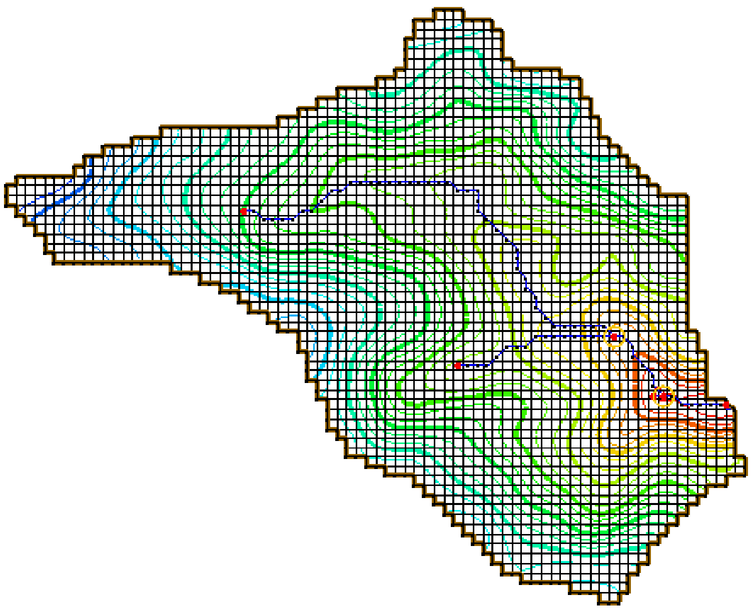
Gridded Surface Subsurface Hydrologic Analysis

What is GSSHA?

- GSSHA is a complete watershed simulation and management model used for hydrologic, hydraulic, sediment and quality simulation and management.
- GSSHA is a fully distributed, physics based model that utilizes a grid to represent the watershed.
- GSSHA is a product of the US Army ERDC
  - Maintained
  - Supported
  - Distributed
- GSSHA is a direct descendent of the surface water hydrologic model CASC2D developed at Colorado State University.
- The original version of GSSHA is the result of my dissertation work at University of Connecticut.

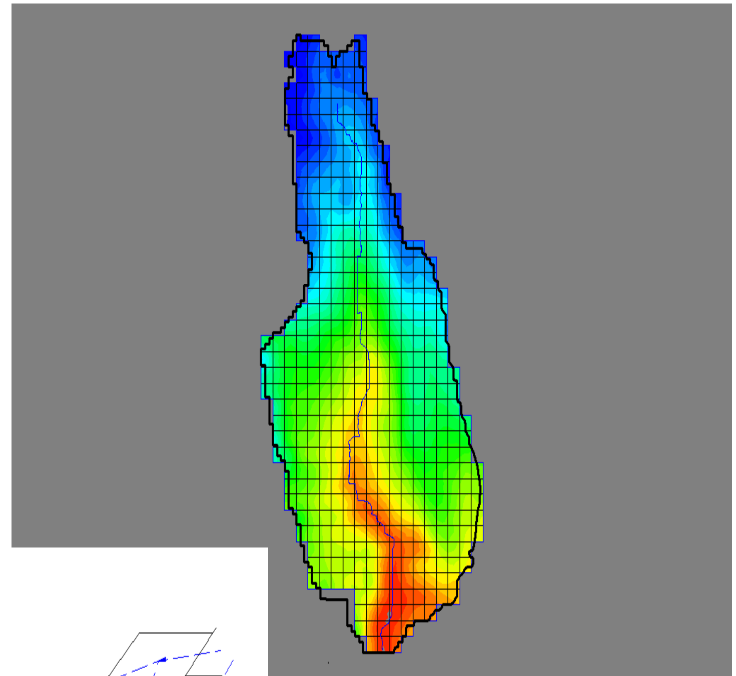


Downer, C. W. *Identification and Modeling of Important Stream Flow Producing Processes in Watersheds,* PhD Dissertation, University of Connecticut, 2002.

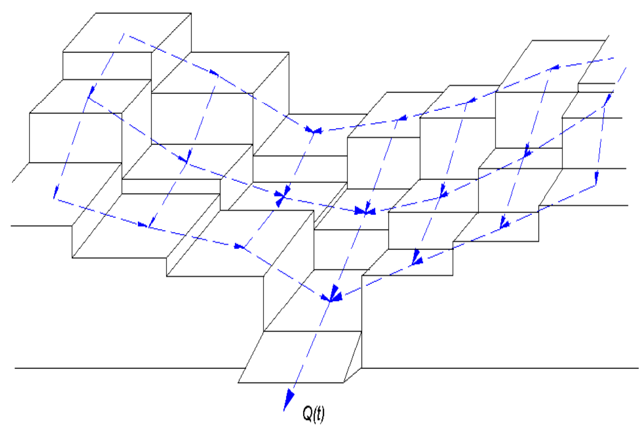
How does GSSHA Work?

- GSSHA works on a uniform spatial grid.
- Basic equations of mass, energy, and momentum conservation are solved with finite volume and finite difference techniques.
- Point processes are solved at the grid level.
- Point responses are integrated to get the system response.

Computational Grid

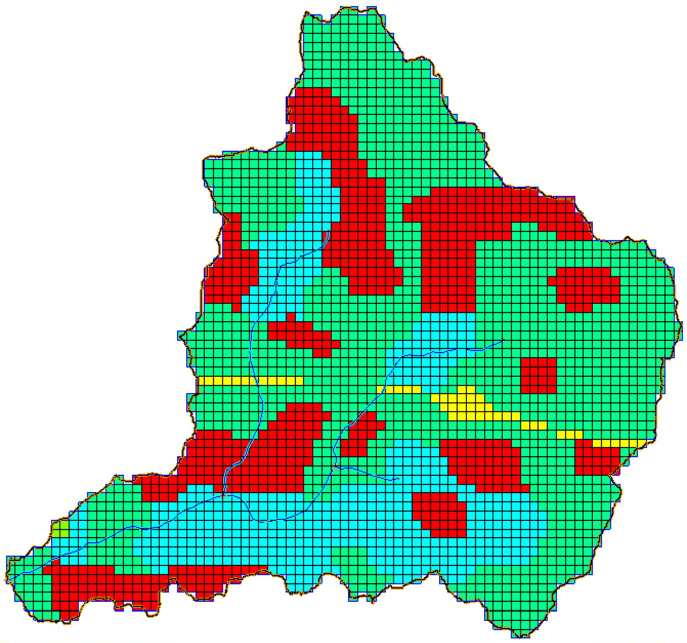


Cascading planes in two dimensions – CASC2D



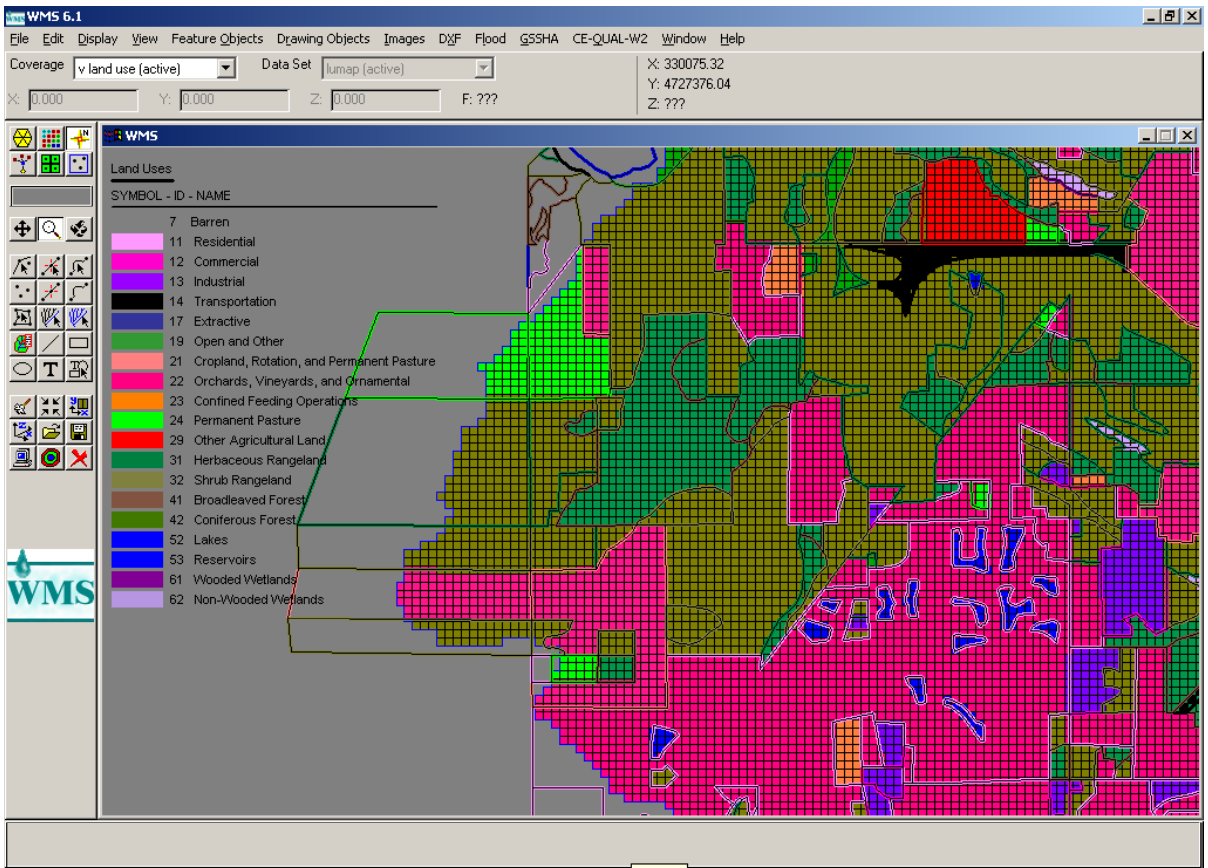
Why Does This Matter?

- Spatial variability.
- Physically based parameters.



Spatial Variability

- Explicitly include spatially heterogeneous features, such as varying land use, source areas, BMPs, etc.

