Report for 2001FL4361B: Development of a Multi-Scale, Multi-Process Hydrologic Model

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Title: Development of a Multi-Scale, Multi-Process Hydrologic Model

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Problem and Research Objectives: The natural hydrology of south Florida has been extensively altered though channelization to provide adequate water for urban growth and agriculture and to provide flood protection to the area. Currently, water resource management in south Florida is governed by a number of federal, state, and county agencies. These agencies have developed or adopted hydrologic models to address a diverse set of needs. These range from large-scale models used to estimate impacts of alternative water management practices across all of south Florida to field-scale models used to predict local impacts such as flooding or agricultural production. A primary difficulty in applying these models to such a diverse setting is the need to address the problem of aggregating a variety of coupled hydrologic processes occurring over a wide range of temporal and spatial scales into a coherent and accurate model of a hydrologic system.

The primary goal of this project is to investigate how hydrologic processes such as ground water flow, river/canal flow, overland flow, infiltration, evapotranspiration, etc., are manifested across a broad range of spatial and temporal scales. Our main focus is on the interaction of these processes. An earlier phase of this project focused on developing the various components of an integrated hydrologic model and establishing the linkages between these components. The current objectives of this research are:

- Use stochastic and/or deterministic averaging techniques to upscale predictions using effective parameters based on the detailed variability of input parameters (current grant year).
- Check the sensitivities of modeled hydrologic processes to spatial and temporal variability in physical parameters (current grant year).
- Test and demonstrate the validity of the model by applying it to the C-111 basin and predicting impacts of alternative water management scenarios on hydroperiod, water supply, and flood prediction (next grant year).

Methodology: To address these tasks, we have been developing a hydrologic model that simulates a number of hydrologic processes. The specific processes modeled for this project are:

1) Unconfined saturated ground water flow.
2) Infiltration through the vadose zone.
3) Evapotranspiration.
4) Overland flow.

These processes are modeled in separate physical domains, and linkage between the domains is accomplished through matching of fluxes through the domain boundaries. The primary objective of our model is to arrive at a solution for the dependent variables (e.g. head and flux) within each subdomain that balances the flux of water between all the domains. This is accomplished using an iterative process that solves the governing equations simultaneously in each subdomain.

Principal Findings and Significance: One of the most challenging aspects of water resource management is the accurate modeling of a wide range of interrelated processes such as ground water flow, infiltration, evapotranspiration, overland flow, river/canal flow, rainfall, etc. Interactions between these processes include the exchange of water between rivers, lakes, and ground water, the relation between the soil moisture content and soil type and the amount of runoff generated from a rainfall event, the partitioning of water in the unsaturated zone between flow into the water table and plant uptake, etc. One of the issues that must be addressed in understanding these interactions is the question of how to take into account the variability of hydrologic parameters such as soil type, surface roughness, topography, evapotranspiration, and hydraulic conductivity, all of which can exhibit significant spatial variability.

To understand these effects, a series of model simulations of coupling overland flow and groundwater flow has been run to determine how the combination of variability in surface topography, surface roughness characteristics (Manning coefficients), and saturated hydraulic conductivity affects recharge to groundwater and runoff. Infiltration through the unsaturated zone is modeled using a one-dimensional form of Richard's Equation. Overland flow is modeled using a two-dimensional Galerkin finite element model of the diffusion wave equation on a triangular mesh. These simulations were loosely based on similar numerical experiments conducted by Zhang and Cundy (1989). The random fields were generated by turning bands algorithms. Simulations with uniform hydrologic parameters were also conducted for comparison. One hundred replicates were simulated for the random Manning coefficient case. One hundred and fifty replicates were simulated for random surface elevation and saturated hydraulic conductivity fields.

The results show that the mean hydrograph for the random Manning coefficient and random surface elevation fields are very close to that generated by the uniform case. However, the mean discharge begins earlier for the simulations with random saturated hydraulic conductivities, and the peak discharge rate is lower than that for the uniform case. The simulations using random Manning's coefficients and surface elevations generated a mean head profile (along the centerline of the mesh, parallel to the down-slope gradient) very similar to that obtained from the uniform case while the random hydraulic conductivity field produced a mean head profile that was slightly lower than the uniform case. Unlike the discharge hydrograph prediction, the uncertainty associated with the prediction of the mean head profile is slightly lower for the random hydraulic conductivity case than the simulations using either random Manning's coefficients or random surface elevations. In all cases, maximum uncertainty about the mean water depth occurs at the upstream boundary.

Flux into the soil was also estimated for all cases. For the simulations using random Manning's coefficients and surface elevations, the predictions for the vertical mean Darcy flux at the soil surface and near soil surface (approximately 19 cm deep) are very close to that obtained from the uniform case. Random variations in the saturated hydraulic conductivity have a much greater influence on Darcy flux within the soil column.

Flow in the saturated zone is modeled with a three-dimensional mixed finite element method applied to the standard groundwater flow equations. To date, coupling between the saturated zone and unsaturated zone has not worked effectively. This is due to the use of a moving-mesh approach for the saturated zone. The convergence properties of this approach are highly dependent on recharge rates, making a number of model problems highly inefficient. As an alternative, we have developed a three-dimension model combining saturated and unsaturated groundwater flow using the head-based form of Richard's equation, which reduces to the standard groundwater flow equation in the saturated zone. This approach does not rely on a moving mesh technique. The current year's modeling of hydrology in south Florida will use this approach.