Two-Dimensional Hydraulic Modeling Training:

Introduction to 2D Hydraulic Modeling and HEC-RAS 5.0

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Identify Hazards, Interpret Risks, Integrate Mitigation

Acknowledgments

Montana DNRC

- Steve Story, P.E.

FEMA Region 8

- David Sutley, P.E.

United States Army Corp of Engineers (USACE)

- HEC folks – Gary Brunner, P.E.

WEST Consultants

- Chris Goodell, P.E. → http://hecrasmodel.blogspot.com

Lecture 1 Overview

- Hydraulic Modeling Defined
- 1D Hydraulic Model Overview
- 2D Hydraulic Model Overview
- 1D versus 2D
- Available 2D Modeling Platforms
- HEC-RAS 5.0 Overview
- FEMA 2D HEC-RAS Example Applications

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Numerical Hydraulic Modeling

- Mathematical representation of physical hydraulic conditions
  - What is the objective of the model?
  - Implicit model assumptions and limitations appropriate for application?

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Other Types of Models

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

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Typical Model Approach

- Numerical approximation of governing physical equations that describe movement of water through a system
  - Continuity Equation
  - Momentum Equation
- Equations can be solved in 1, 2, or 3 dimensions

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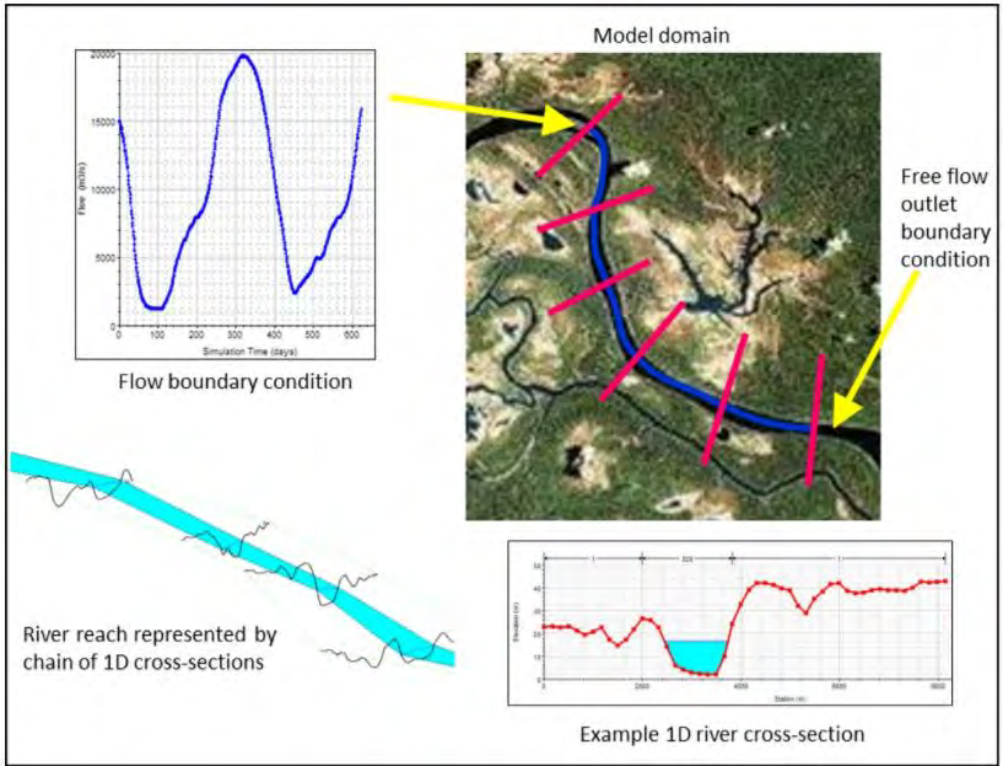
1D Approach

- Geometry defined using cross sections and reach lengths
- Flow is assumed to be perpendicular to cross sections
- Cross-section-averaged velocity and depth calculated for each section
- Standard Step Method (steady)
- Implicit finite difference scheme (unsteady)



1D Model Advantages

- Widely accepted by regulatory agencies
- Less computationally intensive?
  - True for steady flow models
  - Depends for unsteady flow applications
- Floodway analysis
- Lower data requirement threshold

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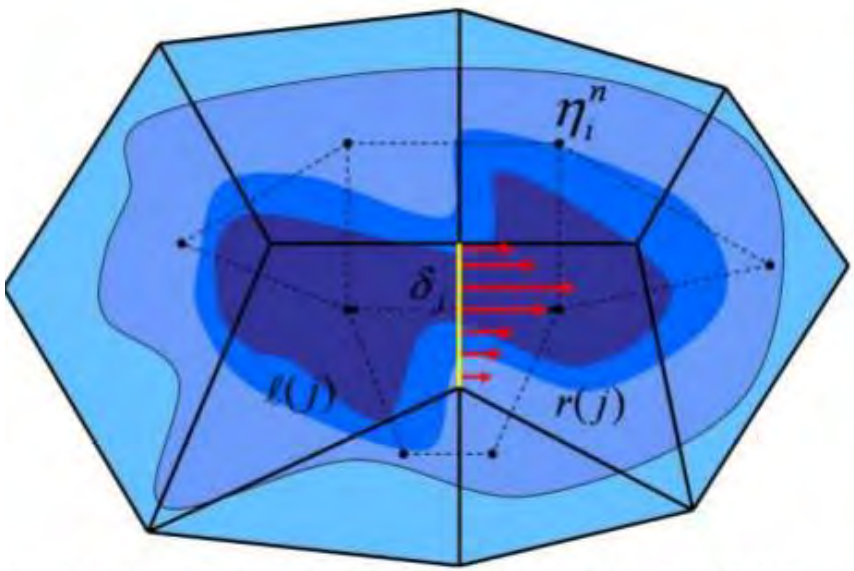
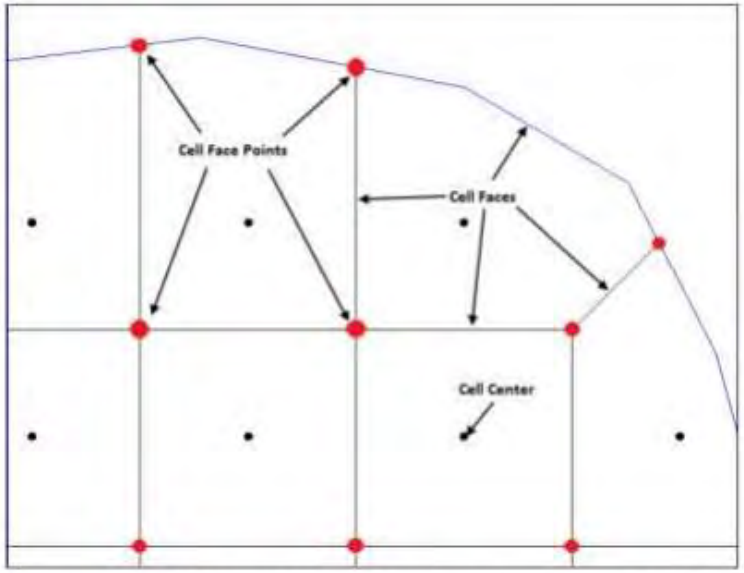
2D Approach