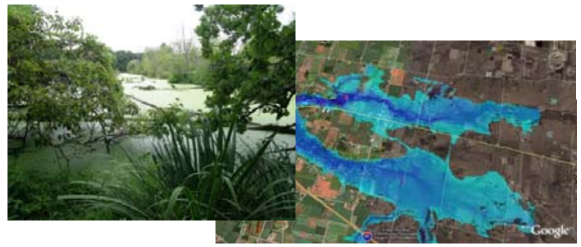


Physically Based Parameters

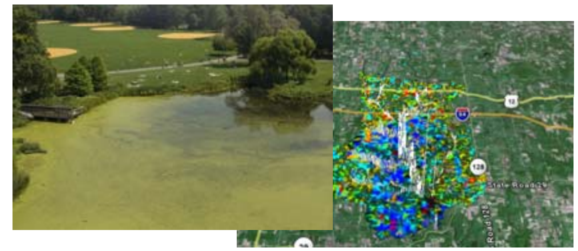
- Values are based on physical conditions in the computational element.
  - requires less calibration data
  - extendible beyond calibration range
- The tie to physical conditions provides a means to logically alter parameters based on changing conditions.
  - land use changes
  - project alternatives
  - climate change

What GSSHA Can Do?

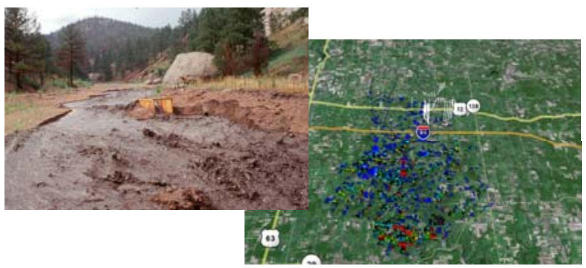
Surface water hydrology



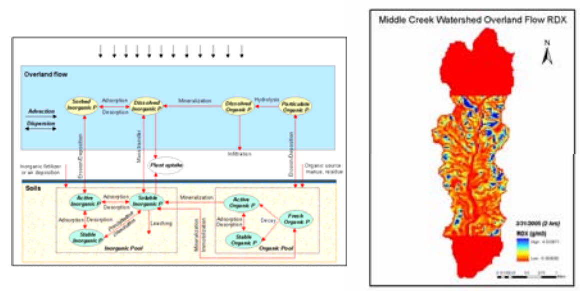
Surface Water/Groundwater Interaction



Surface water quality and TMDL's



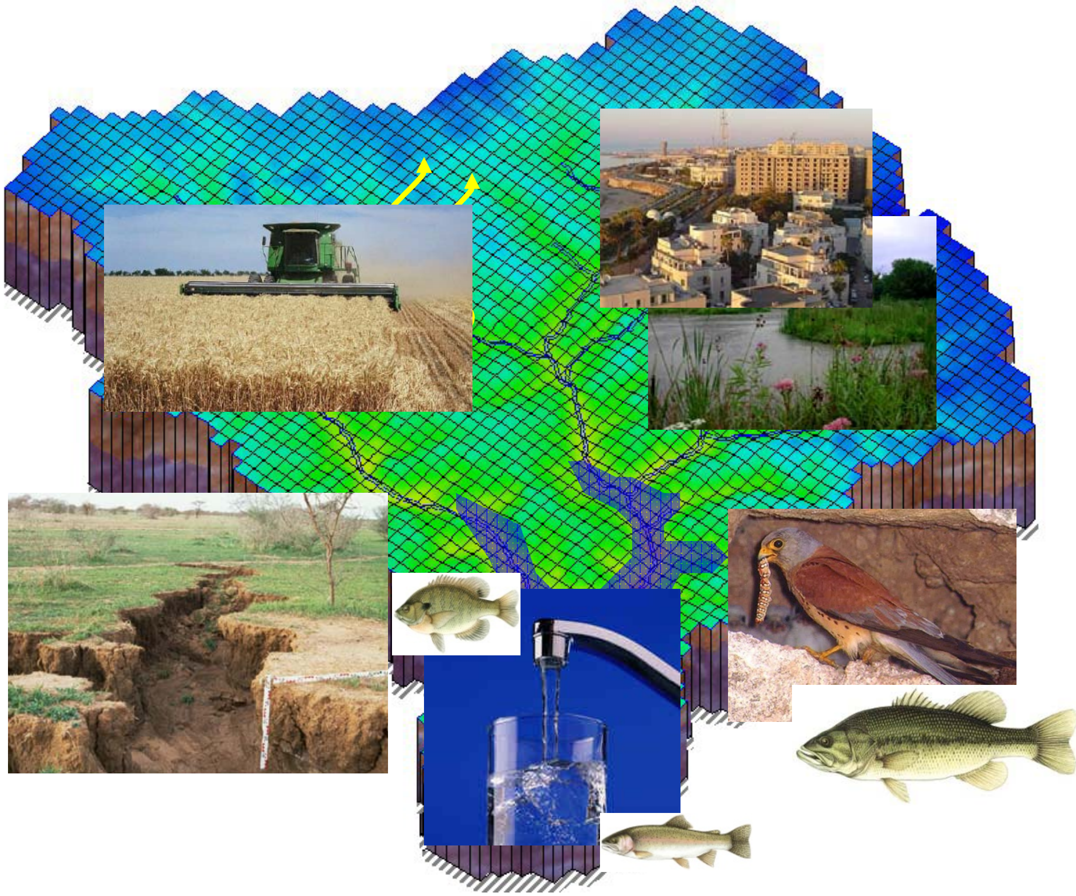
Sediment Management



Contaminant fate/transport in surface water and groundwater and related health risk assessment

Watershed Modeling and Management

Gridded Surface Subsurface Hydrologic Analysis (GSSHA)

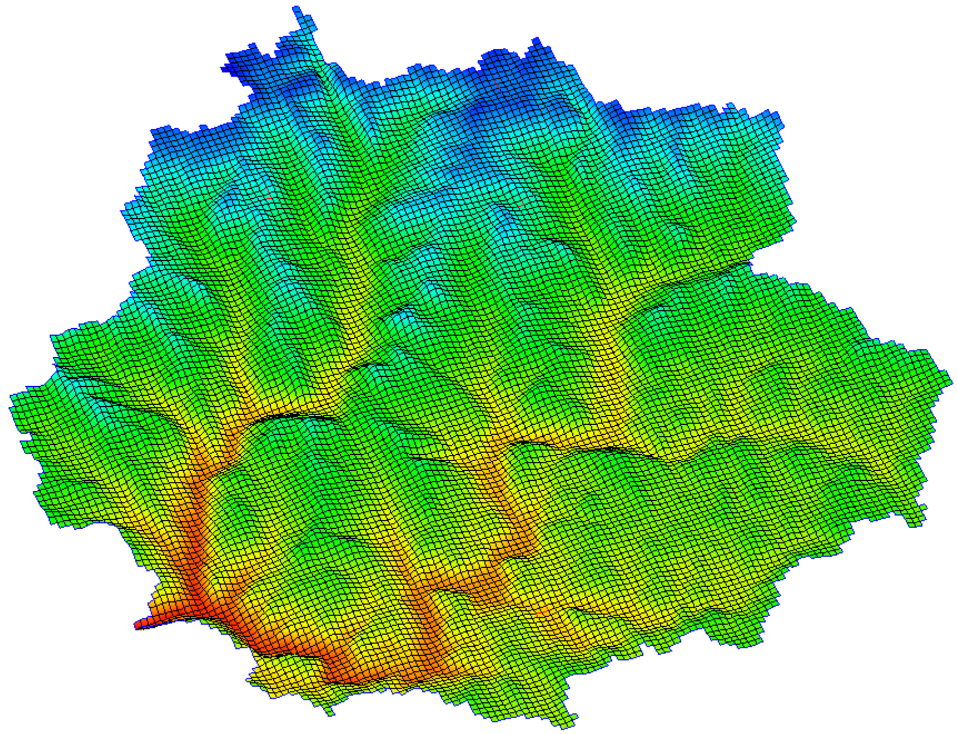


2D Overland Flow

$$\frac{\partial h}{\partial t} = \frac{\partial \vec{q}}{\partial x} + \frac{\partial \vec{q}}{\partial y}$$

$$\vec{q} = \frac{1}{n} d^{5/3} S_{fx}^{1/2} \vec{i} + \frac{1}{n} d^{5/3} S_{fy}^{1/2} \vec{j}$$

$$S_{fx} = S_{ox} - \frac{dh}{dx}; S_{fy} = S_{oy} - \frac{dh}{dy}$$

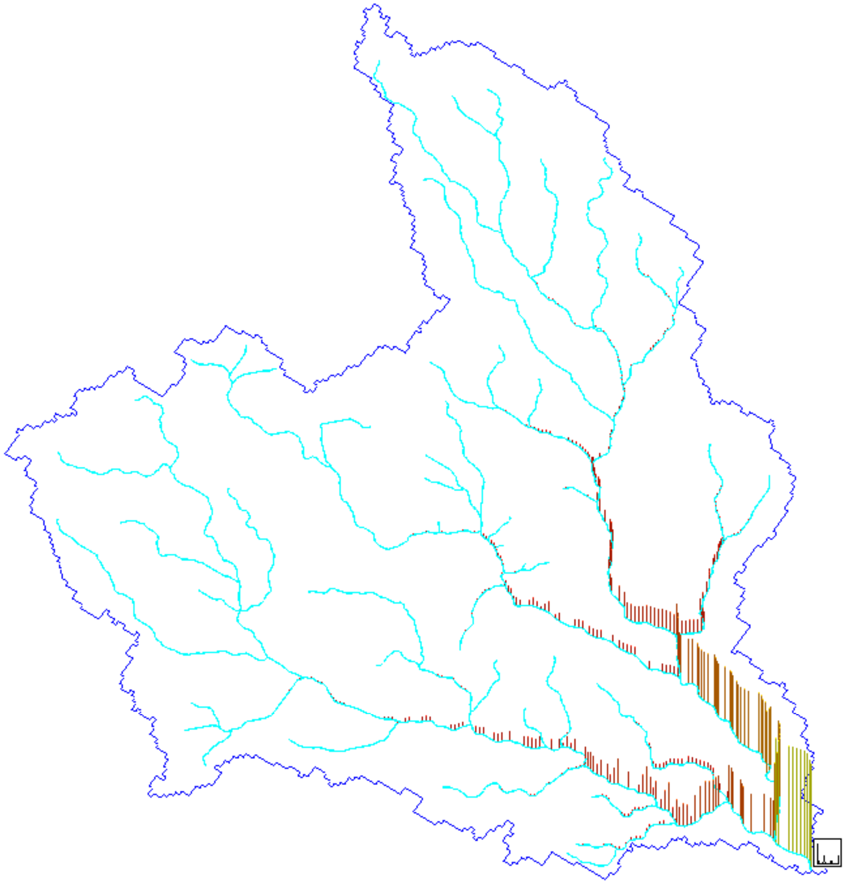


1D Stream Network

$$Q_{i-1/2} = \frac{1}{n} A_{i-1} R_{i-1}^{2/3} S_{f_{i-1/2}}^{1/2}$$

$$\frac{\partial h}{\partial x} = S_o - S_f$$

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = S$$



Infiltration and Evapotranspiration

- Infiltration
  - Richards Equation
    - 3 primary soil layers
    - infinite subdivisions of each layer
  - Green and Ampt, 1 layer
  - Two-layer Green and Ampt w/ Soil Moisture Redistribution
  - Three layer Green and Ampt model with soil moisture accounting
- Evapotranspiration
  - Deardorff bare earth
  - Penman – Montieth

