Development and Application of Watershed Models for Simulation and Management of Nonpoint Source Pollutants

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Non-point Source Pollution

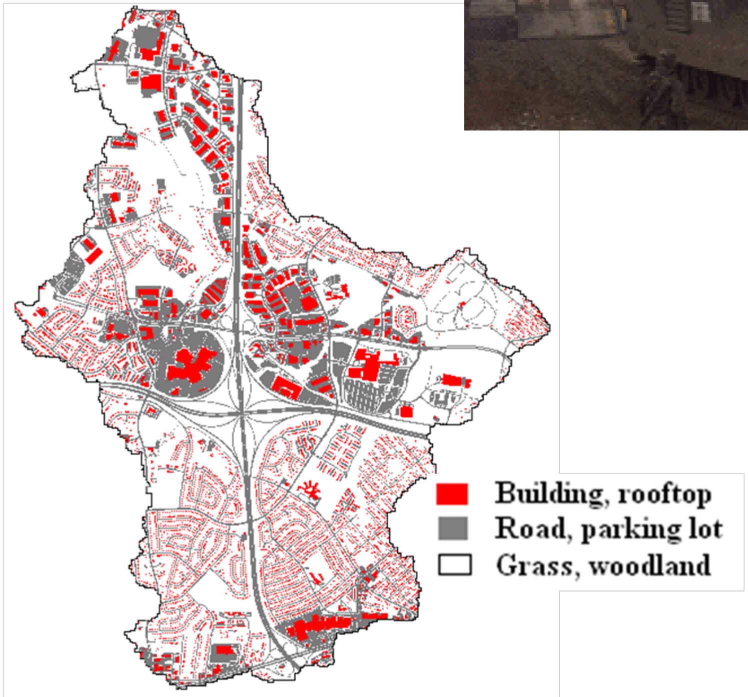
- According to the US EPA, non-point source pollution (NPSP)
  - Comes from many diffuse sources.
  - Caused by rainfall or snowmelt moving over and through the ground.
  - As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water.
  - These pollutants include:
    - Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas.
    - Oil, grease, and toxic chemicals from urban runoff and energy production;
    - Sediment from improperly managed construction sites, crop and forest lands, and eroding streambanks;
    - Salt from irrigation practices and acid drainage from abandoned mines;
    - Bacteria and nutrients from livestock, pet wastes, and faulty septic systems

Extent of Problem

- In it's 2004 Water Quality Inventory Report to Congress, the USEPA reported.
  - A large portion of the nations water bodies do not meet water quality standards
    - 44% river miles
    - 64% ponds, lakes, and reservoirs
    - 30% of estuauries
  - Water quality impairment attributed to NPSP constitutes a large percentage of the impaired water bodies
    - 65% of river miles
    - 30% of ponds, lakes and reservoirs
    - 40% of estuaries

Sources of Non-Point Source Pollution

- Urban development
- Agriculture
- Land disturbance
  - Construction
  - Military training
  - Timber harvest
  - Fire
- Natural causes



Programs Related to Control of NPSP

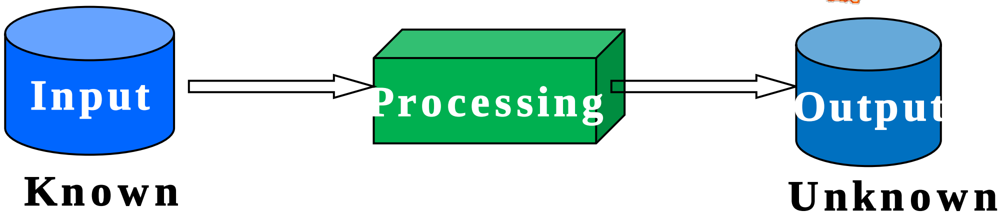
- TMDL Process – Total Maximum Daily Loading
  - Intended to allow states to meet water quality standards
  - The total loading that will allow water quality standards to be met for a given body of water is determined.
  - The total loading is attributed to various sources and land owners.
  - The reduction in total loading needed to meet the water quality standards is also determined.
  - This determines the amount of reduced loading from each source and/or land owner.
  - The EPA, state, land owners develop an implementation plan that will result in the water quality standards being met.
- Low Impact Development (LID)
  - Development is conducted in a way to minimize the effects of urbanization on hydrology and water quality.
  - Water/sediments/pollutants are captured near their source with various management practices – rain barrels, porous pavement, detention basins, etc.

Considerations in Modeling NPSP

- Sources are unevenly distributed on land surface
  - Hot spots
- Flow path is important
  - Loss of water and constituents along flow path
    - Infiltration
    - Decay
    - Transformation
    - Exchange with land surface
  - Increased hydraulic efficiency shortens flow paths and reduces loses
    - Streams
    - Canals
    - Subsurface pipe networks
- To asses the effects of potential changes to the system, such as future land use change or best management practices a physically-based modeling approach is preferred.

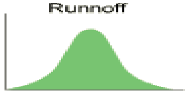
Hydrologic Models

Lumped Models



Precipitation

Watershed Response

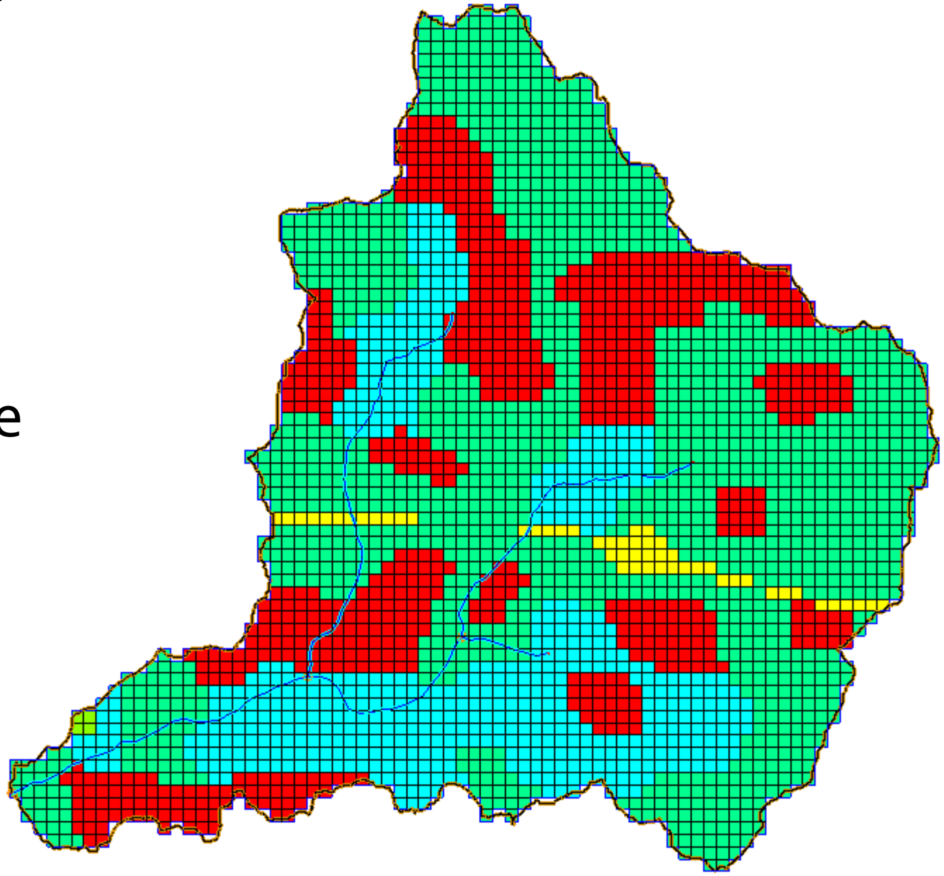


Outflow

Hydrologic Models

Distributed Models

- Fine scale physical processes are simulated at element level
  - Plant interception
  - Infiltration
  - Runoff
  - Evapo-transpiration
- Elemental responses are integrated to determine system response