- Geometry defined by a network of elements and nodes (computational mesh)
- Implicit finite volume calculations used to approximate governing equations



Source: Brunner, G.W. (2014) Combined 1D and 2D Modeling with HEC-RAS



Source: USACE (2016) HEC-RAS 2D Modeling User's Manual (CPD-68A)

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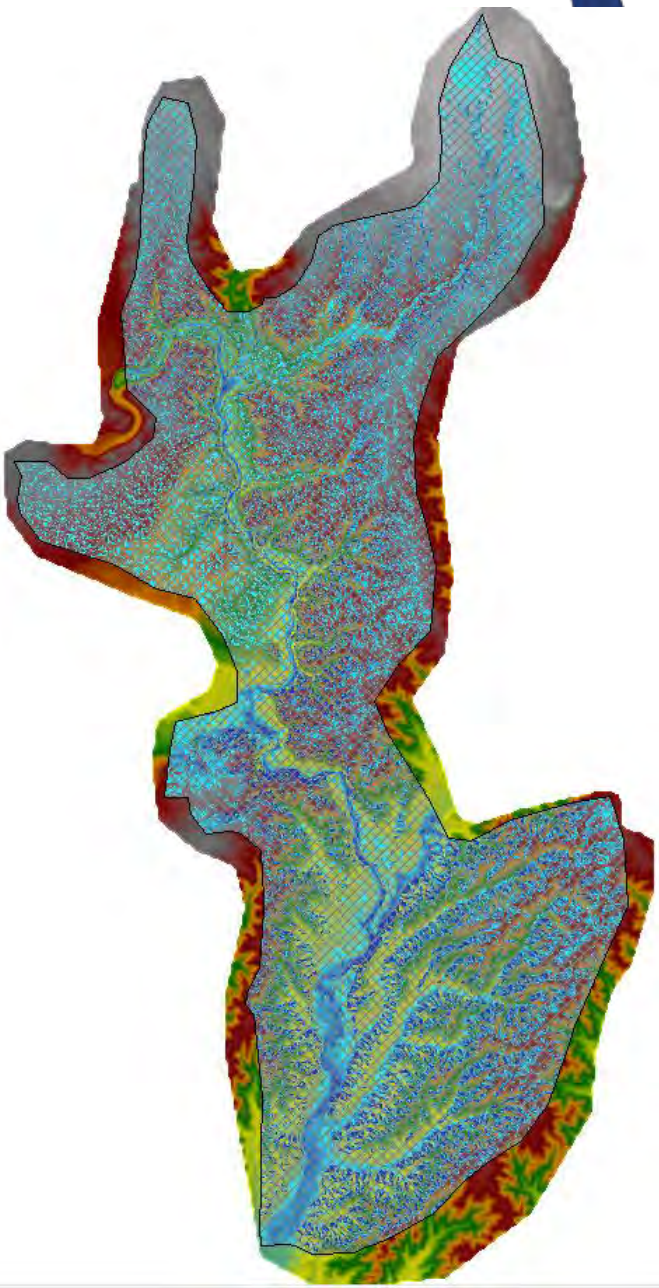
More 2D Approach

- Water is routed across the computational mesh in two-dimensions
- External boundaries are defined at edge of mesh for inflows and outflows



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2D Model Advantages?

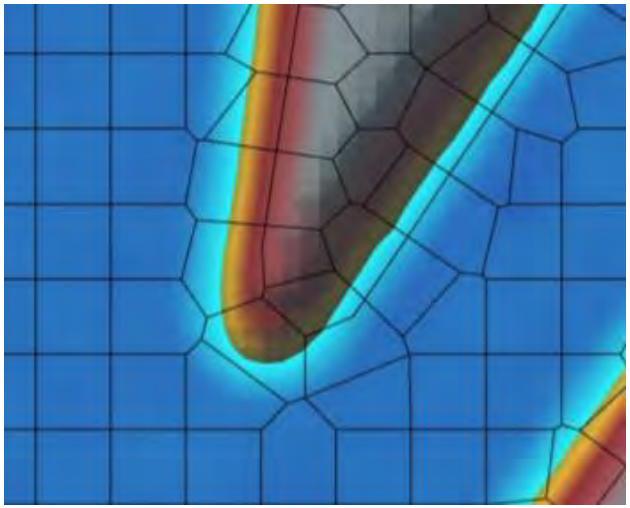
- Often a more realistic representation of hydraulics
- Flexibility in how to represent a system
- 2D models can be easier to build than a 1D model
- Represents hydraulics accurately for range of flow conditions (i.e., high and low flow)

