Report for 2003NJ39B: Validation of the PMF (Preprocessor to MODFLOW for Fractured Media) Package

- Book Chapters:
  - Mun, Yuri and Christopher.G. Uchrin, 2003: PMF package (a Preprocessor to MODFLOW for Fractured Media), In: MODFLOW and MORE 2003 Understanding through Modeling Ed. Poeter. E., C. Zheng, M. Hill, and J. Doherty, Colorado School of Mine, Golden, CO. pp.555-559.
- Conference Proceedings:
  - Mun, Yuri and Christopher.G. Uchrin, 2003: Ground Water Flow Modeling in a Layered Sedimentary Fractured Media Aquifer System using MODFLOW with the PMF package. In: Eos Trans. AGU 84(46), Fall Meet. Suppl., San Francisco, CA, Abstract H42B-1069.
  - Mun, Yuri and Christopher.G. Uchrin, 2003: Pollutant transport in Fractured Media Aquifers, In: Physicochemical Processes in Environmental Systems: Symposium in Honor of Professor Walter J. Weber, Jr. in American Chemical Society, New York, NY. pp.1157-1163.

Report Follows

Validation of the PMF (Preprocessor to MODFLOW for Fractured Media) Package

Yuri Mun

Problem Statement

Ground water is the largest accessible freshwater source in the world. In New Jersey, 50 percent of the population depends on ground water as their water source (Zapecza, 1990). Since public health concerns arise from drinking water being contaminated, the importance of predicting ground water movement and quality has increased. The best tool available for this prediction is usually a ground water model (Anderson and Woessner, 1992).

There are two types of principal aquifers in New Jersey: Coastal Plain aquifers south of the fall line and non-Coastal Plain aquifers north of the fall line. While the Coastal Plain consists of porous media having a continuous change of flow properties, the non-Coastal Plain consists of fractured media having a discrete change of flow properties which can compose the preferred fluid pathways. There are a multitude of well-developed models for ground water in porous media. In contrast, ground water flow in fractured media has often been simulated by either focusing on flow in individual fractures (fracture flow approach (Amadei and Illangasekare, 1994)) or by assuming a uniform distribution of fractures (equivalent porous medium approach). Although the latter approach has been utilized by many hydrogeologists due to its ability to handle the environmental impact of pollutants in a larger geographic area, it might have the limitation to represent the preferred fluid pathways. Therefore, a new approach, which can assist the EPM approach to address its limitations, is needed.

The PMF (Preprocessor to MODFLOW for Fractured media) package was developed in conjunction with the Multi-Media Nonpoint Source Model which investigated the problems of eutrophication with nonpoint sources for the Cranberry Lake system (Mun and Uchrin, 2004; Uchrin et al., 2002). It can depict the preferred fluid pathway in the EPM approach, as it utilizes percolation theory which can describe the connected fluid pathways. The conceptual model, which represents the fractured media by a finite difference grid, must have two or more different categories of cells such that one represents the case of abundant more fractures while the other represents no or less fractures. If MODFLOW is combined with percolation theory, the model domain can have two kinds of cells which are considered as active and inactive (Figure 1). The active cell represents the preferred fluid pathways and the inactive cell represents the part having no flow. This preprocessor can construct the different conceptual models with different percolation numbers. The percolation number is the number which determines the amount of active cells. The appropriate conceptual model and percolation number could be determined by comparison of alternatives (Mun and Uchrin, 2004). The application of the PMF package can assess different simulation scenarios having different percolation numbers which indicate the amount of cells defining preferred flow pathways. If the percolation number (p) is equal to 1, the PMF package is not applied and all cells are defined as active, thus able to transmit ground water flow (like porous media). If the percolation number (p) is 0.6, then 60% of the cells in the model domain define the preferred flow pathway.

