Geosyntec consultants

HECRAS 2D: Are you ready for the revolution in the world of hydraulic modeling?

Rishab Mahajan, Emily Campbell and Matt Bardol | March 8, 2017

Outline

- Reasons for hydraulic modeling
- 1D Modeling
- 2D Modeling- HECRAS
- Building a 2D HECRAS model
- Case Study – Dam Breach analysis

Reasons for hydraulic modeling

- ## Floodplain Mapping

  Flood Insurance Rates

- ## Design Mitigation Measures

- ## Dam Breach Studies
  - Emergency Action Plans
  - Dam Safety Permits
  - Plan for evacuations

About 100,000 cubic feet per second flowing over Oroville Dam Spillway

Image Source : NY Times

Extreme Events are on the rise!!

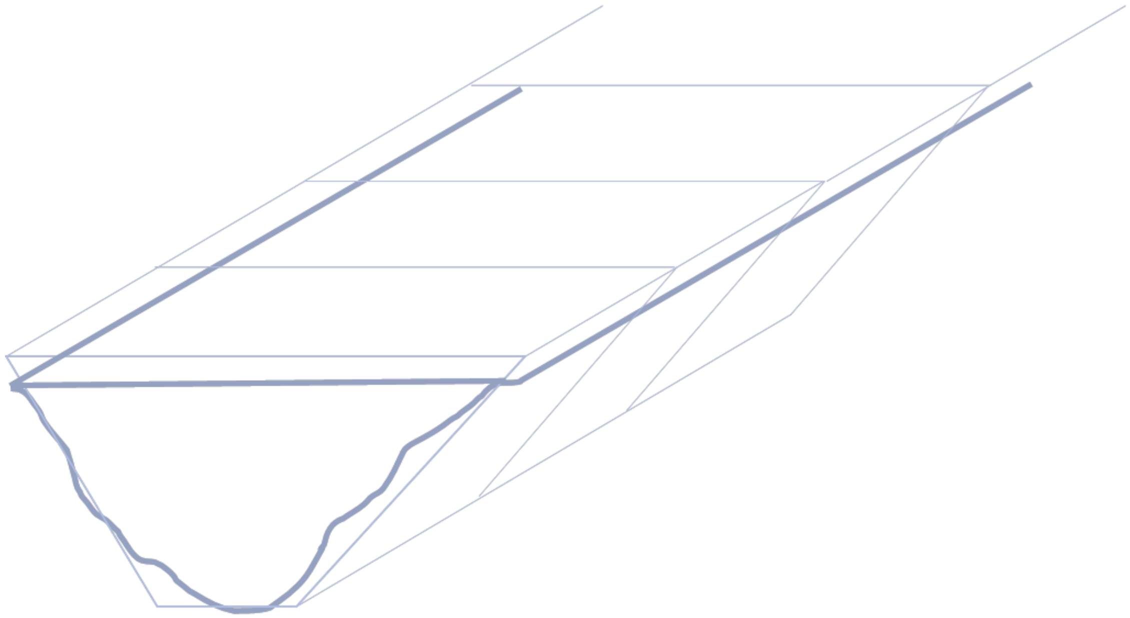
Before Numerical Modeling

Mississippi Basin Model
Vertical scale - 1:100; horizontal scale - 1:2000. Looking upstream on the Ohio River from Evansville. Indiana, Tennessee, and Cumberland Rivers are in the foreground showing the site of the Kentucky and Barkley Dams. Tradewater and Green Rivers are shown center. File No. 1270-4

Numerical Models

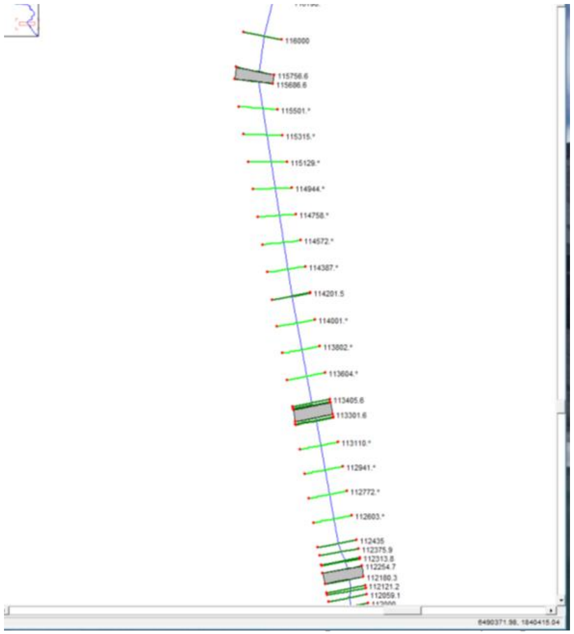
- Solves equations to simulate floodplain inundation
  - Continuity Equation
  - Momentum Equation
- Dimensionality - 1D, 2D or 3D
- Several modeling software - [FEMA approved list]
- HEC-RAS is most widely used tool
  - Developed by US Army Corps of Engineers
  - Public domain and free!!
  - FEMA approved
  - Previously limited to **1 dimension**

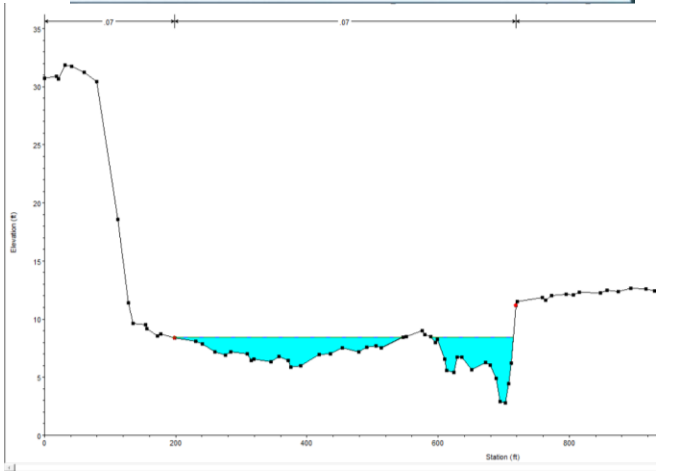
1D Modeling



1D Modeling with HECRAS

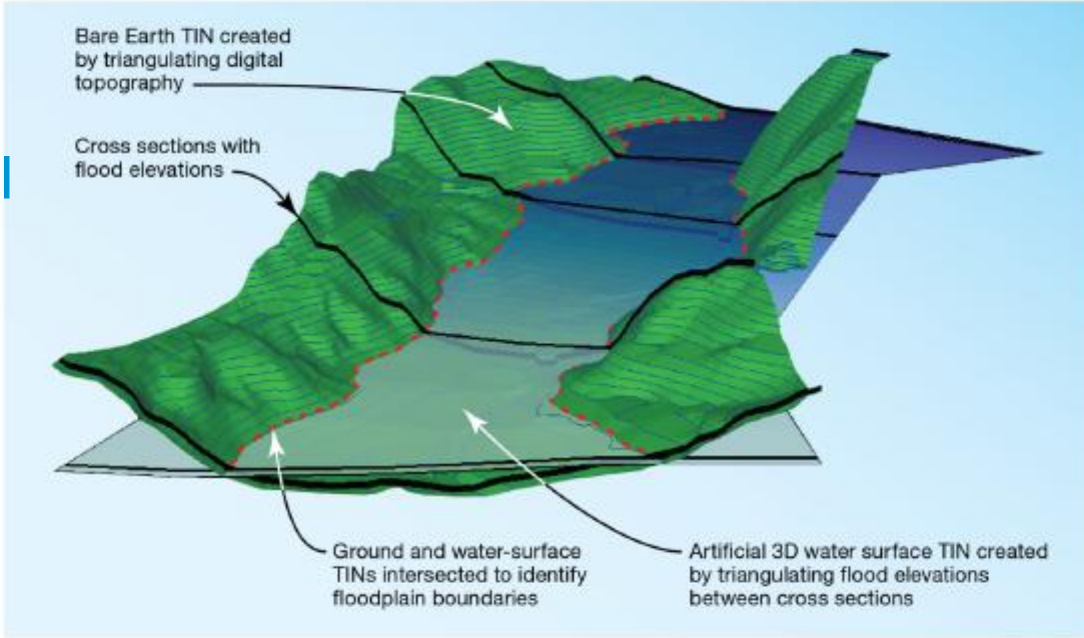
- Cross-sections in one direction
- Hydraulic variables computed in one direction
- Step Backwater Method to calculate water surface profile
- Steady/ Unsteady state





