ADHydro: A Large-scale High-resolution Multi-physics Distributed Water Resources Model for Water Resources Simulations in a Parallel Computing Environment

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1Abstract

Physics-based watershed models are useful tools for hydrologic studies, water resources management and economic analyses in the contexts of climate, land-use, and water-use changes. This paper presents development of a physics-based, high-resolution, distributed water resources model suitable for simulating large watersheds in a massively parallel computing environment. Developing this model is one of the objectives of the NSF EPSCoR RII Track II CI-WATER project, which is joint between Wyoming and Utah. The model, which we call ADHydro, is aimed at simulating important processes in the Rocky Mountain west, including: rainfall and infiltration, snowfall and snowmelt in complex terrain, vegetation and evapotranspiration, soil heat flux and freezing, overland flow, channel flow, groundwater flow and water management. The ADHydro model uses the explicit finite volume method to solve PDEs for 2D overland flow and 2D saturated groundwater flow coupled to 1D channel flow. The model has a quasi-3D formulation that couples 2D overland flow and 2D saturated groundwater flow using the 1D Talbot-Ogden finite water-content infiltration and redistribution model. This eliminates difficulties in solving the highly nonlinear 3D Richards equation, while the finite volume Talbot-Ogden infiltration solution is computationally efficient, guaranteed to conserve mass, and allows simulation of the effect of near-surface groundwater tables on runoff generation. The process-level components of the model are being individually tested and validated. The model as a whole will be tested on the Green River basin in Wyoming and ultimately applied to the entire Upper Colorado River basin. ADHydro development has necessitated development of tools for large-scale watershed modeling, including open-source workflow steps to extract hydrogeomorphological information from GIS data, integrate hydrogeomorphology and water management forcing input, and post-processing and visualization of large output data sets. The ADHydro model will be coupled with relevant components of the Noah-MP land surface scheme and the WRF mesoscale meteorological model. Model objectives include well documented Application Programming Interfaces (APIs) to facilitate modifications and additions by others. We will release the model as open-source in 2014 and begin establishing a user community.

Motivating Questions

● What are the potential impacts of climate change on the long term water yield from the Upper Colorado River basin?
● How will land-use changes due to development and natural causes such as fire and the mountain pine bark beetle outbreak affect water supplies?
● What are the effects of trans-basin diversions and increases in consumptive use on the water storage in Lake Powell in 30-50 years?

Colorado River Basin

Upper Colorado River Basin

● Basin Area: 288,000 km²
● Streams: 467,000 km
● Area above 2700 m (9,000 ft) 14.5%
● Area above 3050 m (10,000 ft) 2.2%
● Population depending on water >30,000,000

ADHydro Model

A high resolution multi-physics model integrating hydrologic process, engineered infrastructure, water resources polices and water management into spatially distributed simulations.

Building blocks:

● 2D overland flow
● 2D saturated groundwater flow
● 1D channel routing with reservoirs
● 1D Talbot-Ogden (T-O) infiltration
● Noah-MP land surface model
● The Weather Research and Forecasting (WRF) meteorological model
● Water management

Model formulation layer

Model inputs:

● Land geometry from Digital Elevation Model (DEM)
● Stream hydraulic geometry from National Hydrography Dataset (NHD)
● Land Use / Land Cover (LULC) data from USGS
● Soil data from Soil Survey Geographic (SSURGO) database
● Dynamic hydrometeorological input variables from WRF
● Water management infrastructure
● Water use and management process parameters

Model characteristics:

● Explicit finite volume solver
● Mass conservation
● Code developed for parallel environment
● Surface water and groundwater explicitly coupled by infiltration

References


Pre-processing work flow

● Acquire Digital Elevation Models and National Hydrography Dataset from USGS
● Hydrologic terrain analysis using TauDEM
● Geoprocessing and generation of shapefiles using OGIS and ArcGIS
● Generate 2D triangular mesh using Triangle

Post-processing

● Large watersheds often span multiple UTM zones - we cannot generally use the UTM projection
● Interrupted sinuosoidal map projection with central meridian through the center of the watershed is a good option
● Lines of altitude are horizontal lines
● Area is perfectly preserved
● Can describe regions 40 degrees in longitude with minimal distortion - the Amazon basin fits in this space

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