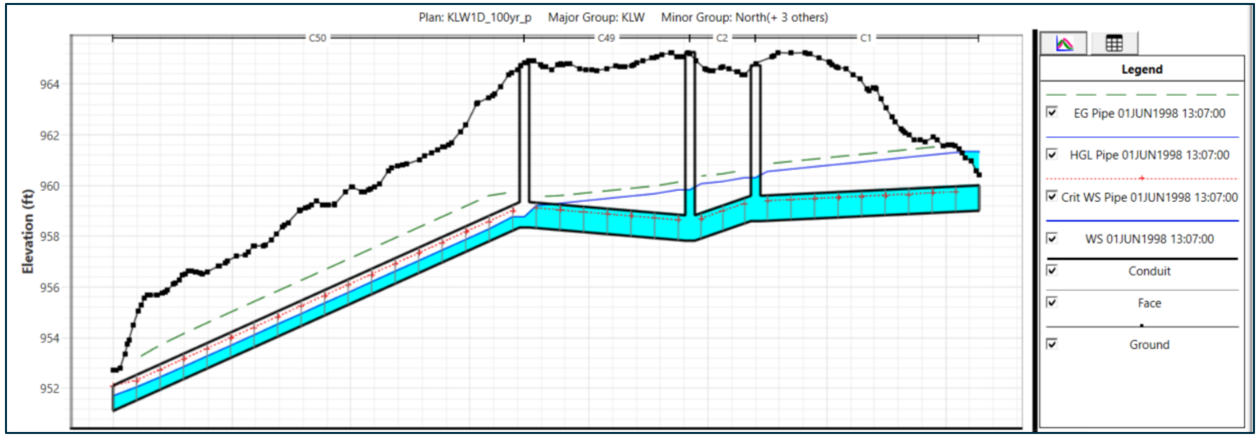
Improved Urban Drainage Modeling in HEC-RAS



California Water and Environmental Modeling Forum
2025 Annual Meeting
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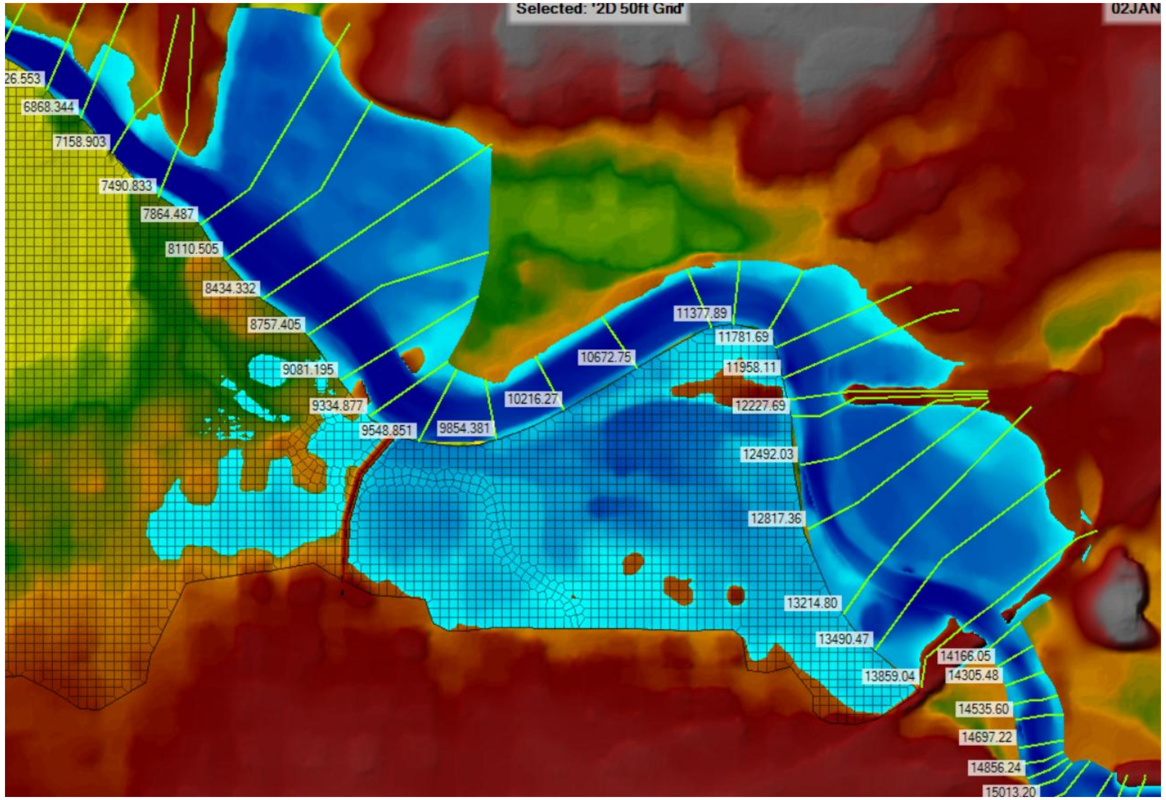
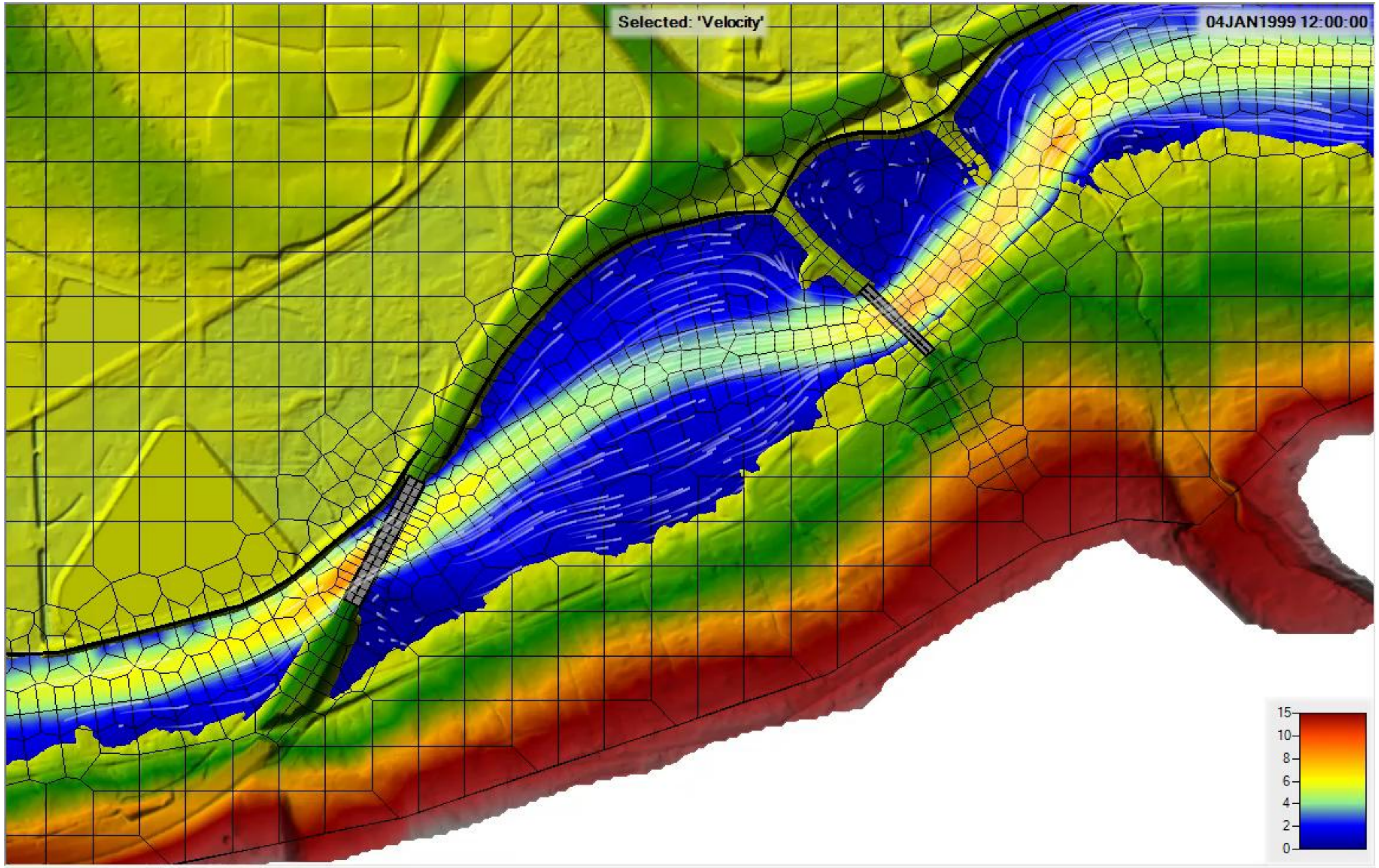
HEC-River Analysis System (RAS)

- Among industry leaders in surface water hydraulic modeling
  - 1D, 2D steady, unsteady flow
  - Floodplain and floodway analyses
  - Dam and levee safety
  - Compound flooding
  - Hydraulic structures
  - Sediment transport, erosion, water quality
- Extensively used by USACE, FEMA, state and local agencies, industry
- Free
- Supported by a great team at HEC

