Development and Application of the Coupled Vadose Zone-Ground Water Flow Modeling Environment: HYDRUS Package for MODFLOW

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Water flow through the variably-saturated (vadose) zone is an important part of the hydrologic cycle. However, regional-scale groundwater models often simplify or ignore vadose zone flow processes. To overcome this problem, we are developing a new one-dimensional unsaturated flow package for the three-dimensional ground water model MODFLOW, one of the most widely used groundwater flow models.

Water flow through the variably-saturated zone is an important part of the hydrologic cycle because it influences partitioning of water among various flow components. Depending upon hydrological, geological and soil characteristics, rain and snowmelt is partitioned at the land surface into runoff, infiltration, evapotranspiration, groundwater recharge, and vadose zone storage. Water flow in the vadose zone especially affects the transfer rates between the land surface and the groundwater table, which are two key hydrological boundaries. Evaluation of almost any hydrological process therefore requires that water flow through the vadose zone is appropriately taken into account. However, modeling of vadose zone flow processes is a complex and computationally demanding task that is often handicapped by the lack of data necessary to characterize the hydraulic properties of the subsurface environment. Consequently, vadose zone flow processes have rarely been properly represented in hydrological models. For example, regional-scale groundwater models often simplify vadose zone flow processes by calculating groundwater recharge externally without proper consideration of changes in groundwater levels. To overcome this frequent simplification, there is an urgent need for methods that can effectively simulate water flow through the vadose zone in large scale hydrological models. This issue is especially important for groundwater models.

To overcome this problem, we are developing a one-dimensional unsaturated flow package for the three-dimensional modular finite-difference ground water model MODFLOW-2000. MODFLOW was developed by the U.S. Geological Survey and is one of the most widely used groundwater flow models. The HYDRUS Package uses the computer program HYDRUS to simulate water movement in variably-saturated porous media by numerically solving the Richards equation. The HYDRUS package considers the effects of infiltration, soil moisture storage, evaporation, plant water uptake, precipitation, runoff, and water accumulation at the ground surface. Being fully incorporated into the MODFLOW program, the HYDRUS package provides MODFLOW with recharge fluxes at the water table, while MODFLOW provides HYDRUS with the position of the groundwater table that is used as the bottom boundary condition in the package. The HYDRUS package provides an optimal trade-off between computational effort and accuracy of model simulations for coupled vadose zone – groundwater problems. Being based on two widely used models for simulating vadose zone flow (HYDRUS) and ground water flow (MODFLOW), the coupled software package has a tremendous potential to become

widely used in both research and management, and to redefine entirely how the complex subsurface flow problems are evaluated.

Expected Results:

There is a wide range of potential applications to which the coupled model (the HYDRUS package for MODFLOW) can be applied. These may include, for example:

- Assessing the threat to water resources from pollution
- Assessing the implications of various climate change forecasts on local water supply
- Evaluating various pollution control measures
- Evaluating the disposal of treated water and its impact on ground water resources
- Evaluating the potential for water storage augmentation by landscape modification
- Evaluating the potential for various augmentations of the water supply
- Evaluating the water needs of ecosystems proposed for protection
- Analyzing existing water supply and demand information to construct a water balance for the catchment or region
- Evaluating the potential for various reductions in water use by conservation
- Evaluating the potential for water reuse

It is indeed impossible to predict at present all potential applications to which the coupled model can be used and all benefits that can follow from its use. When we first released HYDRUS models about a decade ago, we could hardly imagine the wide spread of these models and the diversity of applications. It can be expected, partly because both original models are widely used and represent a state-of-the-art in their respective fields, that the coupled model will be similarly quickly adopted by the public if the four tasks listed above are carried out.

Publications

Twarakavi, N. K. C., J. Šimůnek, and H. S. Seo, Evaluating interactions between groundwater and vadose zone using HYDRUS-based flow package for MODFLOW, *Vadose Zone Journal*, 2008, *7*(2):757-768,.

Twarakavi, N. K. C., J. Šimůnek, and H. S. Seo, Reply to Comment on "Evaluating interactions between groundwater and vadose zone using HYDRUS-based flow package for MODFLOW", *Vadose Zone Journal*, 2009, *8*(3):820-821.

Professional Presentations

Twarakavi, N. K. C., and J. Šimůnek, A coupled modeling approach for incorporating variably saturated water flow and solute transport in ground water models, XVII. International Conference "Computational Methods in Water Resources, San Francisco, CA, July 6-10, 2008.

Twarakavi, N. K. C. and J. Šimůnek, A coupled approach to modeling vadose zone and ground water flow and solute transport at different scales, Soil Science Society America annual meeting, Houston, TX, October 6-9, 2008.

Collaborative Efforts

We are closely collaborating on this project with Hye Seo, a PhD student at the Colorado School of Mines, Golden, Colorado, and Navin Kumar Twarakavi, Assistant Professor at the Department of Agronomy and Soils, Auburn University, Auburn, Alabama, and Miroslav Sejna at PC Progress, Inc., Prague, Czech Republic.

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