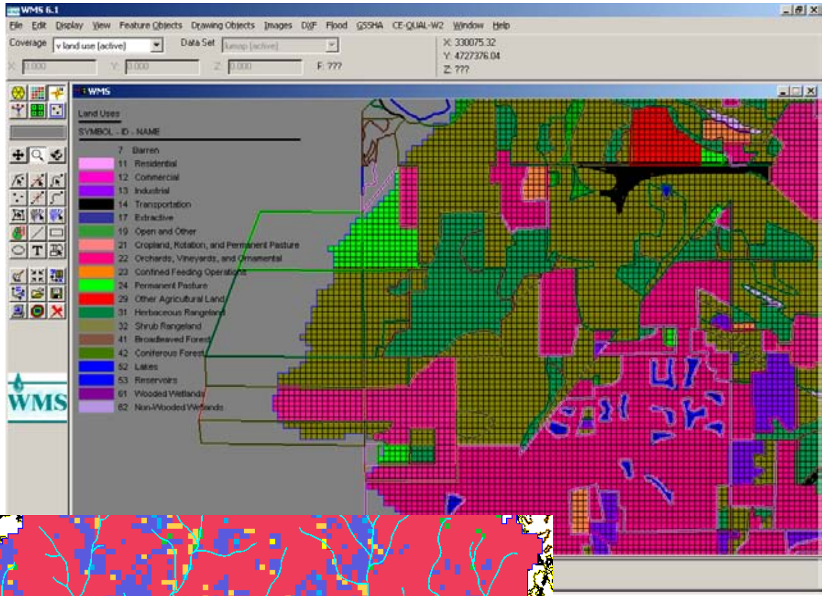


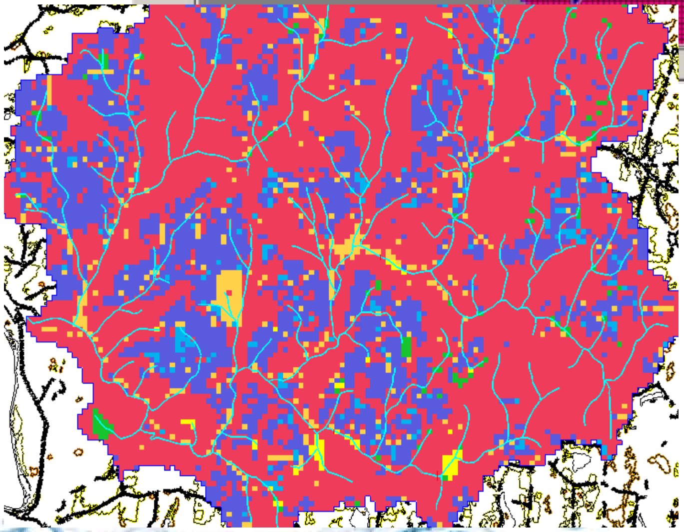
Physically-Based Distributed Parameter Modeling Approach

- Physical Bases
  - Allows use of the model with minimal calibration data
  - Allows extension of the model beyond the range of calibration.
- Distributed Approach
  - Incorporates spatial heterogeneity of watershed features
  - Provides fine scale information for project analysis
- Provides
  - Tool for analysis of watersheds at fine time and space scales
  - A compliment to simpler models which may be used to identify areas that need more rigorous study

Physically-based distributed parameter Modeling Approach

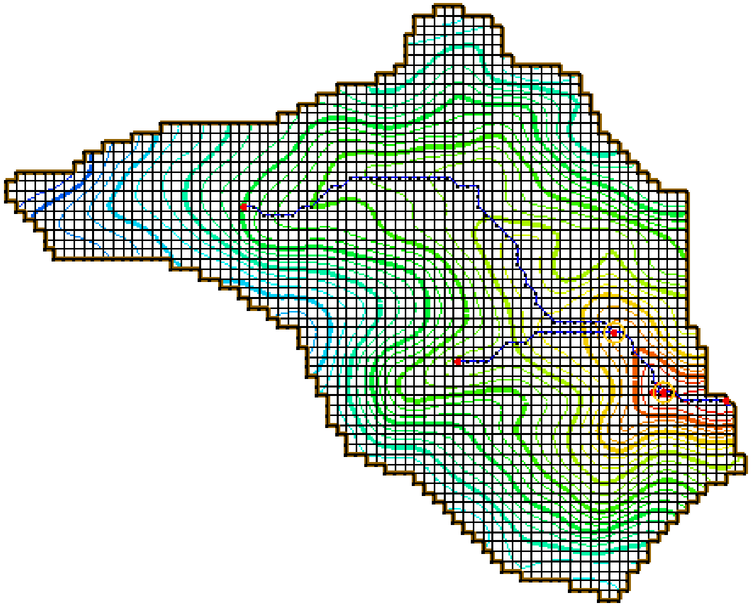
- Spatially varied heterogeneity
- Explicitly resolve features in the grid
  - Land use
  - Soil type
  - Depressions
  - BMPs
  - Roads
  - Wetlands
- Track fate of water, sediment, contaminants along flow path
  - Infiltration along path
  - Settling/erosion along path
  - Reactions along path





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.



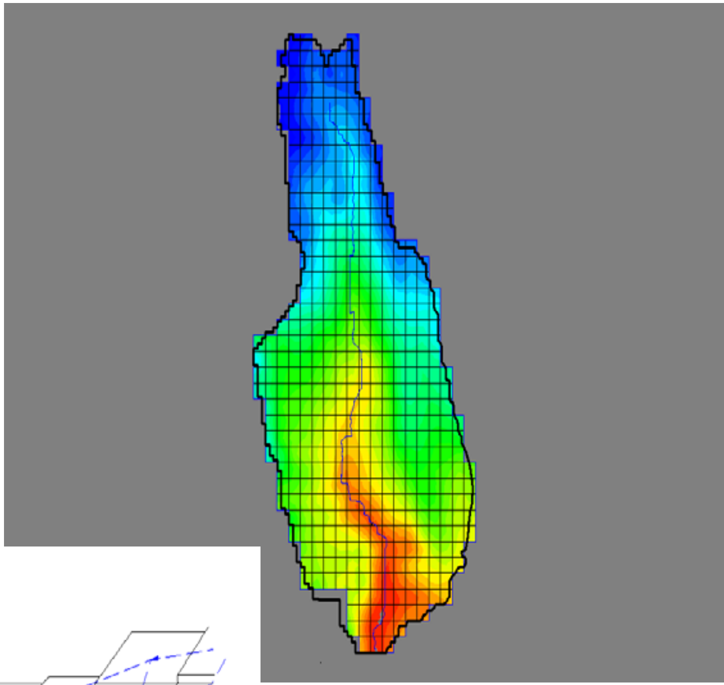
Downer, C. W. *Identification and Modeling of Important Stream Flow Producing Processes in Watersheds,* PhD Dissertation, University of Connecticut, 2002.

Gridded Surface Subsurface Hydrologic Analysis (GSSHA)

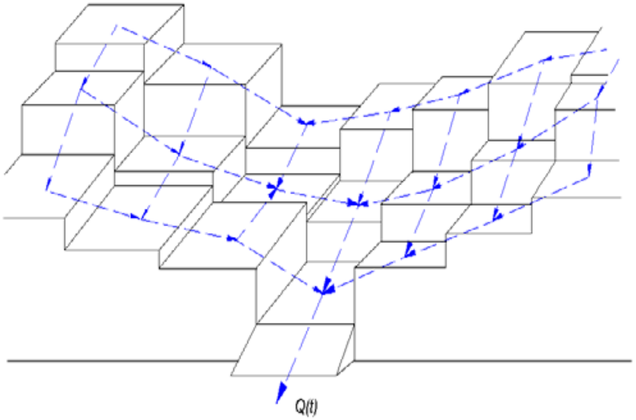
How does GSSHA Work?