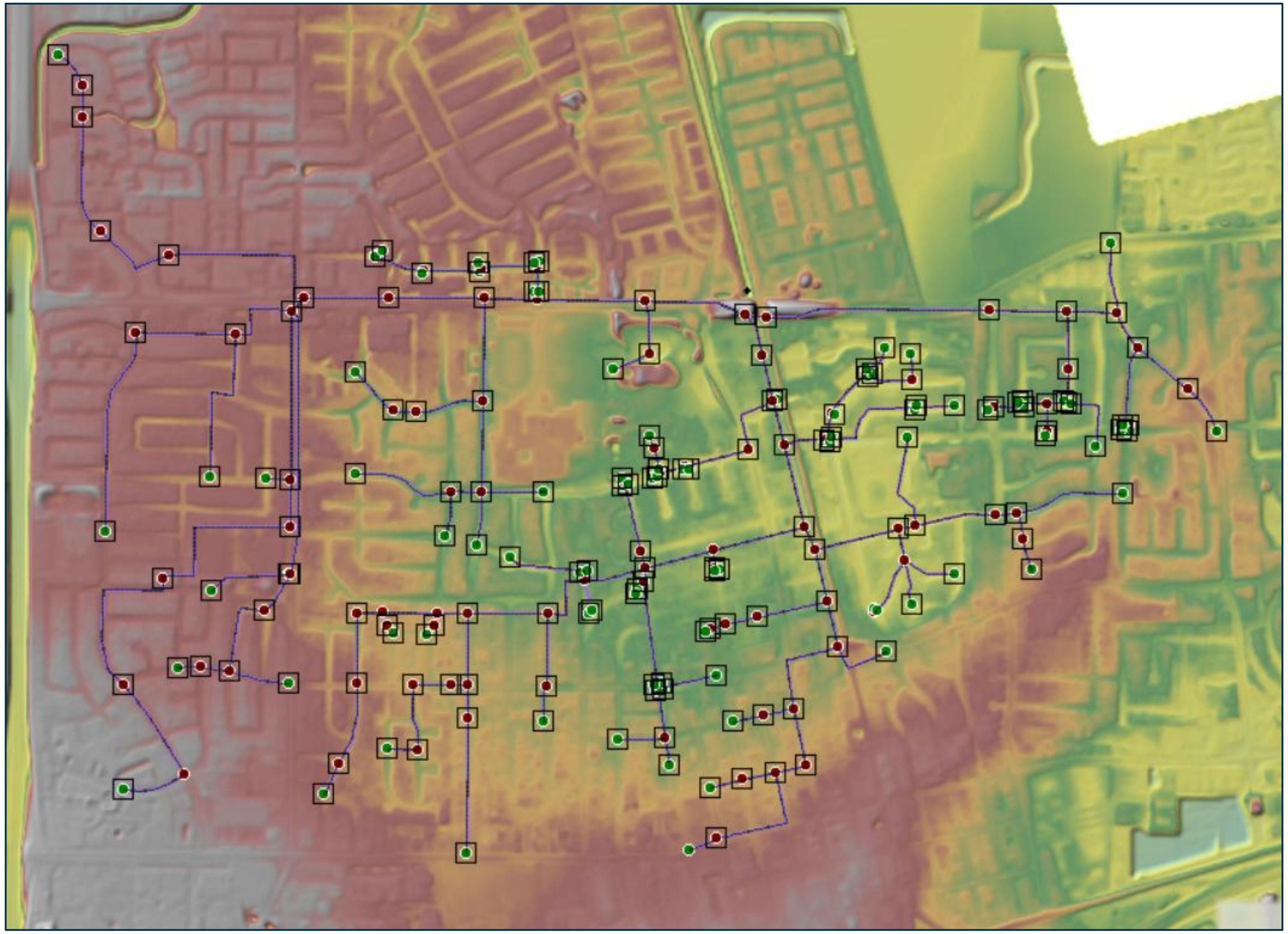


2D Modeling Example



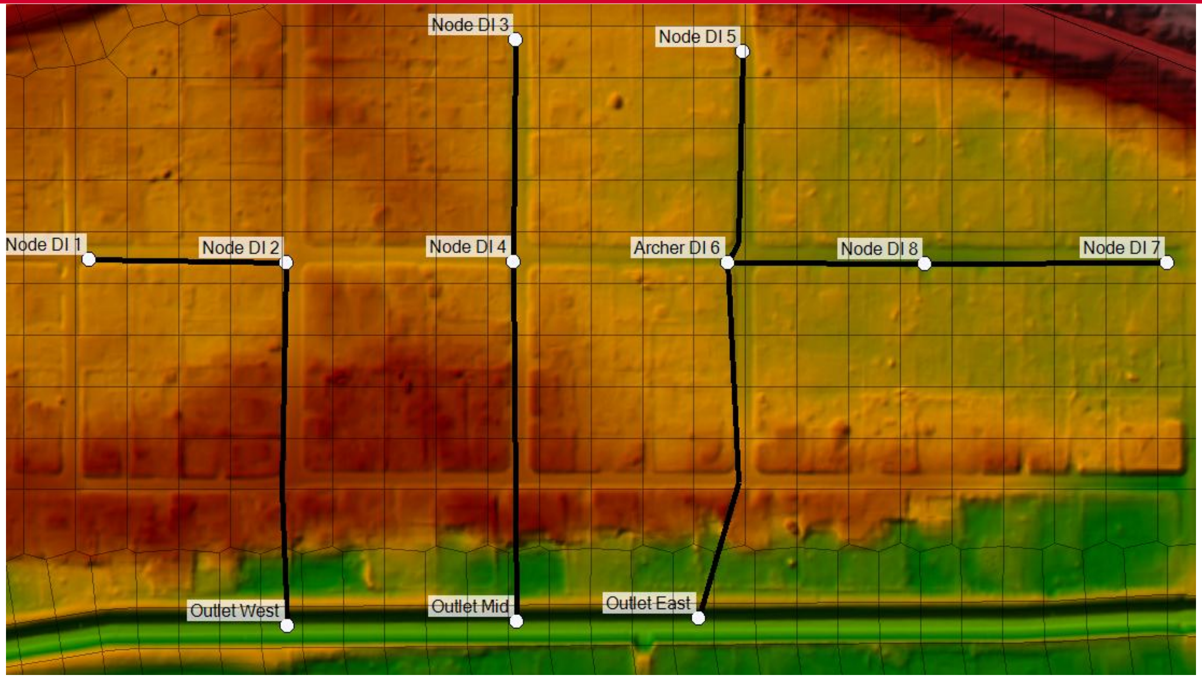
Pipe Networks

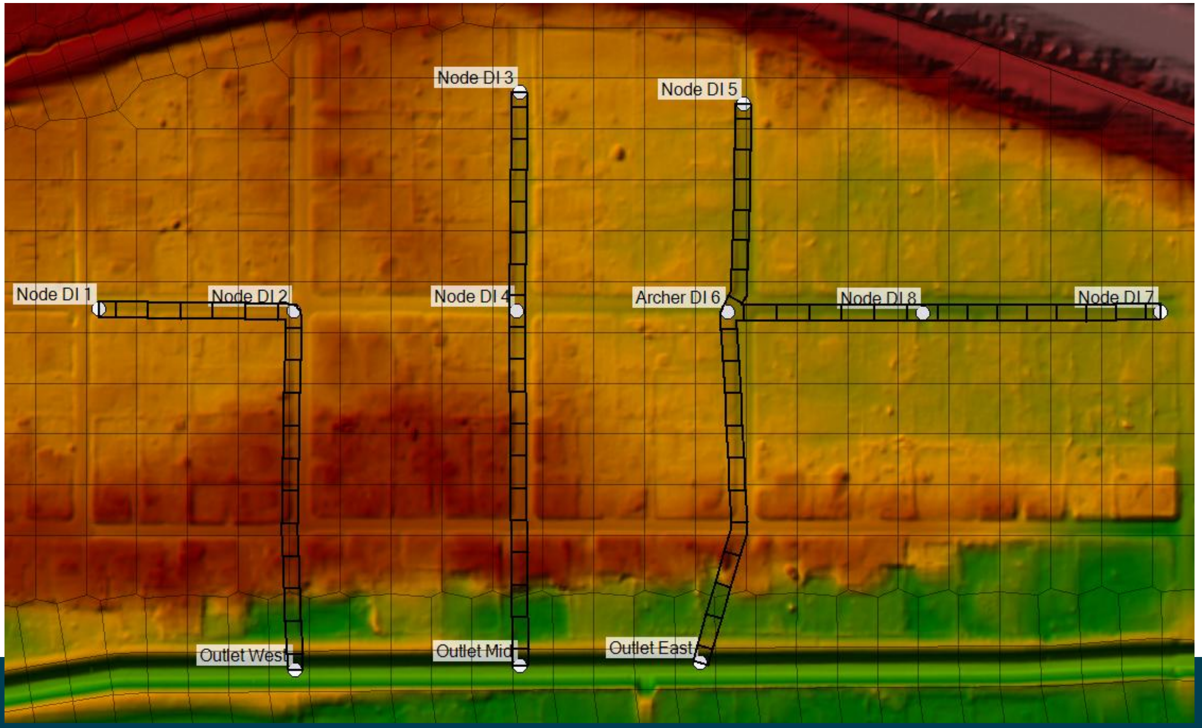
- Added in RAS 6.6
- Replace existing guidance to use Preissman slot approximation
- Short term goal
  - Chicago deep pipe system
- Longer term goals
  - Integration with surface models
  - Improve urban and suburban drainage modeling
  - Assess pluvial flood risk
  - Analyze adequacy of stormwater systems



Computational Methodology

- *Nodes* and *Conduits* GIS layers define pipe geometry
- Pipe network mesh: create cell property tables (just like 2D cells)
- RAS 1D finite volume solver
  - Diffusion wave, full shallow water eqns
  - Modified for pressurized flow
- Accounts for:
  - Losses through system (entrance/exit)
  - Drop inlet and culvert openings
  - Mainline only system modeling





