CI-WATER
A Utah-Wyoming Cyberinfrastructure Water Modeling Collaboration
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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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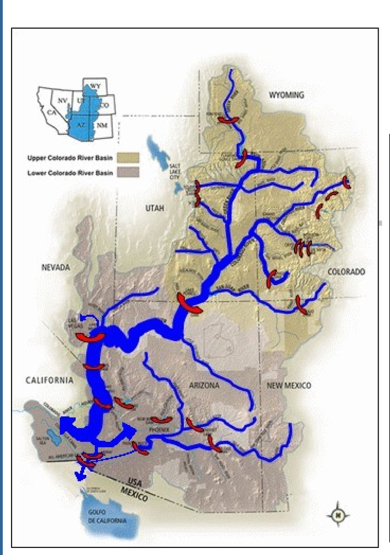
Abstract

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 poster 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 hydromorphological information from GIS data, integrate hydrometeorological 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 users' community.

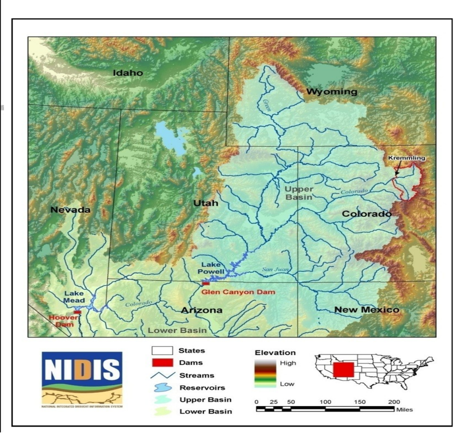
Motivating Questions

- 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



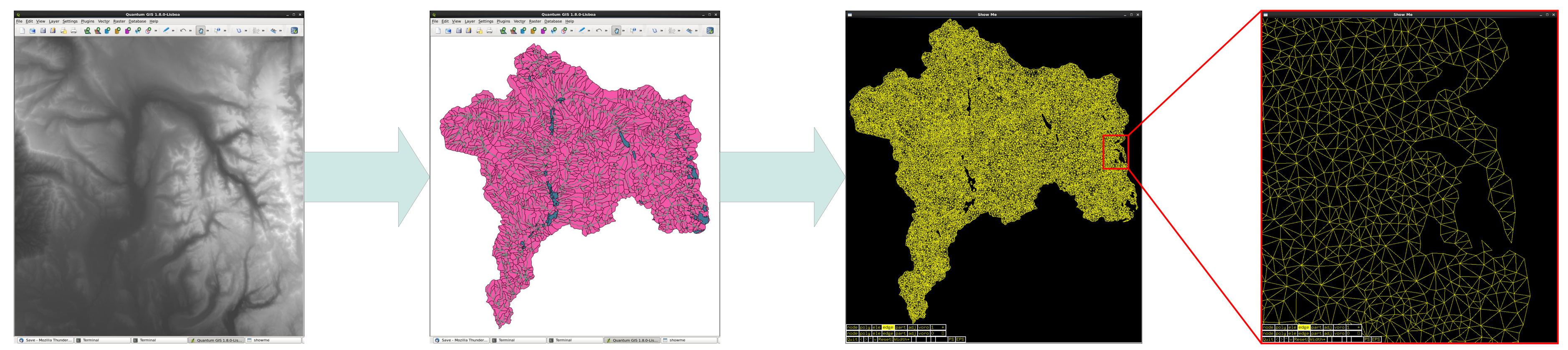
Upper Colorado River Basin