- 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



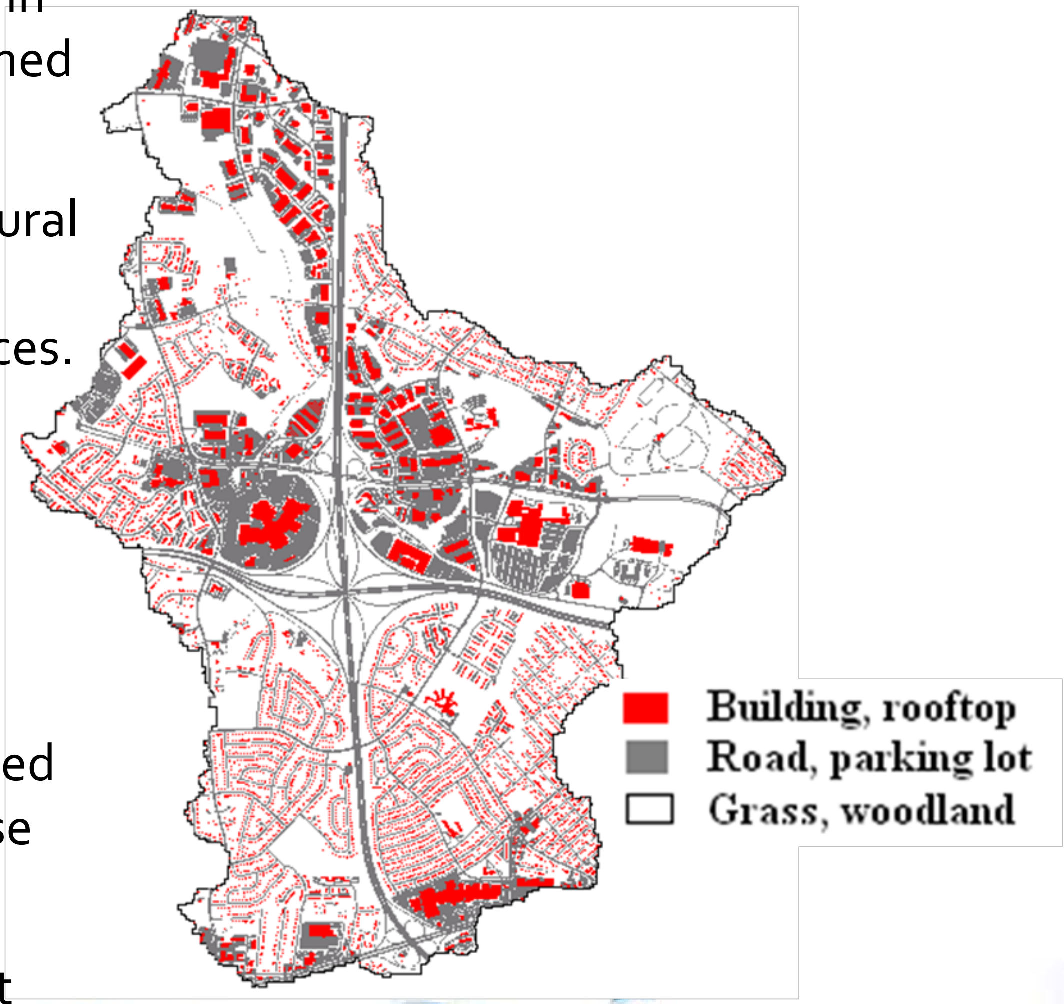
GSSHA

- Includes special features to allow the model to explicitly resolve issues related to NPSP:
  - Land use change
  - BMPs
  - Storm and tile drains
  - Wetlands
  - Sediment transport
  - Constituent transport

Land Use Change

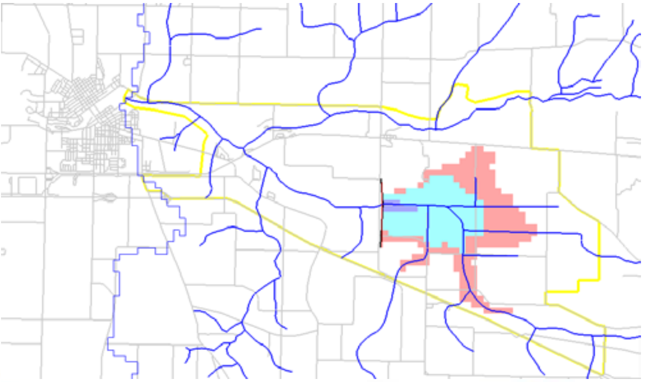
Changing land uses lead to changing in the physical properties in the watershed and alter the stream response.

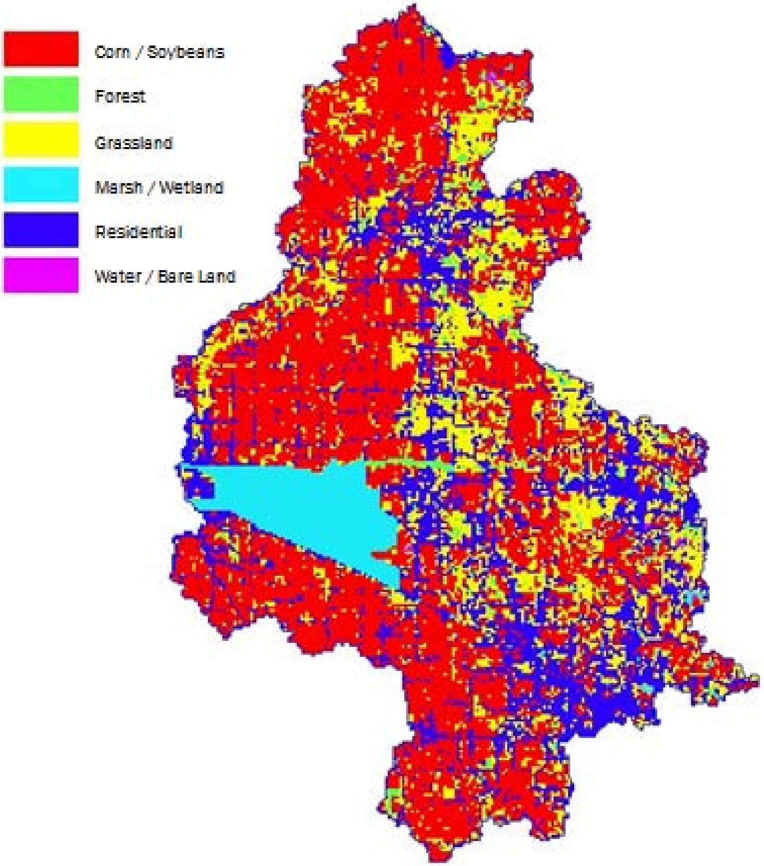
- Converting natural areas to agricultural and urban areas results in more compacted soils and smoother surfaces.
- Urbanization also leads to greater impervious area.
- All these changes result in more runoff.
- Drainage capacity is usually increased exasperating the problems of increase runoff.
- All effects sediment and constituent runoff



Spatial Hydrology: Dealing with Runoff Processes Changes

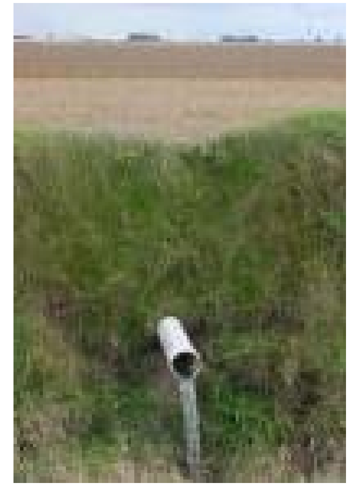
- Spatial effects of land use changes
  - *Where* you put a commercial zone, detention basin, or wetland changes the hydrology
  - Include engineered wetlands
  - Include detention basins
  - Planning and after-the-fact land use changes

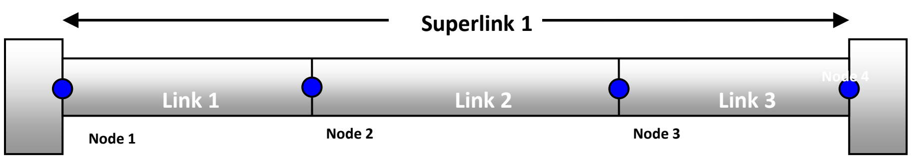


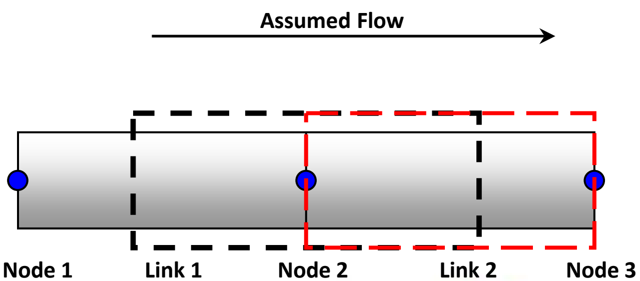


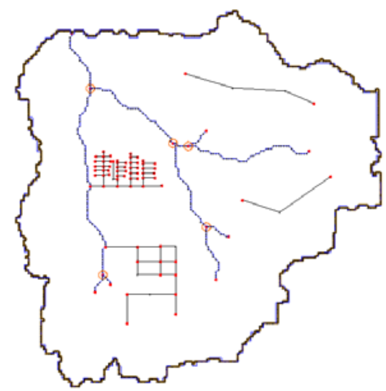
Storm and Tile Drains

- Connected set of pipes, manholes, inlet grates
- Tile drains are porous pipes that drain groundwater in agricultural areas.
- Storm and tile drains increase runoff and short circuit natural treatment mechanisms.



