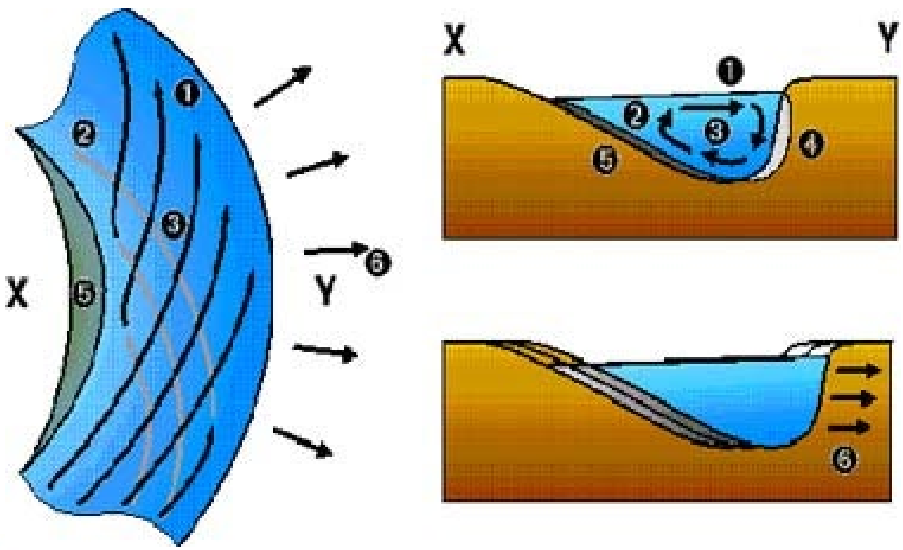
Simulating Stream Flow in GSSHA

Stream Flow

- Concentrated, dynamic flow
- 1D, 2D, and 3D flow patterns, depending on stream size, shape, flow

