fractures with the hydrogeologic properties of the subsurface. They suggest a series of hydrostructural domains which govern direction and quantity of flow. No work has been done to directly quantify the hydrogeologic properties of the Nashoba. As the fifty suburban communities, which lie over the Nashoba, grow the use the fractured crystalline bedrock aquifers is increasing. The need to characterize the hydrogeologic properties of these aquifers grows ever more urgent.

**Methods**

A suite of borehole geophysical tools (fluid resistivity, gamma, caliper, heat pulse flow meter, optical televiewer (OTV), and acoustic televiewer (ATV)) are used to identify and characterize the flow regime of fractures intersecting the borehole. Data from each tool is collected using a Mount Sopris Co winch system and recorded digitally. The fluid resistivity/temperature, gamma, caliper, ATV and OTV logs are interpreted using WELLCAD (Figure 2). Care must be taken to use multiple logs for identifying the presence, characteristics, and nature of fractures. For a more complete description of these and other downhole tools and techniques see Williams et al. (2002) and Johnson et al. (2005).
Figure 2. Example geophysical log from an irrigation well in Shrewsbury, MA. Fractures are traced over the ATV log (center). Groundwater is entering the borehole where there is a change in fluid resistivity at 80 feet.

Results

Data from eleven wells are analyzed with an average well depth of 529 feet. There are over 280 total fractures identified in the wells. Of these 82% of fractures were found to be within 300 feet of the surface, 66% were in the top 200 feet, and almost half (45%) were found within the top 100 feet of the borehole. Of these 26% were found to be water producing fractures (Figure 3). These water producers averaged 191 feet depth. Of these 88% were found to be in the top 300 feet of the well, 63% were in the top 200 feet and 46% were found above 100 feet. It is clear that the groundwater flow in the boreholes examined in this paper, while not restricted, flows predominantly in the upper 300 feet of the terrane. The depth of flowing fractures is proportional to the quantity of available fractures suggesting that the depth of flow is primarily controlled by the presence of fractures. The lack of relief in the Nashoba Terrane and the relatively shallow flow system suggests that flow is topographically driven with recharge occurring locally into open fracture networks.

Discussion and Conclusions

The depth of the regional groundwater flow network in the Nashoba terrane is primarily constrained to the top 300 feet. This is controlled by the density of fractures and by the available recharge of the topographically driven system. This is an important for municipalities in search of groundwater in the Nashoba fractured crystalline aquifer and for understanding the sustainability of these resources under uncertain future climatic conditions.

There are some factors limiting data collection, and thus the results of this study. First, the depth of fractures which could be measured in this study was limited by both the depth of available wells and by the capability of the equipment. It is possible that a deeper flow network exists for which no data could be collected. There is no evidence of such a system here. Second, the stress placed on the fractures through pumping might not be sufficient to “activate” deeper fractures so they could be considered water-producers in this project. It is unlikely that such a network exists since the propagation of fractures is the limiting factor for flow. However, the Nashoba Terrane has a complex tectonic history so fractures could exist at depth near the bounding faults of the terrane that were not exposed in this project. Further work is needed to examine and stress deeper sections of these aquifers.
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References