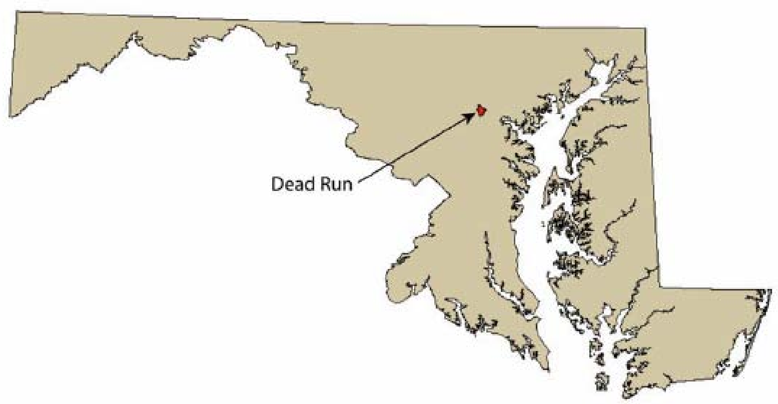


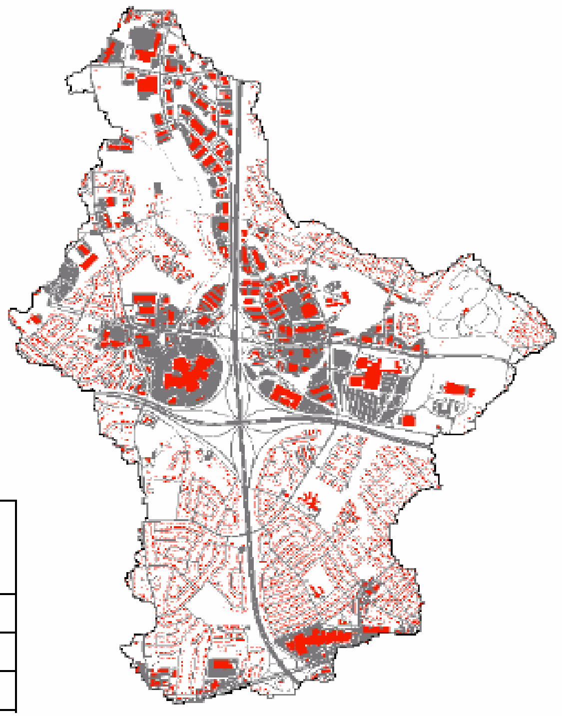




Dead Run Creek

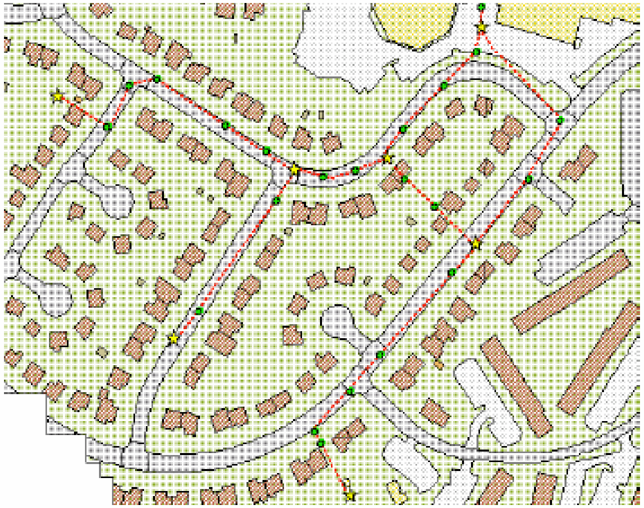
- 14.3 km2 watershed in Baltimore, MD

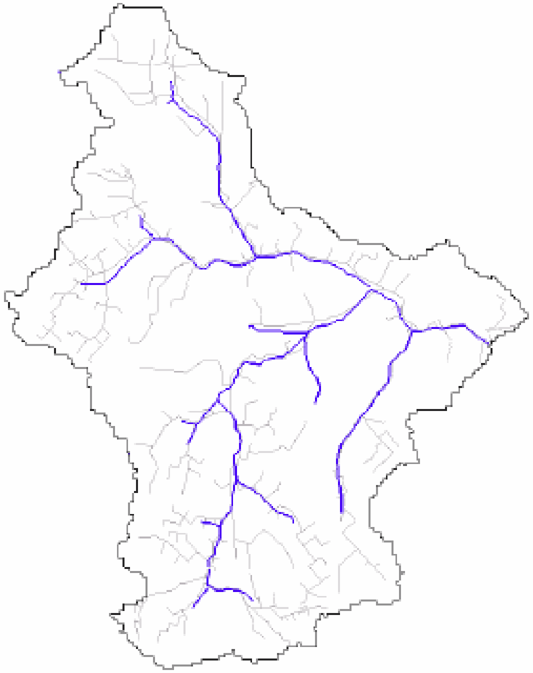




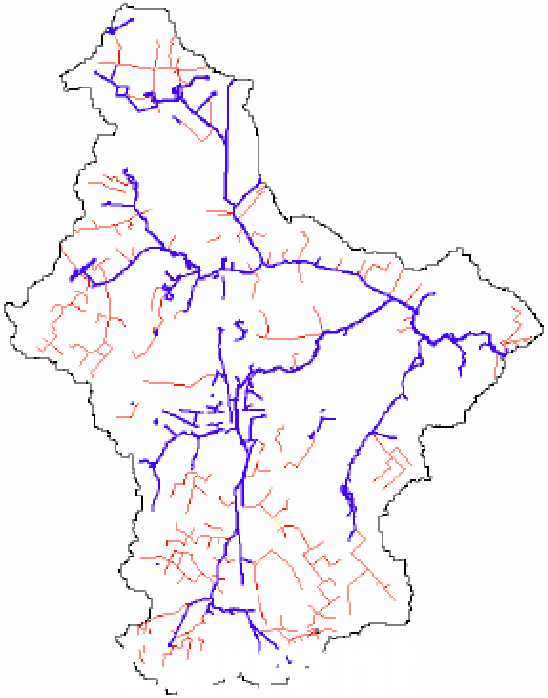
Land Use Classification	Area (km^2)	Percent of Watershed
Road and Parking Lot	1.57	11.0%
Building Rooftop	3.54	24.8%
Grass/Woodland	9.19	64.2%