1D and 2D Assumptions

1D Models	2D Models
Vertical and **lateral** fluid motion is small	Vertical fluid motion is small
Velocity is averaged at a cross-section	Velocity is vertically averaged at a point (Depth Averaged Flow)
Total energy head is the same for all points on a cross-section	Energy head is computed at each point (cell center)

2D Considerations

- 2D previously limited due to cost and computing power requirements
- Current 2D limitations
  - Access to high resolution terrain data for full model area
  - Agency acceptance? Becoming less of an issue
  - Modeler familiarity
  - Floodway analysis



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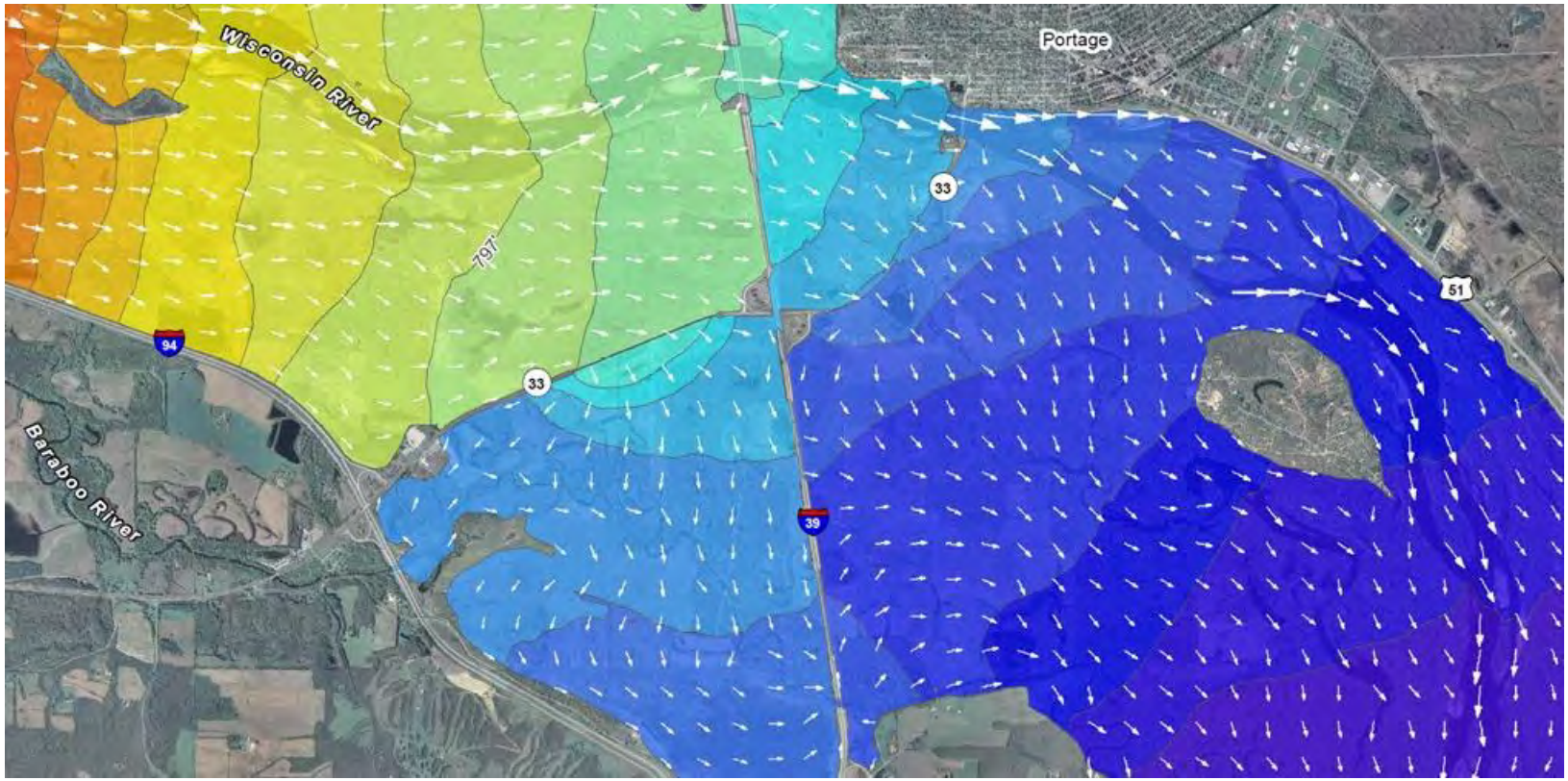

