

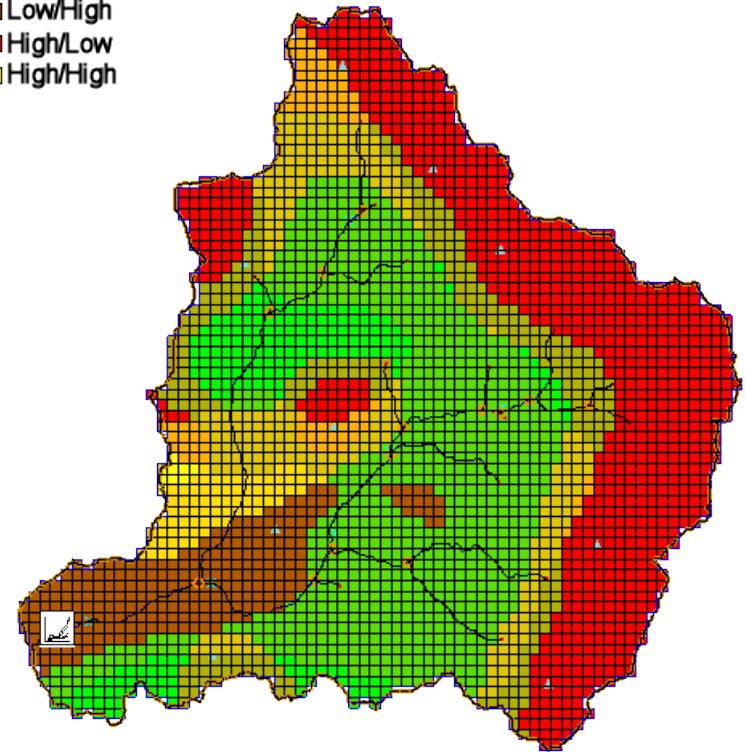


Sediment Transport

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

Erosion/Deposition

- Low/Low
- Low/High
- High/Low
- High/High





GSSHA Sediment Transport

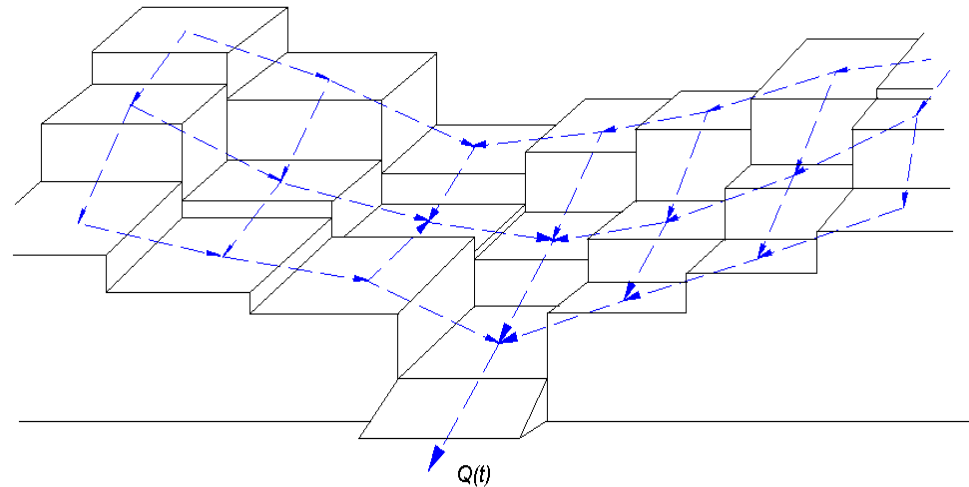
- Simulation of sediment erosion from the overland plane
- Transport across overland plane including deposition and re-entrainment
- Transfer into channels
- Channel routing of bed and wash loads
- Routing of sediments through reservoirs
- Landscape evolution with the capability to do multi-decadal simulations





Overland Sediment Transport

- Any number of sediment particles
 - Size
 - Specific gravity
- Sediment detachment
 - Raindrop impact
 - Overland flow limits
- Transport Capacity
 - Kilinc-Richardson
 - Engelund-Hansen
 - Multiple shear stress formulas
- Deposition



Cell to Cell Advection of Suspended Sediments





Overland Erosion Process in GSSHA

- Particles are detached by rainfall impact and overland shear.
- If sufficient transport capacity is available, the eroded particles are transported to adjacent cells by advection.
- Deposition is computed with trap efficiency.
- Transport and deposition by particle size and density.
- Sediments are accounted for using three storages:
 - Parent material
 - Deposited materials
 - Materials in suspension
- Each pool has its own distribution of particles.
- Deposited materials are assumed to erode first, then the parent material.
- Elevations can be adjusted for erosion/deposition.