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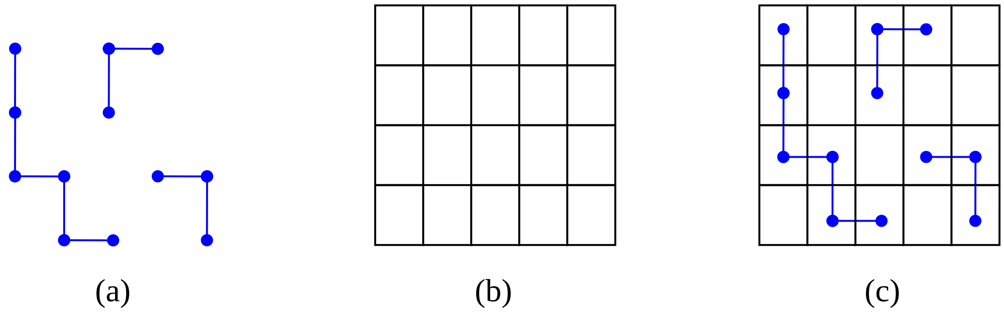

Figure 1. Development of PMF package; (a) Percolation theory: black dots showing occupation and lines showing connection, (b) MODFLOW: a finite difference model and (c) Combination of MODFLOW and Percolation theory.

PMF package was applied to Cranberry Lake system located in the crystalline Highlands Province of northern New Jersey. Its major aquifer is comprised of fractured media and most of the available water is within 300ft of the land surface. Yields from crystalline fractured rock are limited by the degree of weathering and fracturing and do not exceed more than a few hundred gallons per minute. In calculation of the ground water discharge to the lake, while EPM approach employed in the beginning of this project projected 325 percent of the observed value, the application of PMF package projected just 92 percent of the observed value with 100 percent representing a perfect match between calculation and observation (Figure 2). In addition, while the EPM approach showed that larger calculated values have larger residuals which could suggest either a systematic model error or of assumptions, the PMF package showed a random distribution of residuals which should be shown by ideal modeling (Mun and Uchrin, 2004). Therefore, the PMF package can be considered to provide a more rigorous model and to open new chapter of ground water flow modeling in fractured media.

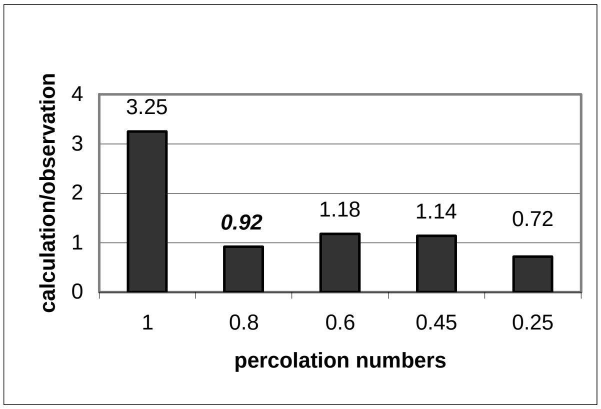

Figure 2. Comparison of Modeling Results between different Percolation Numbers: Water Balance

Even though this PMF package provided a better model for ground water flow in fractured media in one instance, it still needs to be improved and generalized in order to apply it to other fractured media ground water flow system. That is, this new approach needed further validation, which means it has to be determined if the model includes all major processes and can describe suitably observed phenomena (Schnoor, 1996).

Methodology

The validation could be performed by applying the PMF package to other fractured media. This study selected the layered sedimentary fractured media located at the Busch Campus of Rutgers University, which was reported with its ground water contamination by PCE and TCE (Lewis-Brown and dePaul, 2000). Ground water modeling was performed by MODFLOW 2000 after application of PMF package. Since calibration by strictly trial-and-error methods was judged to be both ineffective and inefficient, the inverse modeling technique using nonlinear-regression methods was employed, which was considered to be a better approach to estimate optimal parameter values.