Advanced Processes Covered in Next Course

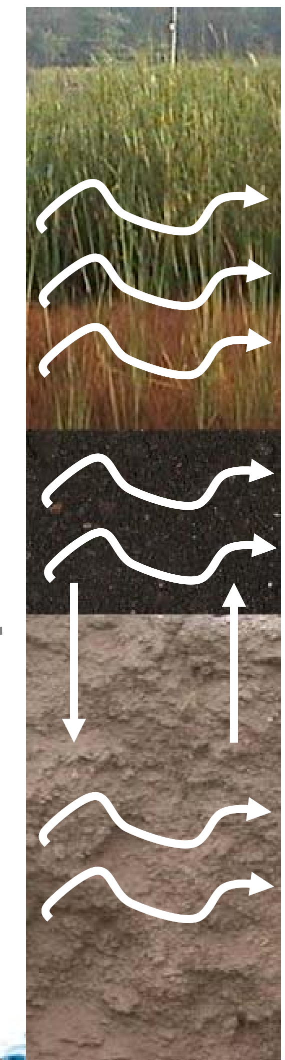
- Continuous simulations with soil moisture accounting.
- Groundwater modeling.
- Surface water/groundwater interaction.
- Hydraulic structures.
- Reservoir and detention basins.
- Embankments.
- Sediment transport.
- Constituent transport.

Wetland Model

Lateral flow through, over vegetation

Lateral flow through peat / muck layer

Vertical infiltration, exfiltration, Lateral Groundwater



Bi-model flow: Linear transition from Darcian flow at bottom to Manning’s flow at overtopping level

Darcian Flow

Infiltration, 2D Groundwater models

Rio Grande Wetlands Model

How Do I Build a GSSHA Model?

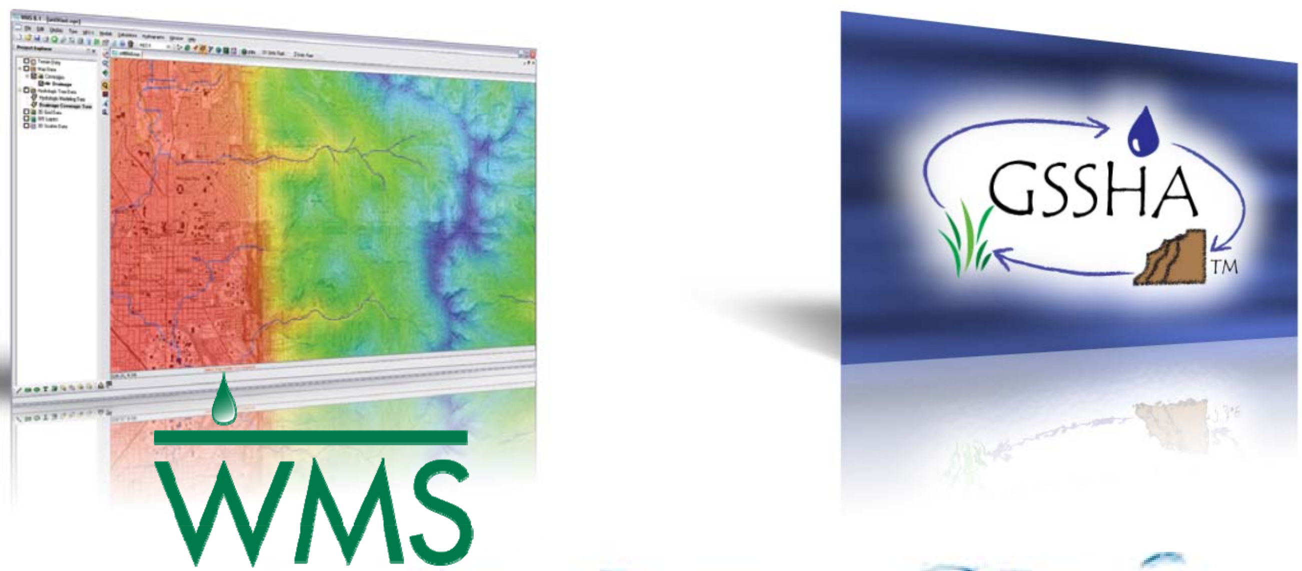
- GSSHA models are most easily built using the WMS software.
- Some files must be built with common text editors or spreadsheets. Additional utilities for building file types not supported by WMS are provided on the GSSHA wiki.
- Once the spatial aspects of the model have been assigned, simple changes to model input may be accomplished by directly editing the project and mapping table files.

How Do I Run GSSHA?

- GSSHA is run from the command line in a Windows Dialogue box.
- GSSHA can also be run from WMS, which basically calls up a Windows Dialogue box and launches GSSHA for you.

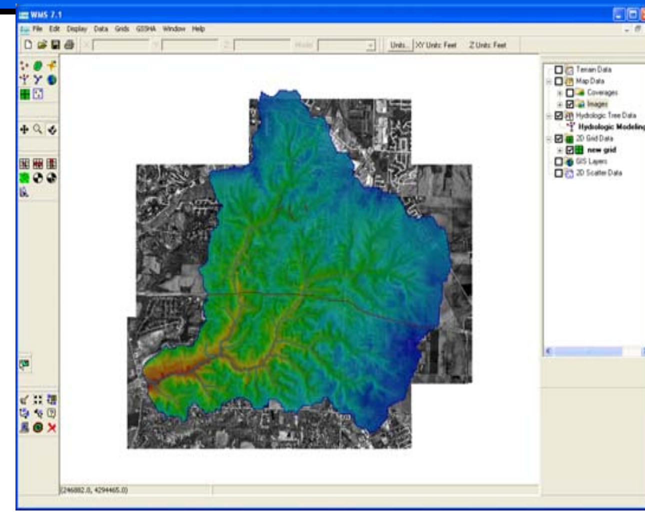
GSSHA and WMS

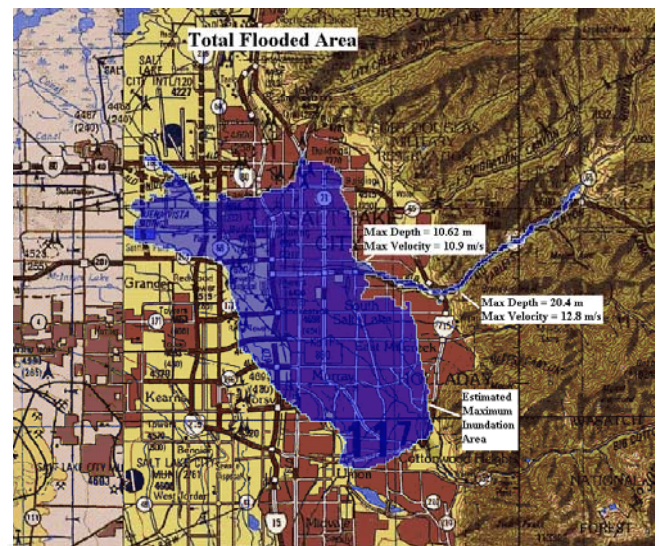
- The Watershed Modeling System (WMS) is a pre- and post-processor for GSSHA and several other hydrologic models, including HEC-HMS and HEC-1.