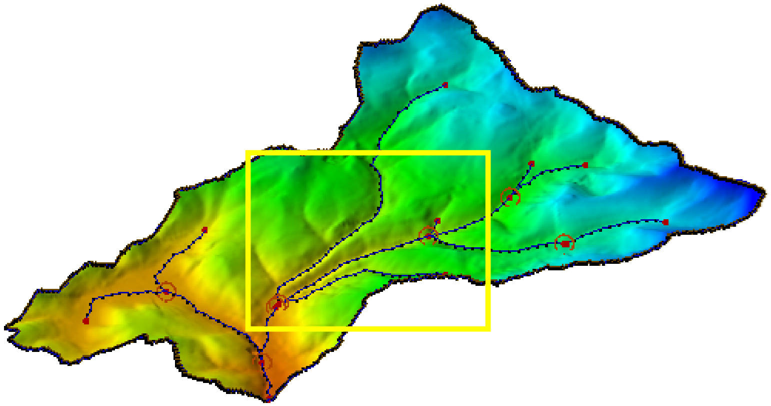


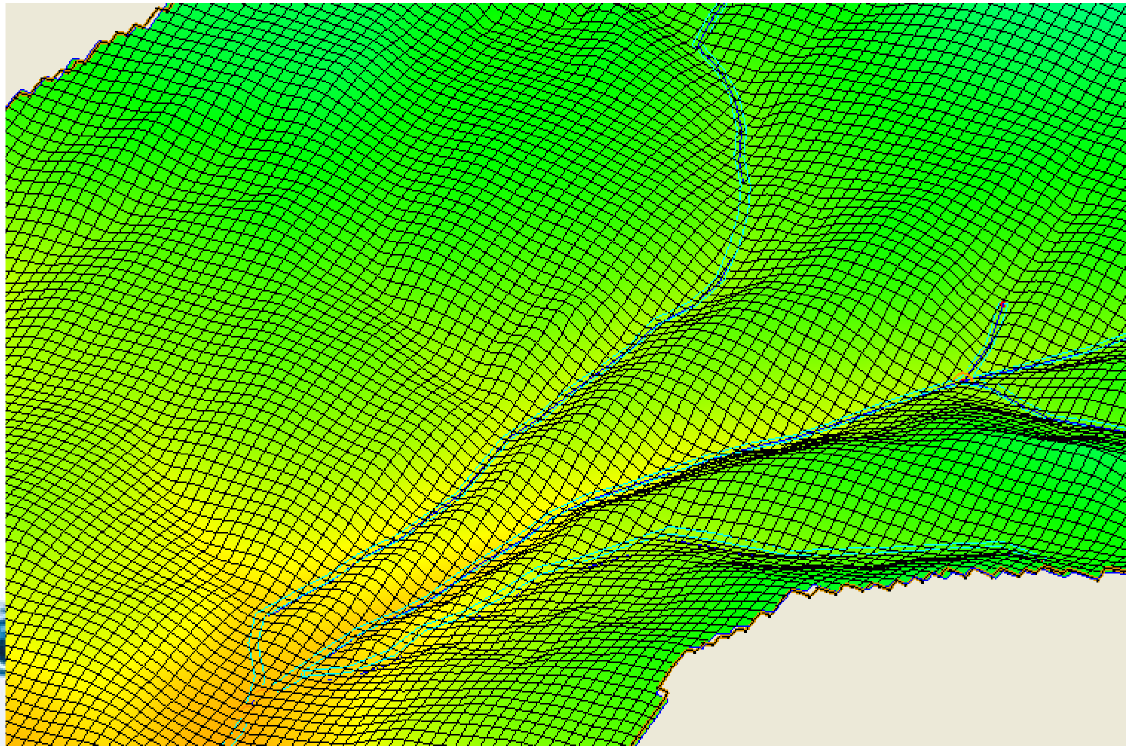
Stream Flow Generation Mechanism

- Overland flow
- Groundwater/interflow
- Storm surge, tidal cycles

Stream Flow in GSSHA

- 1D network of links (reaches) containing nodes (cells)
- Links represent stream reaches of uniform properties.
- Computations are performed on the nodes.





Stream Networks in GSSHA

- 1D channel flow
  - Trapezoidal
  - Natural (Break-point)
- Detention basins / reservoirs
- Hydraulic structures
  - Broad crested weirs
  - Culverts
  - Rating curves
  - Rule curves
  - Scheduled releases

Calculation of Flow

- Shallow water wave equations in one direction (x)

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial x}\left[\frac{q^2}{h}\right] + \frac{gh\partial(h+z)}{\partial x} + \frac{gn^2q^2}{h^{7/3}}$$

Acceleration Advection Pressure Friction

$q =$ unit flow
$h =$ depth
$z =$ elevation
$n =$ roughness
$t =$ time
$x =$ distance

- If the pressure term is large compared to the other terms then

$$\frac{gh\partial(h+z)}{\partial x} = 0$$

- Which can be rearranged to put into what is called the diffusive wave equation

Equations

- Manning's Equation (Uniform open channel flow)

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

- Friction Slope (Diffusive Wave)

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

$$= \Delta x \,(node\, size)$$

- Continuity

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

$$= \Delta t \,(time\, step)$$

Scheme Properties

- Does not require continuous media (avoiding wet/dry issues)
- Avoids problems with shocks found in dynamic and kinematic flow equations
- Diffusion smooths transitions in flow
- Captures backwater effects
- Can be used to bring in outside boundary conditions (tidal surge)
- Has some issues
  - Manning roughness is not constant with depth
  - Can smear the water surface profile near transitions
  - Because the flow has no momentum, flow direction can change due to only small changes in water surface elevation, can become a problem

Inertial Formulation

- Shallow water wave equations in one direction (x)

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial x}\left[\frac{q^2}{h}\right] + \frac{gh\partial(h+z)}{\partial x} + \frac{gn^2q^2}{h^{7/3}}$$

Acceleration Advection Pressure Friction

- If we ignore advection, this can be rewritten as:

$$q_{t+\Delta t} = \frac{q_t - gh_t\Delta t S_f}{1 + gh_t\Delta t n^2/h_t^{10/3}}$$

- Substituted for q based on the Manning formula for the continuity equation
- In theory, is more stable for flooded conditions because giving the water momentum should reduce rapid flow direction changes