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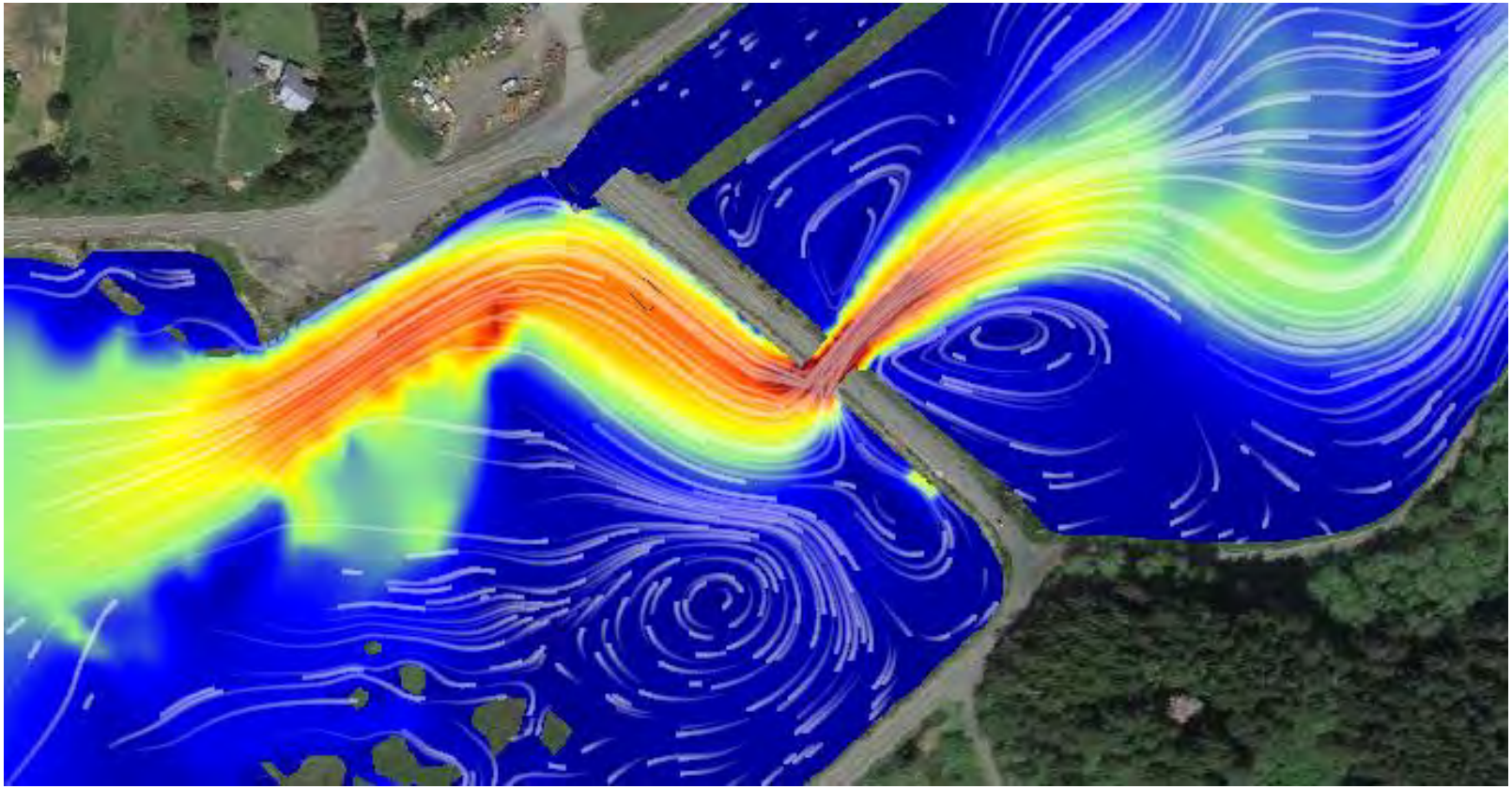
Ineffective Flow



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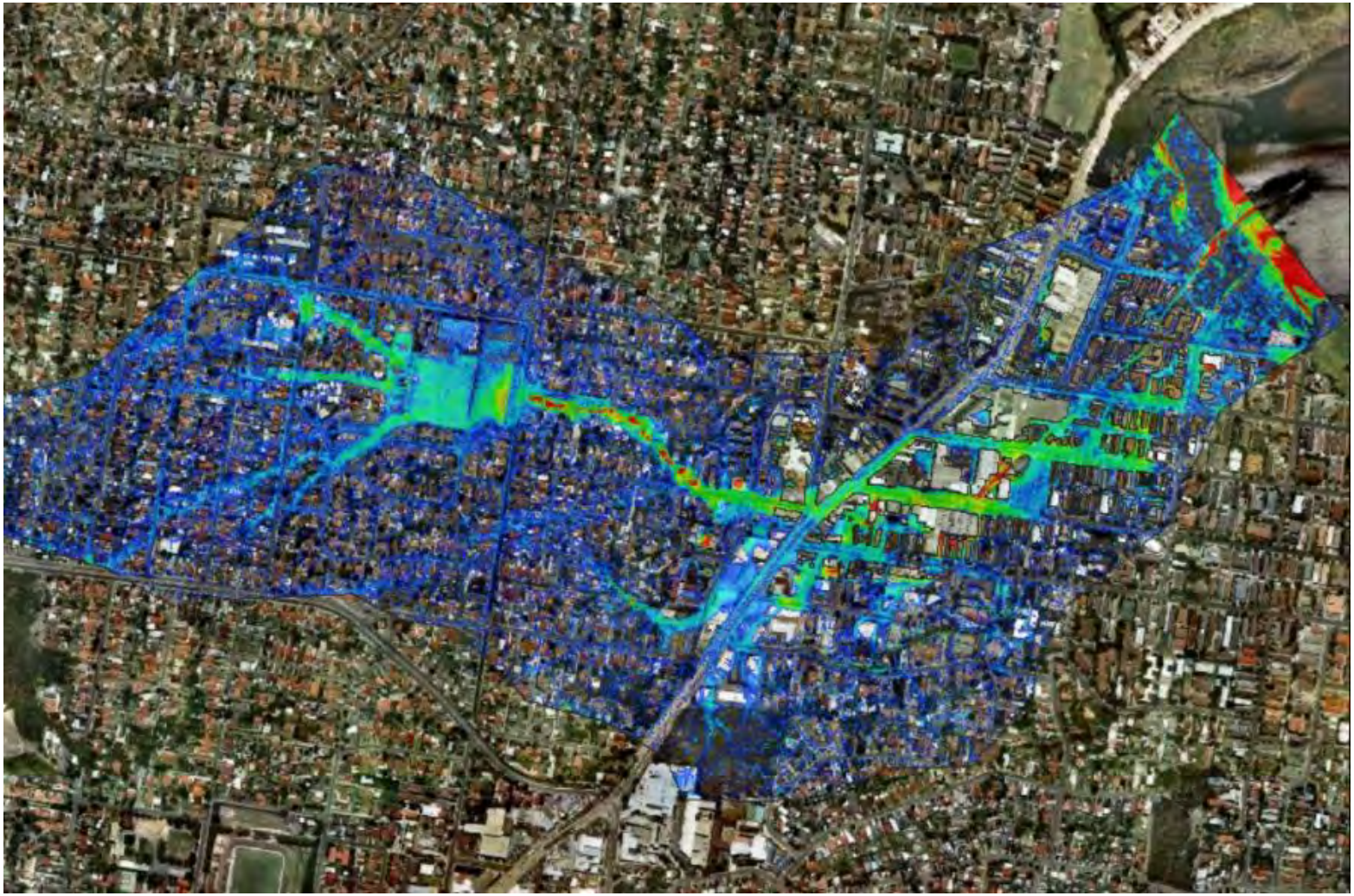
Dynamic Flood Waves (Dam Break)