Floodplain inundation mapping - 1D

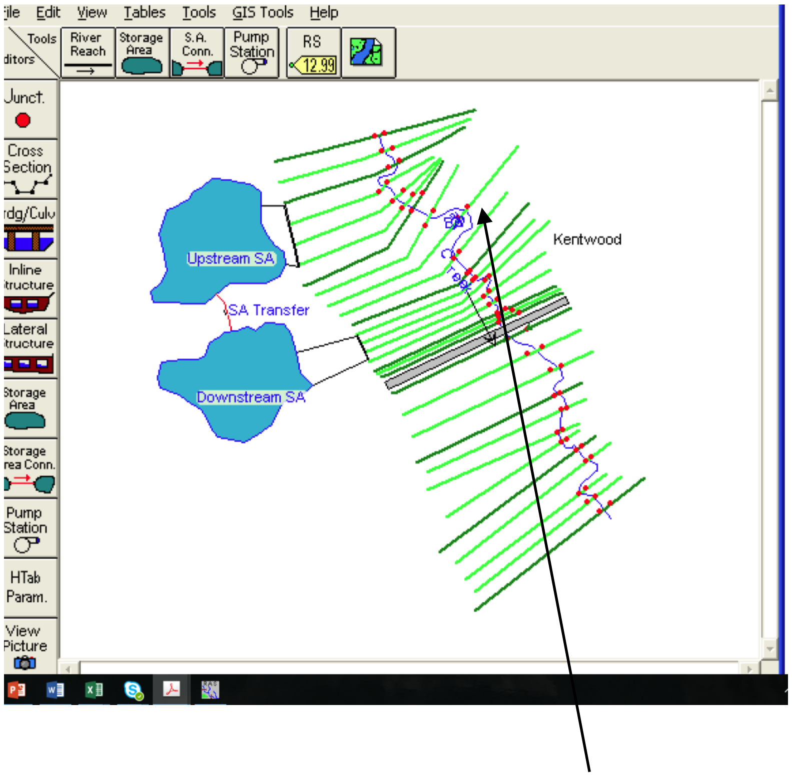
- Simulate Water Surface Elevations (WSE) at each cross-sections
- Export WSEs to external mapping software
  - Typically HEC-GeoRAS in ArcGIS
- Interpolate Water Surface Elevations between cross-sections
- Lay WSE over terrain surface to generate floodplain inundation



Source : Federal Guidelines for Inundation Mapping of Flood Risks Associated with Dam Incidents and Failures (FEMA P-946)

1D HEC-RAS disadvantages

- Flow assumed perpendicular to cross-section
- Laying out cross-sections requires a lot of engineering judgment
- Difficult to represent
  - Split flows
  - Variability in floodplain area
- Loss in resolution of terrain data – cross section spacing



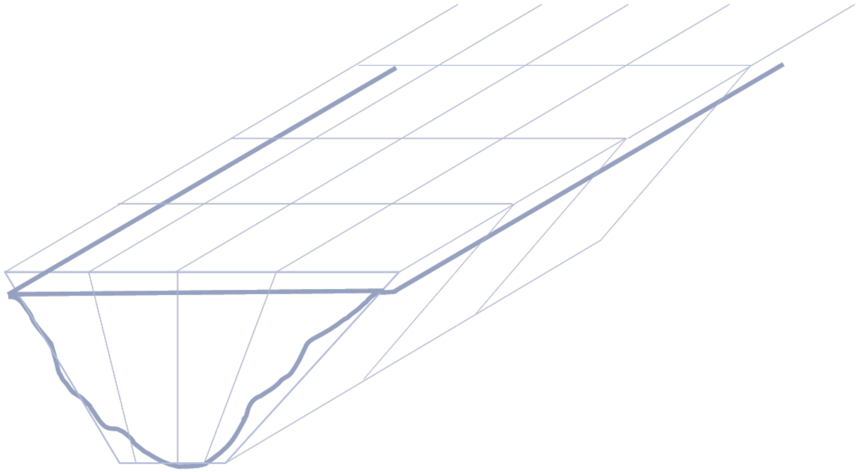
Need to orient cross-section perpendicular to flow

Where 1D does not work adequately?

- Significant meanders or poorly defined channel?
- Shallow Overland Flows
- Low flow condition
- Split flow conditions
- Limiting in case of lateral expansion/contractions of channels

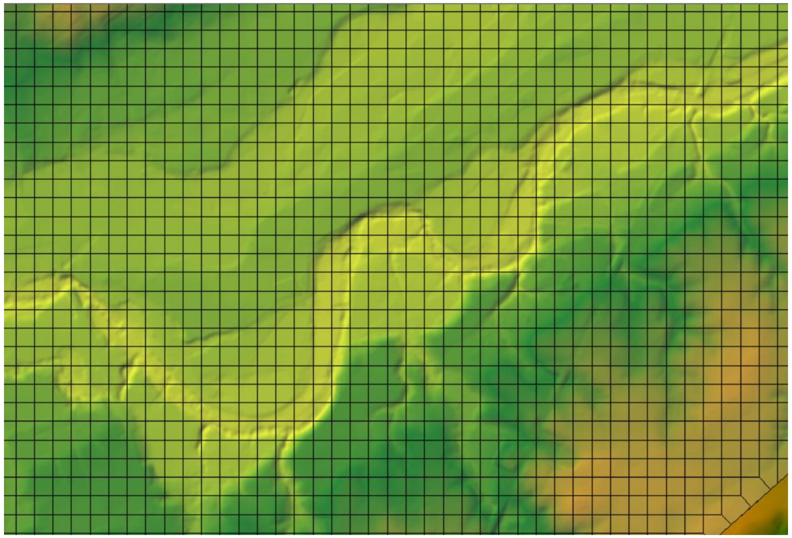
White River, Washington
Source : Wikipedia

2D Modeling



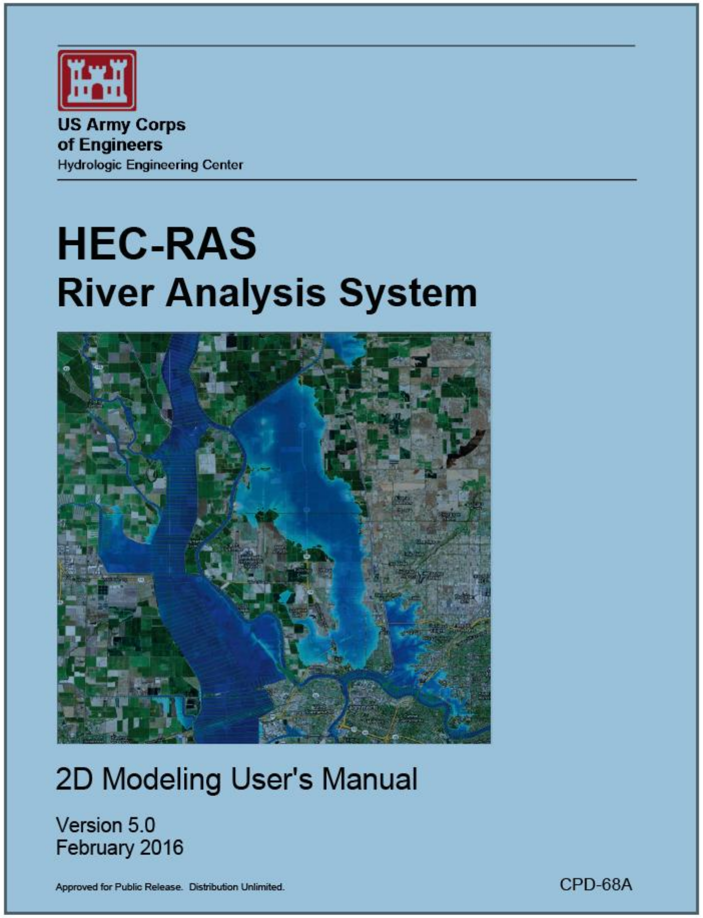
2D Modeling

- Simulates variability across and along the flow path
- Floodplain discretized into grid cells
- Can utilize detailed terrain data with less loss in resolution
- Previously limited application
  - Cost (commercial software)
  - Agency Acceptance
  - Lack of familiarity
  - Run Time