Open Channel Finite Volume Flow Solver

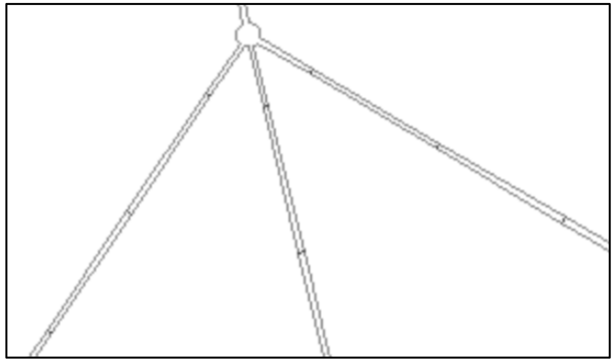
Mass Conservation

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

Momentum Conservation

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} = -g\frac{\partial H}{\partial x} - \frac{\tau_b}{\rho R} - \frac{F_{ML}}{\rho A}$$

Discretize on a mesh



$$\Omega_i^{n+1} + a_{i,i-1} z_{s,i-1}^{n+1} + a_{i,i} z_{s,i}^{n+1} + a_{i,i+1} z_{s,i+1}^{n+1} = b_i$$

$$a_{i,i-1} = -\frac{\Delta t^2 \theta^2 g A_k^{n+\theta}}{(1+\Delta t c_{f,k}^{n+\theta})\Delta x_{e,k}}$$

$$a_{i,i+1} = -\frac{\Delta t^2 \theta^2 g A_{k+1}^{n+\theta}}{(1+\Delta t c_{f,k+1}^{n+\theta})\Delta x_{e,k+1}}$$

$$a_{i,i} = -a_{i,i-1} - a_{i,i+1}$$

$$b_i = \Omega_i^n + \Delta t Q_i + \Delta t \theta \left(F_k A_k^{n+\theta} - F_{k+1} A_{k+1}^{n+\theta}\right) + \Delta t (1-\theta) \left(V_k^n A_k^{n+\theta} - V_{k+1}^n A_{k+1}^{n+\theta}\right)$$

$$F_k = \frac{B_k^n}{1+\Delta t c_{f,k}^{n+\theta}}$$

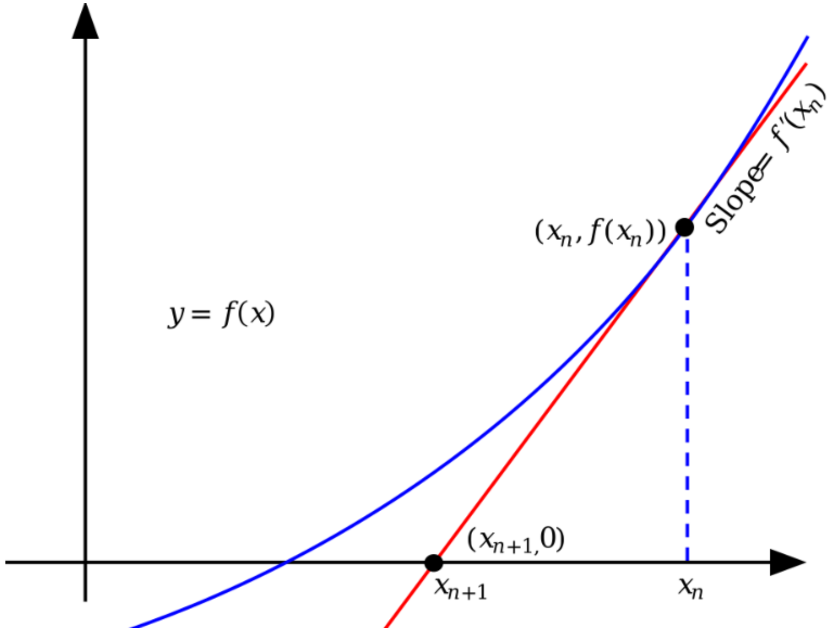
$$B_k^n = V_X^n - (1-\theta)\Delta t g \frac{z_{s,i}^n - z_{s,i-1}^n}{\Delta x_e} - \Delta t g S_{h,k} + \Delta t \nu_{t,k}^n \left(\frac{\partial^2 V}{\partial x^2}\right)_X^n + \Delta t \frac{\tau_{s,k}}{\rho h_k^n}$$

Matrix Equation

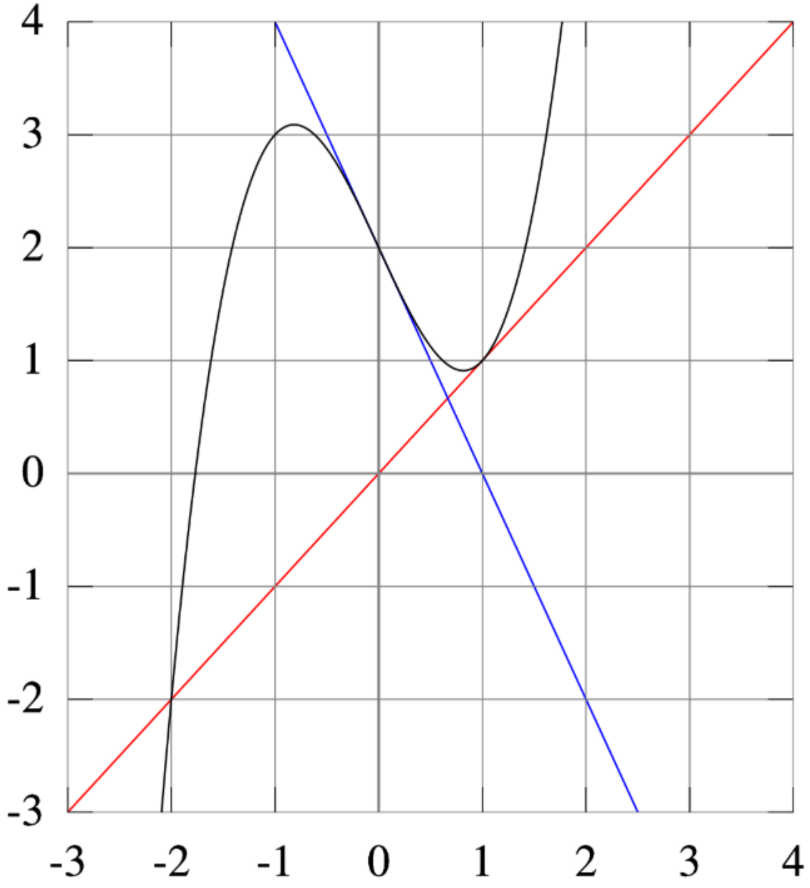
$$\boldsymbol{\Omega}(\boldsymbol{Z}) + \boldsymbol{\Psi}\boldsymbol{Z} = \boldsymbol{b}$$

Solve using Newton's Method

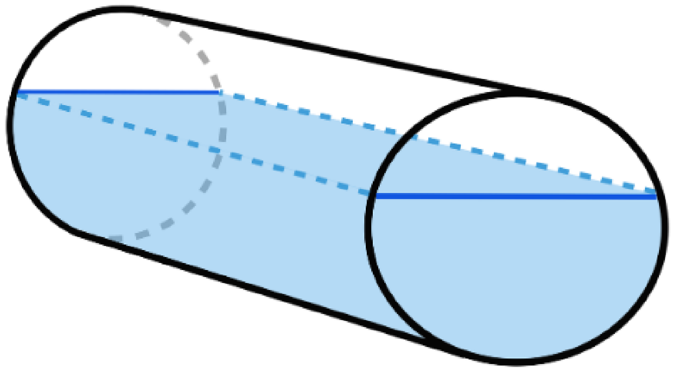
$$\boldsymbol{Z}^{m+1} = \boldsymbol{Z}^m - \left[\boldsymbol{\Psi} + \boldsymbol{A}^m\right]^{-1} \left(\boldsymbol{\Omega}^m + \boldsymbol{Z}^m - \boldsymbol{b}\right)$$



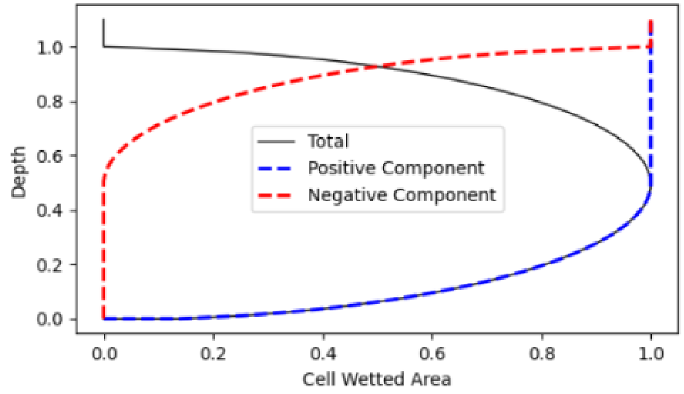
Pressurized Finite Volume Flow Solver

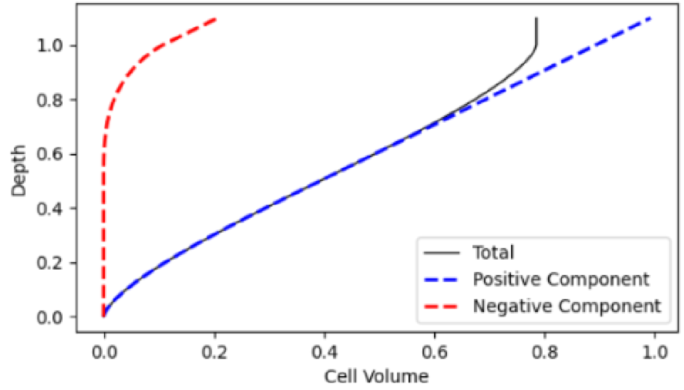


Non-convergence of Newton's Method



Decompose Property Tables into Positive and Negative Contributions





$$\boldsymbol{\Omega}^{+}(\boldsymbol{H}) + \boldsymbol{\Omega}^{-}(\boldsymbol{H}) + \boldsymbol{\Psi}\boldsymbol{H} = \boldsymbol{b}$$