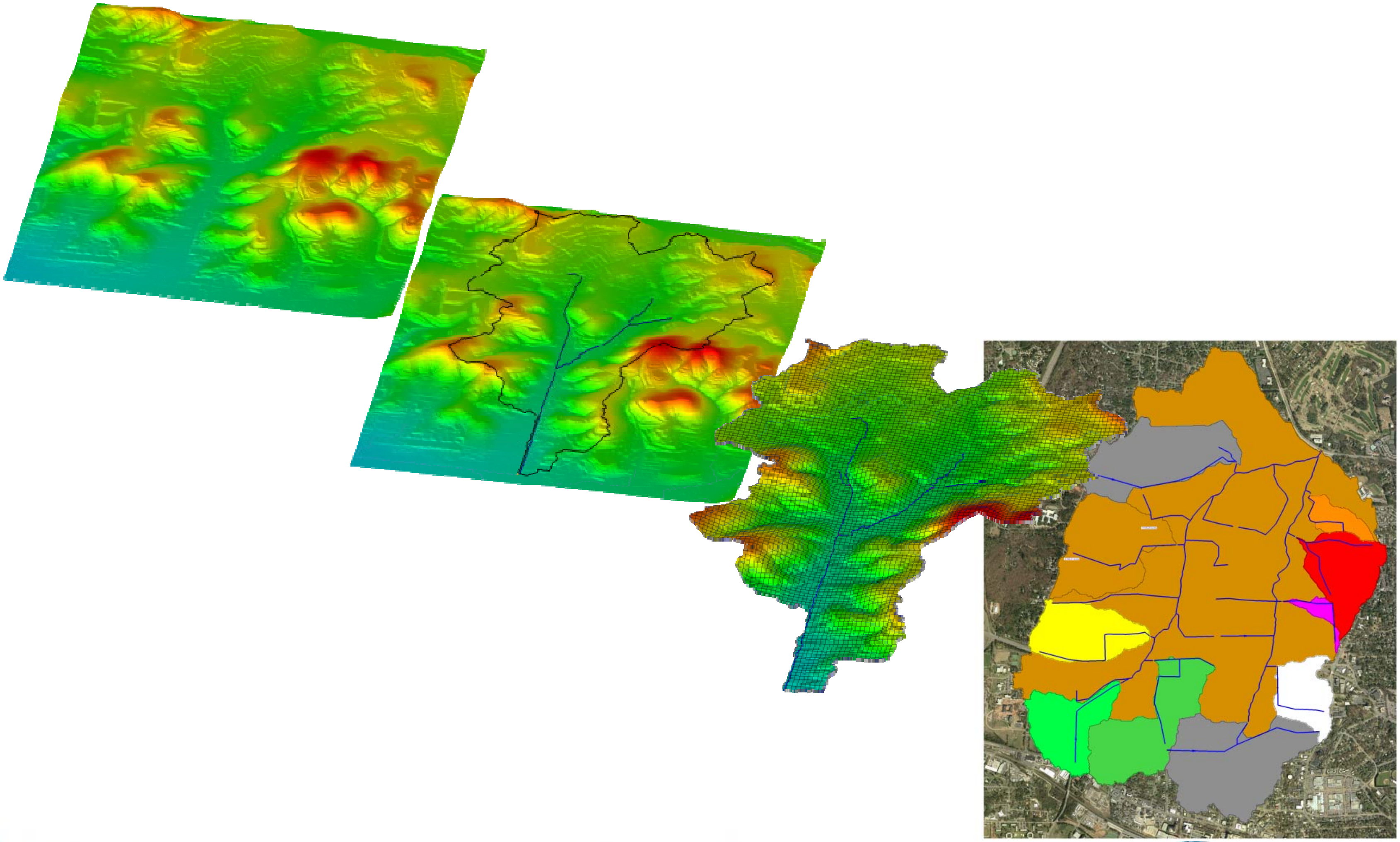
WMS Overview

- Comprehensive system for watershed modeling
- Multiple computational models supported
  - Empirically-based, lumped parameter models (e.g. HEC-HMS, HSPF, TR-20, etc)
  - Physically-based, distributed spatial parameter model (GSSHA)
  - Riverine models (e.g. HEC-RAS)
  - Reservoir models (e.g. CE-QUAL-W2)
- Integrates
  - Models to understand system-wide effects
  - Multiple data sources to automate model parameter definition
  - With GIS through ESRI's ArcObjects
  - With public data sources through web services
- Widely used for civil and military applications





Watershed Modeling



Why use GSSHA?

- Model floods, water balance, and ecological flows
  - Flexible processes selection tailored to watershed and project characteristics
- Integrated Process Modeling
  - Changes in one process affect other processes
  - Coupled groundwater, soil moisture, stream, and overland flow models
- Spatially explicit formulation: can evaluate impacts of *where* changes occur
  - Location of wetlands addition
  - Location of land use change
- Physical Process-driven model: can simulate fundamental changes in processes such as
  - tile drain removal,
  - addition of wetlands, and
  - changes in land use

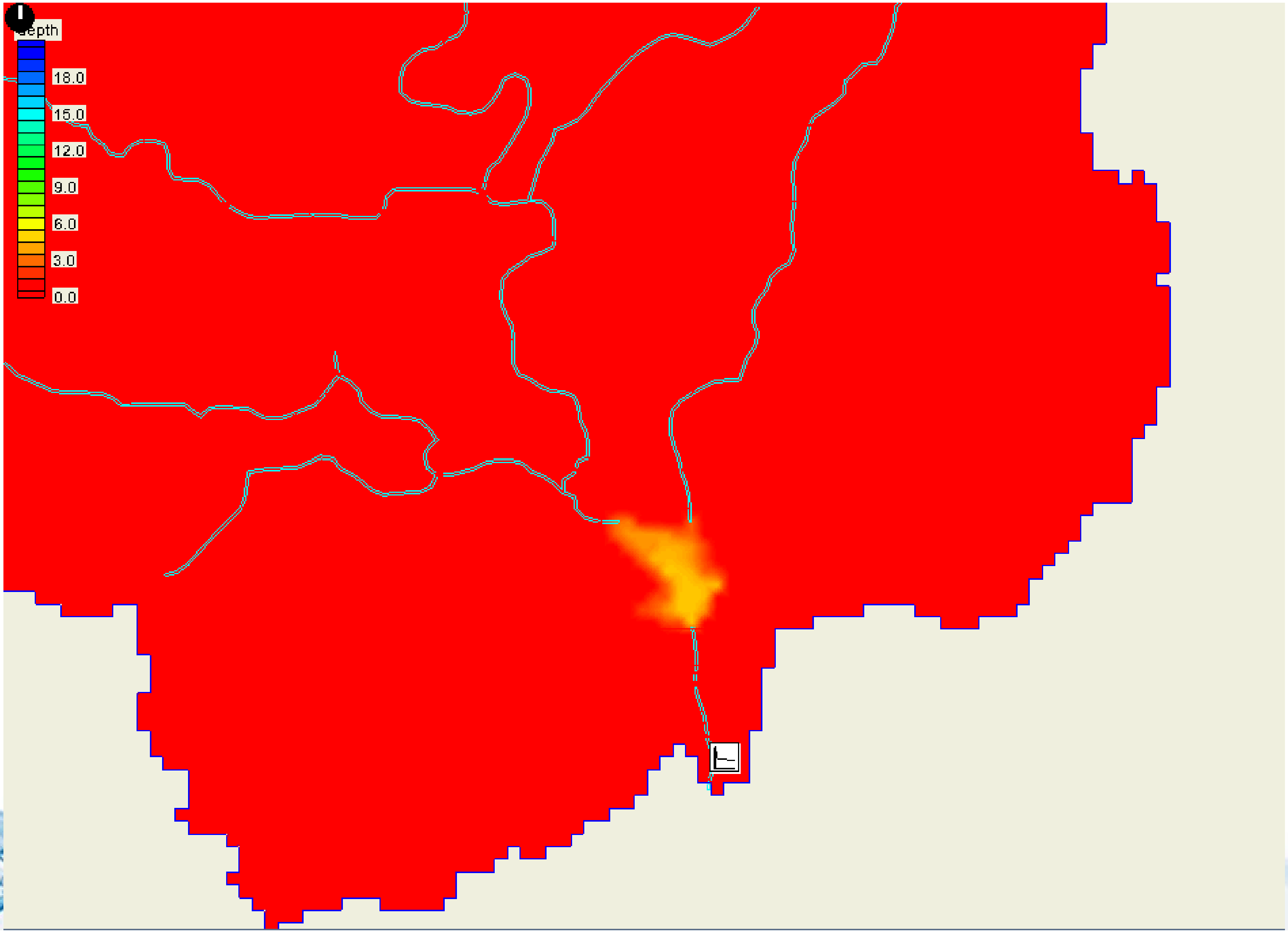
Why use GSSHA?

Integrated Surface and Overland Modeling

- Stream channels are integrated with the overland and groundwater flow regimes.
- Allows water in 2D systems to enter/exit the stream channel at correct time and location.
- Reservoirs are simulated as both channel and overland features. Reservoirs can expand and contract in both the channels and on the overland flow plane.

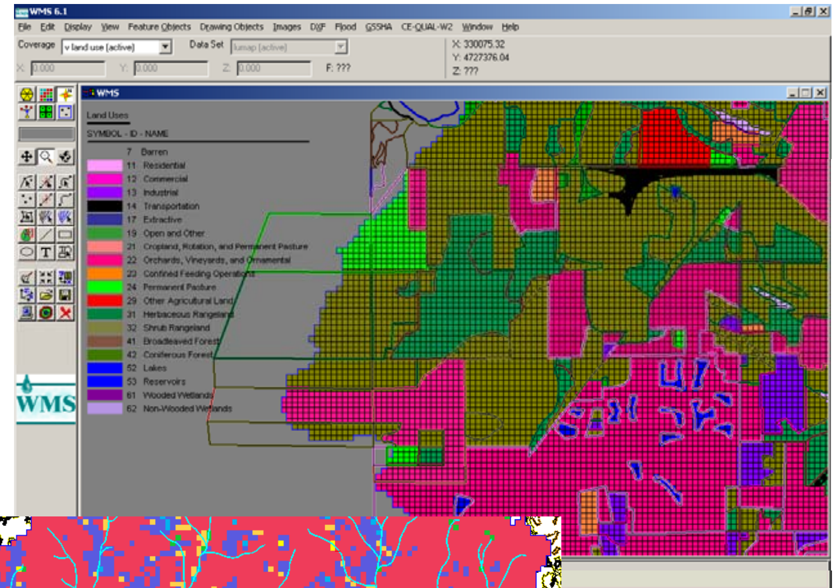
- *Each physically simulated processes is allowed to interact with and be affected by the other physical processes. This allows for impacts and changes to be more realistically modeled.*

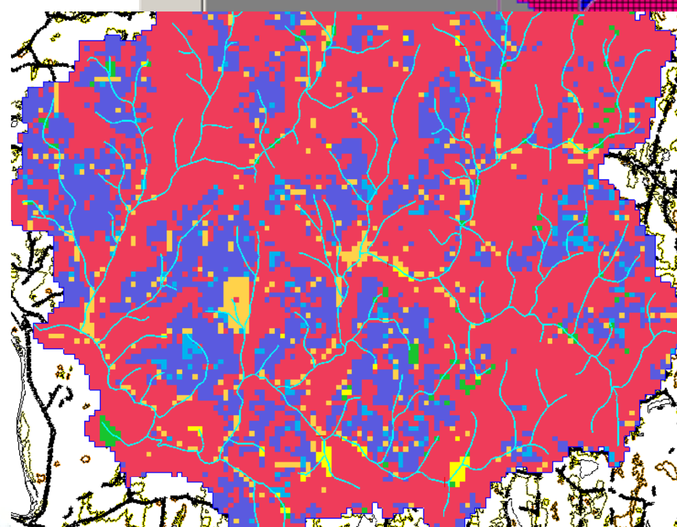
Dynamic Reservoir Simulation



Why use GSSHA?
Explicit Spatial Process Descriptions

- Spatially varied heterogeneity
- Explicitly resolve features in the grid
  - Land use
  - Soil type
  - Depressions
  - BMPs
  - Roads
  - Wetlands
- Track fate of water, sediment, contaminants along flow path
  - Infiltration along path
  - Settling/erosion along path
  - Reactions along path