Solution

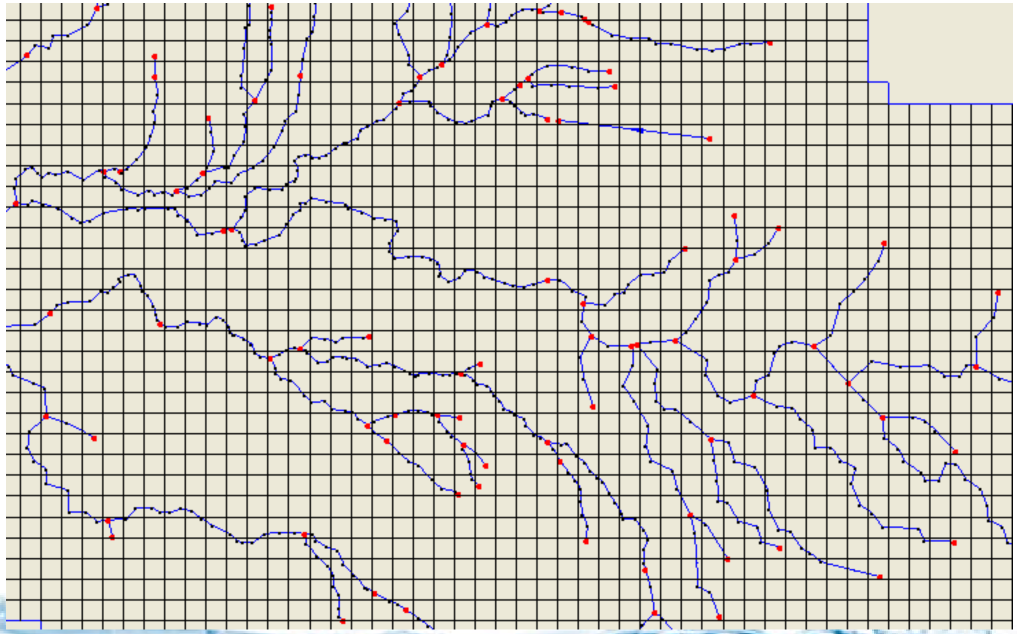
- Finite volume method
- Forward weighted (dependent on flow direction)
- Variable time step dependent on stability criteria
- Predictor-corrector method
  - Fluxes estimated from initial heads
  - Intermediate heads estimated from flow
  - Fluxes calculated with new heads
  - Two fluxes averaged
  - Heads updated with new fluxes
- Picard iterations until flow areas converge

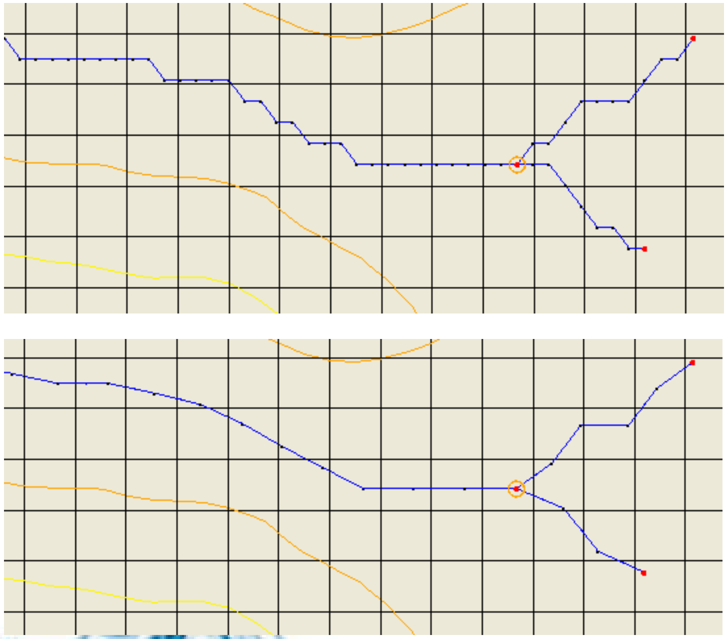
Links

- Links represent a stream reach of uniform area.
- Transitions between cross sectional areas in links should be smooth.
- Include enough links to avoid abrupt changes in cross section or slope.