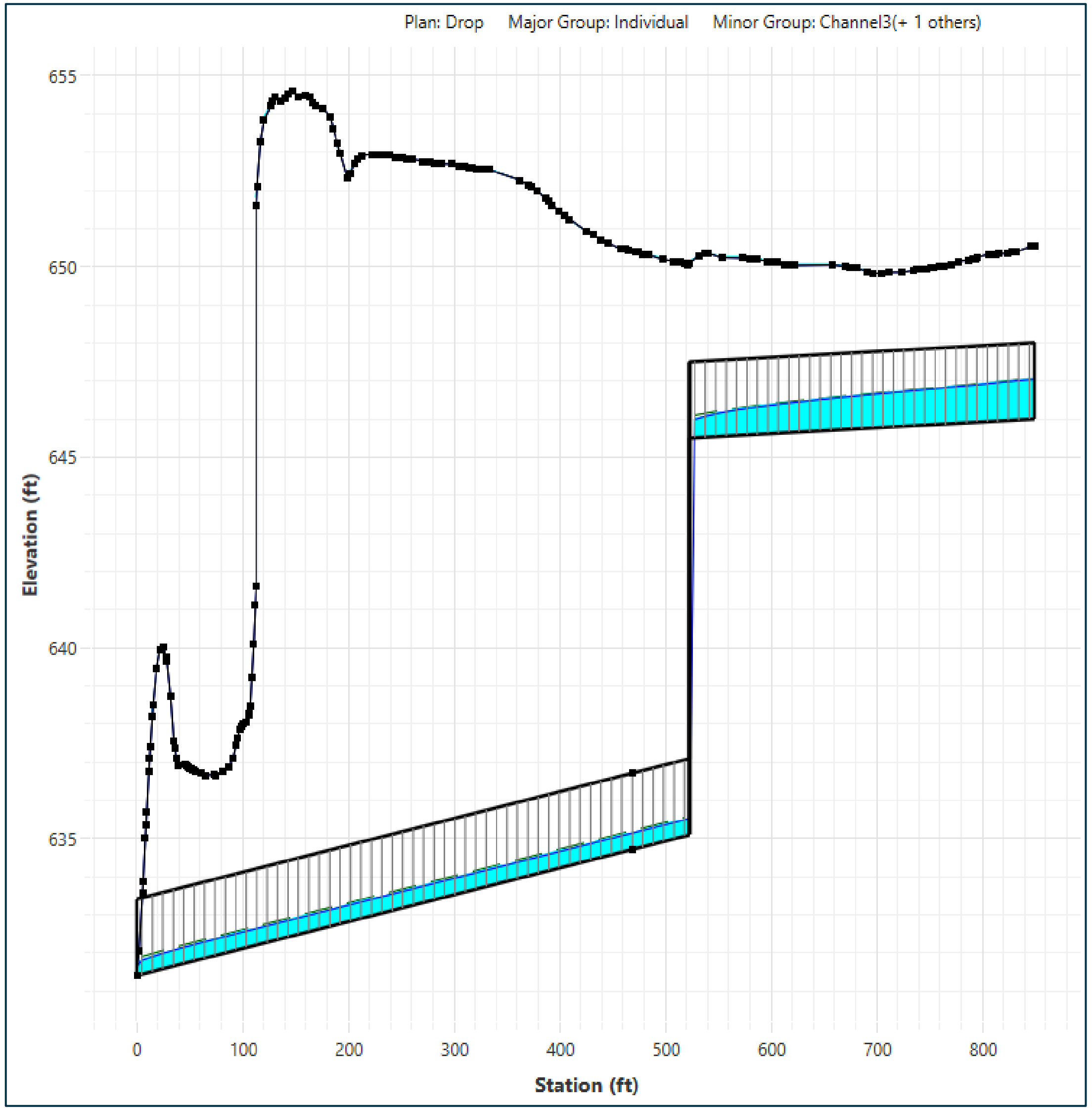
Solve with Nested Iterations (Casulli and Stelling, 2013)

$$\boldsymbol{\Omega}^{-}(\boldsymbol{H}^{m+1}) = \boldsymbol{\Omega}^{-}(\boldsymbol{H}^{m}) + \boldsymbol{A}^{-}(\boldsymbol{H}^{m})(\boldsymbol{H}^{m+1} - \boldsymbol{H}^{m})$$

$$\boldsymbol{\Omega}^{+}(\boldsymbol{H}^{m+1,k+1}) = \boldsymbol{\Omega}^{+}(\boldsymbol{H}^{m+1,k}) + \boldsymbol{A}^{+}(\boldsymbol{H}^{m+1,k})(\boldsymbol{H}^{m+1,k+1} - \boldsymbol{H}^{m+1,k})$$

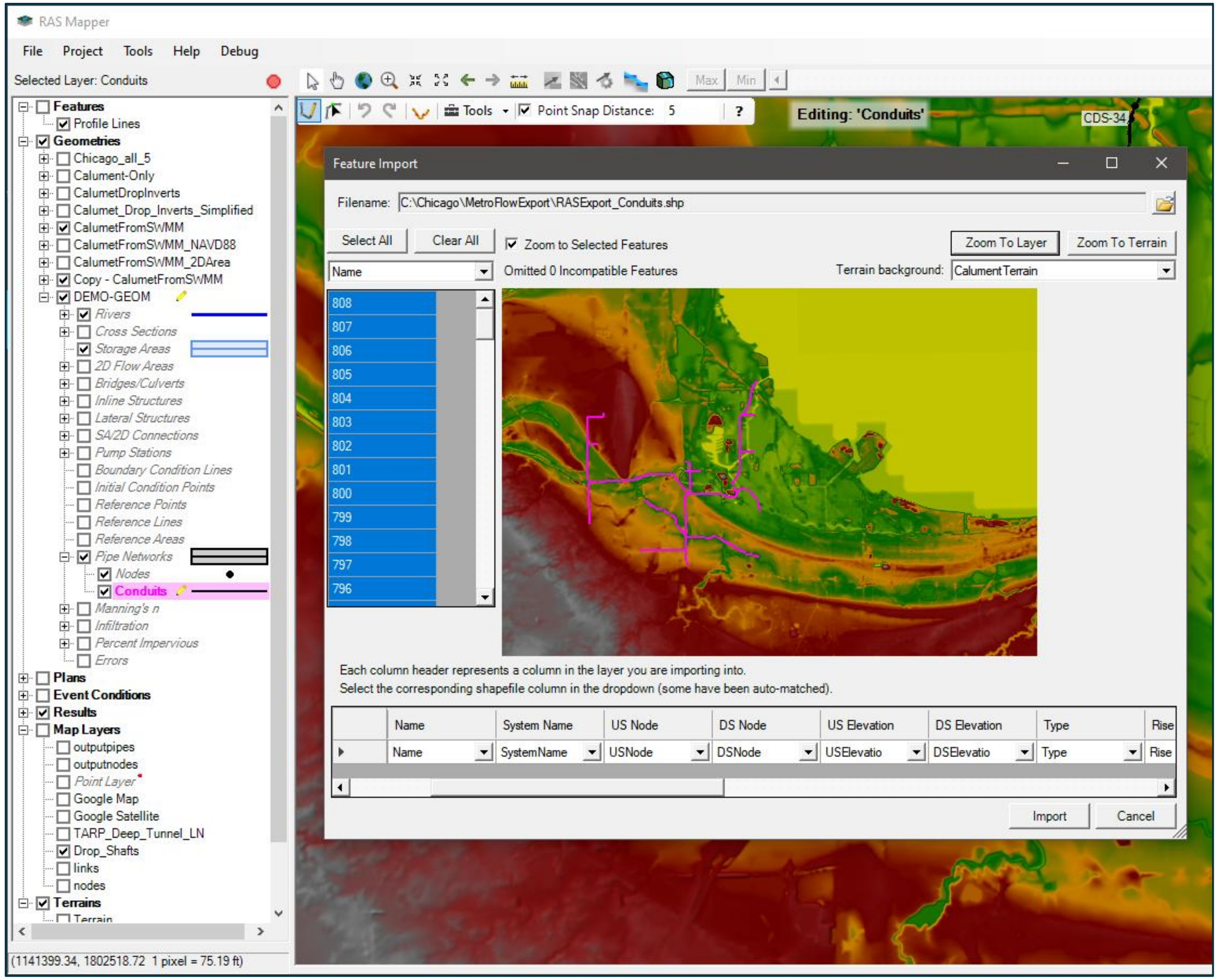
Computational Methodology

- Advantages
  - Wetting/drying
  - Flow transitions
    - Sub/super-critical, pressurized/unpress
  - Plunging flow into junctions
  - Stability with steep pipes
  - Variable system discretization
  - Transient flow computation
- Disadvantages
  - Longer compute times than simpler approaches
  - No pressure transients explicitly modeled (e.g., the water hammer effect)