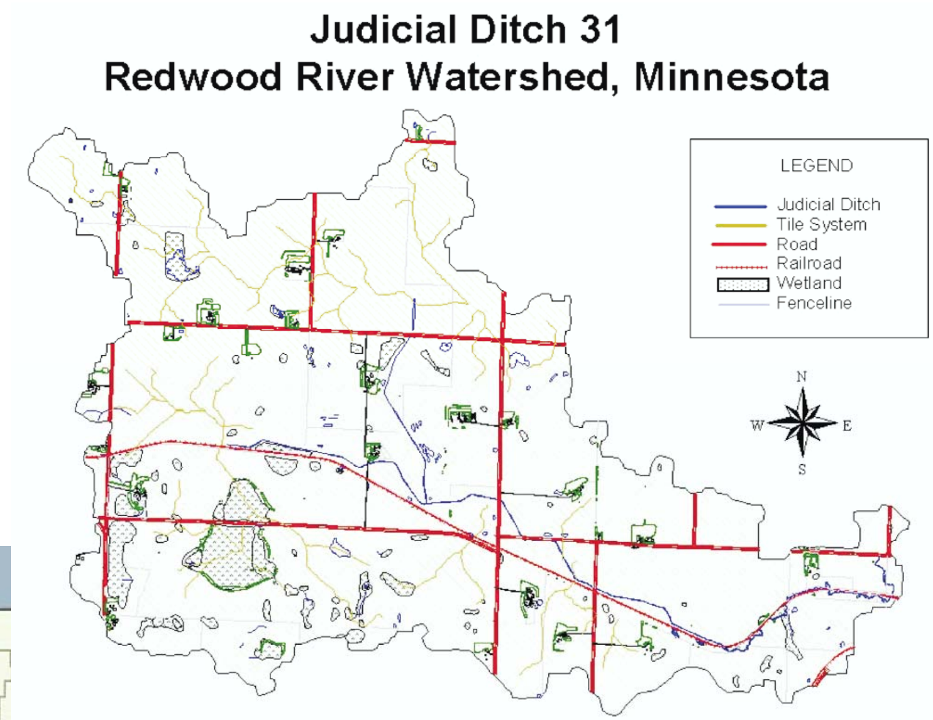


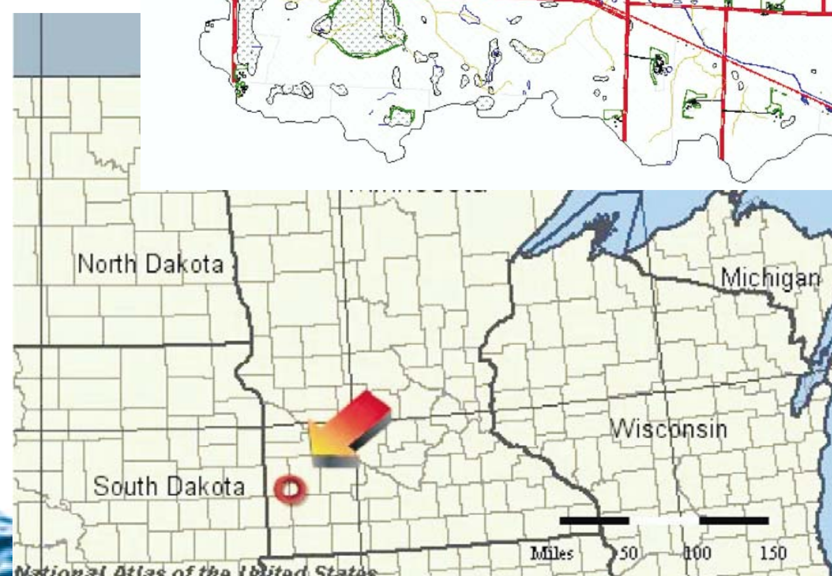
Why use GSSHA?
Modeling changes in physical processes

- Converting from tile drained fields to wetlands is a change in the fundamental runoff mechanisms
- GSSHA simulates the actual runoff processes in their spatial context
- By simulating the physical processes we are able to model changes to the watershed that include
  - Precipitation events outside the calibration range
  - Changes in fundamental runoff generation mechanisms
  - Changes in runoff transport mechanisms
  - Resulting impacts to nutrient and sediment production and transport

Modeling Process Changes: Tile Drains and Wetlands
Coon Creek Watershed – JD31

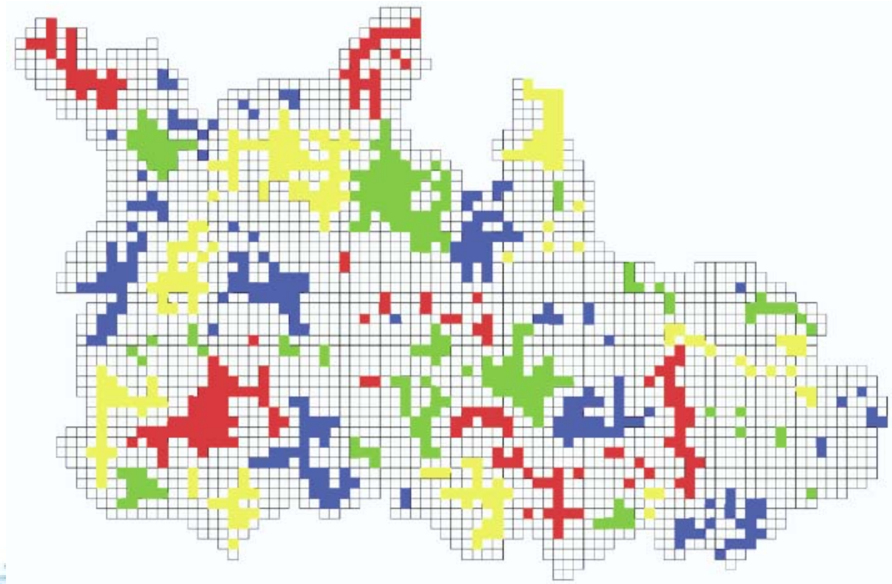
- Wetlands converted to agriculture
  - Drainage ditch
  - Tile drains
- Needed information
  - Examine wetland restoration scenarios
  - Assess stream flow impacts
- Unknowns/Uncertainty
  - Subsurface information
  - Tile drain system





Modeling Approach

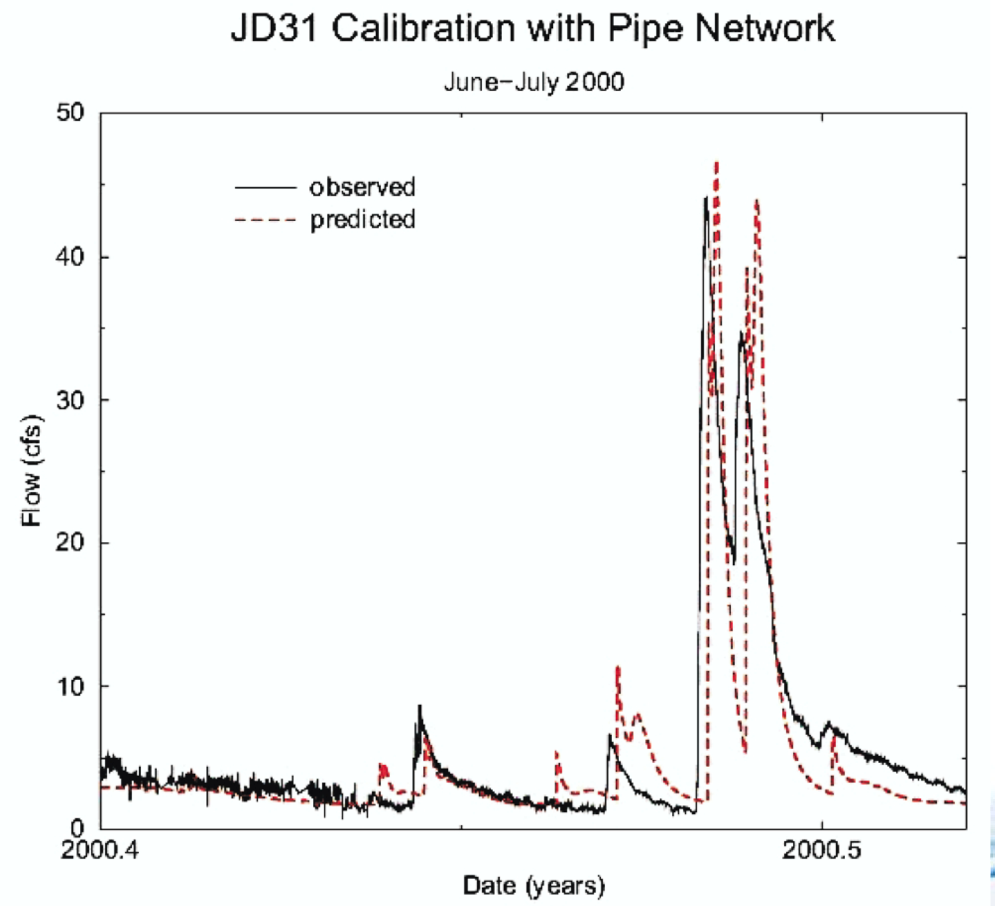
- Apply the GSSHA model
- Couple the GAR infiltration model to the saturated groundwater model
- Groundwater consist of homogeneous material
- Represent only the major drainage system as streams with groundwater recharge
- Compute 0%,25%, 50%, 75%, 100% restoration of wetlands