Drainage Networks



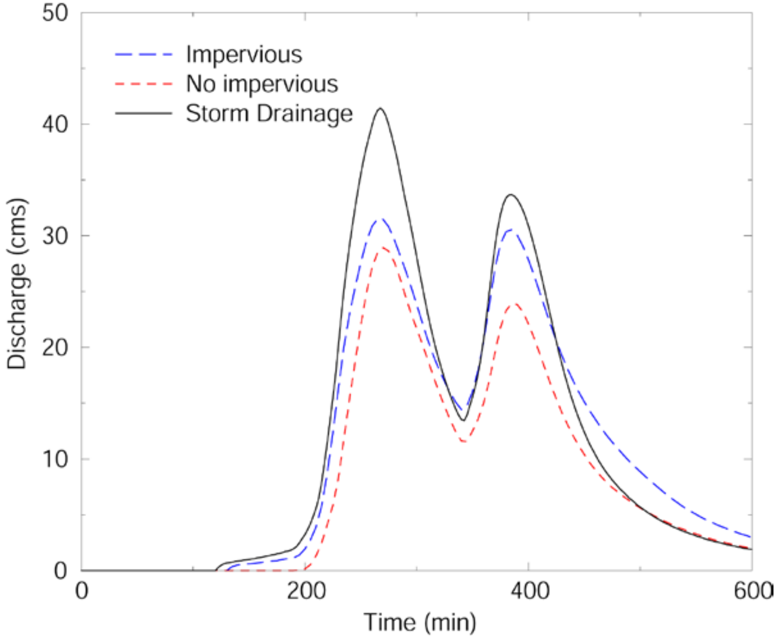


Historical Stream Network

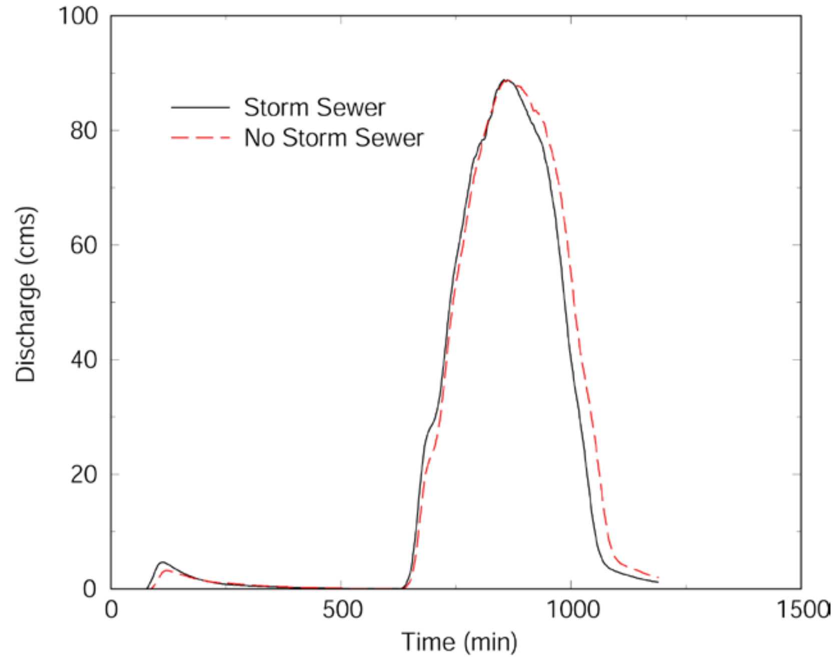


Stream and Storm Drain Network

Results

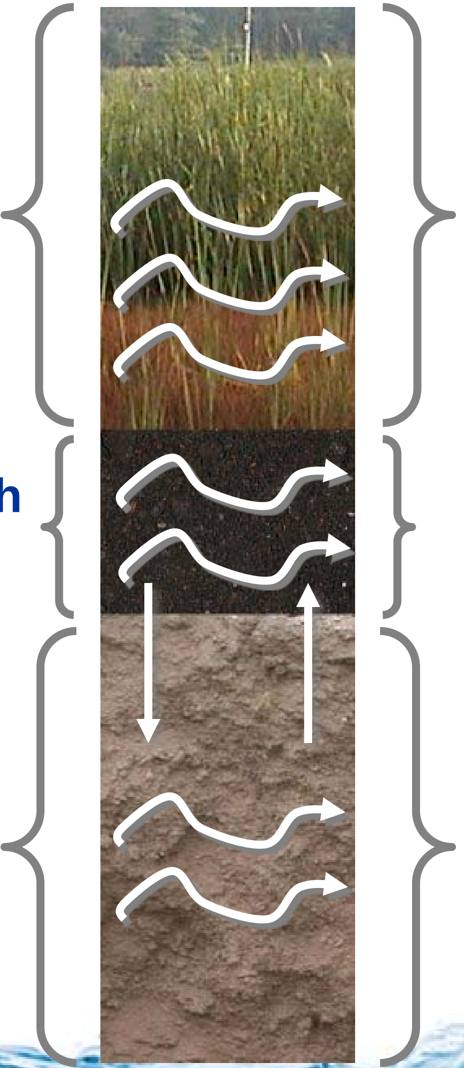


Hurricane Isabel



Ft. Collins Flash Flood

Wetland Model



Lateral flow through, over vegetation

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

Lateral flow through peat / muck layer

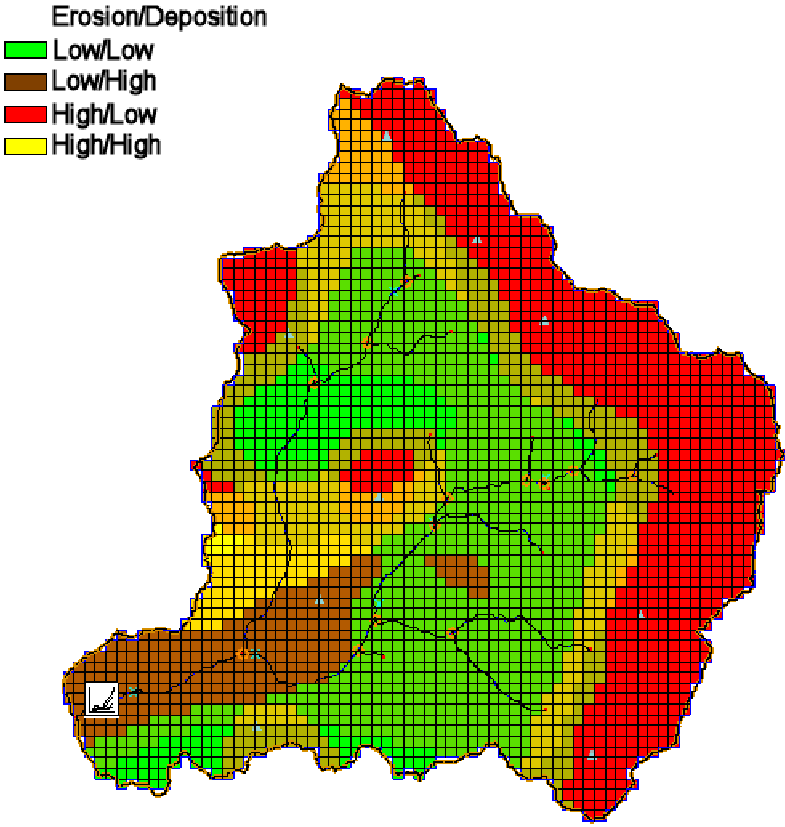
Darcian Flow

Vertical infiltration, exfiltration, Lateral Groundwater

Infiltration, 2D Groundwater models

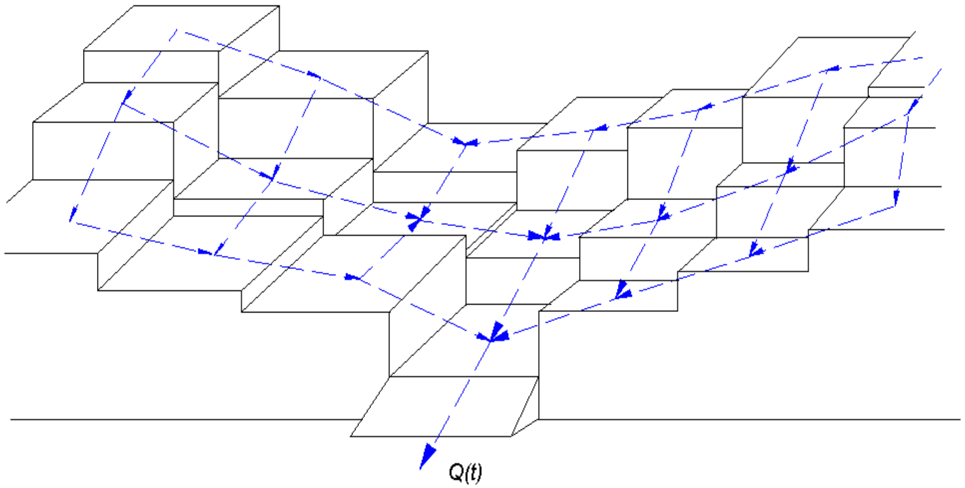
Sediment Transport

- Event based erosion and deposition model (not USLE-based)
  - Overland
  - Streams
- User-defined sediment properties