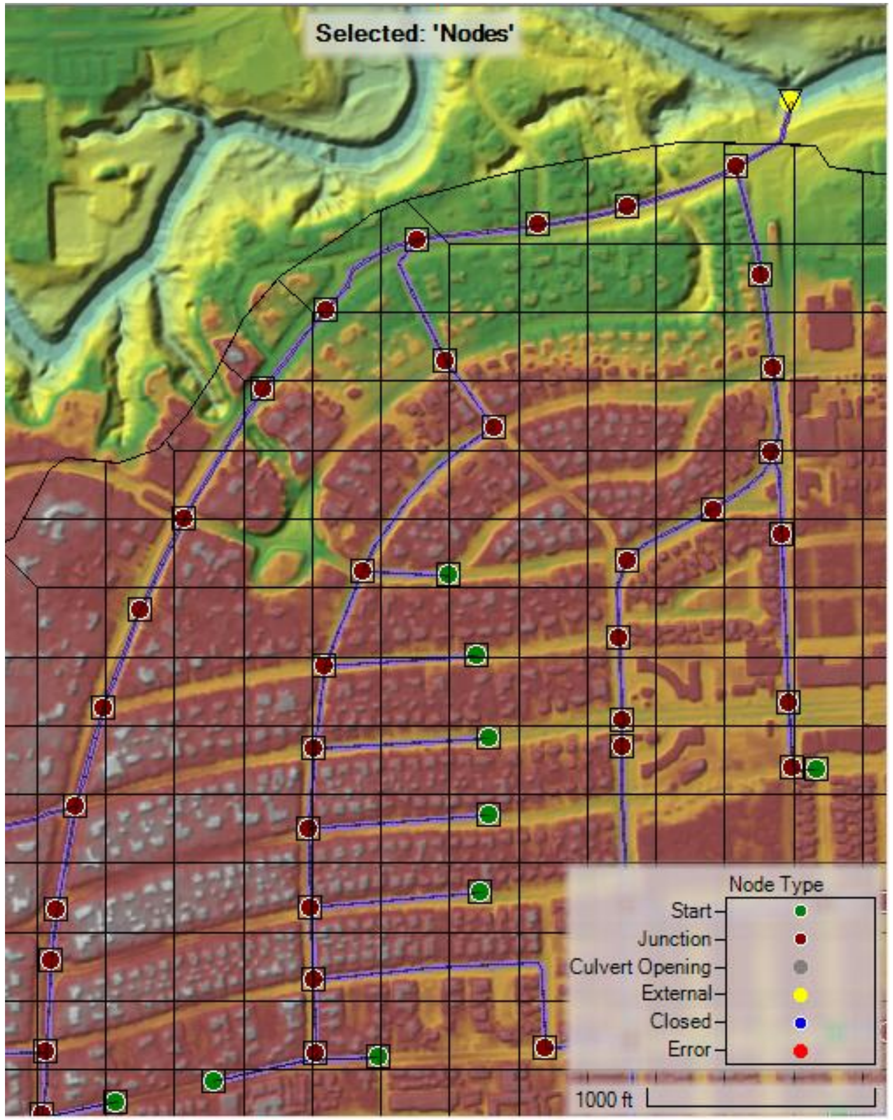


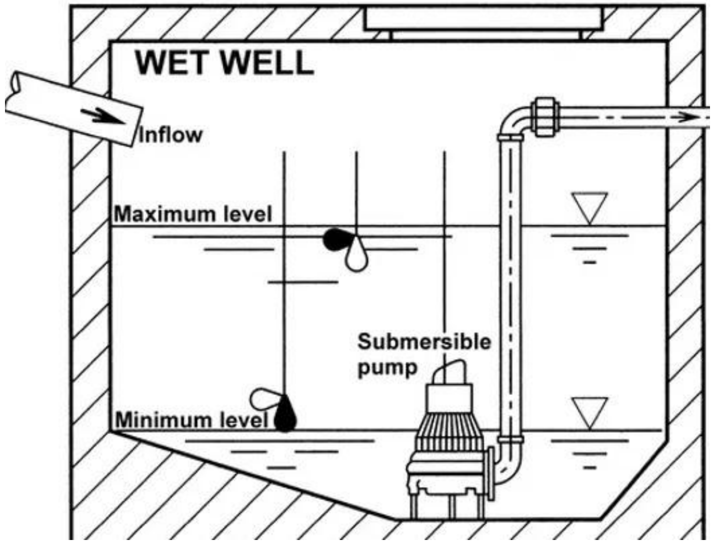
Creating a Pipe Network

- Use existing GIS database
  - Import shapefiles
  - Remap attribute fields
- Import EPA-SWMM based models
  - Industry standard for stormwater modeling
- Draw from scratch in right in RAS



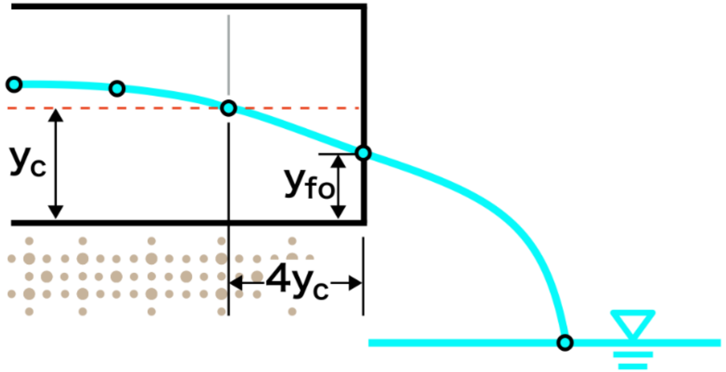
Boundary Conditions – Surface Connections