The Revolution has begun

- Possible alternative to many free and commercial 2D hydraulic models
- HECRAS 2D has been validated extensively
- Can update old 1D HEC-RAS models with 2D areas
- Need to understand framework and assumptions behind HECRAS 2D



HEC-RAS 2D - Capabilities

- 1D, 2D, and combined 1D and 2D modeling
- Implicit Finite Volume algorithm
- High resolution sub-grid model
  – Large cells still retain terrain details
- Detailed floodplain mapping and animations – RAS Mapper
- Ability to use multiple cores– Cloud Computing

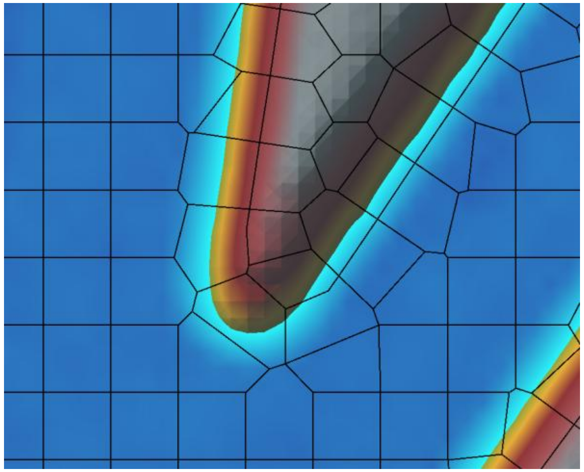
Computational Methods

- Equations Solved
  - Diffusion Wave – Faster but less accurate in some cases
  - Full Momentum – Slower but more accurate

- Full Momentum (Full St. Venant) vs Diffusion Wave:
  - Use Diffusion Wave to develop model, then try Full Momentum
  - If significant differences exist, trust Full Momentum
  - Full Momentum recommended for:
    - Dynamic flood waves (e.g. dam breaches)
    - Sudden expansions and contractions
    - Wave propagation analysis
    - Super elevation around bends
    - Multiple hydraulic structures (bridges, bridge piers etc.)

Computational Mesh

- Unstructured or structured computational mesh (up to 8 sides)
- Orient cells along terrain and flow barriers using break lines
- Manual editing of cells
- Optimum cell size
  - Water surface slope changes rapidly – smaller cell size
  - Tradeoff between run time and model stability



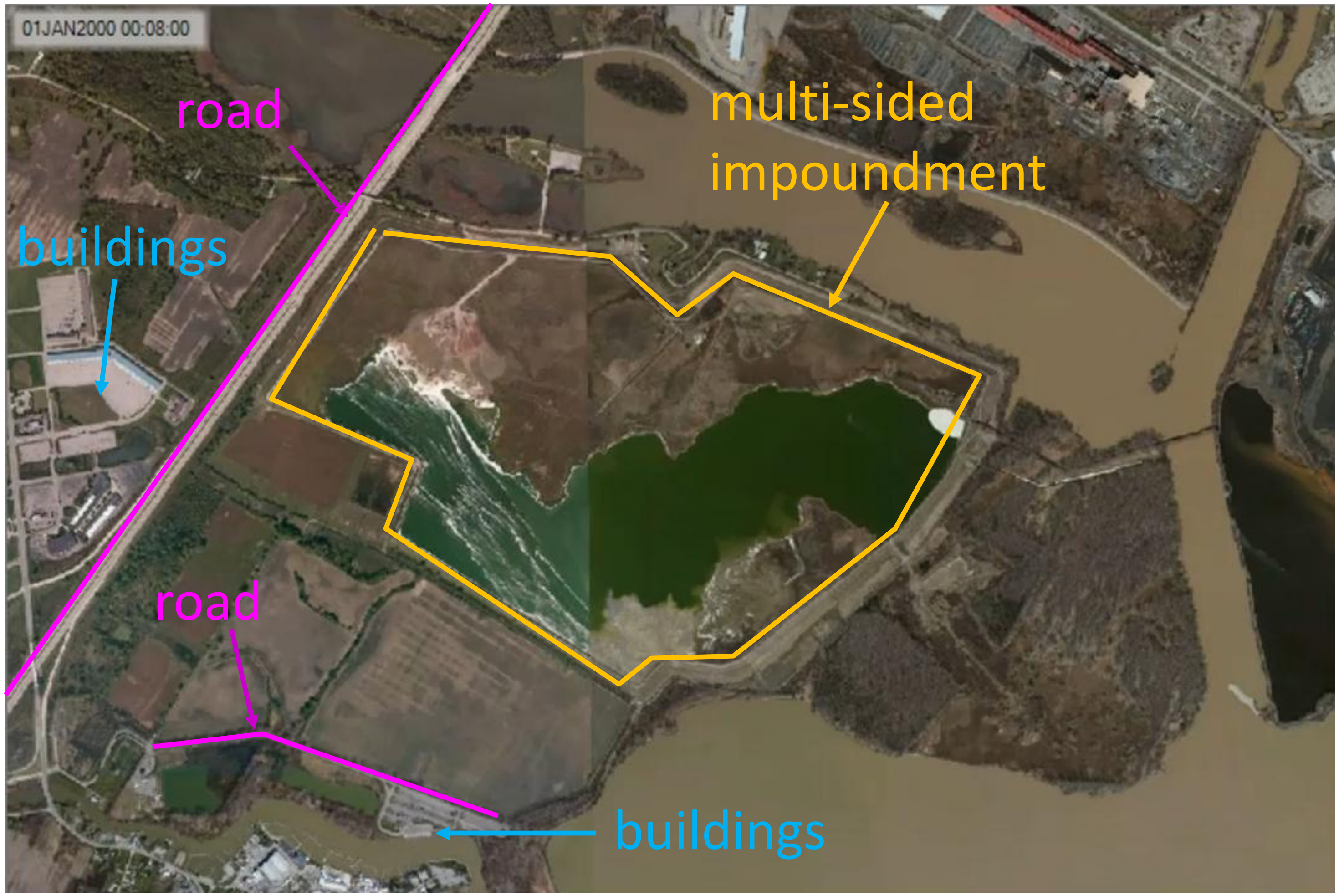
Model Stability

Model instability due to solution not meeting numerical tolerances

- Use optimum time step based on Courant Number (V*delta T) / delta X <=1
- Specify initial conditions created using lower flows
- Use ramp up inflow hydrographs
- Adjust 2D computation options and tolerances
  - Theta (0.6 – 1.0)
  - Theta Warm-up (0.6 – 1.0)
  - Water Surface Tolerance (ft)
  - Volume Tolerance (ft)
  - Maximum Number of Iterations

Building a HEC-RAS 2D Model

Dam Breach Analysis: How would you model this?



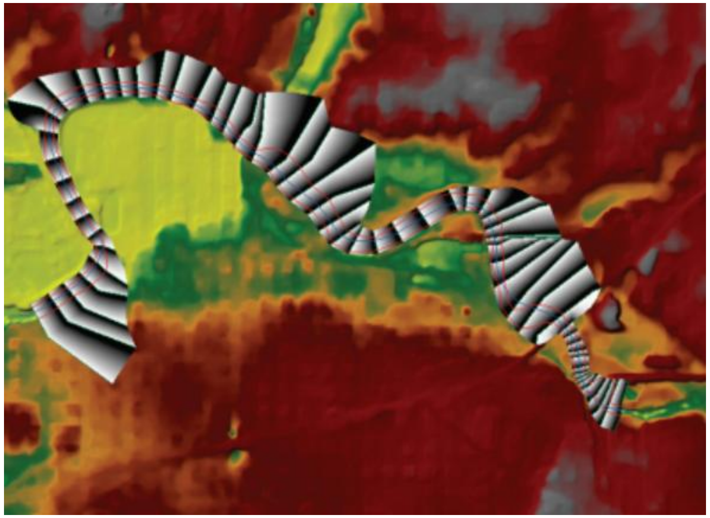
2D Model Setup

- Elevation Pre-Processing
  - Lidar (Terrain) – Floodplain
  - Bathymetry – Channel
- Land Cover Input
- Mesh Development
- Boundary Conditions
- Calculation of Table Properties

- Model is only as good as the (terrain) data!
  - Very important to have good terrain (DEM) data.
  - Terrain data usually does not include bathymetry.
  - For flood plain studies, not a big problem.
  - For channel flow analysis, bathymetry is very important to get details in river.