Factors Affecting Detachment and Transport Capacity

- Soil particle size – finer particles are more erodible.
- Cover conditions – any type of vegetative or manmade cover protects the particles from detachment and transport.
- Management actions – actions taken to prevent erosion, no-till, contour plowing, etc. lessen erosion.
- Erosive forces
 - Rainfall intensity
 - Discharge
 - Land surface or friction slope
 - Shear stress





Detachment by Rain

- Detachment of particles by rainfall is a function of momentum, which is a function of rainfall intensity.
- Rainfall detachment ($\text{kg m}^{-2} \text{s}^{-1}$) is calculated as the product of several factors related to:
 - K_I – soil erodiability
 - C_w – correction for water depth
 - C_G – vegetative canopy cover factor
 - C_i – cover-management factor, and
 - M_R – rainfall momentum squared.

$$D_R = K_I C_w C_G C_i M_R$$





Overland Flow Detachment

- Overland flow detaches particles by exerting a shear stress that breaks particle bonds.
- Erosion occurs in rills.
- Within a cell overland flow and rill erosion are assumed uniform, so that calculations are for gross rill erosion.
- Detachment capacity rate ($\text{kg m}^{-2}\cdot\text{s}^{-1}$)

$$D_c = a(\tau - \tau_c)_r^b (1 - G/T_c)$$

- a and b are empirical coefficients,
- τ = the flow shear stress (Pa),
- τ_{cr} = the critical shear stress,
- G = the sediment load ($\text{kg m}^{-2}\cdot\text{s}^{-1}$), and
- T_c = the sediment transport capacity of surface runoff ($\text{kg m}^{-2}\cdot\text{s}^{-1}$).





Transport Capacity

- Is the amount of sediment that the flow is capable of moving.
- The flow may not be capable of transporting all of the eroded material.
- The flow may be capable of transporting more than the eroded material.
 - In this case the transport capacity will not be satisfied.





Kilinc-Richardson

- Transport capacity is for bulk particles in suspension. Particles will be transported in relation to fraction in suspension.

- Formulation:
$$q_s = 25500 q^{2.035} S_f^{1.664} \frac{K}{0.15}$$

q_s = sediment unit discharge ($\text{ton m}^{-1} \text{s}^{-1}$),

- q = unit water discharge ($\text{m}^2 \text{s}^{-1}$), and
- S_f = friction slope.
- The erodibility constant – K is the product of the three factors
 - Soil erodibility factor (0-1) - large stones to fine silt.
 - Cover factor (0-1) – concrete to bare.
 - Crop management factor (0-1) – perfect to none.





- Transport for individual particle sizes or types

$$G_i = K_i \frac{0.045 B^5 V^{3/2} S^{3/2}}{(s-1)^2 D_i \sqrt{g}}$$

- G_i = the volumetric sediment transport rate of i -th size fraction,
 - K = the calibration coefficient (= 1 for standard equation),
 - F_i = the proportion of i -th fraction in the parent material or deposited layer,
 - B = the width of flow,
 - V = the mean water velocity,
 - h = the flow depth,
 - S = the water surface slope,
 - s = is the specific gravity of i -th fraction,
 - g = the gravitational acceleration,
 - D_i = the mean size of i -th fraction.
- Appropriate method if particles are from materials other than quarts, i.e. the specific gravity is not approximately 2.65.





Empirical Formulations

Everaert (1991) conducted flume experiments to attempt to relate the D_{50} (median grain size - μm) and several physical constants to observed unit discharge of sediment (q_s $\text{kg m}^{-2} \text{s}^{-1}$) in the flume. While he derived many such formulations, we found only four to produce usable results, as transport capacity is implemented in GSSHA. One advantage of using these methods is they require no parameter specifications. All parameters are calculated internally as follows.





Effective Stream Power

Stream Power ($\text{N m}^{-1} \text{s}^{-1}$)

$$w = \rho g q S_f$$

Density

Gravity

Unit Discharge

Friction slope

Effective Stream Power

$$\Omega = \frac{\omega^{1.5}}{R^{\frac{2}{3}}}$$

Unit Discharge ($\text{kg m}^{-1} \text{s}^{-1}$)

$$q_s = 4.6 \cdot 10^{-7} \Omega^{1.75} D_{50}^{-0.56}$$





Unit Stream Power

Unit Sediment Discharge
($\text{kg m}^{-2} \text{s}^{-1}$)

$$q_s = 0.316 (S_f Vel)^{2.59} D_{50}^{-0.39}$$

D_{50} in μm





Slope and Unit Discharge

$$D_{50} < 33 \quad q_s = 6.16595 (S_f)^{1.9} q^{1.1}$$

$$33 < D_{50} < 61 \quad q_s = 10.964 (S_f)^{1.94} q^{1.1}$$

$$61 < D_{50} < 122 \quad q_s = 9.332 (S_f)^{1.77} q^{1.79}$$

$$122 < D_{50} < 190 \quad q_s = 64.565 (S_f)^{2.96} q^{2.18}$$

$$D_{50} > 190 \quad q_s = 10.964 (S_f)^{1.94} q^{1.1}$$

D_{50} in μm

A decorative graphic at the bottom of the slide showing a splash of blue water with many bubbles.