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2D Modeling Software

- Public Domain (freeware)
  - HEC-RAS: (1D and 2D) - USACE
  - FLO-2D: (2D) – FLO-2D (also a pay version)
  - SRH-2D: (2D) – FHWA (also a pay version)
- Private Domain (software for purchase)
  - TUFLOW: (1D and 2D) - BMT Group Ltd
  - MIKE FLOOD: (1D and 2D) – DHI Water and Environment Institute
  - XP-SWMM: (1D and 2D) – XP Solutions
  - RiverFlow2D: (2D) - Hydronia

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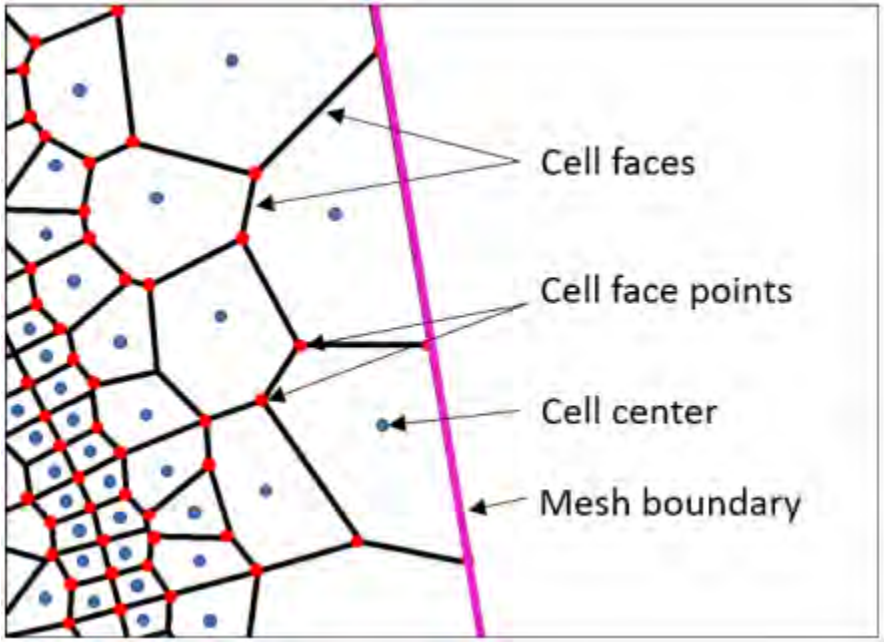
Terminology Overview

- 2D flow area, grid cell mesh, computational mesh, or just <u>mesh</u>
- Grid cell
- Cell faces
- Cell face points
- Cell center



HEC-RAS 5.0 Overview

- 1D, 2D, or 1D/2D coupled models
- Structured or unstructured mesh (8 sides)
- Implicit finite volume solver
- Full St. Venant Equations or Diffusion Wave Equations
- Hydraulic properties for 2D computational cells and cell faces
  - High resolution sub-grid model

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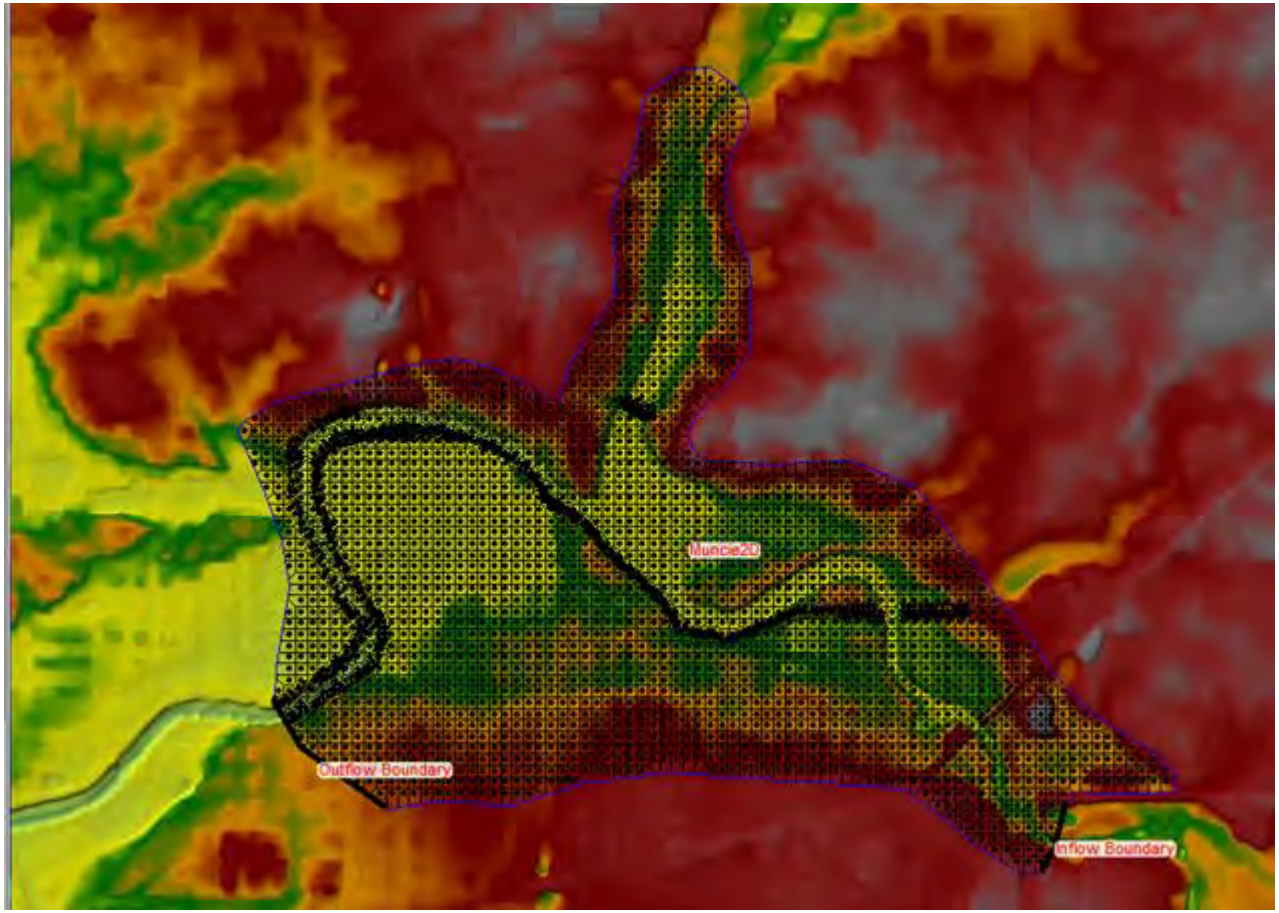
HEC-RAS 5.0 2D Only