Selecting Node Size

- Small enough to capture required sinuosity.
- Large enough for numerical efficiency.
  - Channel flow tends to be a limiting factor in computational considerations





Data Needs

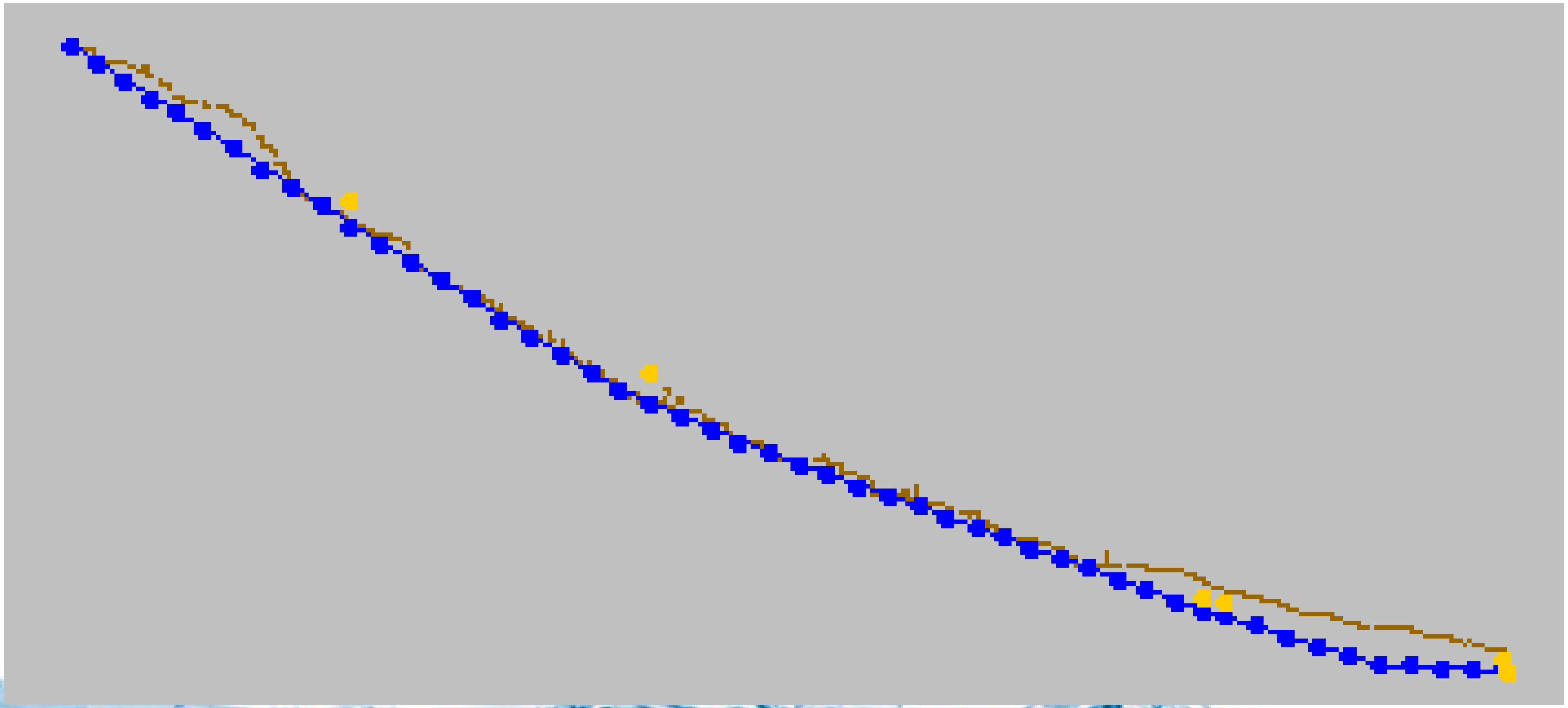
- Channels
  - Cross-section profile
  - Thalweg profile
  - Roughness
- Detention Basins
  - Min, Max, Initial water surface elevation
- Hydraulic Structures
  - Geometry, hydraulic coefficients