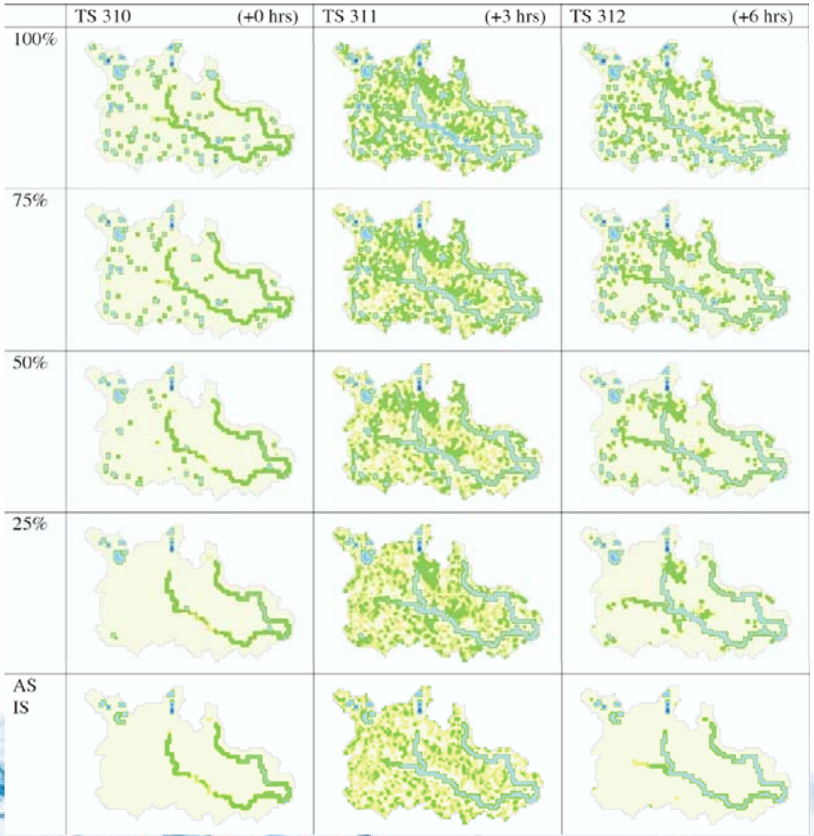


Results of Modeling Process Changes

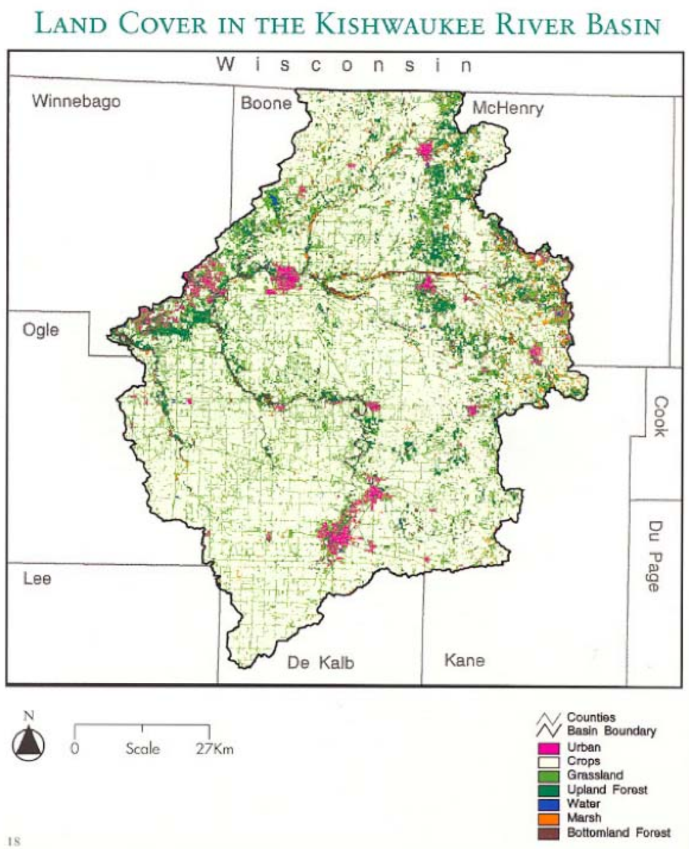
Resulting model able to history match flows resulting from surface water, groundwater, and drainage network

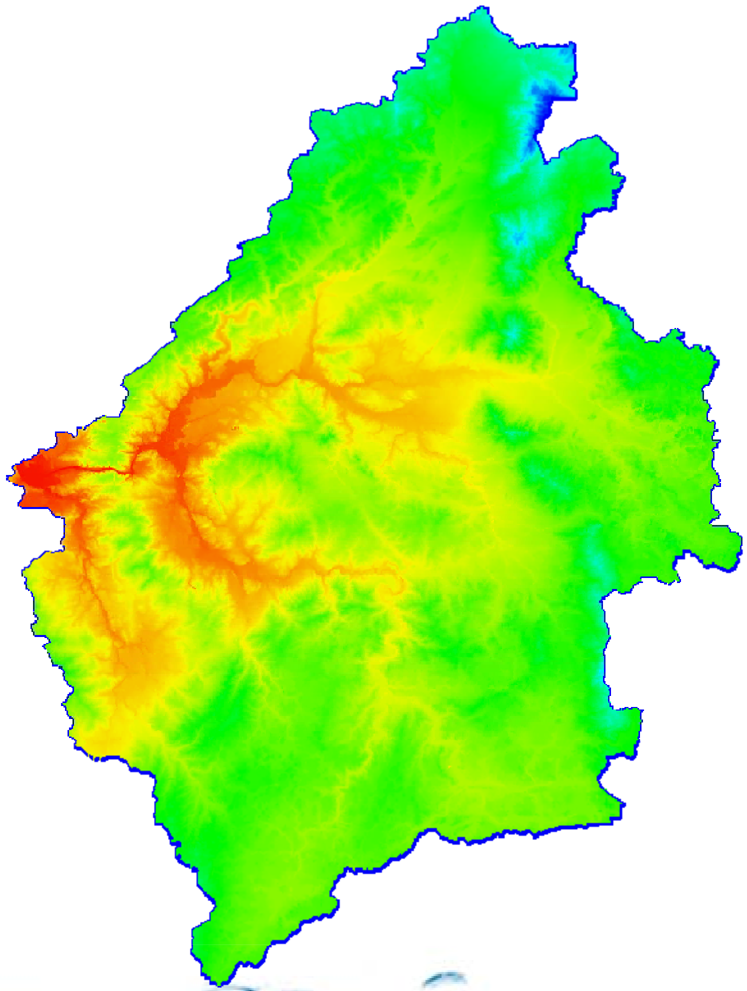
Model rapidly assesses varying wetland restoration configurations





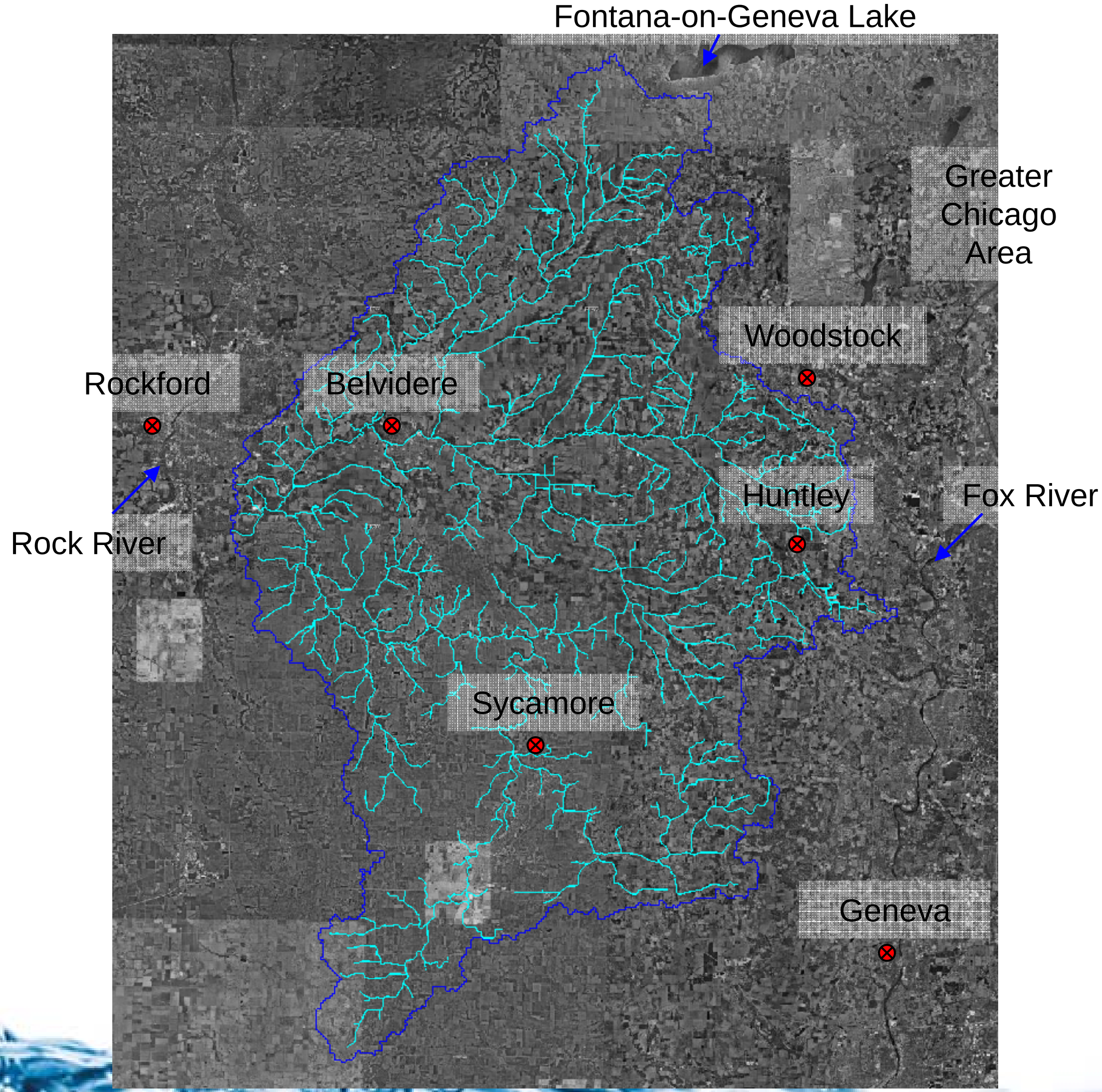
Urbanization and Wetlands Creation in the Kishwaukee Watershed