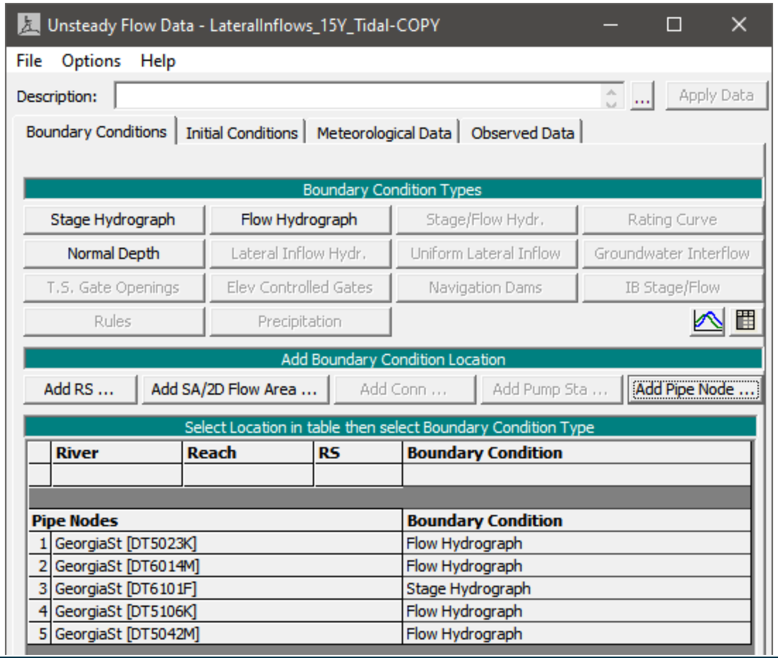


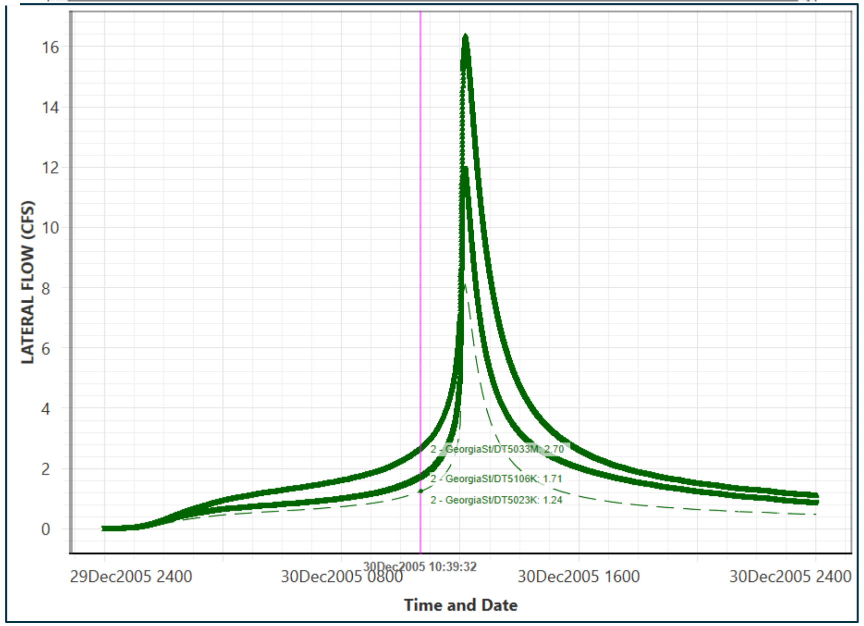


Boundary Conditions - External

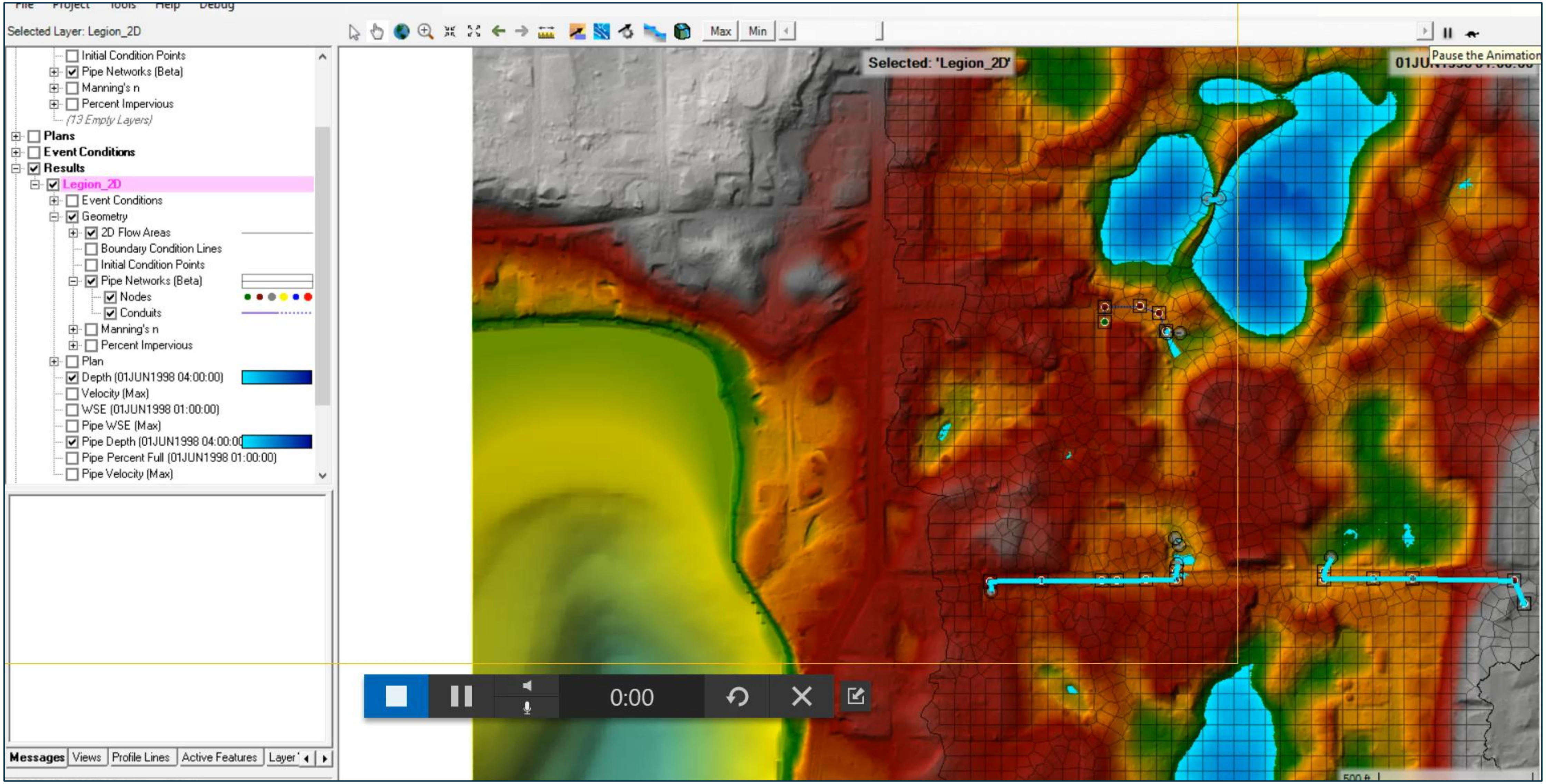
- Applied at nodes
- Types
  - Flow Hydrograph
  - Stage Hydrograph
  - Normal Depth
- Allows use of data from external sources or models
  - Watershed model inputs, e.g.