Elevation Data Pre-Processing

- Remove redundant data points
- Produce a bare earth terrain by Lidar
  - Bridge decks
  - Vegetation Trees
  - Overwater passes



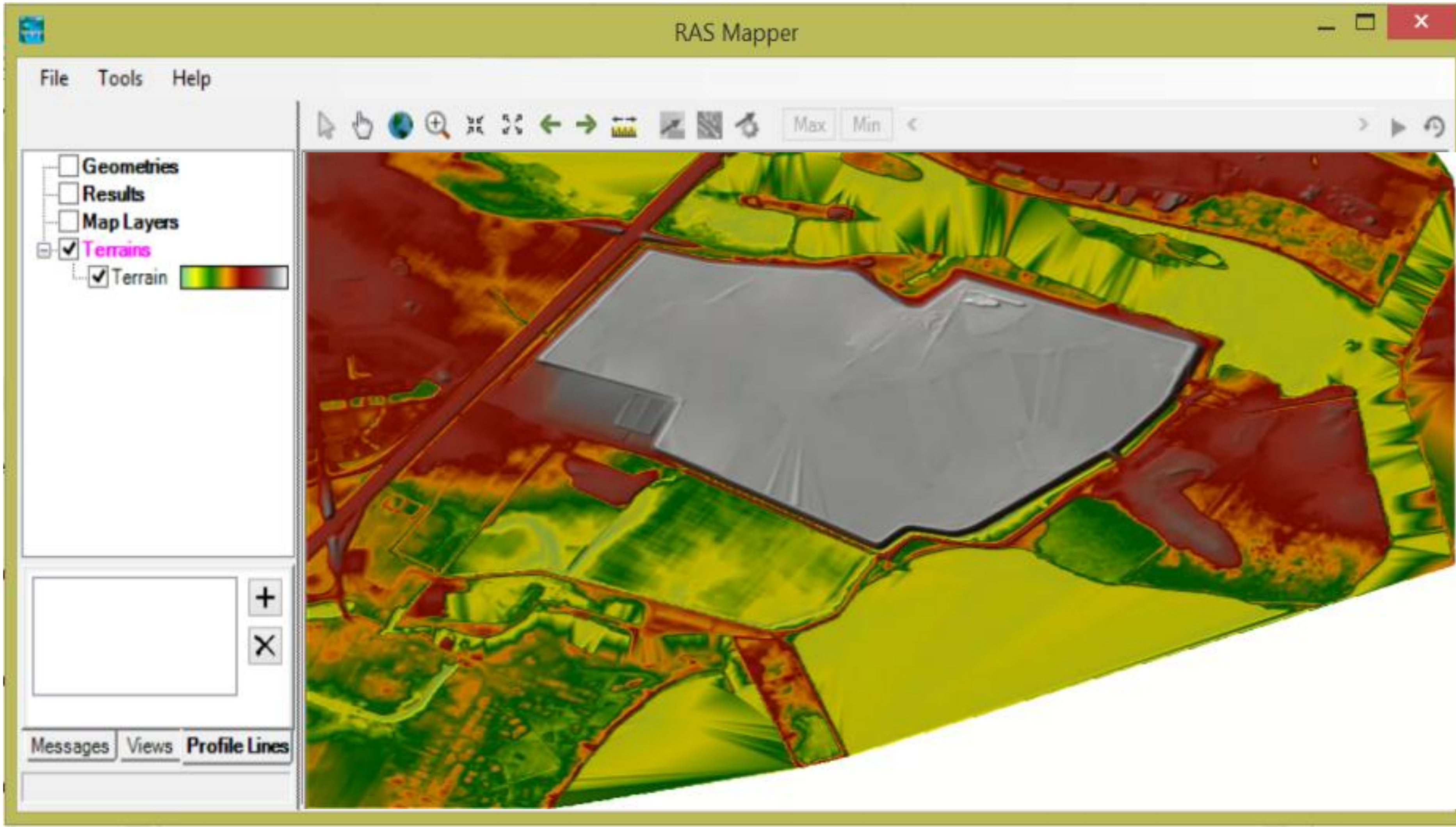
Source : HECRAS User Manual

- Superimpose channel bathymetry data