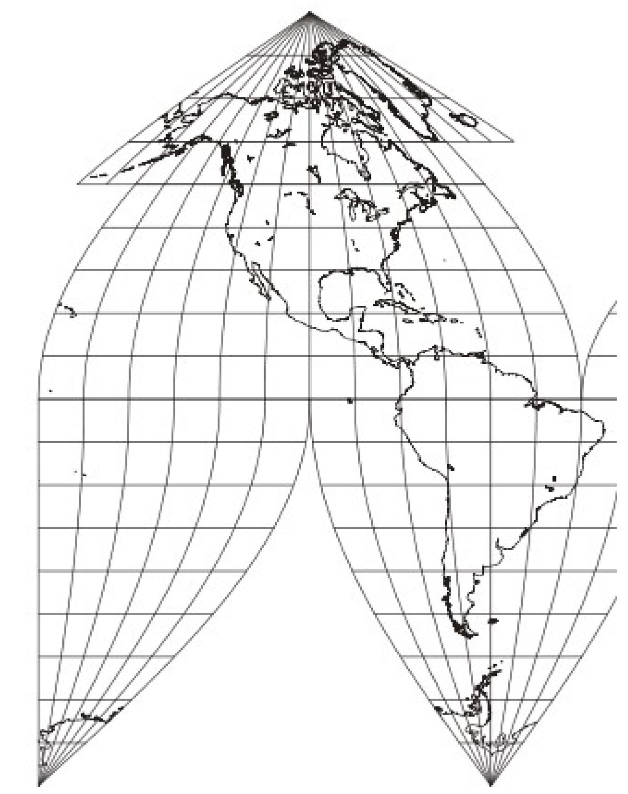


- Basin Area: 288,000 km^2
- Streams: 467,000 km
- Population: 900,000 (USBR)
- Area above 2700 m (9,000 ft) 14.5%
- Area above 3050 m (10,000 ft) 3.2%
- Population depending on water >30,000,000

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 QGIS and ArcGIS
- Generate 2D triangular mesh using Triangle





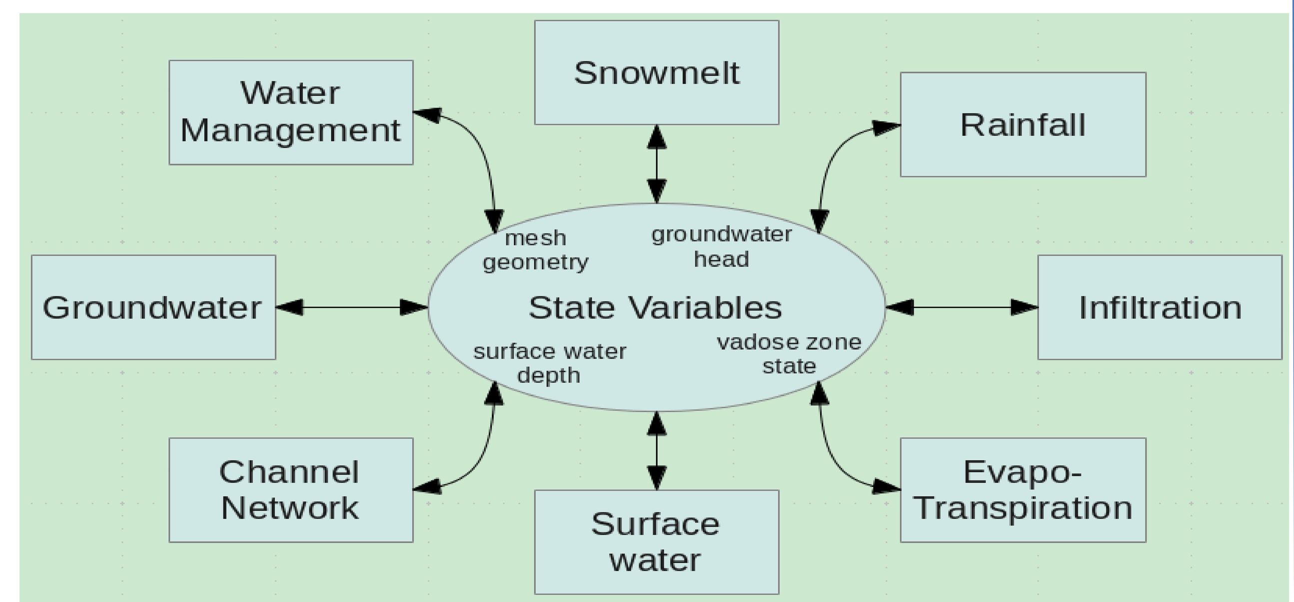
- Large watersheds often span multiple UTM zones - we cannot generally use the UTM projection
- Interrupted sinusoidal map projection with central meridian through the center of the watershed is a good option
  - ➔ Lines of latitude are horizontal lines
  - ➔ Area is perfectly preserved
  - ➔ Can describe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

