INTEGRATED MODELING OF RIVER BASINS TO ASSESS WATER SECURITY

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INTRODUCTION

As the 21st Century begins, the critical state of water resources has been recognized and issues of water security are paramount. The Global Water Partnership goal for water security is that for all levels from household to global, every person has access to sufficient water at affordable costs to lead a clean, healthy, and productive life, while ensuring that the natural environment is healthy and enhanced. Even in a post-9/11/2001 U.S., this definition of water security is applicable. In meeting this goal, integrated water resources management becomes the primary approach to understand needs and to develop the infrastructure. Water resource managers will be required to predict the status and trends in water supply and quality with more accuracy in the future because of the increasing pressure on water resources brought by population, economic, and environmental issues. Climatic variability, whether interannual, decadal, or over centuries further complicates the prediction of water resources through precipitation cycles (droughts) and changes in other forcing variables such as radiation and temperature that affect the water balance. In the context of this presentation, integrated models couple regional atmospheric, land surface and subsurface components or modules to form an interactive modeling systems that simulates the water balance and other key features of a river basin. This presentation will outline the components and development of an integrated model being developed jointly by Los Alamos National Laboratory and the Center for Sustainability of semi-Arid Hydrology and Riparian Areas for the Rio Grande Basin.

COUPLED REGIONAL MODEL

Past efforts at evaluating water resources have focused on results from climate models or very specific regional analyses. Climate and hydrologic models differ in their representations of elements of regional water balances. Climate model often simplify hydrology in their land surface modules by ignoring lateral movement of water across the landscape and groundwater processes. Energy balance components in hydrologic models are frequently nonexistent or else their parameterizations are oriented towards evapotranspiration without consideration of radiative transfers. Efforts are underway to incorporate more realistic hydrology - such as the Variable Infiltration Capacity model (Liang et al., 1994) - into global climate models. However, global climate models do not have sufficient resolution to evaluate tradeoffs among uses within river basins.

Recent approaches have linked mesoscale weather models to hydrologic models to provide a more realistic hydrologic response (Yu et al. 1999; York et al., 2002; Seuffert et al., 2002). The Los Alamos Distributed Hydrologic System (LADHS) is constructed using the same philosophy. The advantages to this approach are: 1) the river basin is placed in a global context through boundary conditions affecting the regional climate model; 2) the lateral redistribution of water and subsurface processes are included; and 3) the model grid spacing can be adapted to the water resources questions being asked so that fine-scaled processes like land-use change, soil moisture distribution, localized groundwater recharge, erosion, and flooding can be addressed. LADHS is currently composed of four components: regional atmosphere, land surface, subsurface, and river modules. The LADHS model retains the essential physics of all elements of a water balance, allows feedback between them, and can provide high-resolution data to answer regional and local questions about water security.

Regional Atmosphere

The LADHS regional climate component uses RAMS, the Regional Atmospheric Modeling System (Pielke et al., 1992). RAMS provides precipitation, temperature, humidity, and wind data to the hydrology component. RAMS allows LADHS to compute the water resources of climate change and variability. These nonstationary effects cannot be captured by alternatives like interpolation or stochastic estimation that are based on historical records. The capability to simulate a nonstationary climate is important for design and policy as related to regional analyses.

Land Surface

The Land Surface Hydrology (LaSH) component uses a grid-based discretization to partition precipitation or snowmelt into evaporation, transpiration, soil water storage, surface runoff, lateral subsurface flow, and subsurface recharge. Snow accumulation and melt are based on temperature. Lateral subsurface flow is routed between grid elements using Darcy’s equation.

Subsurface Hydrology

Groundwater is a major water resource that is not considered in current climate and most regional models. LADHS uses the Finite Element Heat and Mass code (FEHM) to model subsurface flows (Zyvoloski et al., 1997). FEHM is a three-dimensional multi-phase flow code that can simulate flow through both saturated and unsaturated porous media. Currently the upper boundary condition for FEHM is supplied by LaSH, through a recharge term and by the channel code through streambed infiltration.

River Routing

The channel routing component is an important element of regional assessments in a river basin. Reservoir operations are critical to determining regional effects of climate variation because reservoir management can alleviate or modify the impact of variability. Initial effort used a simple routing code for unregulated streams, but we recognized the importance of regulated flows so we are evaluating other codes for their ability to include reservoirs and complex drainage patterns.

