Groundwater Modeling in Minnesota
by Erik Anderson, Richard Pennings, and Otto D.L. Strack

Minnesota relies heavily on its water resources. About 60 percent of the state's population drink groundwater, and the recreational opportunities offered by Minnesota's rivers and lakes are an important part of the state's economy. These resources are not static. Instead, water flows between lakes, rivers, and the groundwater-bearing layers known as aquifers in a continuous movement and exchange. The movement of water is part of a complex hydrological system. There are numerous threats to the quality and quantity of water in this system. Volatile organic chemicals, nitrates, pesticides, and other contaminants are often found in public wells, and may come from any number of sources, such as leaking underground storage tanks, leaching landfills, or pesticide and fertilizer use. Real estate development and agricultural use of land intensifies the consumption of water resources while altering the contents and amount of surface runoff entering the system. Identifying specific sites of water contamination or consumption is only one aspect of water resource conservation. Because surface water and groundwater interact, use of water within a specific site can have a much wider impact as the water flows beyond that site's boundaries.

As concern for the state's water resources has intensified, so have efforts to monitor the use of these resources, often with the help of computer models of groundwater movement. For example, to assist in monitoring of Twin Cities groundwater levels and quality, the Legislative Commission on Minnesota Resources recently allotted funding to develop a computer model of the aquifers underlying the metropolitan area. And in rural areas, the Minnesota Pollution Control Agency (MPCA) relies on computer modeling of groundwater movement to track the impact of non-point source pollution on wetlands, lakes, and streams.

The need for increasingly precise and geographically specific information in these and similar cases has revealed limitations in existing computer models. Originally designed for large scale regional studies, these models often oversimplify local interactions between surface and groundwater. Yet as conservation efforts focus on discrete surface-water bodies or specific municipal water supplies, it becomes more important to calculate local water movement precisely. The goal of our project was to provide guidelines for adjusting the existing models to account for these complex local interactions.

Current Modeling Techniques
Groundwater flow is three-dimensional, capable of moving in any direction. In large scale regional studies, including the complexities of three-dimensional flow is often not necessary. Horizontal flow is typically dominant in such studies because aquifers tend to be much broader than they are deep. The simplifying omission of resistance to vertical flow, which reduces the mathematical problem to a two-dimensional horizontal flow, is known as the Dupuit-Forchheimer assumption. This has in most large scale studies proved to describe groundwater levels accurately, and groundwater discharges even more precisely.

In areas where vertical flow is more dominant, a Dupuit-Forchheimer model's predictions of discharge may remain accurate, although its predictions of groundwater levels are more likely to be in error. At local points of interaction between groundwater and surface-water bodies such as rivers and lakes, however, predictions of both groundwater levels and movement may be in significant error. In these areas, vertical flow dominates and discharge between the groundwater and the river or lake often passes through a layer of sediment or silt.

Improved Modeling
While Dupuit-Forchheimer solutions are accurate within a short distance of a river or lake, they produce poor results near and directly beneath either one. By looking at the characteristics of groundwater movement near a river, we can see why a standard Dupuit-Forchheimer model will produce poor results (Figure 1A). The river in this illustration is surrounded by two aquifers: first, an upper, unconfined aquifer from which water may pass vertically through a leaky layer (an aquitard), and second, a lower aquifer, bounded below by an impermeable base. Groundwater in both the upper and lower aquifers interacts with the surface water in the river. The arrows illustrate the direction of groundwater flowpaths discharging into the river and between aquifers. Discharge from the river into the aquifers also occurs, but this is not shown in the illustration. Discharge from the aquifers into the river passes through a sediment layer of varying thickness and low permeability that lines the riverbed.
The vertical cross-section shown in Figure 1A gives a fairly complete picture of groundwater flowpaths near the river. These paths tend to approach long, thin surface-water bodies at right angles. Because of this tendency, we are able to rely on two-dimensional vertical planes to investigate errors resulting from the existing models' focus on two-dimensional horizontal planes.

Our correction of Dupuit-Forchheimer models relies on exact mathematical solutions computed for an idealized version of the actual situation (Figure 1B). In this idealized rendering of Figure 1A, we have assigned a uniform thickness to the sediment layer lining the river bed, and have evenly distributed the discharge from the upper into the lower aquifer. Note that in this idealized model, as in the actual situation, the greatest component of vertical flow occurs near and directly beneath the river, where Dupuit-Forchheimer models are most often in error.

We looked for a factor that could be incorporated into existing Dupuit-Forchheimer models to account for the effects of vertical flow. Numerous parameters affect vertical flow near a surface-water body, including the actual resistance of the sediment layer lining the river or lake, the flow of groundwater in the aquifer from the right or the left, the aquifer's thickness, the aquifer's permeability (property controlling the rate at which water passes through it), and the length of the river or lake. What we found, however, was that there can be large variations in the factor which is the product of these parameters. In other words, a single factor adequately represents a wide assortment of aquifer conditions, and can be used to improve existing Dupuit-Forchheimer models. When incorporating this factor into the existing models, we describe it as an effective resistance to vertical flow in the aquifer and lump it with the actual resistance of the sediment layer lining the river or lake in question.