ADHydro Model

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

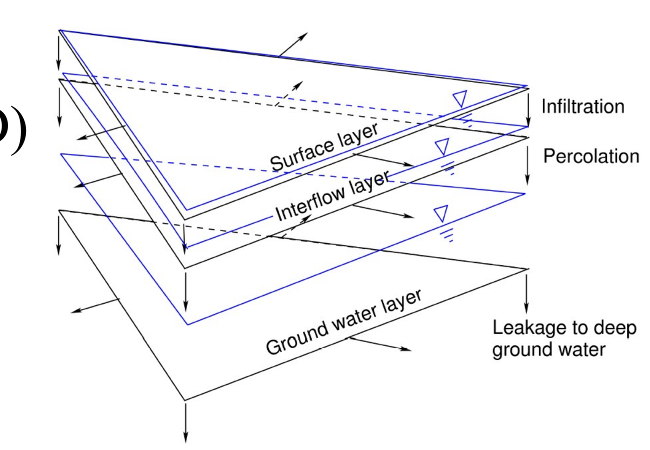
Building blocks:

- 2D overland flow
- 2D saturated groundwater flow
- 1D channel routing with reservoirs
- 1D Talbot-Ogden (T-O) infiltration[1]
- Noah-MP land surface model[2]
- The Weather Research and Forecasting (WRF) meteorological model[3]
- Water management



Model inputs:

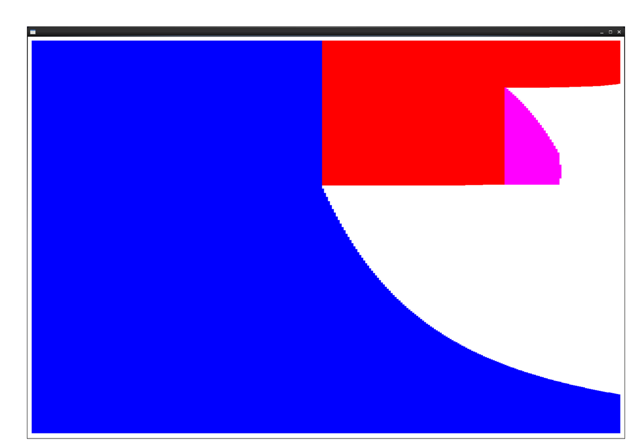
- Land geometry from Digital Elevation Model (DEM)
- Stream hydraulic geometry from National Hydrography Dataset (NHD)
- Land Use / Land Cover (LULC) data from USGS
- Soil data from Soil Survey Geographic (SSURGO) database
- Dynamic hydrometeorological input variables from WRF
- Water management infrastructure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



Model formulation layer

Model characteristics:

- Explicit finite volume solver
- Mass conservation
- Code developed for parallel environment
- Surface water and groundwater explicitly coupled by infiltration
- Both overland flow and channel routing have the dynamic wave and diffusive wave options