Shear Velocity

Shear Stress (N m^{-2})

$$\tau = \rho g h S_f$$

Shear Velocity (m s^{-1})

$$u = \left(\frac{\tau}{\rho} \right)^{0.5}$$

$D_{50} < 33 \mu > 1.4$

$$q_s = 0.035 (u - 1.40)^{2.88}$$

D_{50} in μm

$33 < D_{50} < 61 \mu > 1.4$

$$q_s = 0.052 (u - 1.40)^{2.95}$$

$61 < D_{50} < 122 \mu > 1.45$

$$q_s = 0.029 (u - 1.45)^{3.74}$$

$122 < D_{50} < 190 \mu > 1.55$

$$q_s = 0.024 (u - 1.40)^{4.14}$$

$\mu > 1.8$

$$q_s = 0.0092 (u - 1.80)^{5.06}$$



Computation of D50

D_{50} is computed from the material properties in each overland cell. Each cell can/will have a unique distribution of particles and particle sizes that evolves over time as erosion and deposition occur. Assuming a semi-log distribution, the mean diameter is computed as (http://cirp.usace.army.mil/wiki/CMS-Flow_Multiple-sized_Sediment_Transport) :

$$d_k = \exp \left[\ln d_1 + \ln (d_N/d_1) \frac{k - 1}{N - 1} \right]$$





Particle Settling

Particle settling is calculated using the trap efficiency (Johnson, 2000) which describes the fraction of each particle size detained in the current cell

$$T_{Ei} = 1 - e^{\frac{-X\omega_i}{hV}}$$

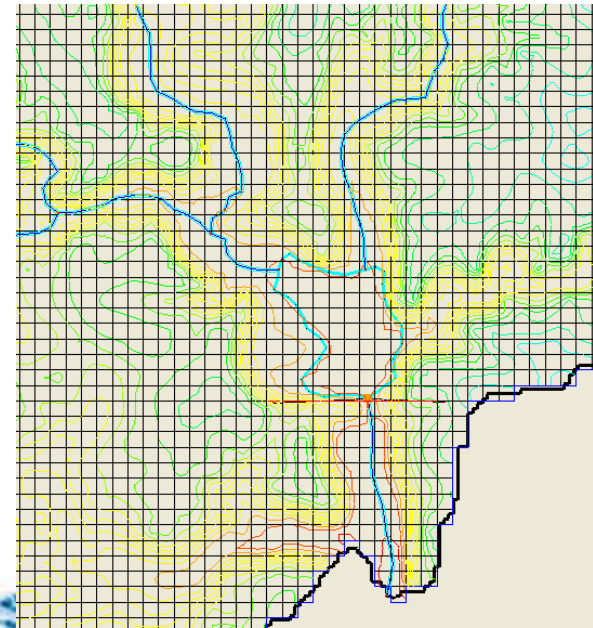
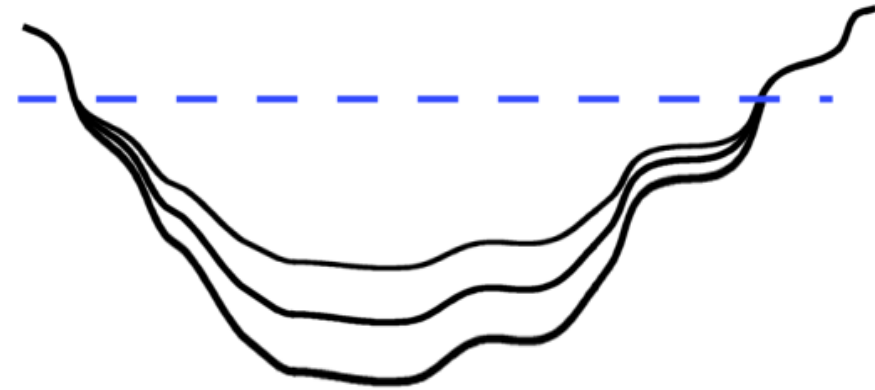
- T_{Ei} is the trap efficiency for the i^{th} size fraction,
- X is the grid cell size (m),
- ω_i is the fall velocity of the i^{th} size fraction (m s^{-1}),
- h is the overland flow depth (m), and
- V is the overland flow velocity (m s^{-1}).