Data Sources

- Stream locations
  - GIS data
  - Derived from DEM data
- Stream shape
  - Surveyed data
  - Estimated
- Stream Roughness
  - Estimated from photos, calibrated

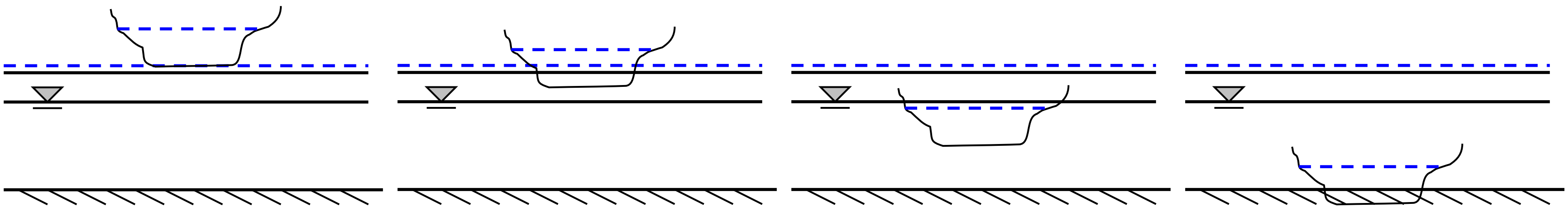
Vertical Thalweg Profile

- Can be estimated relative to the land surface
- Must be relatively smooth, may contain small adverse slopes



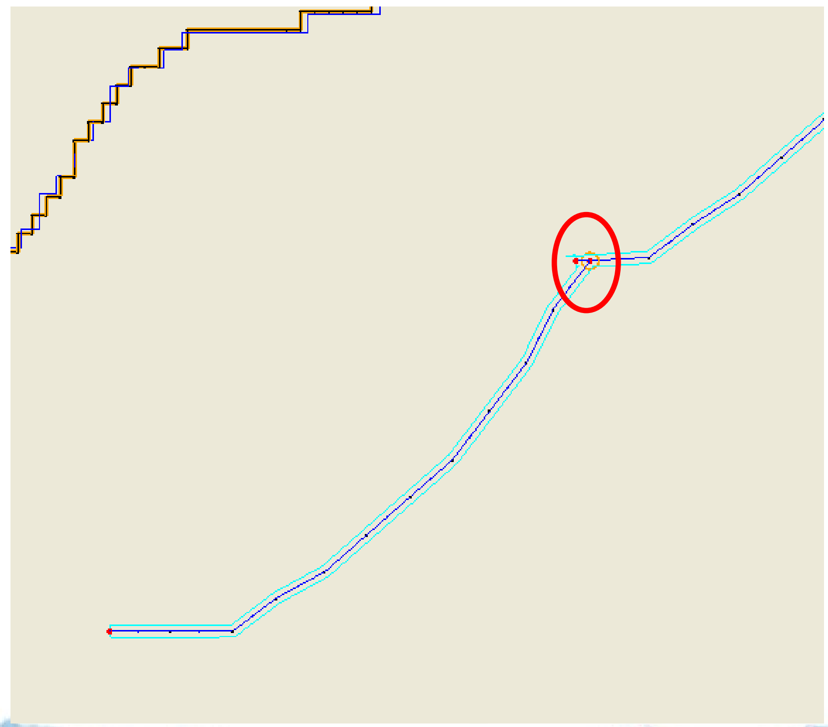
Integrating the Channel Model: Vertical Location