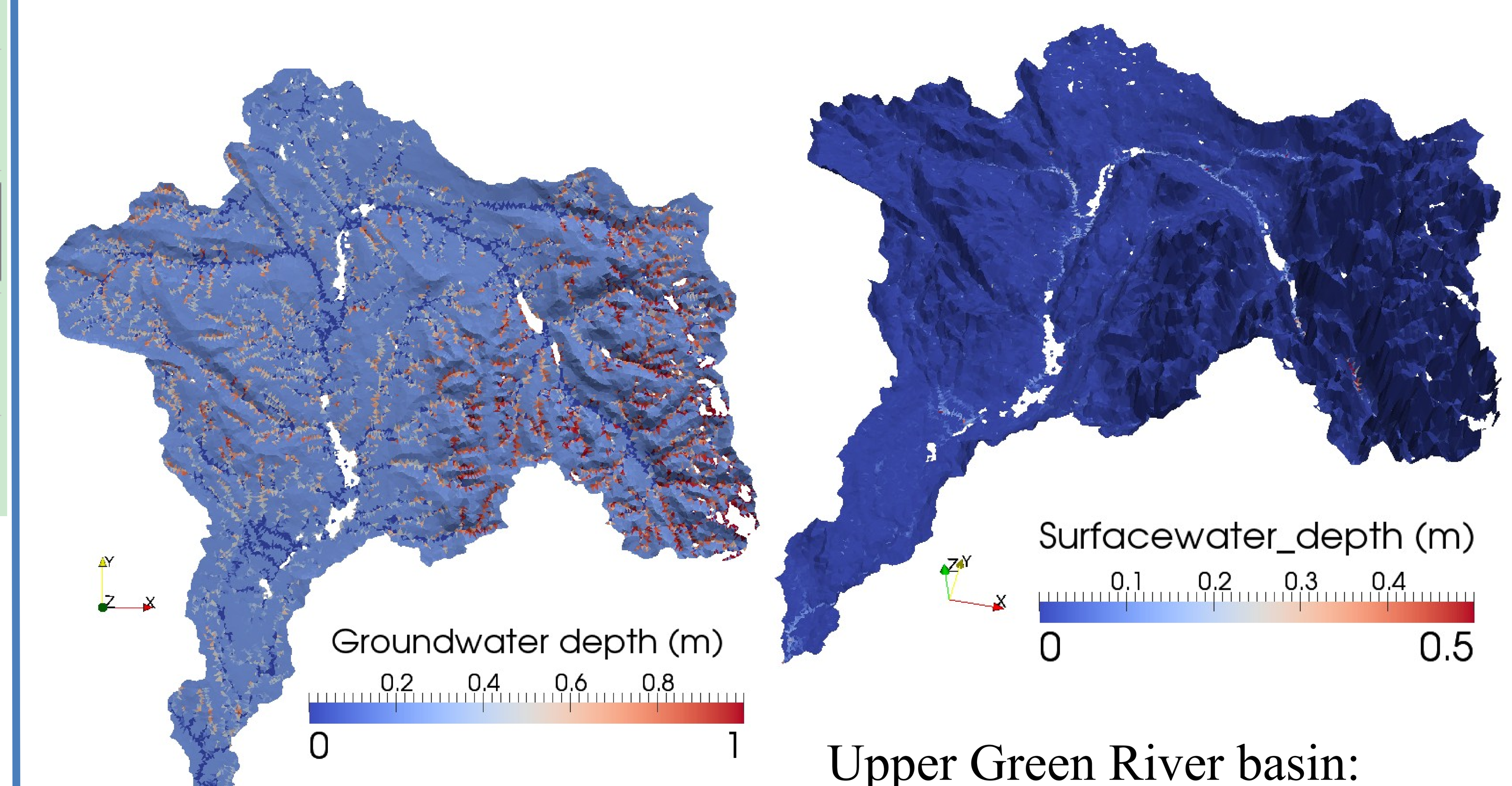
T-O infiltration model

References

[1] Talbot, C. A., and Ogden, F. L. (2008). A method for computing infiltration and redistribution in a discretized moisture content domain, Water Resour. Res., 44(8), W08453, DOI:10.1029/2008WR006815.
[2] Niu, G.-Y., et al. (2011). The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements, J. Geophys. Res., DOI:10.1029/2010JD015139.
[3] Michalakes, J., et al. (2004). The Weather reseach and forecast model: Software architecture and performance, Proceedings of the 11th ECMWF Workshop on the Use of High Performance Computing In Meteorology, Reading U.K. Ed. George Mozdzynski.

Post-processing

- Store and manage data using HDF5 files
- Visualize data sets using Paraview



Upper Green River basin:

- Basin area: 1220 km^2
- Streams: 1572 km

Model Development Philosophy

- Open Source
- Process fidelity, mass conservative
- Process solver flexibility - provide many options
- Well defined API for modularity
- Do nothing prohibitive
- Develop user group, give the code a life of its own (Linux model) – Spring 2014.
- Contact: Fred Ogden (fogden@uwyo.edu)

Our Collaborators

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