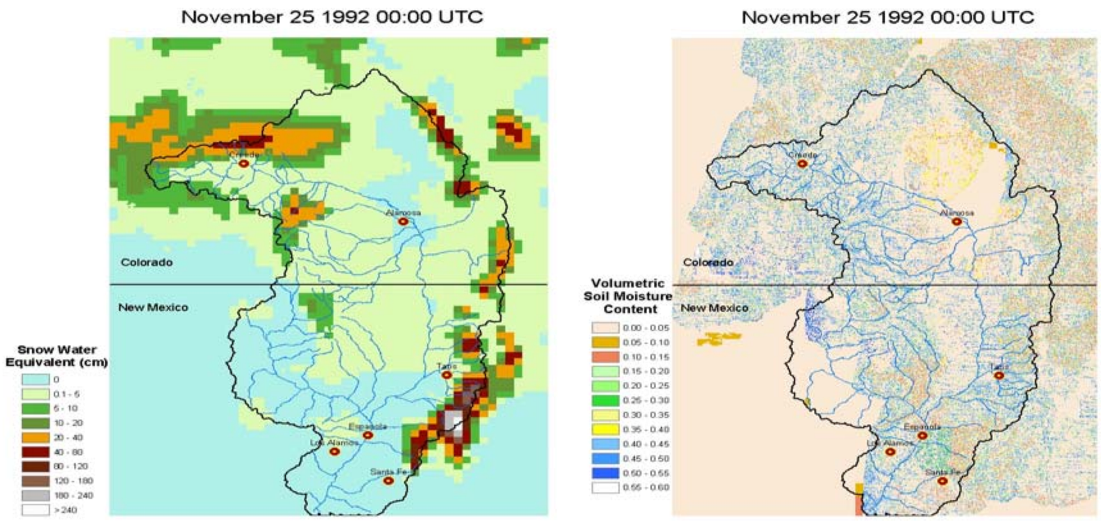
Computational Approach

The individual component models are implemented as loosely coupled processes on distributed memory parallel computers at Los Alamos National Laboratory. Processes are embedded in the Parallel Applications Workspace where prior to runtime each process is assigned its own memory space and a number of physical processors. The advantages of this approach are that it does not require extensive re-writing of existing model component software or development of a complicated control structure.

MODEL TESTING

The model is being developed and tested on the Rio Grande Basin from its headwaters in Colorado to the New Mexico – Texas border. The Rio Grande represents a good test for this approach because it has both surface and groundwater issues, rapid changes in land use, topography, soils and vegetation, and a bimodal annual precipitation cycle with winter snow accumulation and summer rainfall. Our target simulation is the Rio Grande for Water Year 1993, which was an El Niño year. The elevation data were based on the U.S. Geological Survey 30-m digital elevation model. Soils data were obtained from USDA-STATSGO database (http://www.ftw.nrcs.usda.gov/stat_data.html), and vegetation data were from VEMAP (http://www.daac.ornl.gov/VEMAP/vemap.html).

The RAMS simulation of the Rio Grande used a nested grid approach with the high-resolution grid over the Rio Grande of 5 km (Costigan et al., 2000). The distribution of snow water equivalent (SWE) on the 5 km grid above Cochiti Reservoir is shown in Figure 1A. One can see in Figure 1A that the grid cells with high SWE values are located in the mountains as expected. Soil moisture distribution for the 100 m cells is provided in Figure 1B. The effect of the finer grid spacing can be seen by the redistribution of the 5 km inputs, whether rain or snow, into a more refined structure across the watershed. This type of information along with streamflow and groundwater levels will allow more informed decisions to be made about water resources using these types of models.



A **B**

Figure 1. Snow water equivalent at 5 km spacing (A) and soil moisture distribution at 100 m spacing from LADHS simulation for 1993 Water Year.

FUTURE WORK

Future efforts will see a more tightly coupled RAMS and LaSH interface with more direct exchange of energy and mass. FEHM will be evaluated to replace LaSH's subsurface dynamics providing a continuous representation of the subsurface by one code. The grid-based computational model will be replaced by a tree-based data structure that can take advantage of specific features of flow through watersheds and enhance parallel computations.

REFERENCES

Costigan, K. R., J. E. Bossert, and D. L. Langely. 2000. Atmospheric/hydrologic models for the Rio Grande Basin: Simulation of precipitation variability. *Global and Planetary Change*:83-110.

Liang, X., D. P. Lettenmaier, E. F. Wood, and S. J. Burges. 1994. A simple hydrologically based model of land surface water and energy fluxes for GCMs. *J. Geophysical Research* 99(D7):14415 – 14428.

Pielke, R. A., W. R. Cotton, R. L. Walko, C. J. Tremback, M. E. Nicholls, M. D. Moran, D. A. Wesley, T. J. Lee, and J. H. Copeland. 1992. A comprehensive meteorological monitoring system – RAMS. *Meteorology and Atmospheric Physics*, 49:69-91.

Seuffert, G., P. Gross, C. Simmer, and E. F. Wood. 2002. The influence of hydrologic modeling on the predicted local weather: Two-way coupling of a mesoscale weather prediction model and a land surface hydrologic model. *J. of Hydrometeorology* 3(5):505-523.

York, Jennifer, P., M. Person, W. J. Gutowski, and T. C. Winter. 2002. Putting aquifers into atmospheric simulation models: An example from the Mill Creek Watershed, northeastern Kansas. *Advances in Water Resources*. 25:221-238.

Yu, Z., M. N. Lakhtakia, B. Yarnal, R. A. White, D. A. Miller, B. Frakes, E. J. Barron, C. Duffy, and F. W. Schwartz. 1999. Simulating the river-basin response to atmospheric forcing by linking a mesoscale meteorological model and hydrologic model system. *J. of Hydrology* 218:72-91.

Zyvoloski, G. A., B. A. Robinson, Z. V. Dash, and L. L. Trease. 1997. Summary of models and methods for FEHM application – A finite element heat and mass transfer code. *Los Alamos National Laboratory Report* LA-13307-MS, Los Alamos, NM.

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