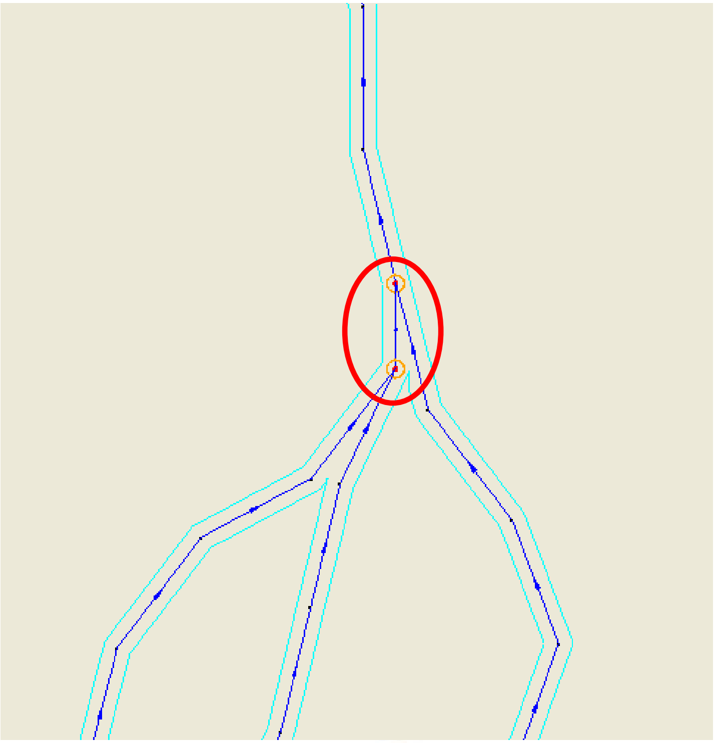
- Full interaction with:
  - Overland flow
  - Groundwater



Integrating the Channel Model: Horizontal Location

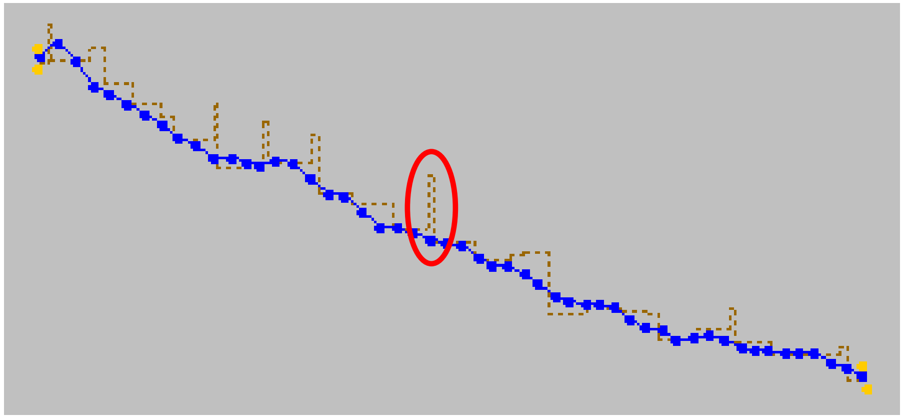
- Remove very short streams (1 node streams)

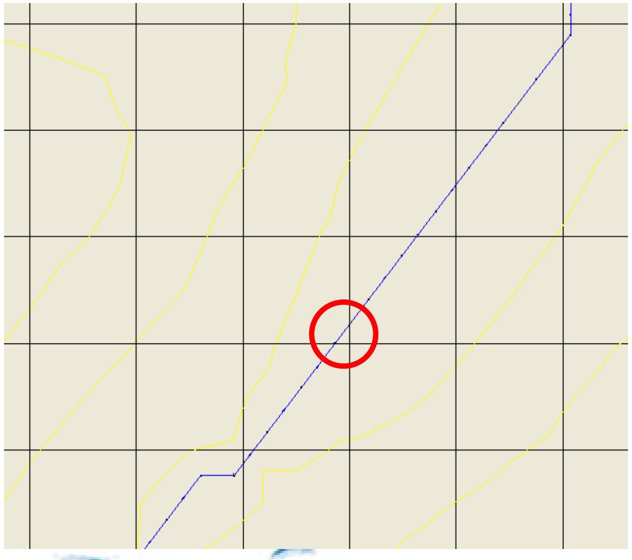




Integrating the Channel Model: Horizontal Location

- Adjust nodes laterally to lie in lowest nearby cells
- Caused by cell size differences between DEM and GSSHA grids.





Start Simple, Build on Success

- Start with the main channel.
- Add lower order streams as necessary.
- Stop adding lower order streams when the addition of more streams no longer affects the observations of interest.

Eau Galle River, Wisconsin