A comparison of flowpath lines generated using different models demonstrates the extent to which this factor improves flowpath predictions near and beneath a river or lake. To clarify the comparison, we show the interaction between a single aquifer and a surface-water body in which the groundwater flows predominantly from left to right. The exact solution for an idealized version of this situation shows that the flowpath lines cluster together at the left edge of the surface-water body, and become more widely dispersed as we move to the right (Figure 2A). A standard Dupuit-Forchheimer model, however, would distribute these lines evenly across the bottom of the surface-water body, incorrectly representing the points at which groundwater discharge enters the surface water (Figure 2B). In comparison, the corrected Dupuit-Forchheimer model (including a factor for effective resistance) offers a highly accurate prediction of groundwater distribution across the surface-water bed (Figure 2C), closely corresponding to the exact solution.
Putting the Model to Use

This project was conducted with the close cooperation of the Minnesota Pollution Control Agency (MPCA), which was able to put the model to immediate use and give feedback on the model's effectiveness. MPCA's Division of Water Quality is using the model to evaluate the impact of a proposed high-capacity irrigation project in the Straight River area in northern Minnesota. The irrigation project has both water quantity and quality implications. It would allow agricultural land near the Straight River to be converted to more intensive potato farming. Potatoes require both more irrigation and a heavier use of pesticides and fertilizer than the crops currently grown on the land. Converting the land to potato farming thus raises the possibility of groundwater depletion and contamination.

Preexisting groundwater models had enabled the MPCA to quantify the overall balance of water in a hydrological system and describe absolute interchanges of water within the system. But these models were not able to define precisely what occurs at specific sites of interaction between surface water and groundwater. Because MPCA is concerned with maintaining the integrity of the state's rivers and lakes, understanding what is happening at such sites is extremely important. In the Straight River project, which is still in progress, MPCA has found that the more refined estimates of groundwater discharge produced by the improved model allow them to verify more surely actual measurements of groundwater discharge into the river.

Computer models are necessary in part because the tools available to MPCA for measuring actual groundwater discharge are limited. To determine whether groundwater consumption could affect water levels in the Straight River, for example, MPCA installs monitoring wells to track groundwater depth and stream gauges to measure river flow. If the gauges indicate that the river's flow increases downstream, then the river is presumably drawing water from an aquifer. The monitoring wells and stream gauges cannot, however, measure the exact rate at which this water is drawn from the aquifer. The improved model's more accurate estimates of the rate of groundwater discharge into the river help to determine whether a depletion of that discharge would impact the river's water level.

MPCA has found that the improved model's more accurate predictions of the rate of groundwater discharge into the river help to determine to what extent the river interacts with an aquifer. Rivers are typically endpoints of groundwater movement. If the river fully or even partially penetrates an aquifer, contaminants passing through the groundwater may pass directly into the river. If, however, discharges from an aquifer are low or non-existent, contaminants in the aquifer may pass under the river, keeping it free from pollution.

Because MPCA was closely involved in developing the improved model, and was able to gain feedback by putting the model to use, they anticipate that the model will be useful in future MPCA studies of groundwater interaction. The improved model should play an important role in maintaining the integrity of Minnesota's rivers and lakes.

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This study was supported in part by an interactive research grant from CURA and the Office of the Vice President for Research, University of Minnesota. Interactive research grants have been created to encourage University faculty to carry out research projects that involve significant issues of public policy for the state and that include interaction with community groups, agencies, or organizations in Minnesota. These grants are available to regular faculty members at the University of Minnesota and are awarded annually on a competitive basis.

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New CURA Publications


For more than a decade schools and social service systems have been searching for ways to collaborate so that children will receive the social services they need to support their children's education, health, and growth. In September 1995 a conference was held at the University of Minnesota to examine how various partnerships between schools and social service systems are going. Have models emerged? Do schools have what they need? Do social services have what they need? What are the problems? What works? This publication presents a summary of the conference proceedings.


It is in our homes and our neighborhoods that society reproduces itself, and if things begin to go awry at home or in the neighborhood, we correctly sense that trouble is brewing for society at large. Shifts in the housing landscape often parallel changes in the direction of our society. This report, based on the 1990 census and earlier census data, presents a profile of selected features of the Minnesota housing landscape—a landscape we have created over the years, and that is now shaping our lives. The housing supply, vacant housing, changes in the demand for housing, low income housing, poverty populations, and minority housing are all examined along with commentary on the role of housing in American life and housing policy in Minnesota.


Critics of subsidized housing claim that it depresses property values, increases crime, and attracts poor newcomers to a neighborhood thus increasing the concentration of poverty and destabilizing the neighborhood. This study of subsidized multi-family housing, however, shows that critics' fears are largely unfounded. Twenty-three housing projects that had been developed by nonprofit community development corporations in central Minneapolis were studied. Property values actually went up near the subsidized housing, crime went down, and the residents in the projects tended to come from the neighborhood and to be more stable than others in the neighborhood. Large differences in race and class between tenants in subsidized housing and tenants in the surrounding neighborhood may be the real basis for opposition to subsidized housing.