Watershed Overview

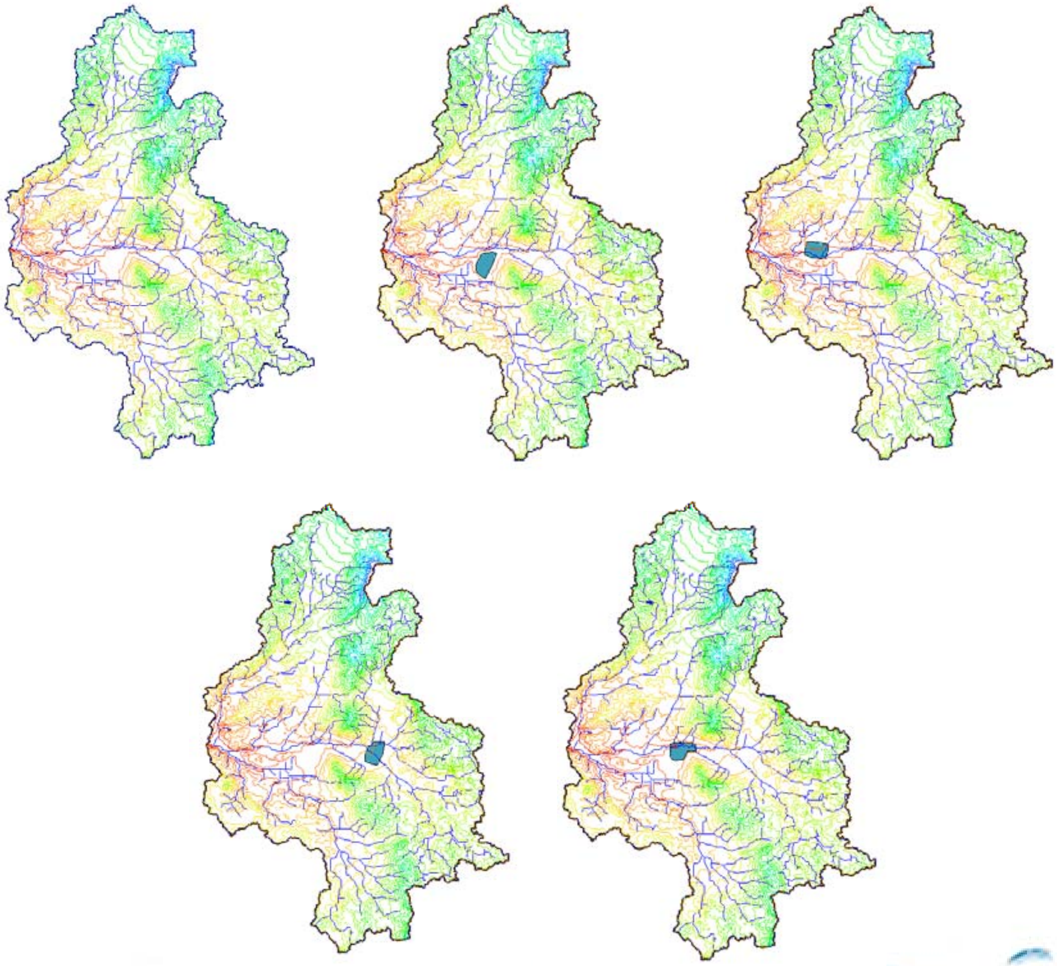
- Watershed Area:
  ~1100 mi^2
- Stream Miles:
  ~1000 mi
- Overland flow
- Stream flow
- Infiltration
- Groundwater
- Tile Drains
- Detention Basin
- Wetland Hydraulics



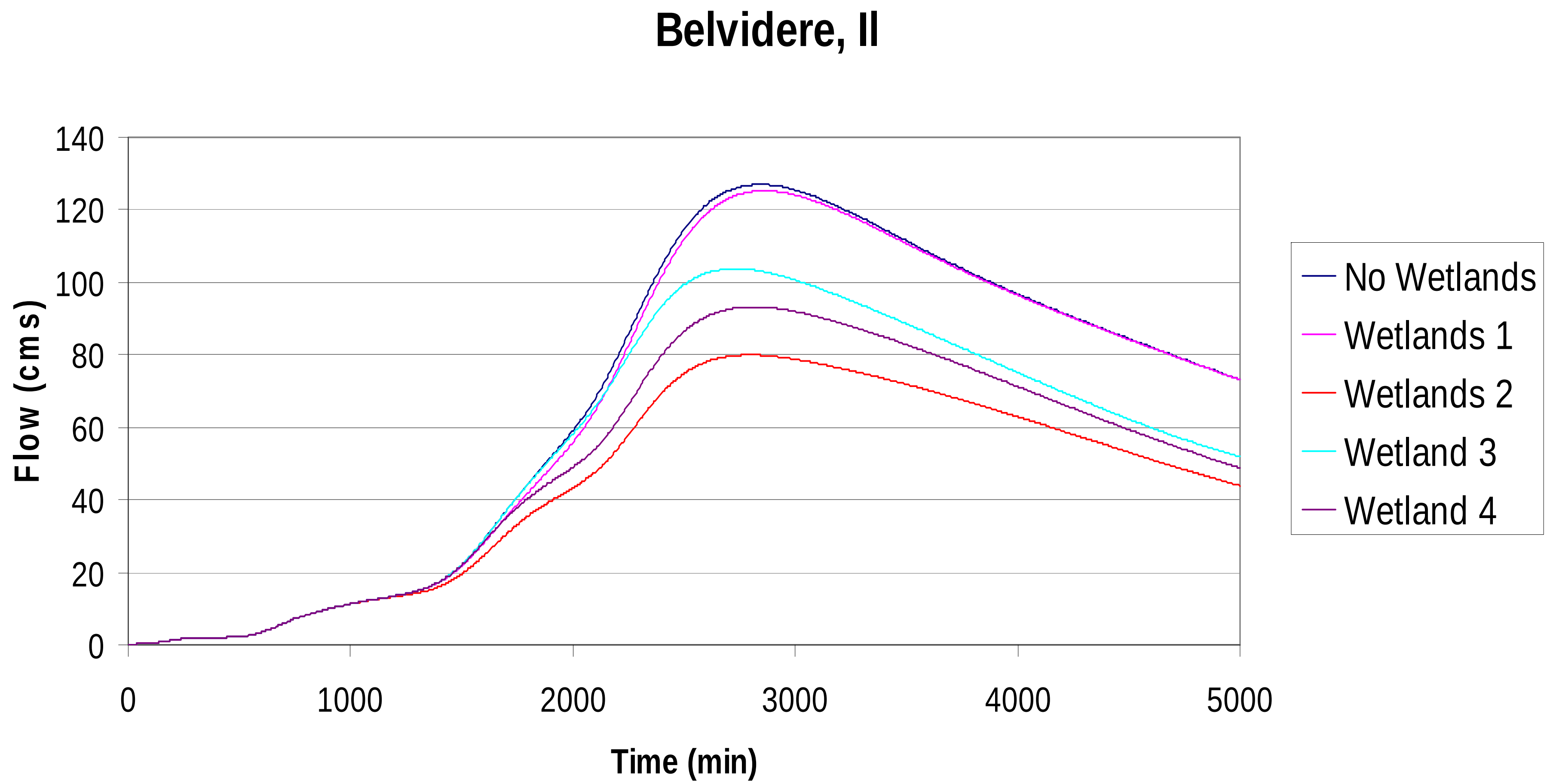
Project Goals

- Develop Watershed Management Plan
  - Placement of 1600 ac of wetlands
  - Removal of tile drains
  - Assess impacts of future land use

Impacts of Spatial Location: Wetlands Location Study

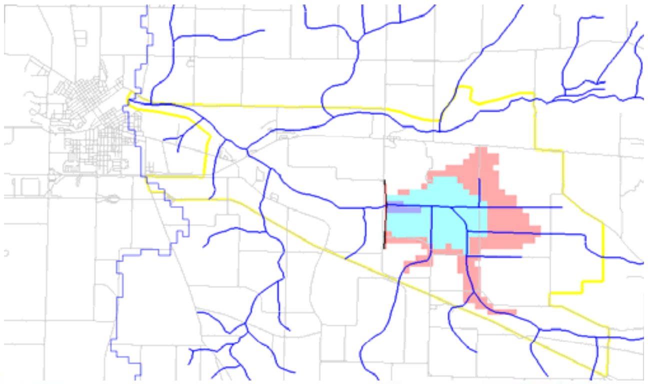


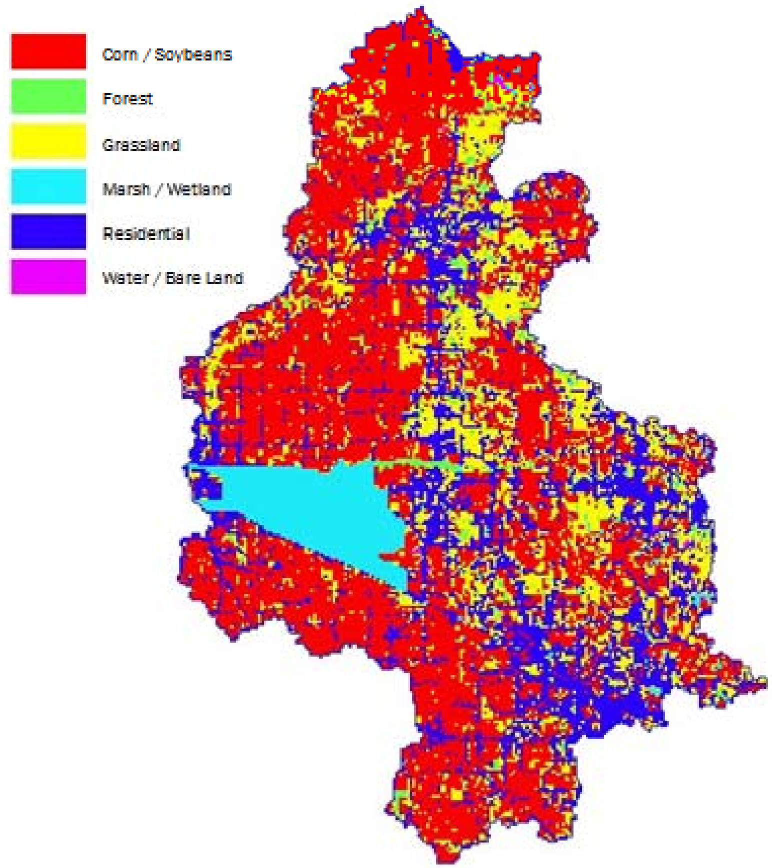
Wetlands Location Results



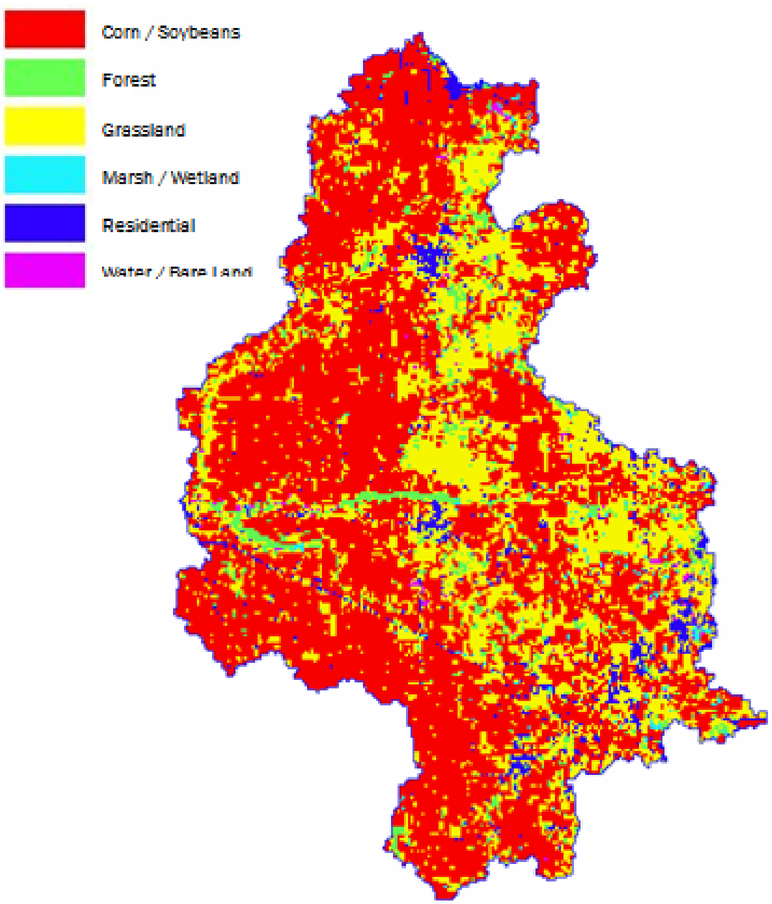
Spatial Hydrology: Dealing with Runoff Processes Changes