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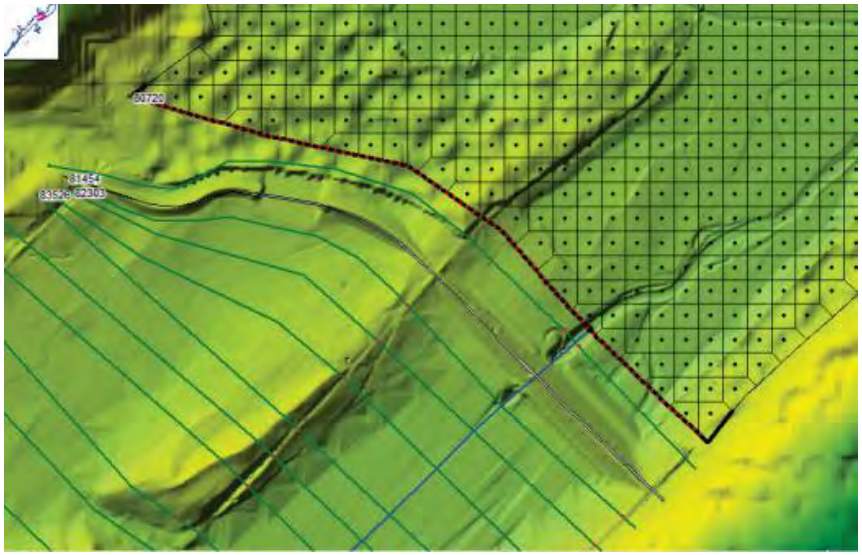
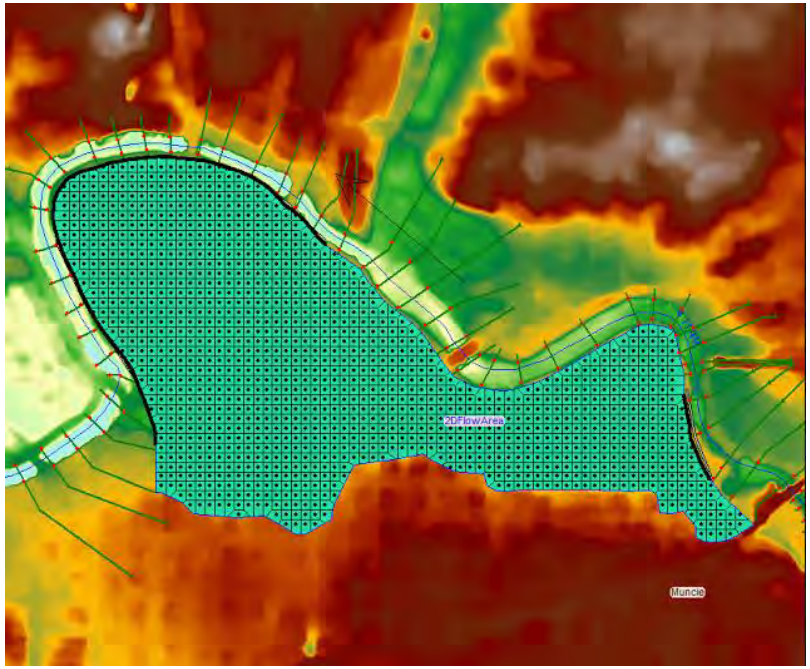
HEC-RAS 1D/2D Coupled





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HEC-RAS 5.0 – Sub-grid Resolution

- Represents terrain resolution below grid cells

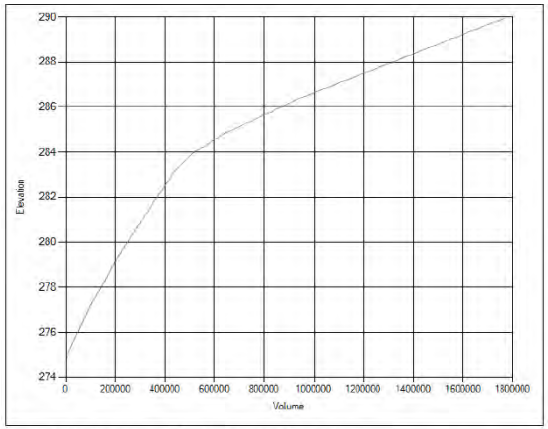


Figure 3-23. Elevation – Volume relationship for a 2D cell.