Sediment in Streams

- Particles larger than sand (user specified) treated as bed load and routed with Yang's method
- Smaller particles treated as wash load – advection dispersion equation
- Stream cross sections adjusted for erosion and deposition
- Particles settle or can be passed through reservoirs





Interaction with Reservoirs

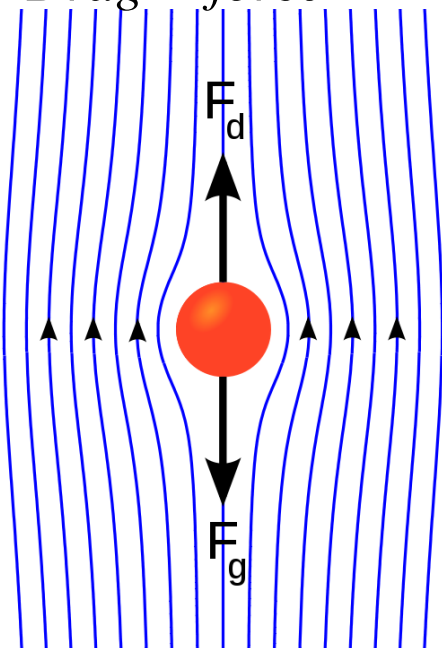
- Sands from overland plane into reservoir are deposited in boundary reservoir cells.
- Sands from upstream channel network are removed from system and accounted for.
- Fines from overland and channels are accounted in reservoir, and can flow through.
- Reservoir is a completely mixed reactor.
- Fines settle in overland cells within the reservoir.
- Fines are discharged at the reservoir outlet.





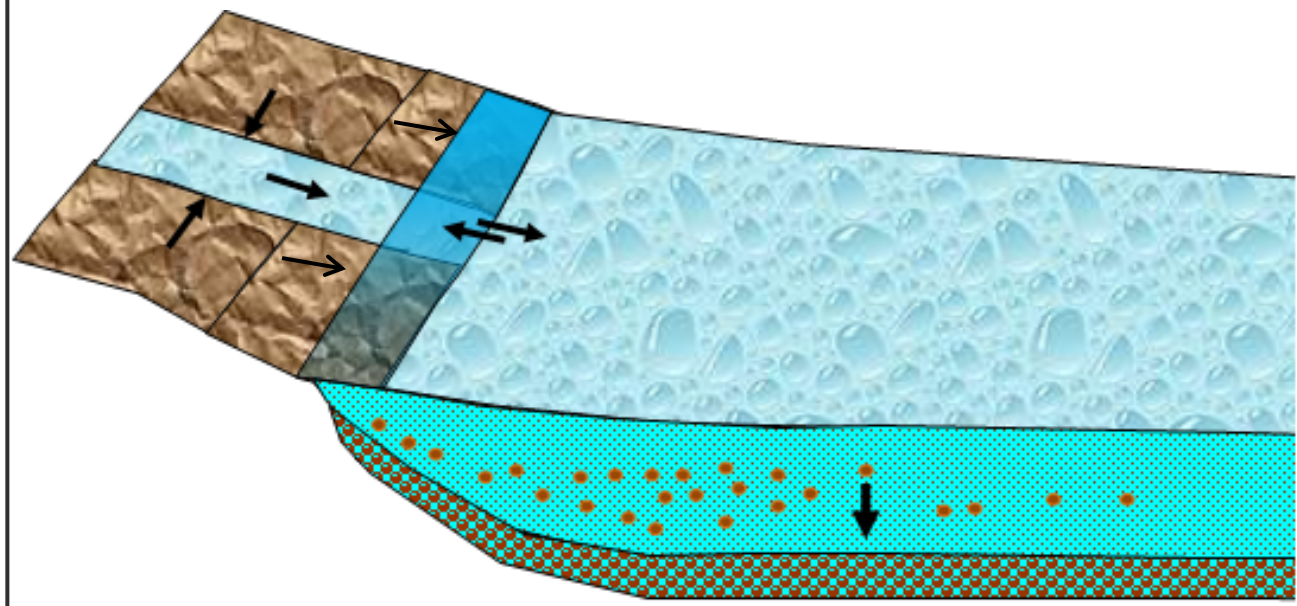
Interaction with Reservoirs

$W = F_b + D$
 $W = \text{Weight of object}$
 $F_b = \text{Buoyancy force}$
 $D = \text{Drag force}$