Results and Discussion

The selected system consists of two major geologic structures: a water bearing unit and a confining unit. The water bearing unit generally has a higher hydraulic conductivity and horizontal flow, while the confining unit has lower hydraulic conductivity and vertical flow. This system was tested with five different simulation scenarios with five percolation numbers (1.0, 0.8, 0.6, 0.45 and 0.25). Modeling calibration result using hydraulic head and stream flow shows that the scenarios with the percolation numbers of 0.8 and 0.45 provided the smallest values for sum of error squared (Figure 3). Only the scenario with p = 0.45, however, provides agreement with the characteristics of the geologic system which shows horizontal flow in the water bearing unit and vertical flow in the confining unit (Table 1) and is therefore the best representation of the real system. Figure 4 exhibits the resultant three-dimensional piezometeric surface for p = 0.45.

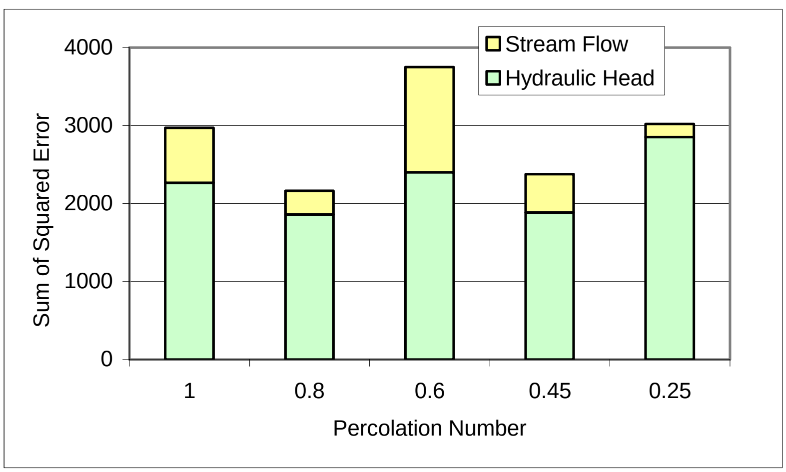

Figure 3. Calibration Results: Sum of Squared Error

Table 1. Selected Calibrated Parameters

	Percolation Number	1.0	0.8	0.45
Water Bearing Unit	Horizontal Hydraulic Conductivity	2.131	2.5	16.68
	Vertical Hydraulic Conductivity	2.674	25	2.704
Confining Unit	Horizontal Hydraulic Conductivity	N/A	0.5	0.883
	Vertical Hydraulic Conductivity		0.005	1.747

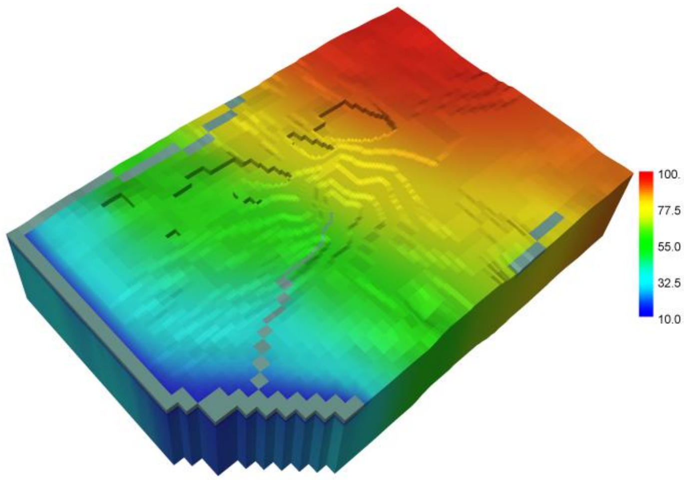

Figure 4. 3-dimensional Piezometric Surface at Busch Campus (unit: feet)

Summary

The PMF package has been constructed as a preprocessor to MODFLOW by employing percolation theory so that it can assist the EPM approach for simulation of groundwater flow and transport in fractured media. This project validated the superiority of this new method by applying it to two different geologic systems.

References

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