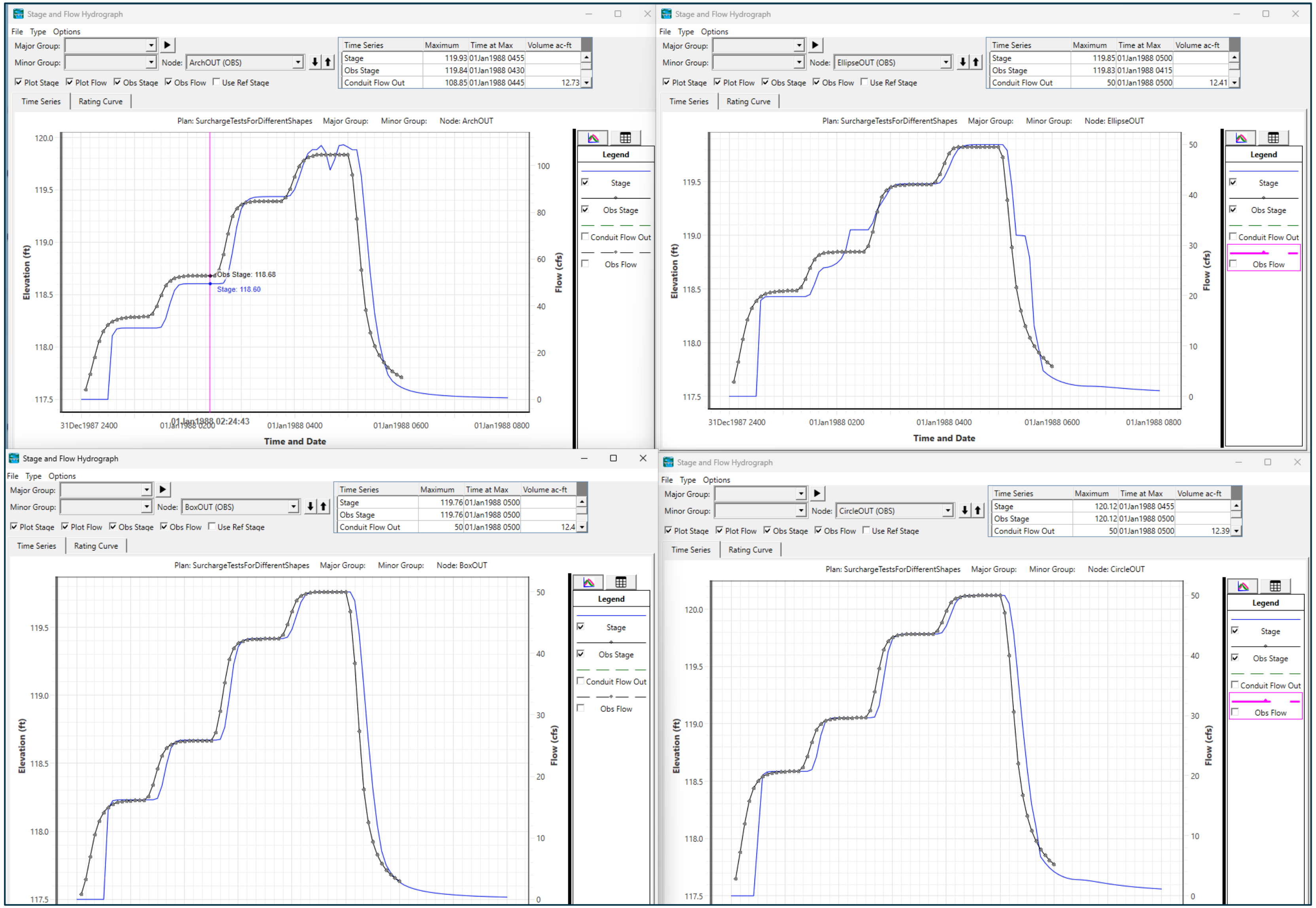


Results Visualization in RAS Mapper



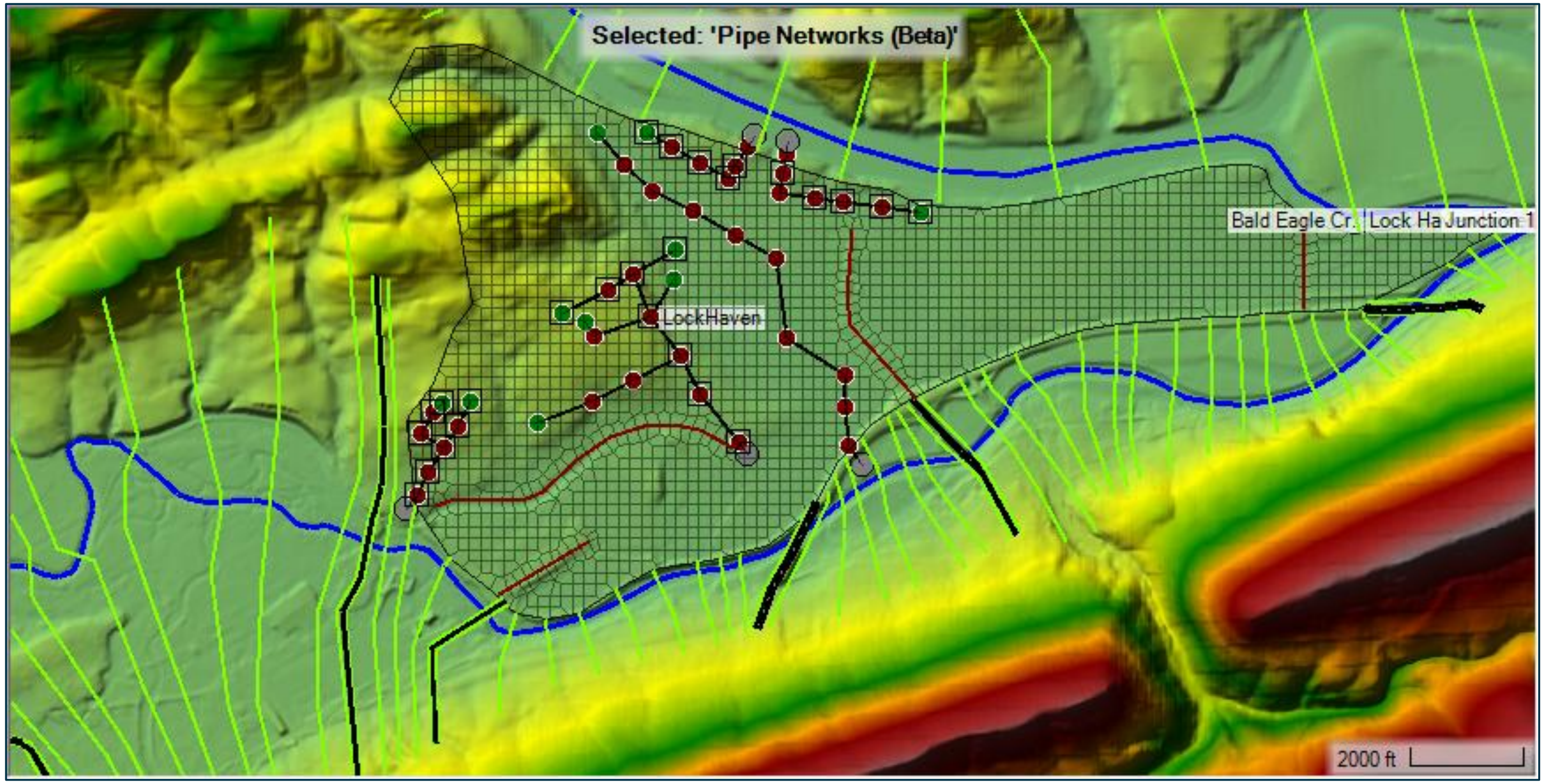
Testing

- Analytical test cases
- Field datasets
- SWMM results comparisons



Outcomes

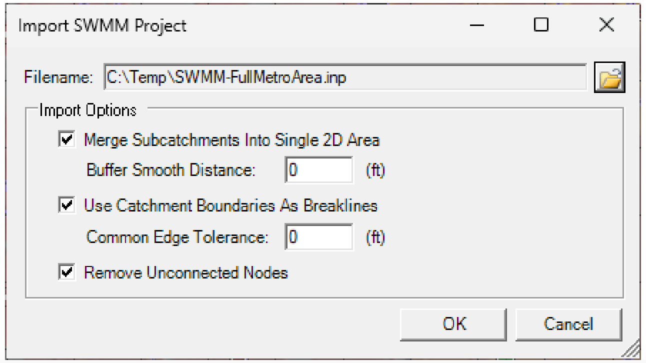
1. More accurate riverine + stormwater flood modeling
   - Replace need for separate models and complex, iterative linking

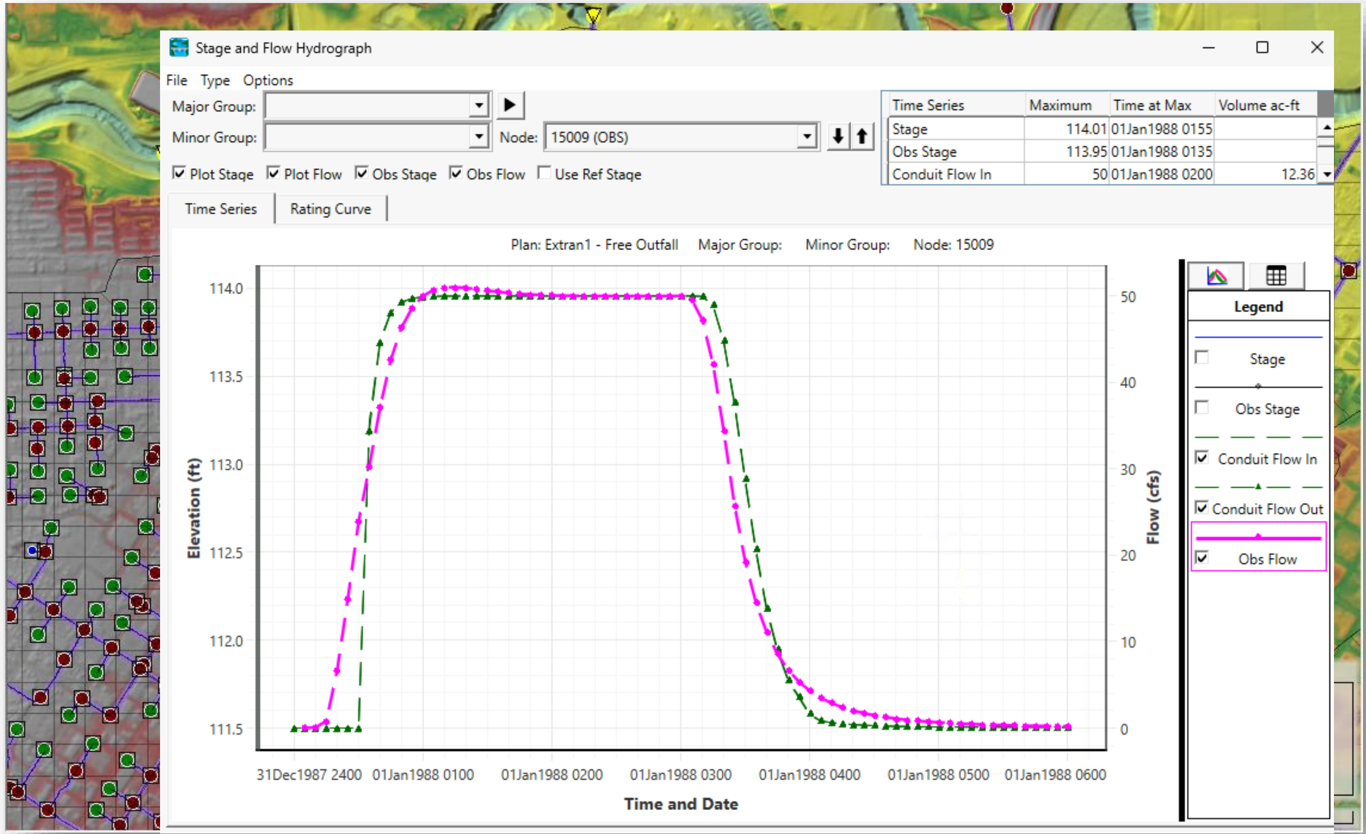


Outcomes

2. Leverage existing HEC-RAS, EPA-SWMM based models, and GIS data

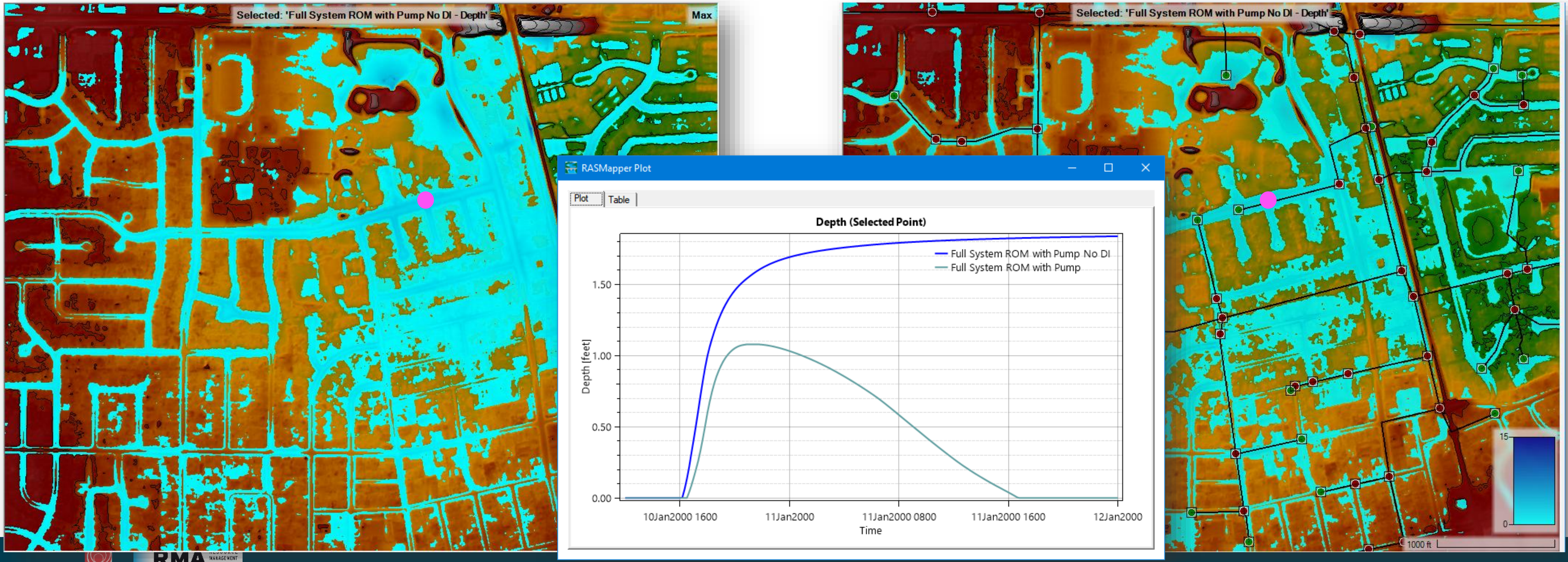
- Import tools
  - SWMM / GIS geometry importer
  - SWMM results importer
- Free
  - No managing expensive licenses