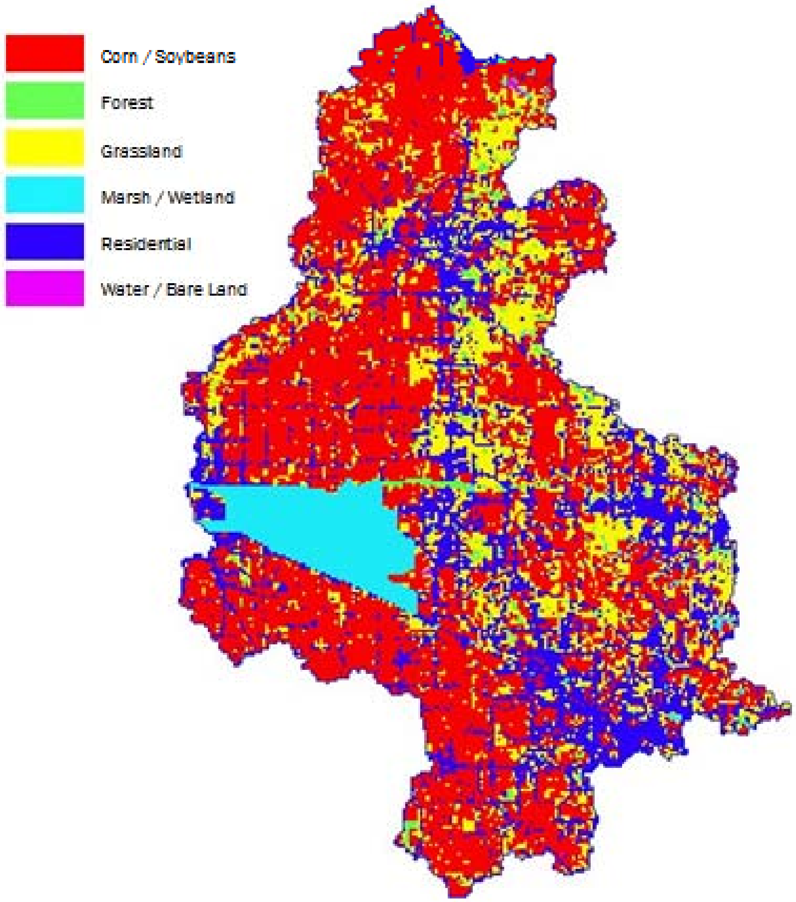
- Spatial effects of land use changes
  - *Where* you put a commercial zone, detention basin, or wetland changes the hydrology
  - Include engineered wetlands
  - Include detention basins
  - Planning and after-the-fact land use changes



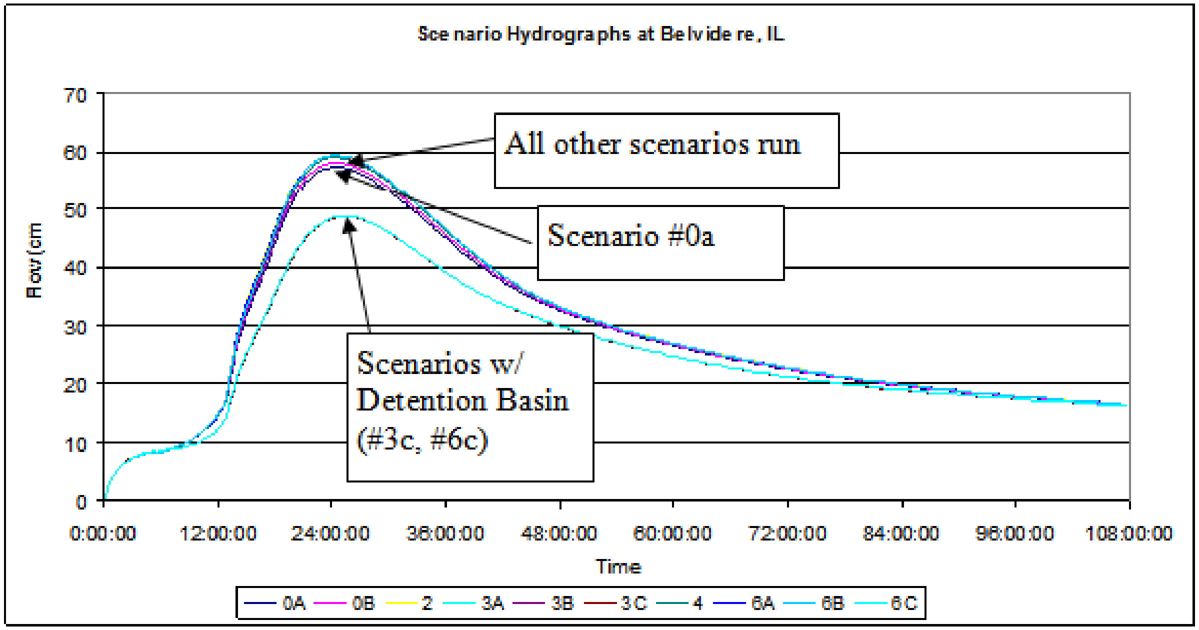


Urbanization: Kishwaukee Watershed

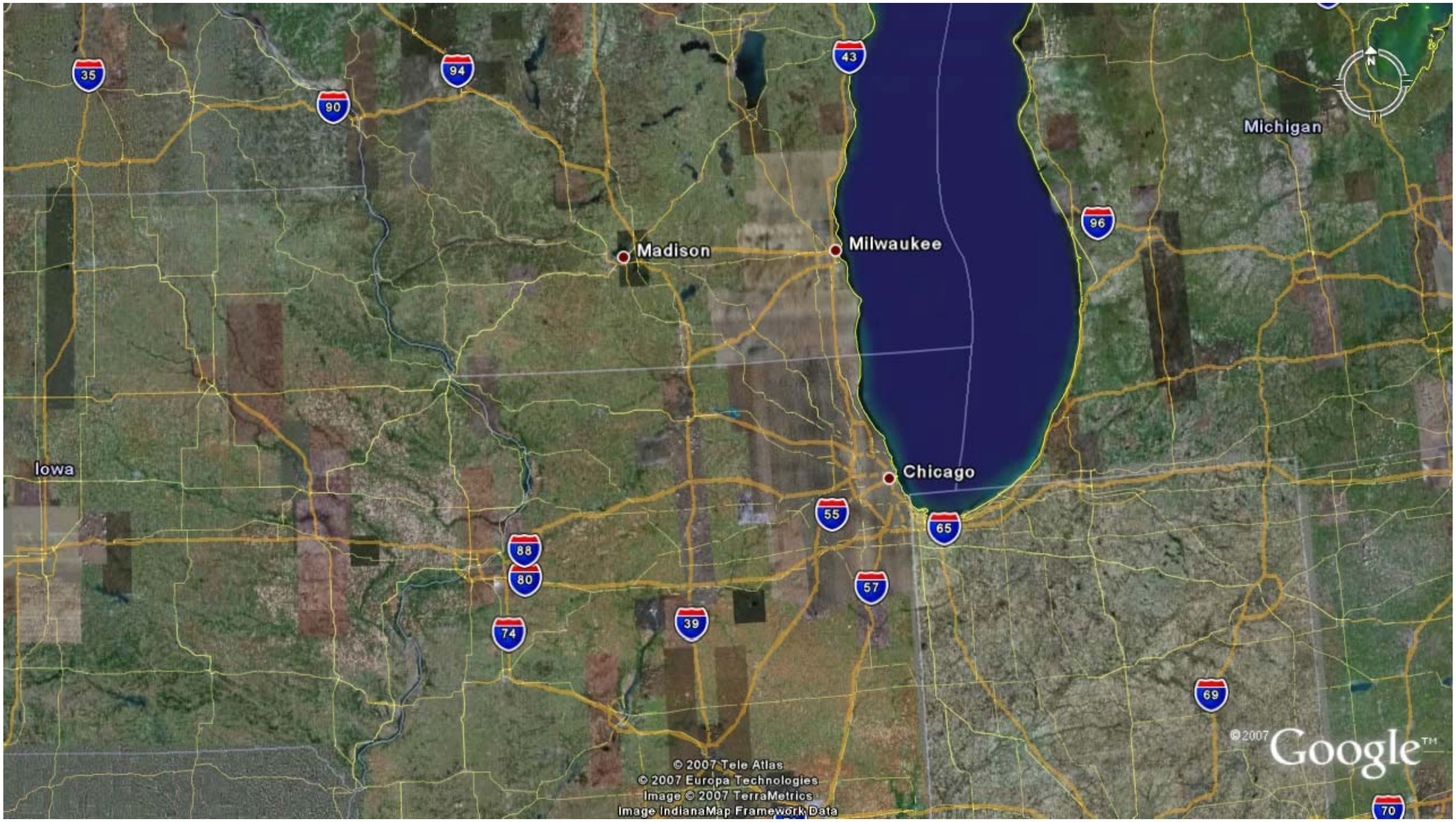




Urbanization: Kishwaukee Watershed Results



Central Kishwaukee Flooding



Summary

- GSSHA is fully distributed, physics based watershed analysis and management tool.
- It can and has been used for a variety of analysis and engineering studies.
- The spatially explicit nature of the model allows user to directly incorporate important project features into the model.
- The physical basis allows parameter values to be logically adjusted for changing conditions – land use, BMPs, climate conditions.
- The spatially explicit physics based approach offers advantages over simply models for analysis of conditions outside the range of calibration, changing, and inherently distributed processes such as sediment transport and non-point source pollution.

New Orleans