$$V_t[K] = \frac{gd^2}{18\mu(\rho_s - \rho)}$$

$$concentration[k] = \frac{suspended_volume[k]}{reservoir_volume}$$



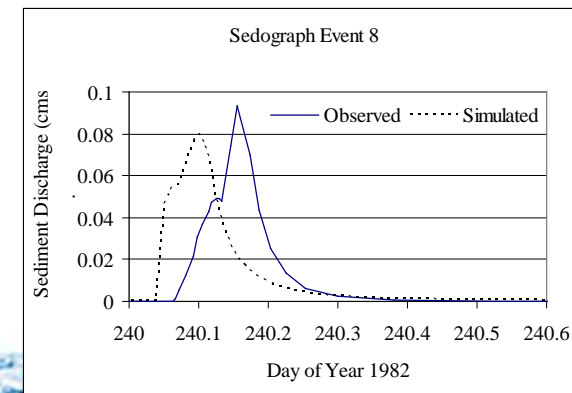
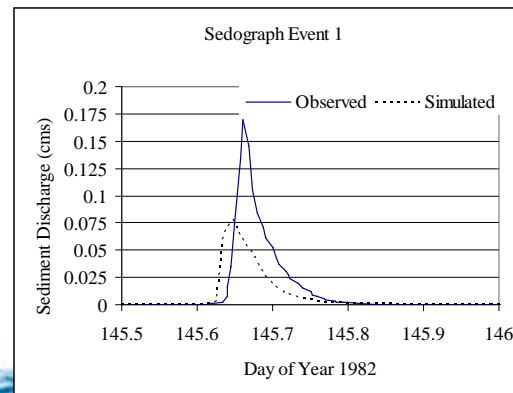
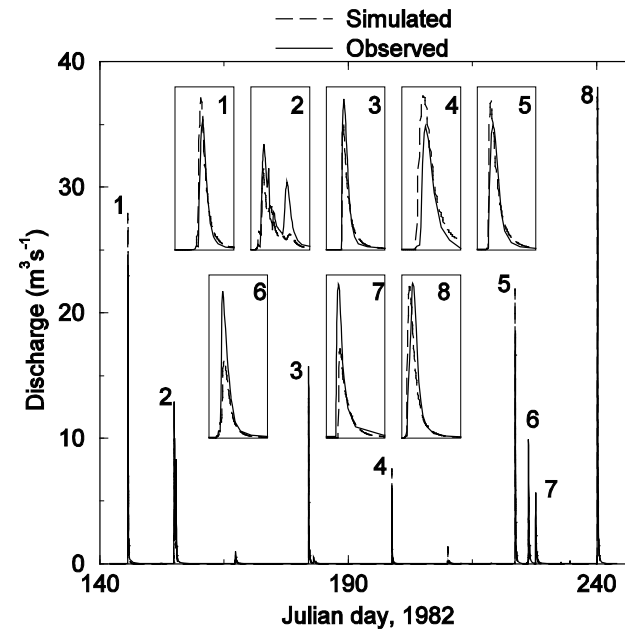
$$settled_vol[k] = concentration[k] \cdot V_t[k] \cdot dt \cdot reservoir_area$$

The settled volume is uniformly distributed over all cells currently within the lake.