Overland Sediment Transport

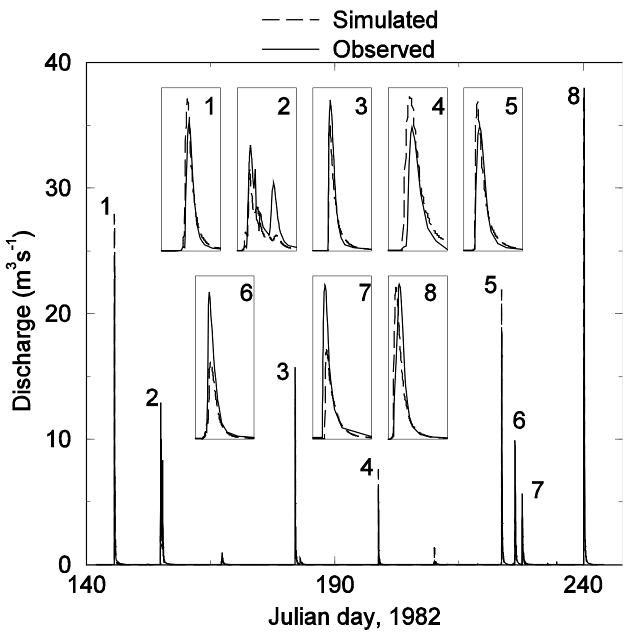
- Any number of sediment particles
  - Size
  - Specific gravity
- Erosion is due to
  - Raindrop impact
  - Overland flow
- Overland erosion
  - Kilinc-Richardson
  - England-Hansen
  - Multiple shear stress formulas
- Deposition

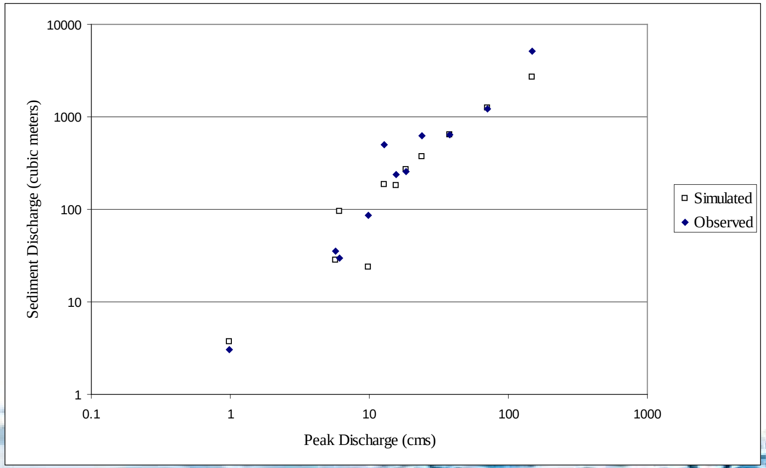


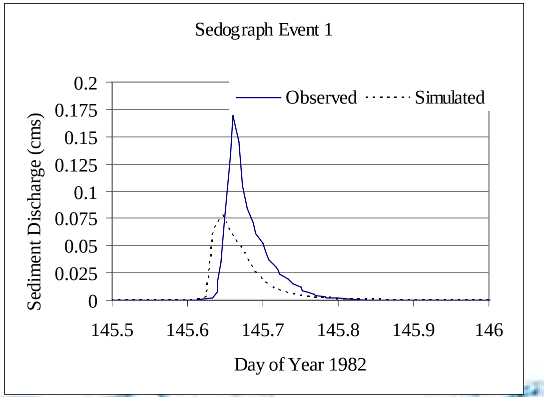
Cell to Cell Advection of Suspended Sediments

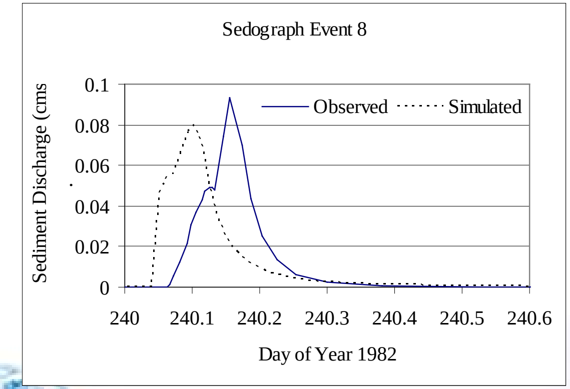
Continuous Simulations

- Simulates each event with memory of previous events
  - Erosion
  - Deposition
  - Changes in particle distribution
- Simulates events more than 4 orders of magnitude different without change in parameter values



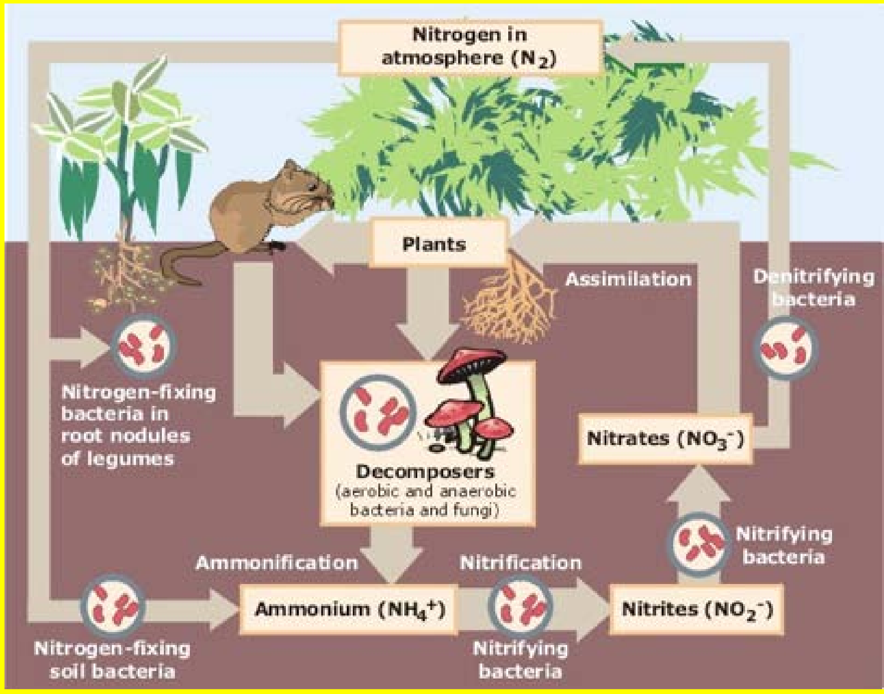






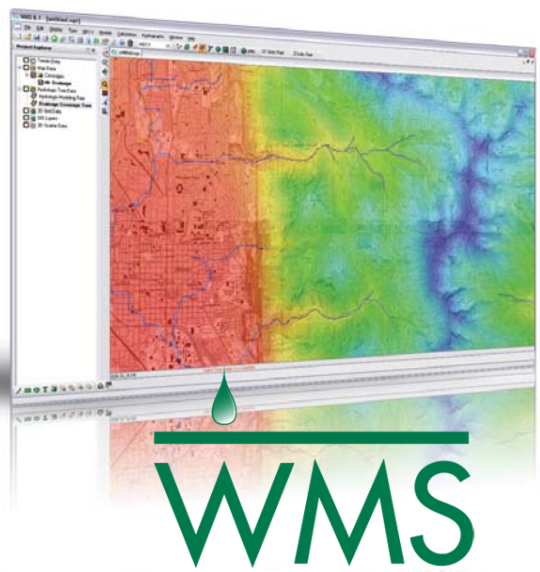
Constituent Transport

- GSSHA has the capability to simulate constituent fate and transport in surface water components of the model.
  - Soil column
  - Overland
  - Streams
- Kinetics
  - First order
  - Nutrient Simulation Model (NSM)
    - Not currently in release model
- Dissolved and sorbed phases