Can be done in RAS Mapper/ GIS

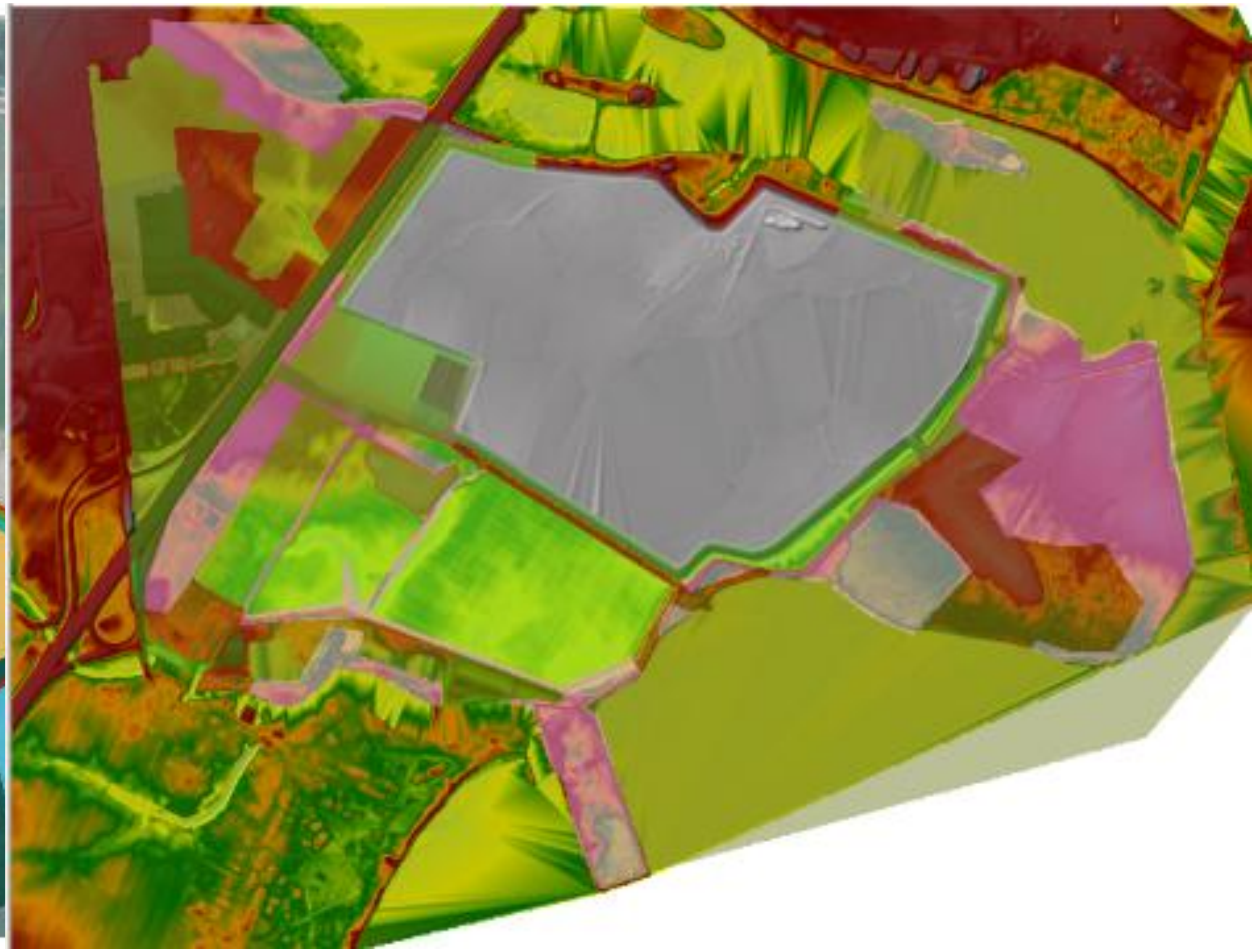
Elevation Data Pre-Processing

- Creating a terrain model

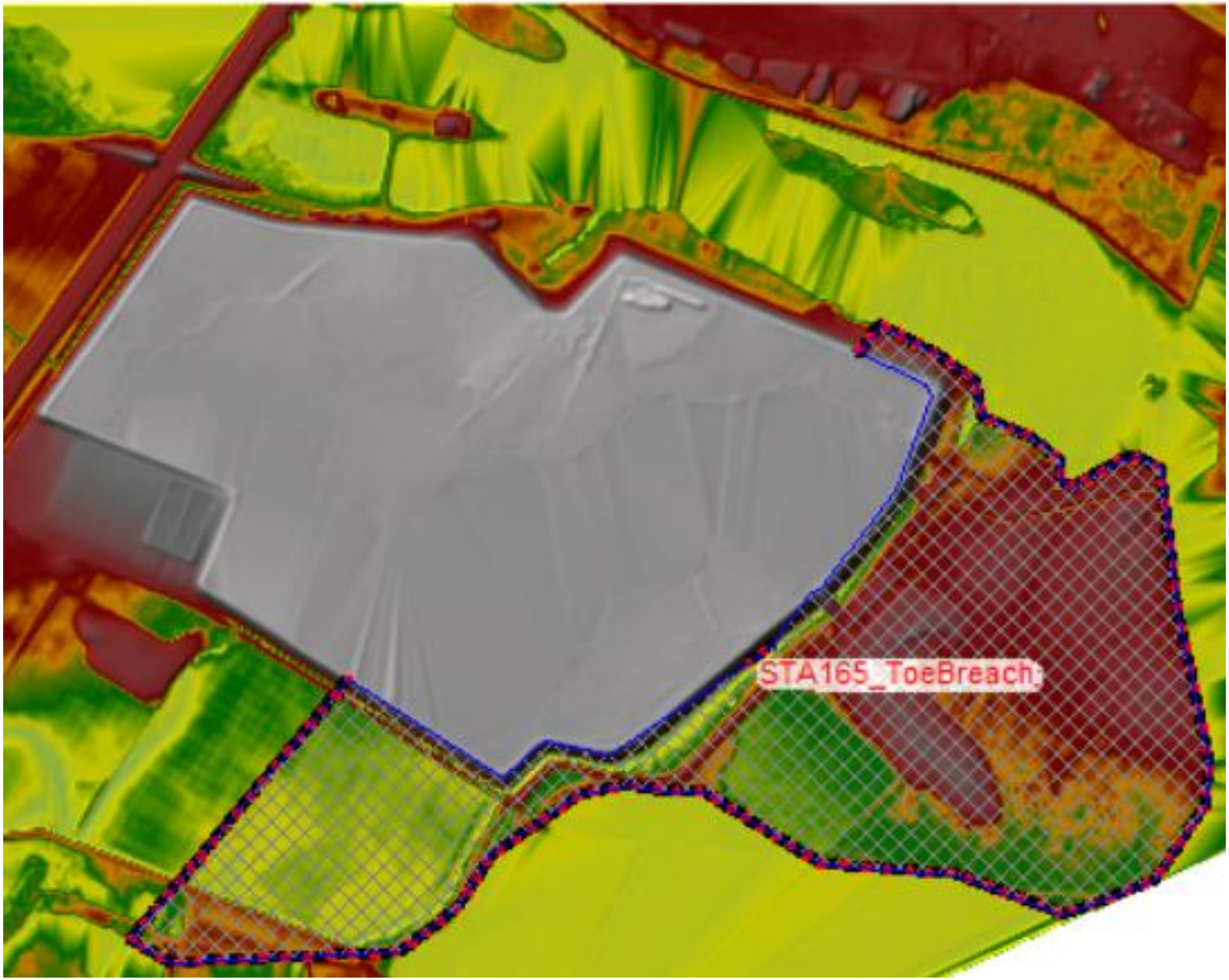


Land Cover Input

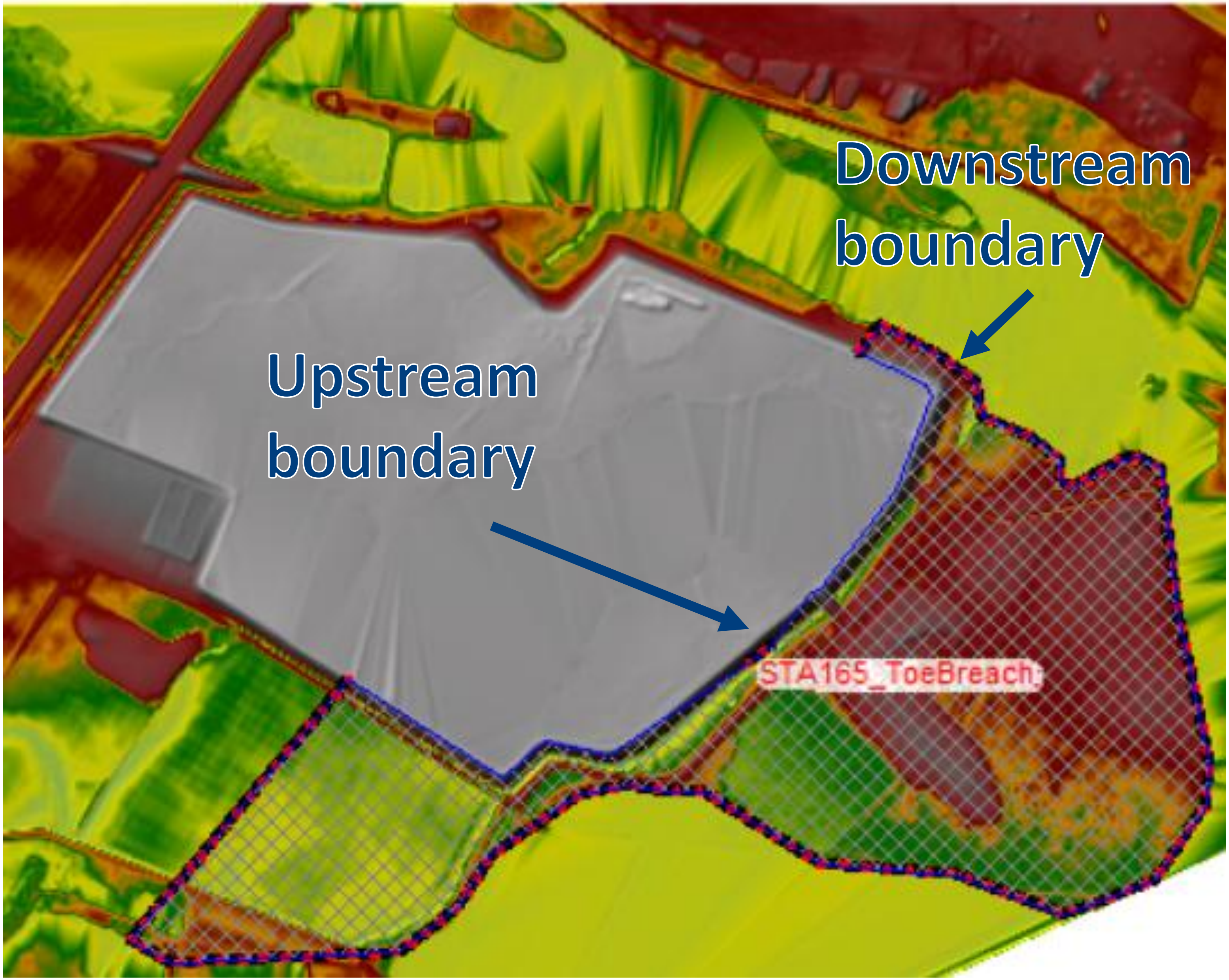
- Build in GIS → import with RAS Mapper (.shp)