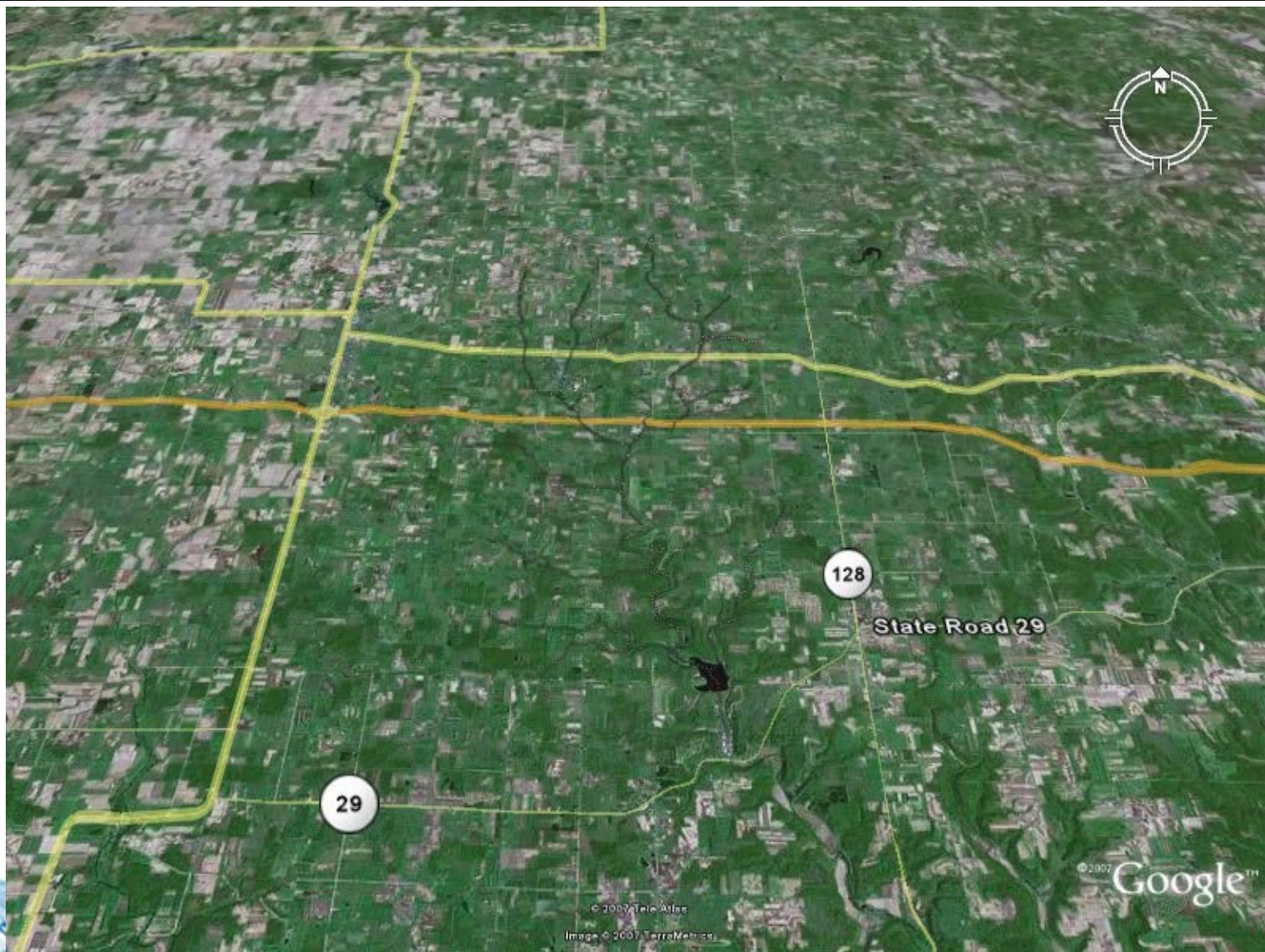
Continuous Simulations

- 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





Eau Galle Sediment Transport





Simulating Sediment Transport

- Select Sediment erosion in the job properties.
- Specify the transport capacity method.
- Specify the distributions of particle sizes and specific gravities.
- Specify the sediment erosion parameters.
 - Index map
 - Mapping table
- Specify the fraction of each particle size in each soil type.
 - Index map
 - Mapping table
- Set the stream erosion parameters.
 - Water temperature
 - Maximum erosion in each stream link
 - Particle size of sand
 - All particles sand size or larger will be treated as bed load
 - All particles smaller than sand size are treated as wash load.



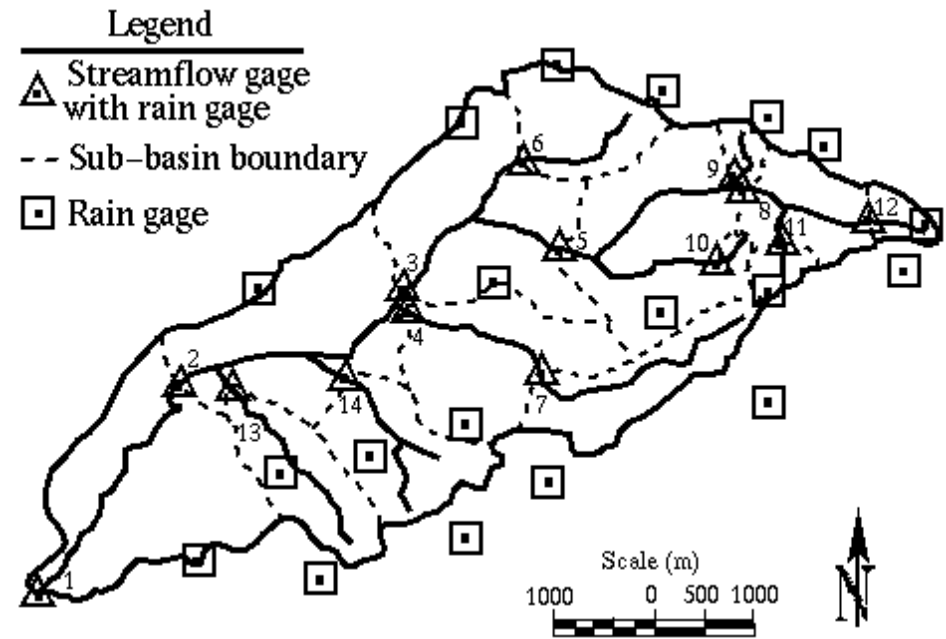


Example

Goodwin Creek
Experimental Watershed
near Oxford, Mississippi,
est. 1981.