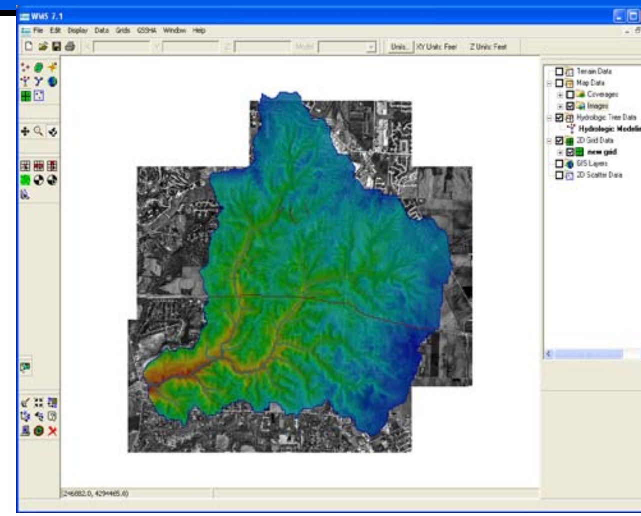
GSSHA and WMS

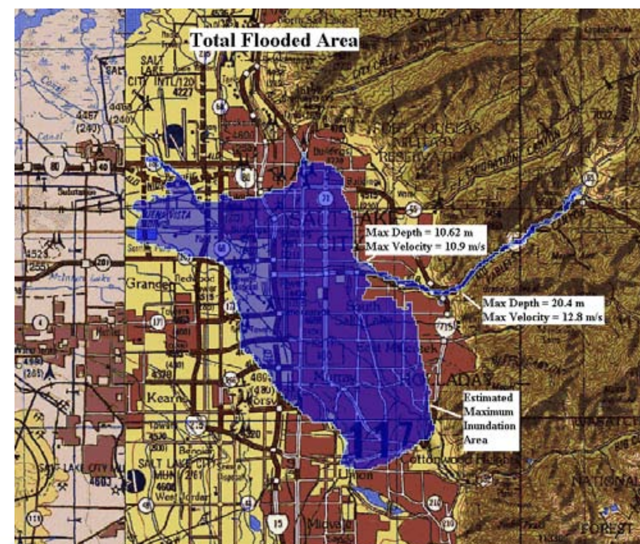
- The Watershed Modeling System (WMS) is a pre- and post-processor for GSSHA and several other hydrologic models, including HEC-HMS and HEC-1.



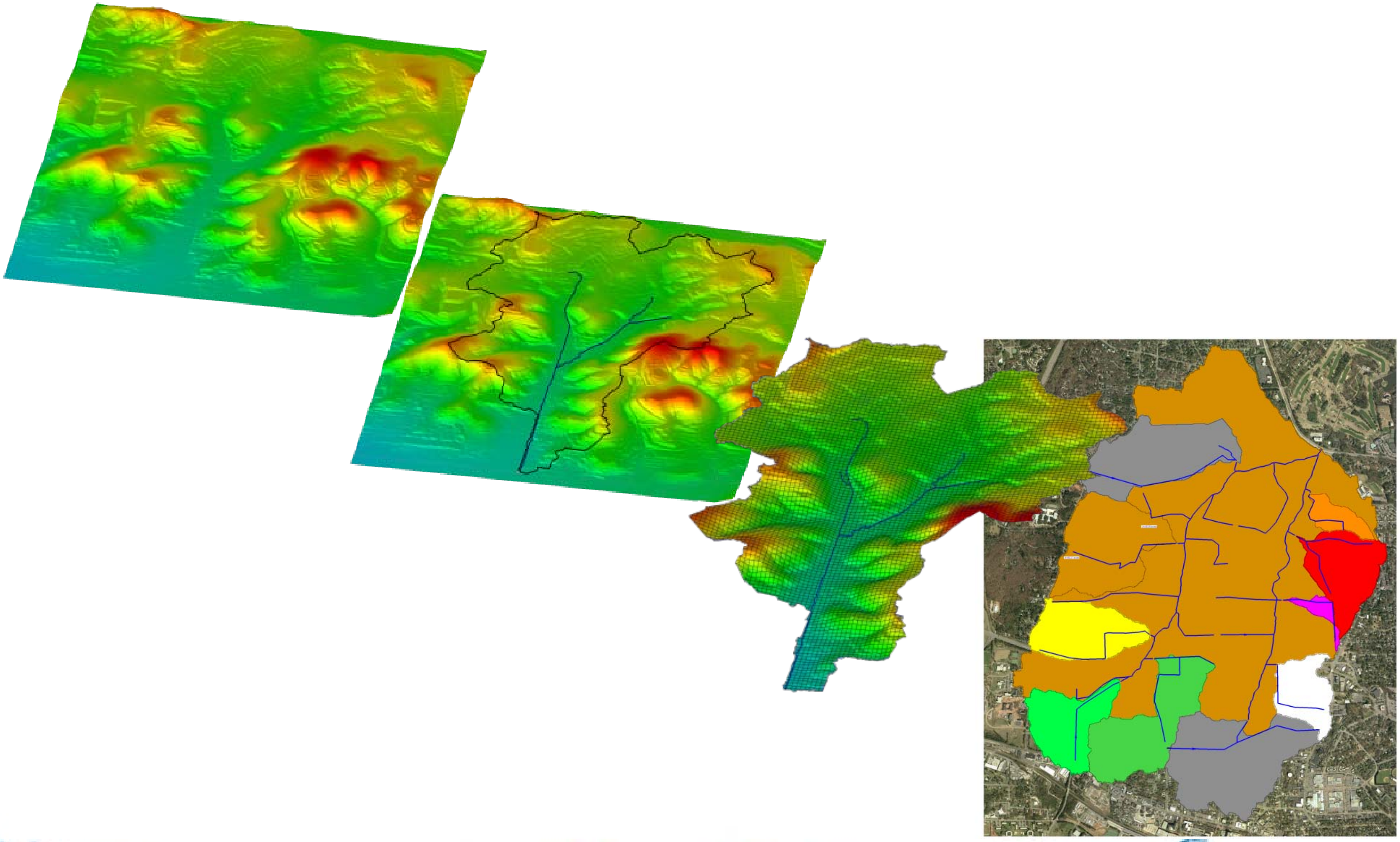
WMS Overview

- 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



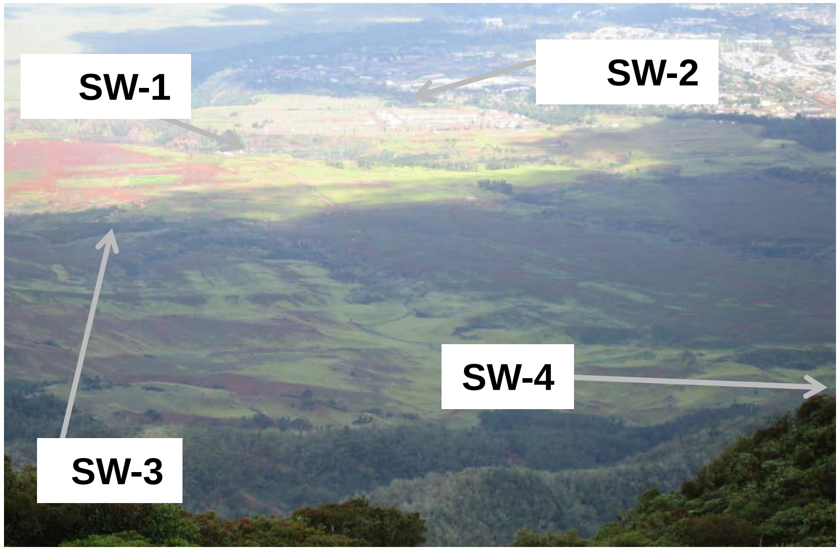


Watershed Modeling



Military Watershed TMDL Applications

- Naval Computer and Telecommunications Area Master Station Atlantic (NCTAMS)
  - Install stormwater samplers and rain gages
  - Build GSSHA model to calculate nitrogen and sediment loadings
  - Recommend BMPs, if necessary
- Schofield Barracks / Makua EIS
  - Install stream flow and stormwater samplers
  - Build GSSHA models to compute sediment, nitrogen and phosphorous loadings to the near-shore environment
  - Recommend BMPs, if necessary
- SERDP Applications
  - Assess impacts of training, climate change on sensitive hydrology and sediment transport situations (e.g. permafrost)