Mesh Development

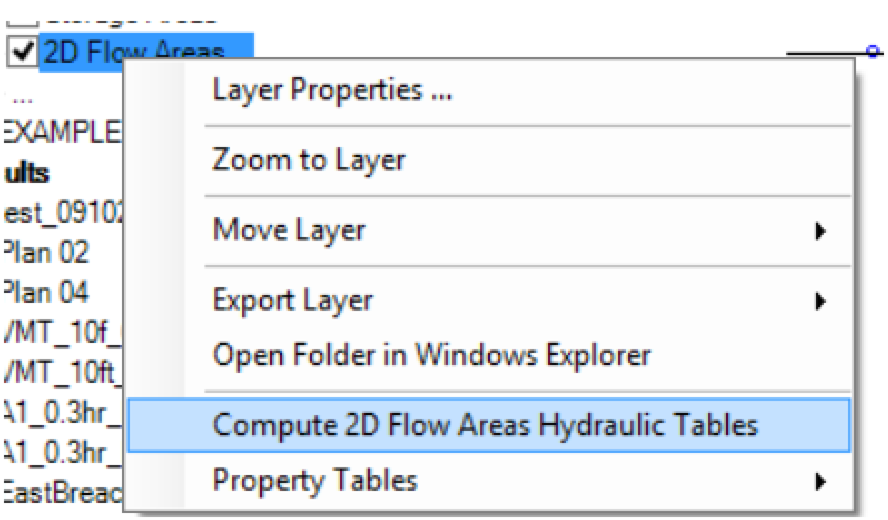


Boundary Conditions



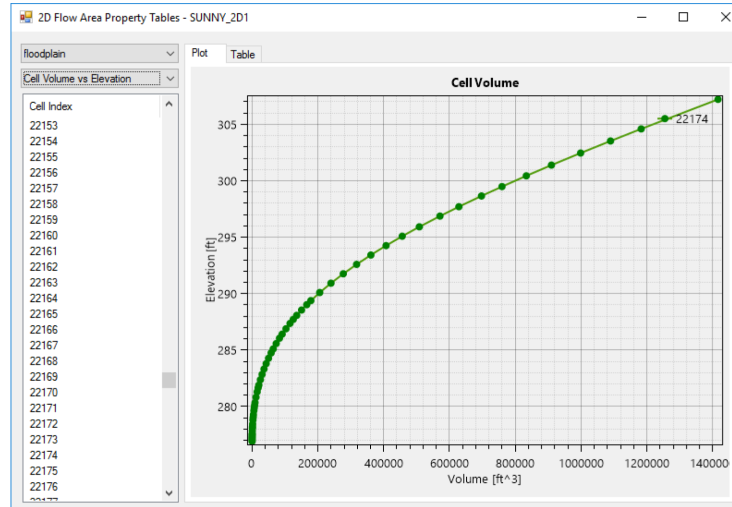
Calculation of Hydraulic Properties

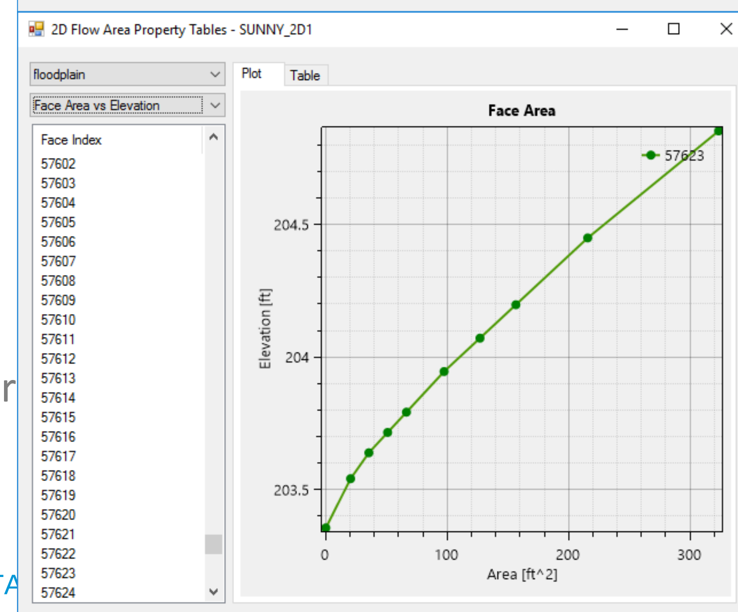
RAS uses all the input data to compute hydraulic properties of all cells and cell faces



Elevation versus area, wetted perimeter, roughness calculated for each cell face

Elevation- Volume relationship created for each cell using the underlying terrain





Running a 2D HEC-RAS

- Running the model
- Model stability

HEC-RAS Unsteady Computation Options and Tolerances

General (1D Options) | 2D Flow Options | 1D/2D Options

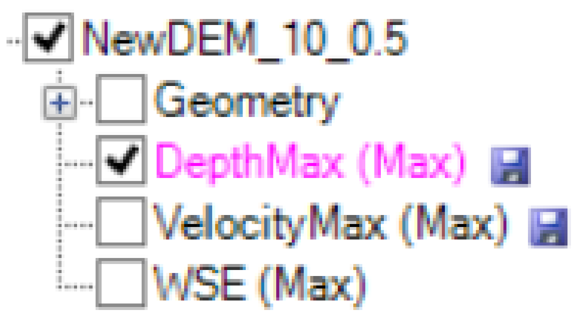
☐ Use Coriolis Effects (only when using the momentum equation)

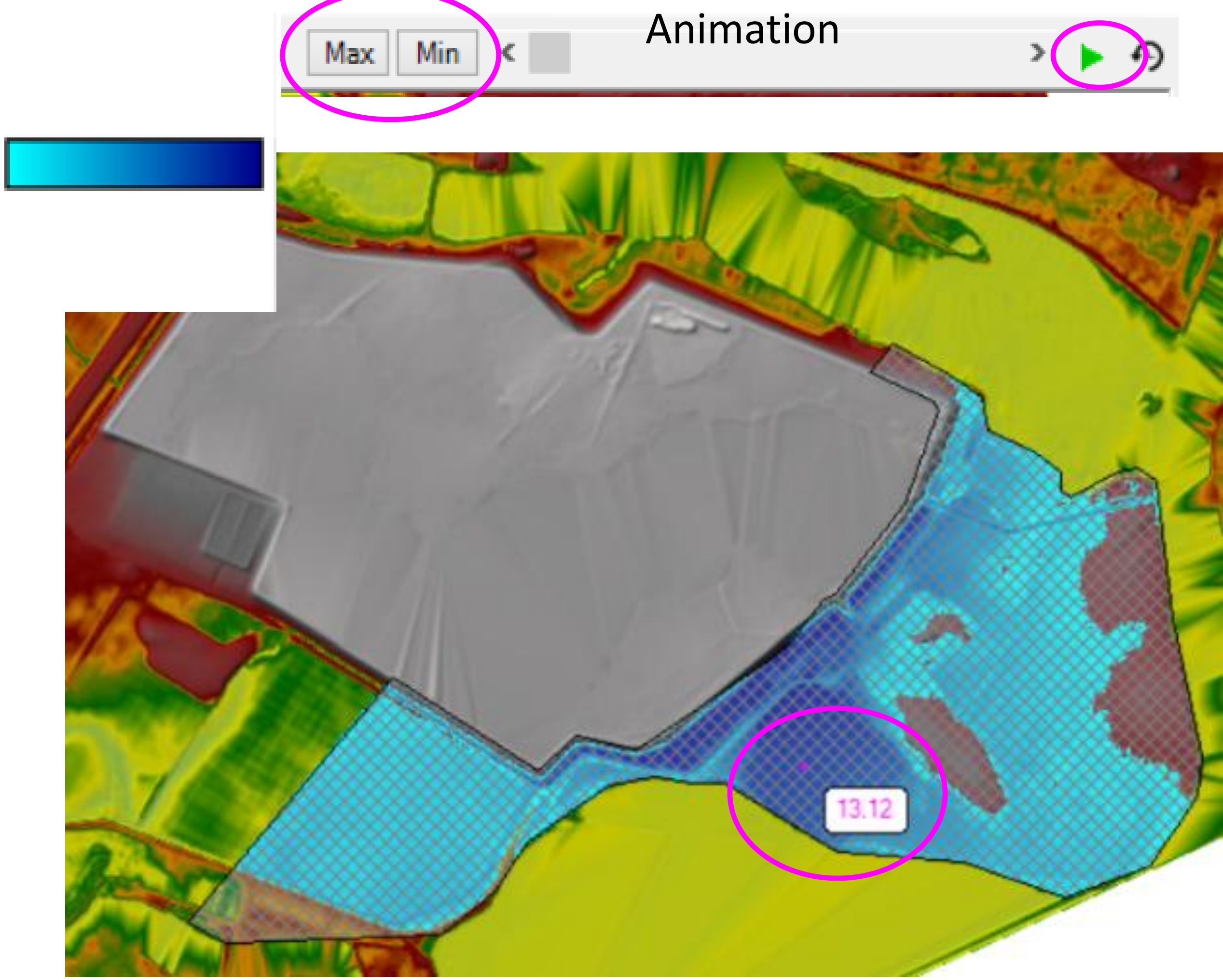
Number of cores to use in 2D computations: All Available