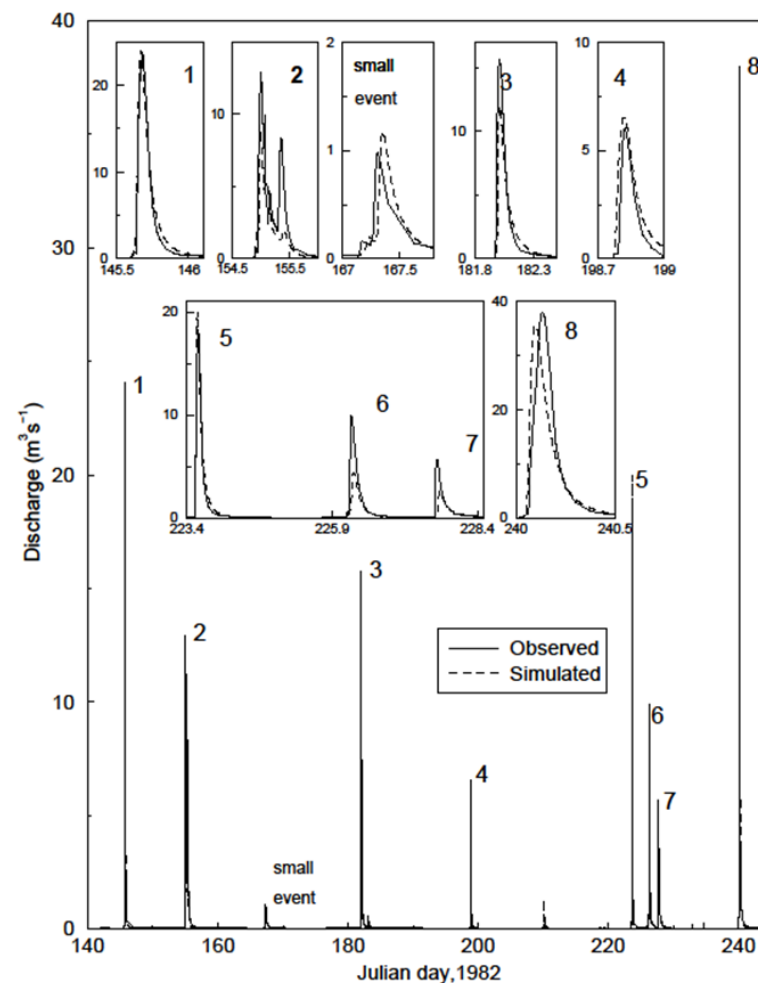
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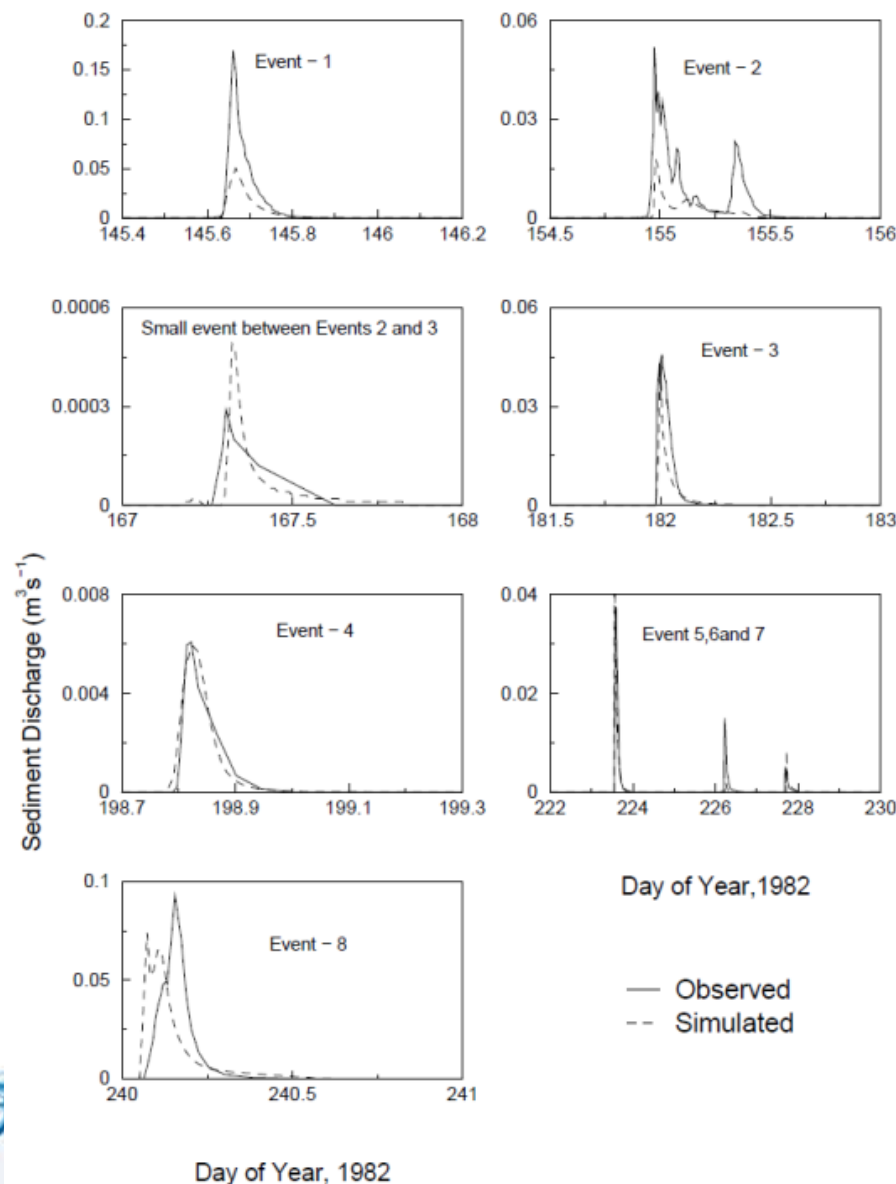