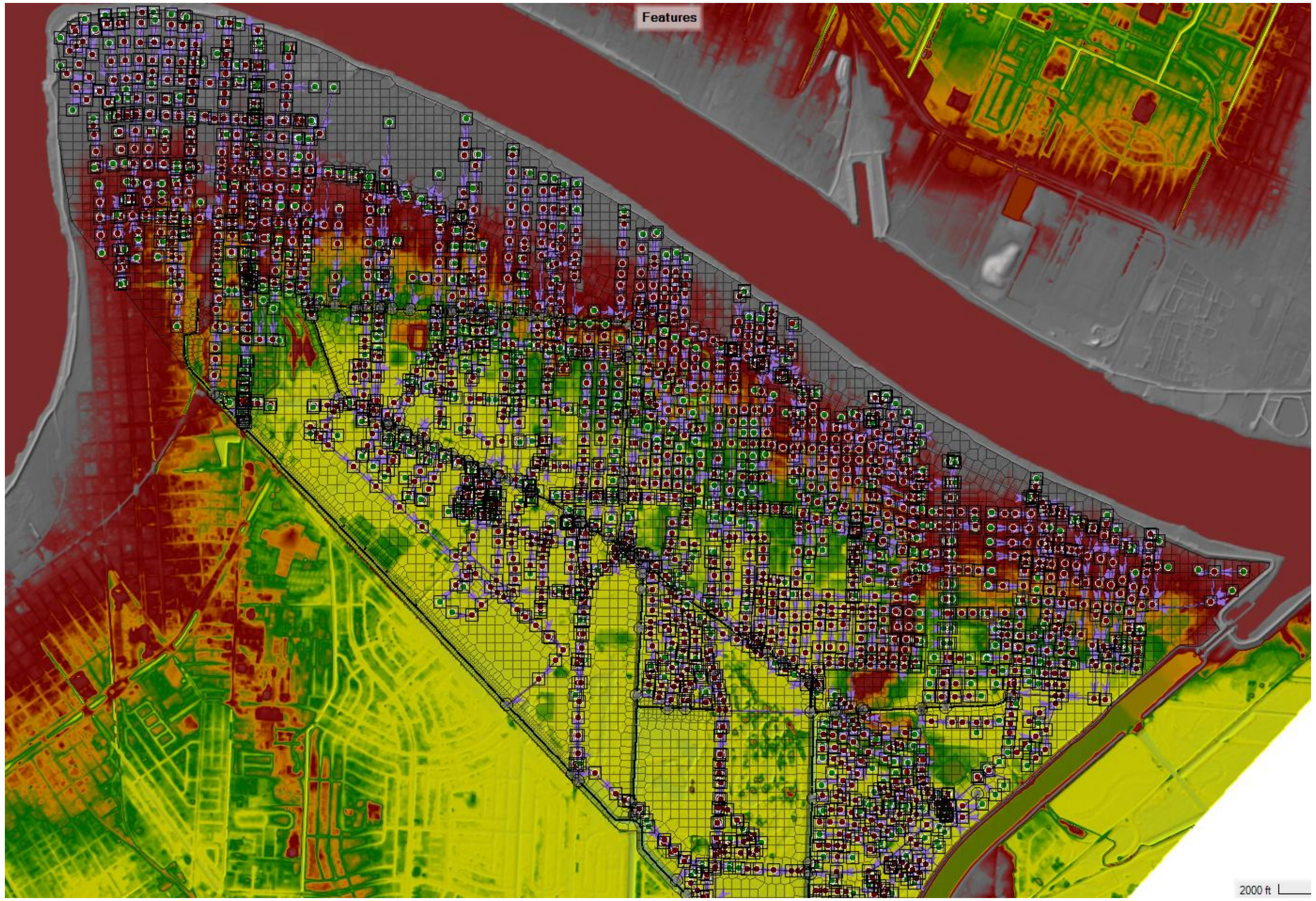
Outcomes

- 3. Visualize and communicate outcomes of stormwater infrastructure alternatives with HEC-RAS Mapper



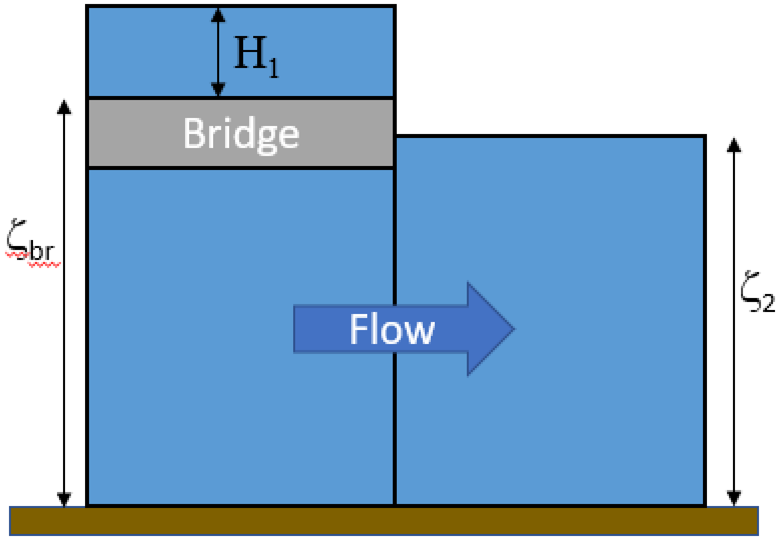
Status

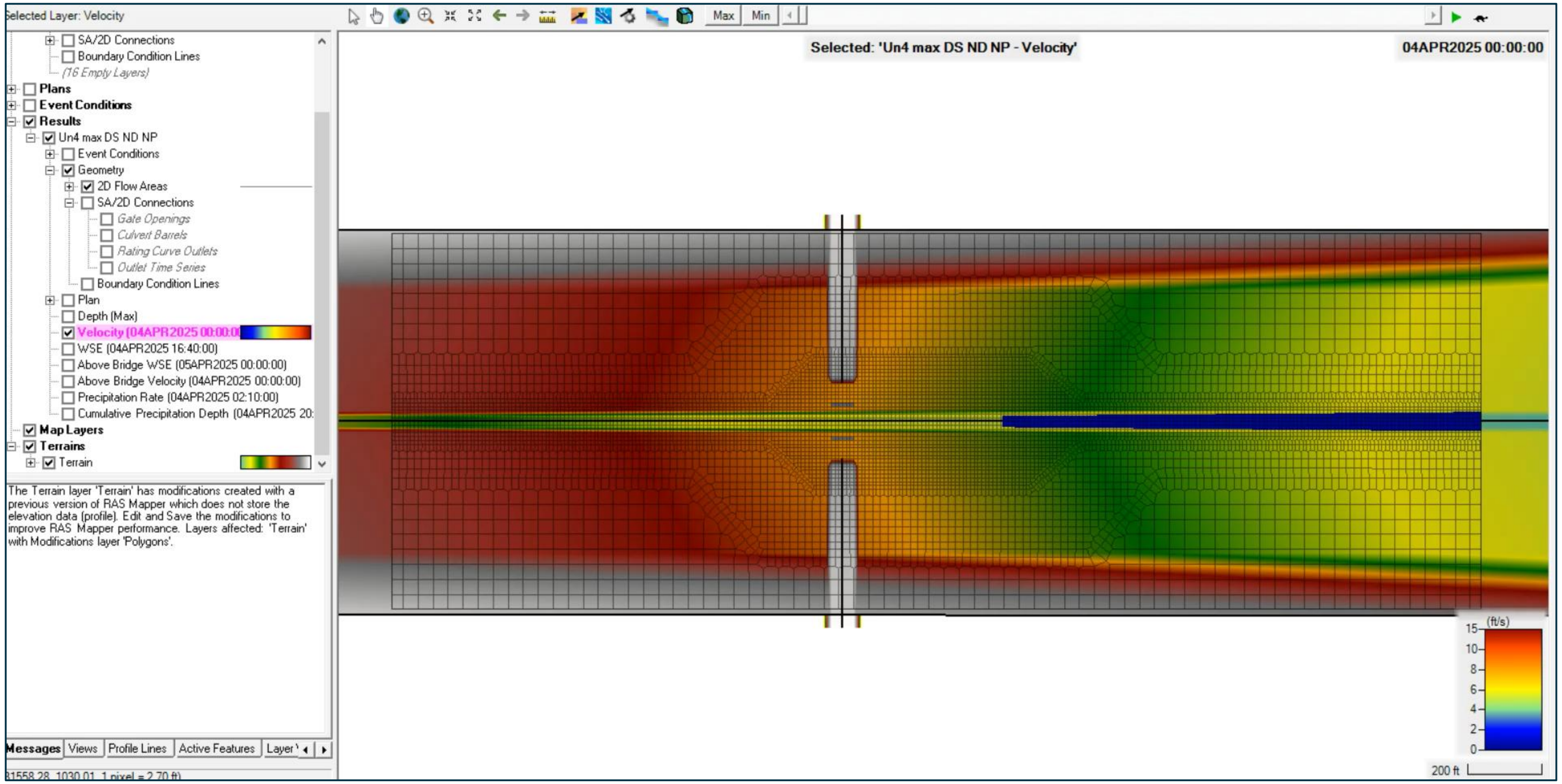
- Pipe Networks (beta) in HEC-RAS Version 6.6 - Released October 1st
  - HEC gathering feedback
- Additional beta releases
  - Bug fixes and minor enhancements for pipes
  - Additional pipe shapes
- What's next:
  - Weirs and gates in pipe networks
  - Computation engine efficiency improvements
  - Streamlined model building / auditing tools
  - RAS 2025



Also: 2D Bridges!

- Pressurized flow solver implemented in 2D
- Above deck and below deck 2D cells





Questions?

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