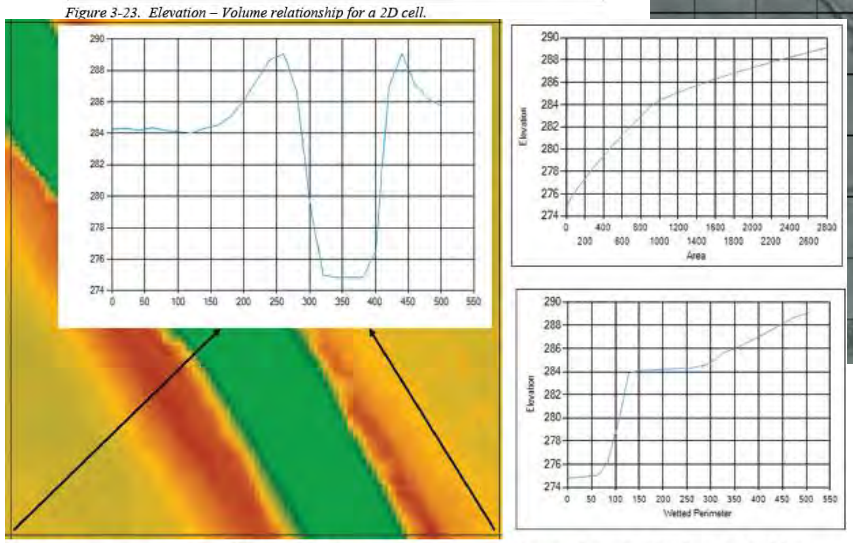
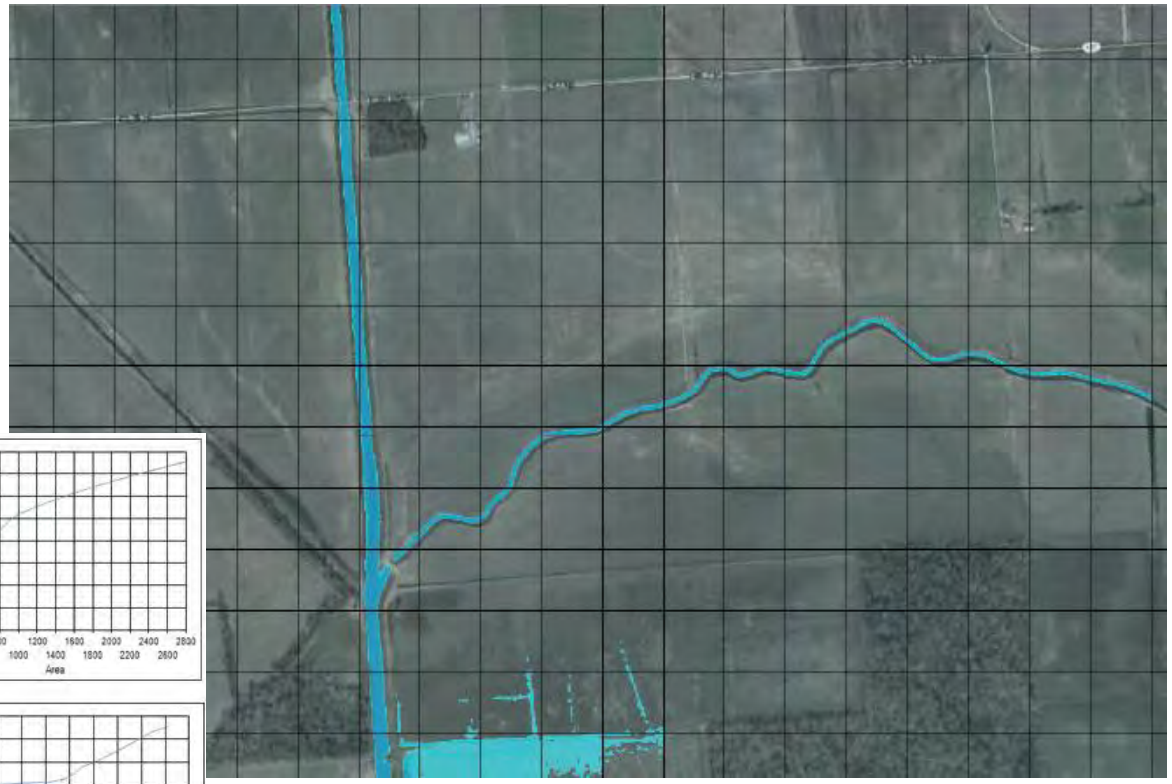


Figure 3-24. Example of how Cell Faces are processed into detailed hydraulic tables.