GSSHA Model Hydrologic Performance





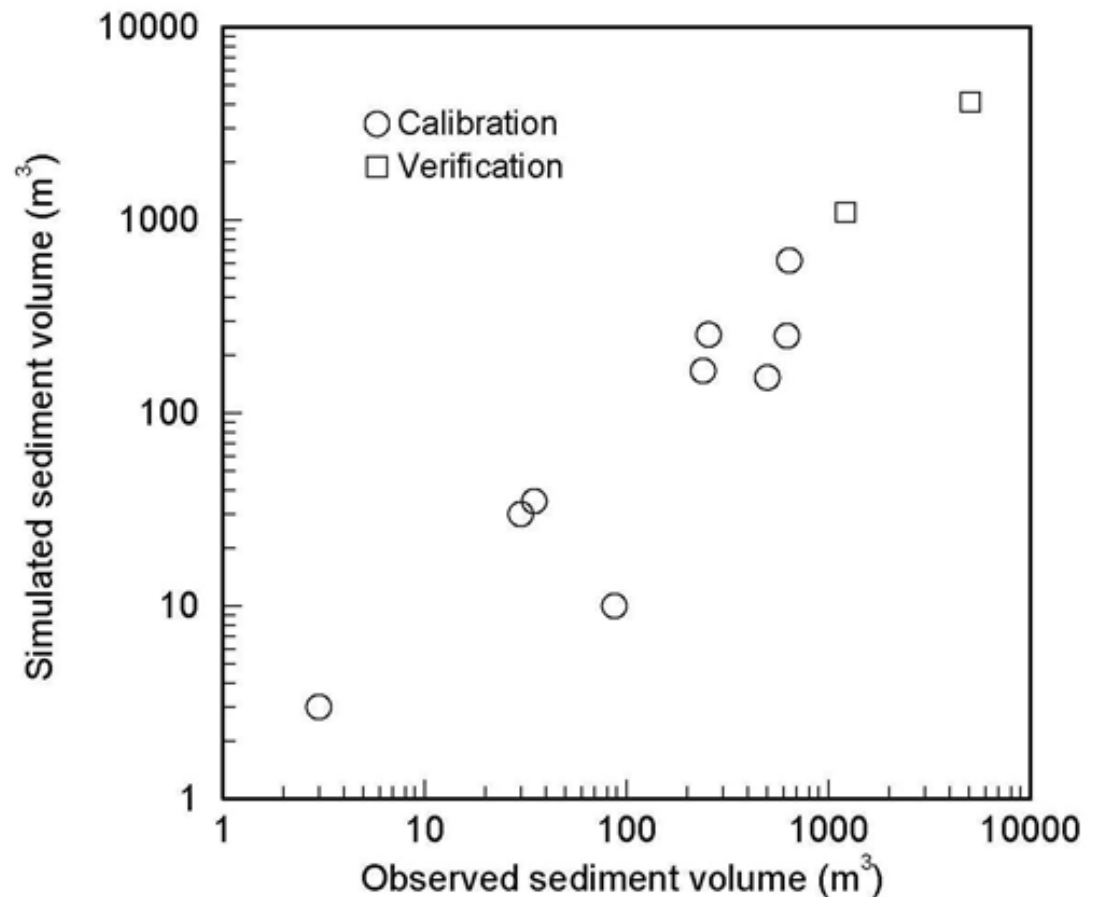
Suspended Sediment Calibration/Verification Results





Extended Calibration/Verification Results

- Included two additional large events in verification period.
- Four orders of magnitude in event size.
- Mean absolute error across all events is 28%.
- No real trend between event size and accuracy.





Recommendations

- If the particle is not silica based, the specific gravity is not 2.65, you must use the England-Hansen equation.
- If you have observed sediment data to calibrate to, use the Kilinc-Richardson equation.
- If you have no observed sediment data to calibrate to, use the slope-unit discharge equation.





Additional Information

- Chapter 10 of the User's Manual on the GSSHA wiki.
- Downer, C. W., F. L. Ogden, N. R. Pradhan, S. Liu, and A. R. Byrd. 2010. Improved soil erosion and sediment transport in GSSHA. *ERDC TN-SWWRP-10-3*, U.S. Army Engineer Research and Development Center, Vicksburg, MS.
<https://swwrp.usace.army.mil/>
- Downer, C. W., N. R. Pradhan, F. L. Ogden, and A. R. Byrd, 2014. Testing the effects of detachment limits and transport capacity formulation on sediment runoff predictions using the US Army Corps of Engineers GSSHA model. *JHE*, 04014082 1-11, doi: 10.1061/(ASCE)HE.1943-5584.0001104.





Current Developments

- Currently reworking the in-stream sediment transport formulation
- The advection-dispersion equation will be used for all particle sizes
- Linking GSSHA with the SEDLIB model for in-stream sediment erosion and deposition processes
- Should be available in 2018