	Parameter	(Default)	EastEmbankment
1	Theta (0.6-1.0):	1	1
2	Theta Warmup (0.6-1.0):	1	1
3	Water Surface Tolerance (ft)	0.01	0.01
4	Volume Tolerance (ft)	0.01	0.01
5	Maximum Iterations	20	20
6	Equation Set	Diffusion Wave	Full Momentum
7	Initial Conditions Time (hrs)		
8	Initial Conditions Ramp Up Fraction (0-1)	0.1	0.1
9	Number of Time Slices (Integer Value)	1	1
10	Eddy Viscosity Transverse Mixing Coefficient		
11	Boundary Condition Volume Check	☐	☐
12	Latitude for Coriolis (-90 to 90)		

OK | Cancel | Defaults ...

- Results are viewed in RAS Mapper

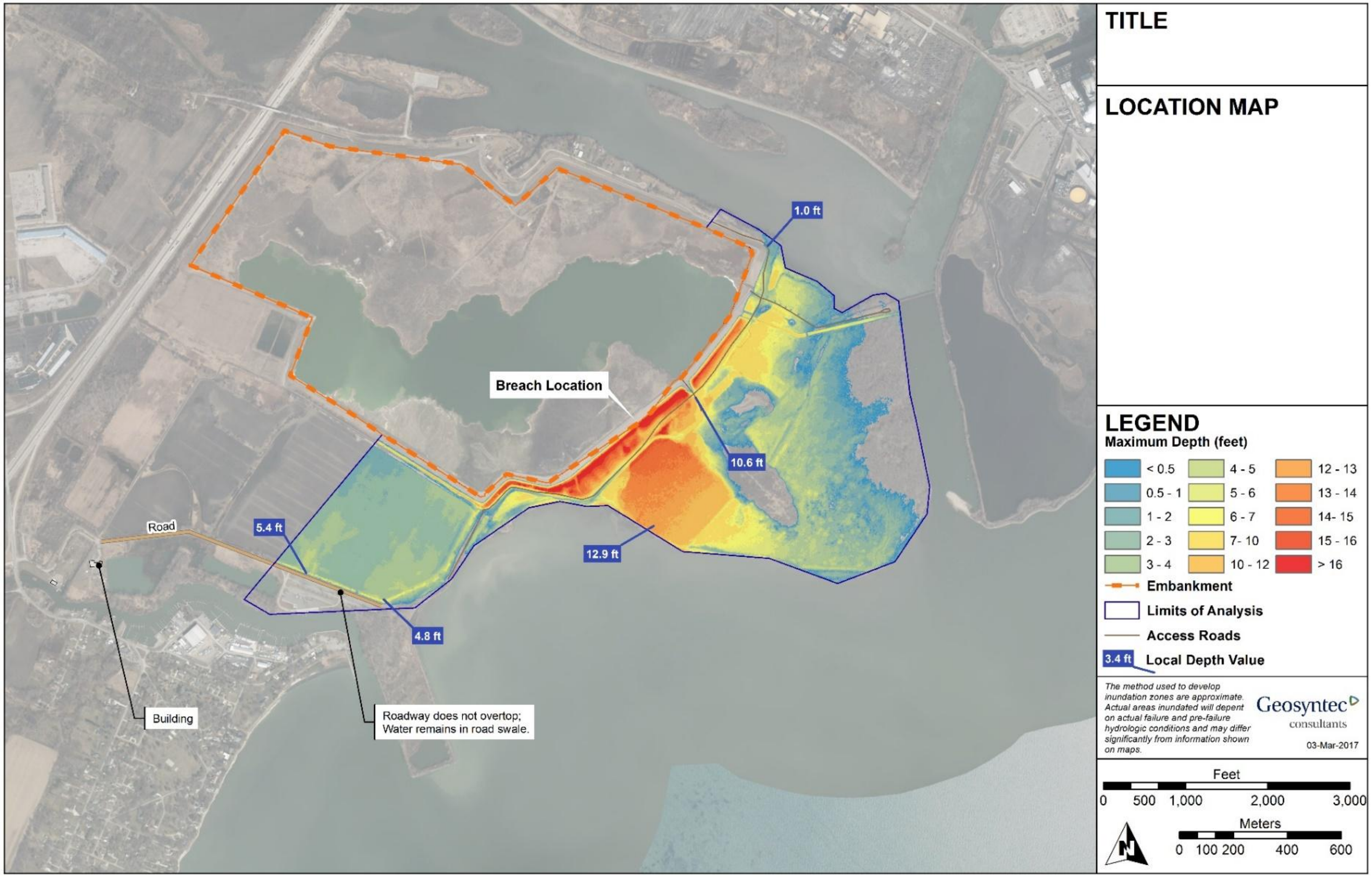




Note:
When checked value is **PINK**, you can view individual values, min/ max, press “play”