Surface-water Monitoring Sites for Makua EIS and GSSHA Modeling

Hawaii Training Ranges EIS/TMDL Program Objectives

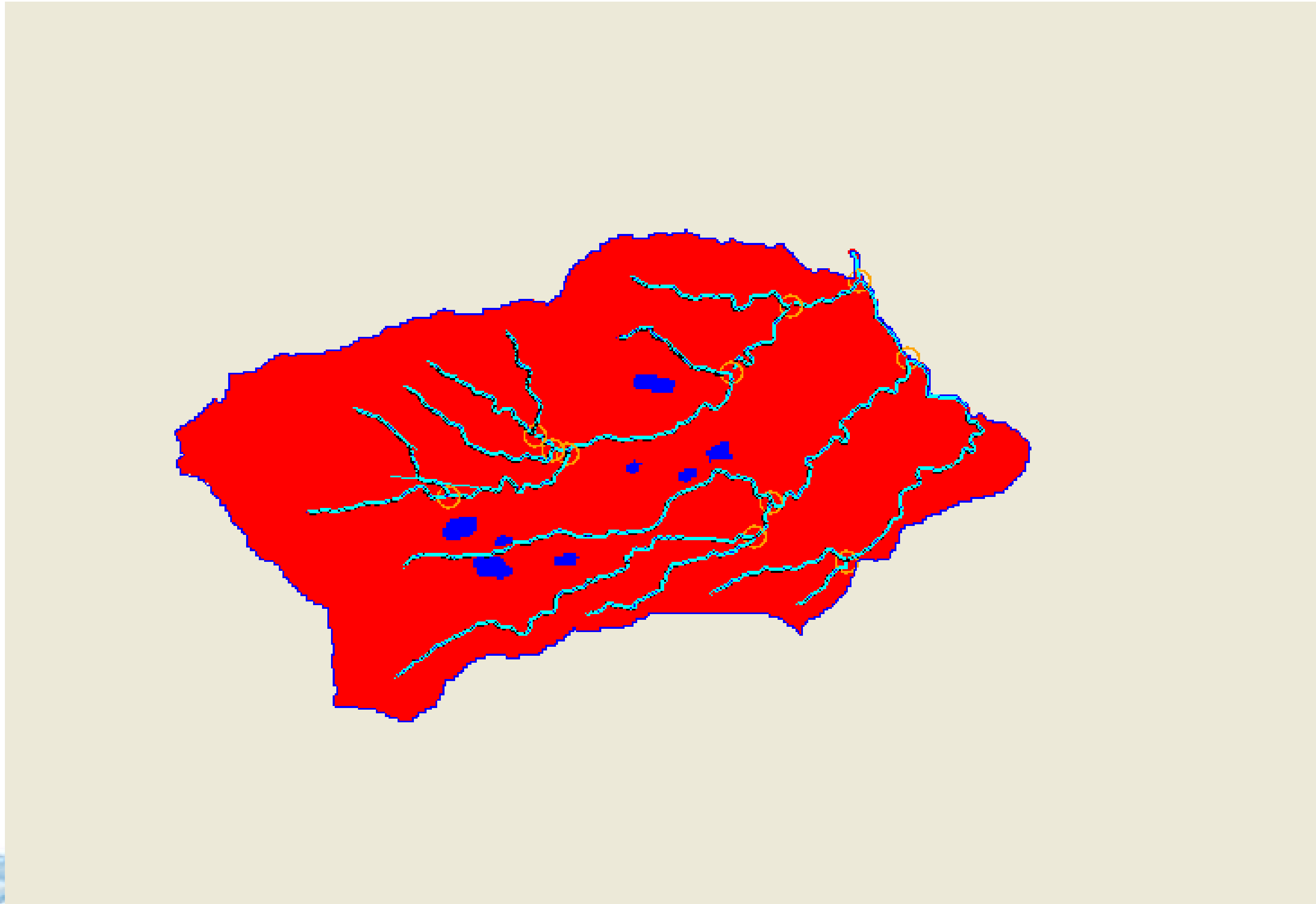
- Maintain operation of Training Ranges in Hawaii to meet training needs:
  - *Reduce erosion of training lands, and reduce nutrient and sediment content in streams leaving installation (all ranges).*
  - *Identify potential pathways and rates of munitions' constituent transport from training areas.* Determine whether Munitions Constituents are leaving the sites in surface water or groundwater (live fire ranges). Sampling program designed to evaluating impacts of munition constituents (explosive, metals) and nutrients (nitrogen, phosphorus) on surface water, and munition constituents on groundwater.
  - *Validate that Depleted Uranium is not leaving live-fire training ranges (live fire ranges).* Sampling for depleted uranium (DU) was added for Schofield Barracks surface water as recommended by Joint Munitions Command (JMC), AEC, as well as U.S. Army Garrison-Hawaii

Evaluation Methods

- 3 Years of field data collection at each site to evaluate TMDLs
  - Kaukonahua Stream (2007, 2008, 2009)
  - Waikele Stream (2008, 2009, 2010)
  - East Range (2009, 2010, 2011)
  - Kahuku Range (2010, 2011, 2012)
  - Kawailoa Range (2012, 2013, 2014)
- Data Analysis
- GSSHA model created at each watershed to evaluate data, compute TMDLs, and assess BMPs
- Provide TMDLs to State of Hawaii and EPA
- Install BMPs if necessary

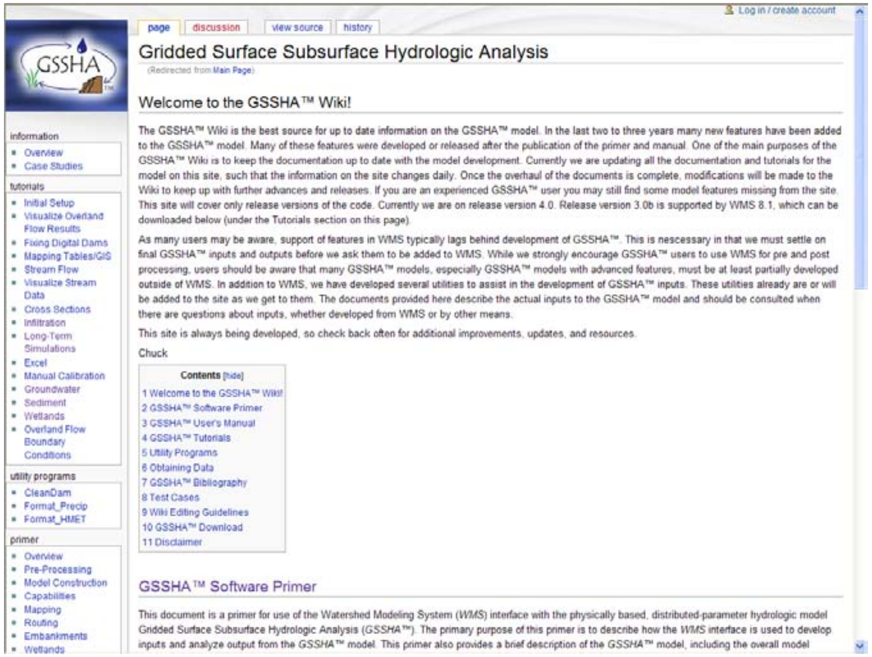


Transport of Sorbed Materials in Isolated Hotspots



Further Information

- GSSHA reference materials:
  - http://www.gsshawiki.com/
  - http://chl.erdc.usace.army.mil/gssha
    - Tutorials
    - Primer
    - Reference Manual
    - Download GSSHA Model



- WMS reference materials:
  - http://www.xmswiki.com/
  - http://chl.erdc.usace.army.mil/wms

Questions

GSSHA forensic simulation of New Orleans flooding (USACE-ERDC)