Images from HEC-RAS 5.0 2D Modeling Users Manual

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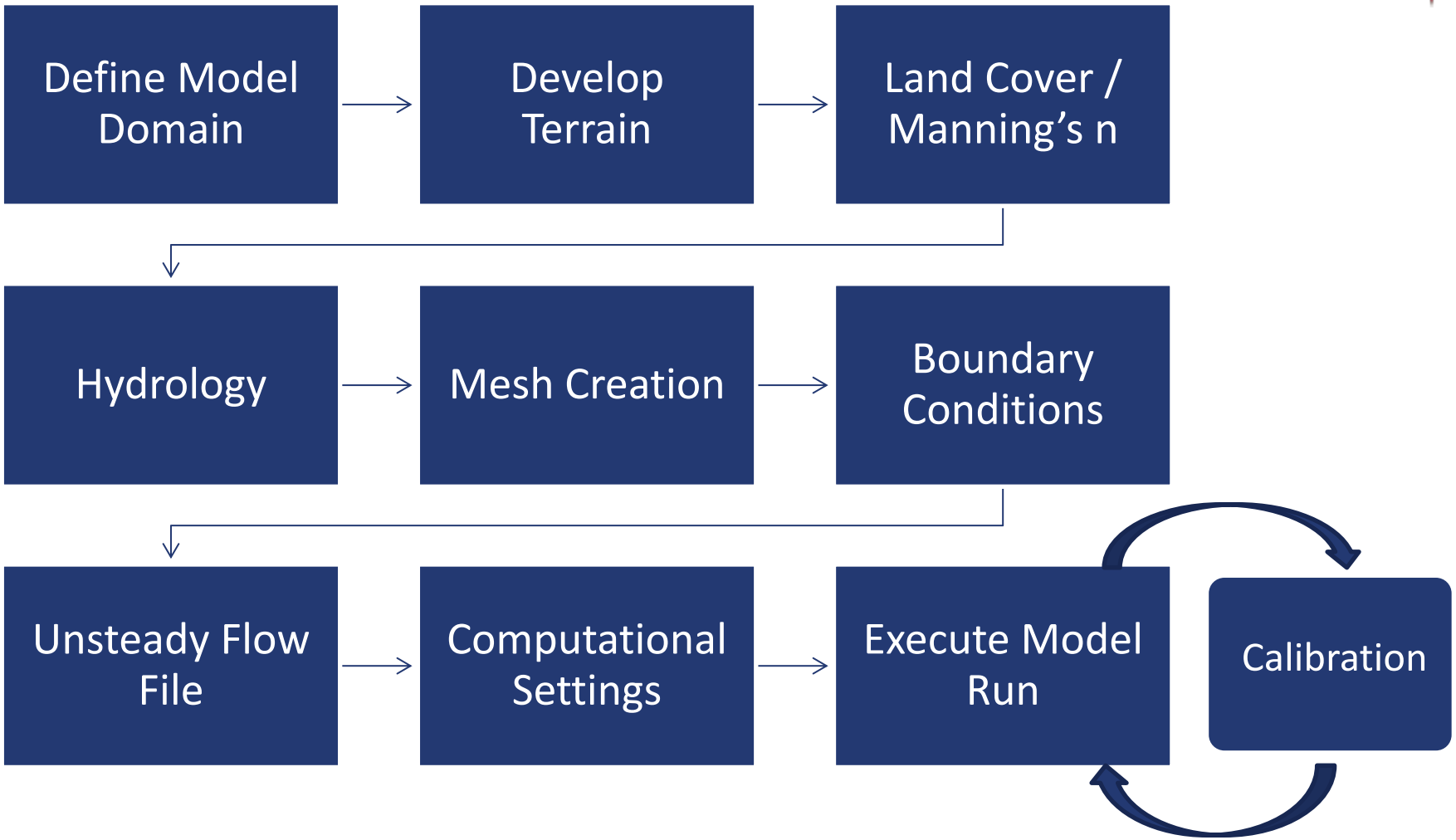
Overview of Modeling Process



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HEC-RAS 5.0 Limitations

- Bridge crossings
  - Can’t model pressure flow
  - Several options for estimating bridge hydraulics
- Leakage across flow impediments
  - Requires diligence in breakline application
- Results rendering issues
- Error identification

Advantages of Other 2D Software

- SRH-2D
  - Easy terrain adjustments
  - Detailed structure representation
  - Scour analysis
  - 2D Sediment Transport
- TUFLOW
  - Easy terrain adjustments
  - 1D and 2D representation of structures
  - Link to closed conduit elements
- MIKE Flood
  - Easy terrain adjustments
  - 1D and 2D representation of structures
  - Link to closed conduit elements
- FLO2D
  - Open source coding
  - Easy terrain adjustment
  - Link to closed conduit elements

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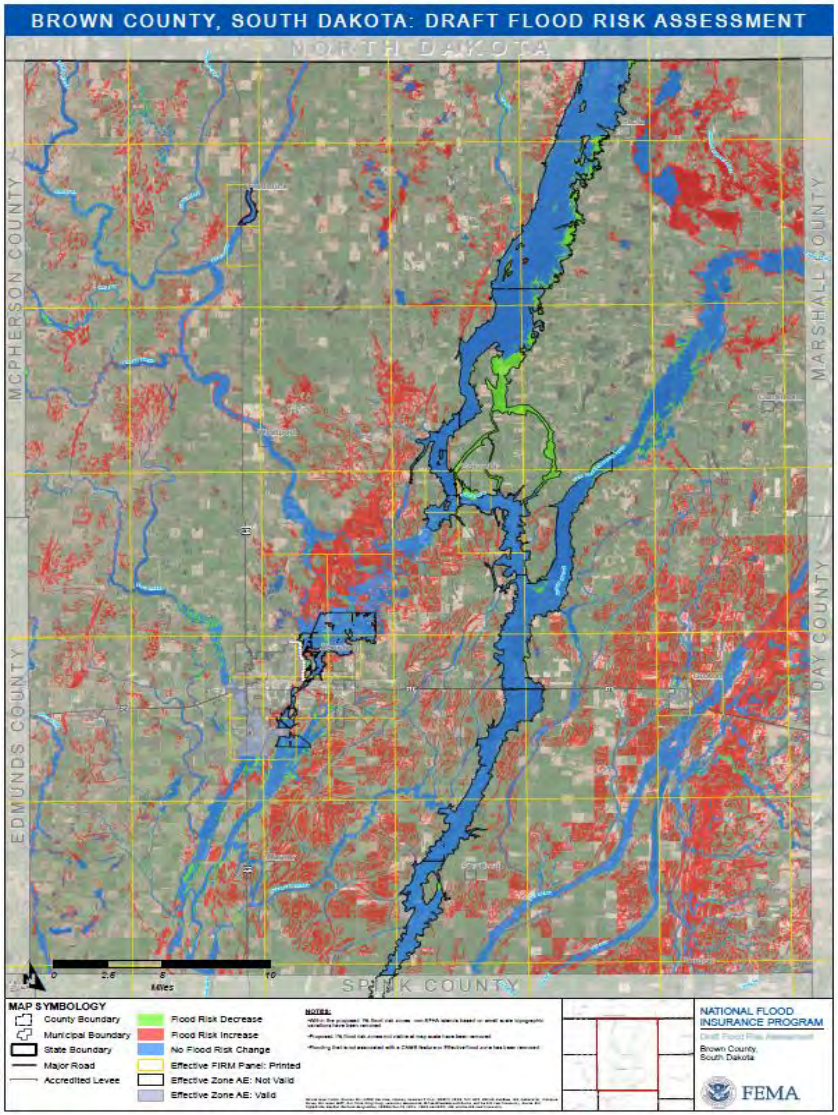
FEMA Applications

- Detailed studies
  - Becoming more common, especially 1D/2D coupled
- Alluvial fans
- Shallow flooding
- Large Scale Base Level Engineering
  - Zone A ready



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Questions

Photo from FEMA

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