Post Processing

- Results cab be exported to raster and GIS can take it from there

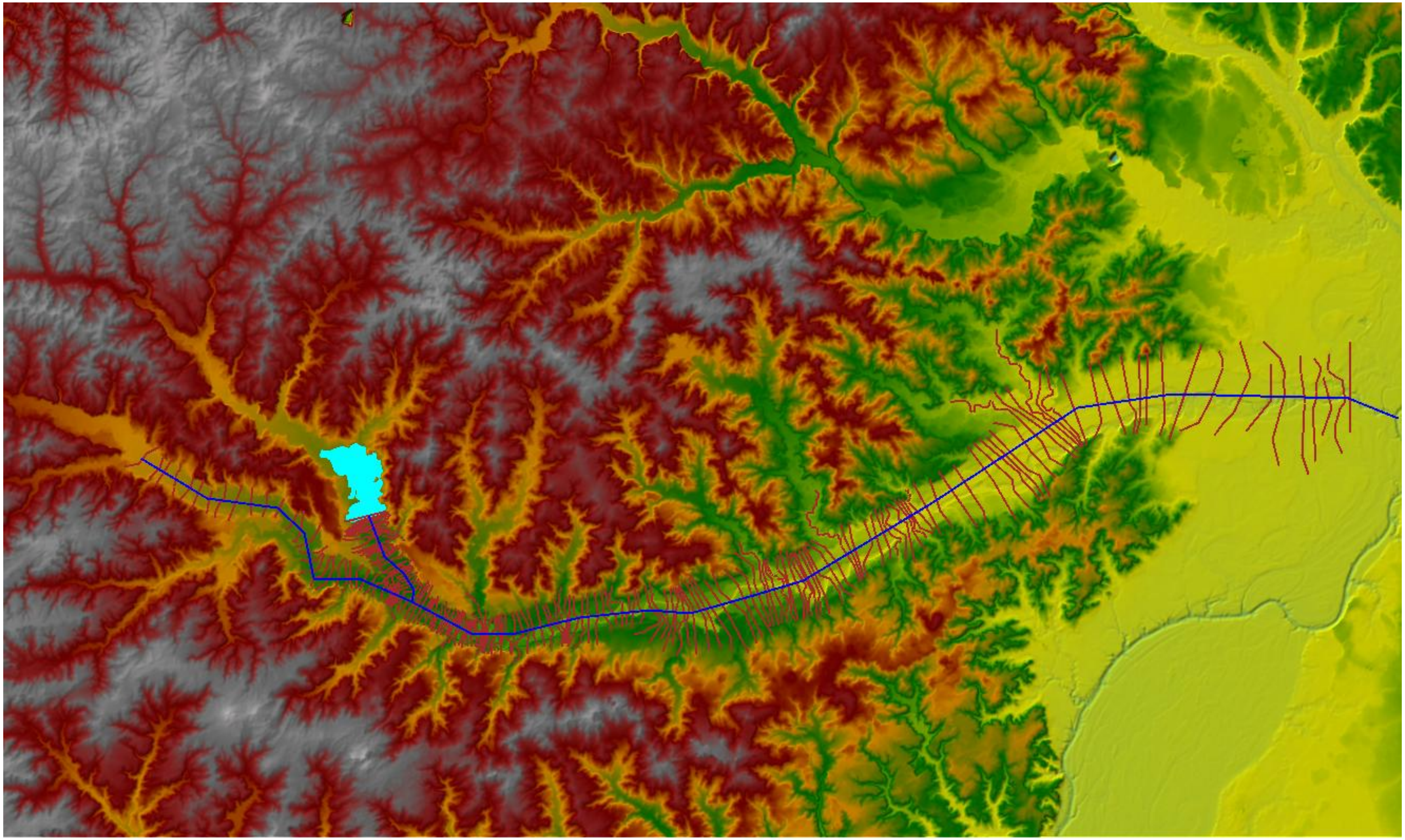


Case study : 1D Vs 2D- Dam Breach

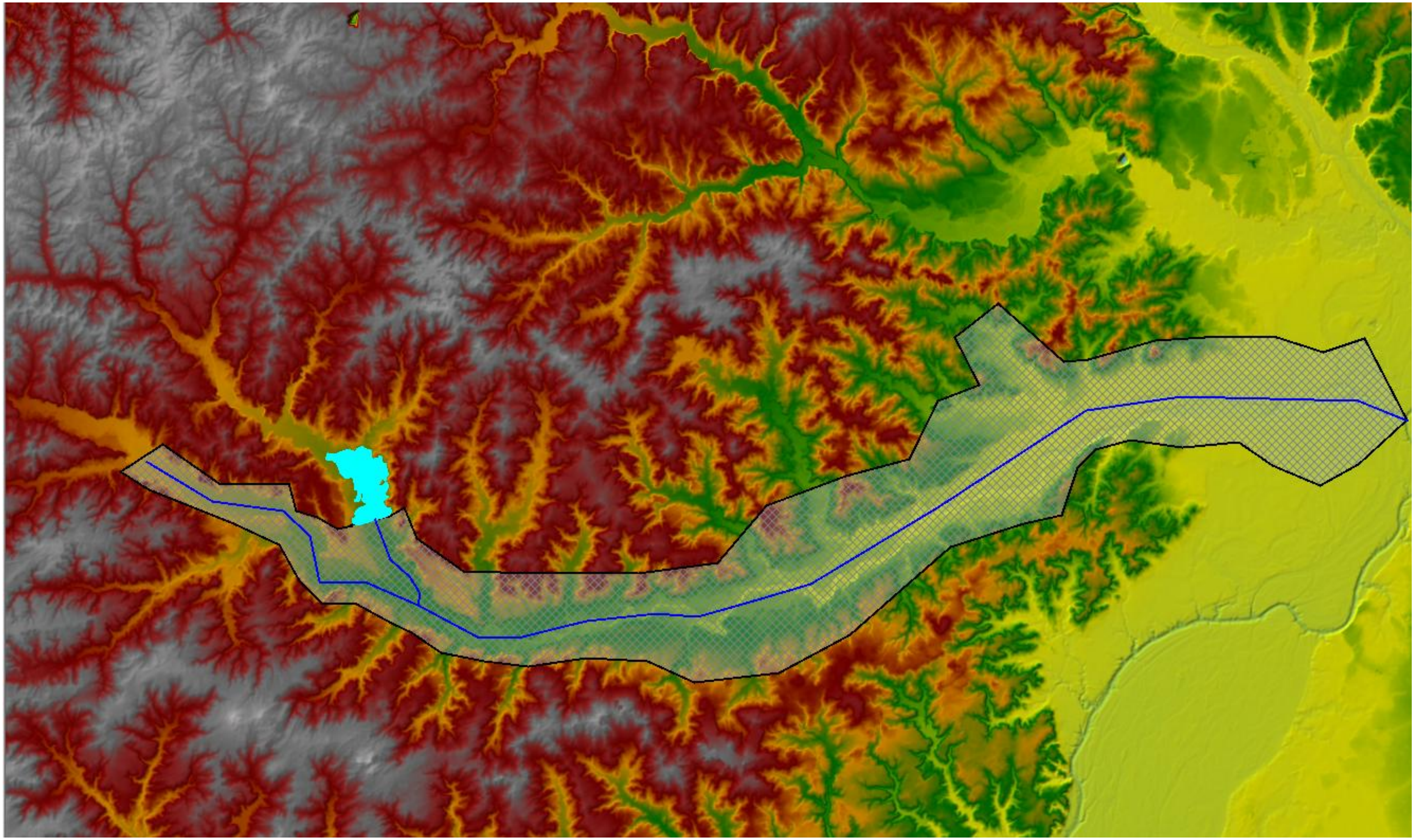
Dam Breach Simulation Case Study

- Dam Breach Analysis
  - Crest length – 5200 ft
  - Height - 23 feet,
  - Maximum impoundment area of 10,000 acre-feet
- Simulated a piping failure for the dam- Sunny Day
- Peak flow of 17,000 cfs for breach hydrograph

1D Model



202 Cross Sections – Spaced approx. 800 ft. apart

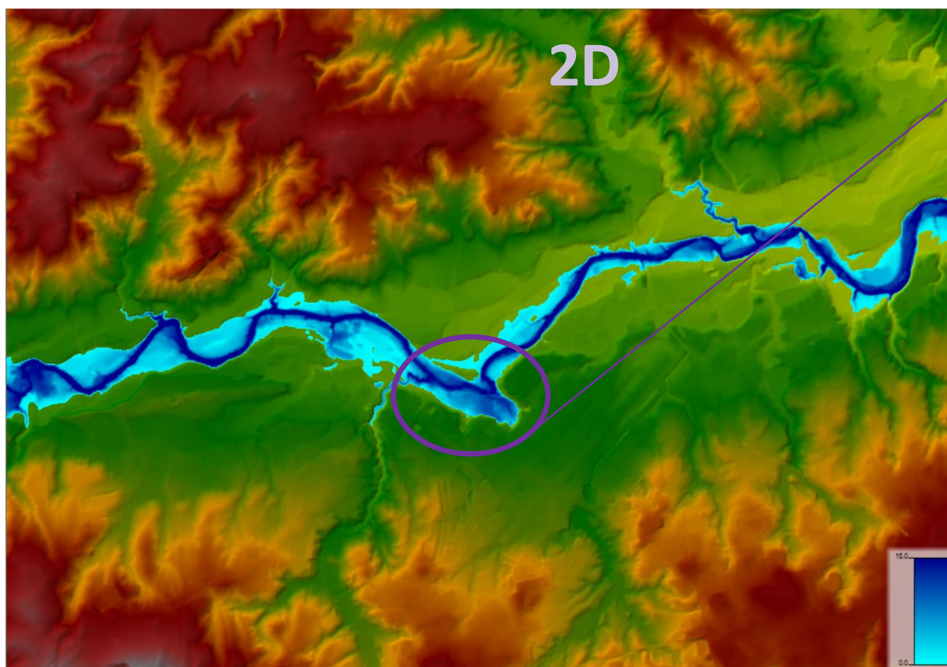


300*300 ft grid cells

Results

Output results look just as fancy, however…

More backwater effects and larger depths in 2D case



2D shows more floodplain inundated

1D, 1D+2D or pure-2D?!

When should you go….

- Pure 2D:
  - Flow expected to spill into floodplain
  - Alluvial fans and estuaries
  - Meanders and loops
  - Cool hydrodynamic animations!
  - Access to good terrain data

Source: HEC-RAS 2D Modeling User's Manual

- Pure 1D:
  - Mostly uni-directional flow within channel
  - Minimum lateral expansion
  - Run time is a constraint
  - Need to extract a lot of data (velocity, Froude #, shear, normal depth, critical depth etc.)
  - Limited/low quality terrain data
- 1D+2D, when you need both 2D and 1D features

THANK YOU

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