

# Overview of Unsteady Flow Modeling for Dam Breach Analysis

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Hydrologic Engineering Center



# Overview:

1. Overview of Unsteady Flow
2. Overview of Dam Breaches Options
3. Examples



# Overview:

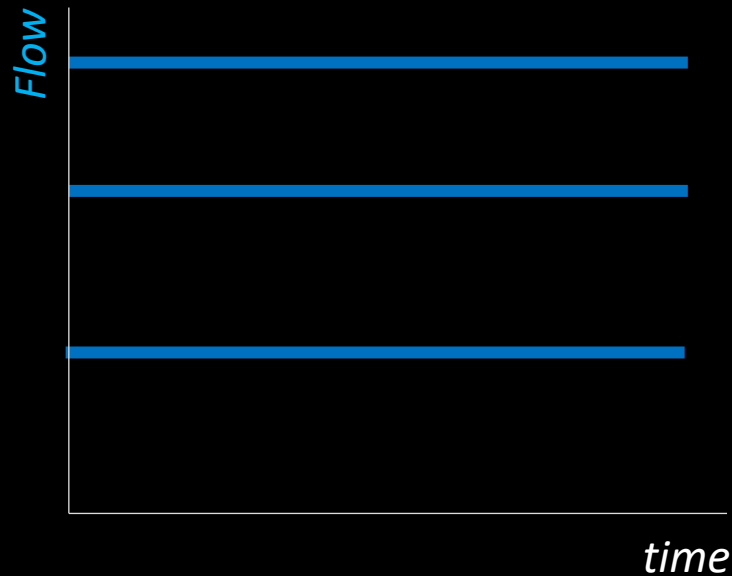
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# 1. What is Unsteady Flow?

## Steady Flow

$$Q(\cancel{t})$$

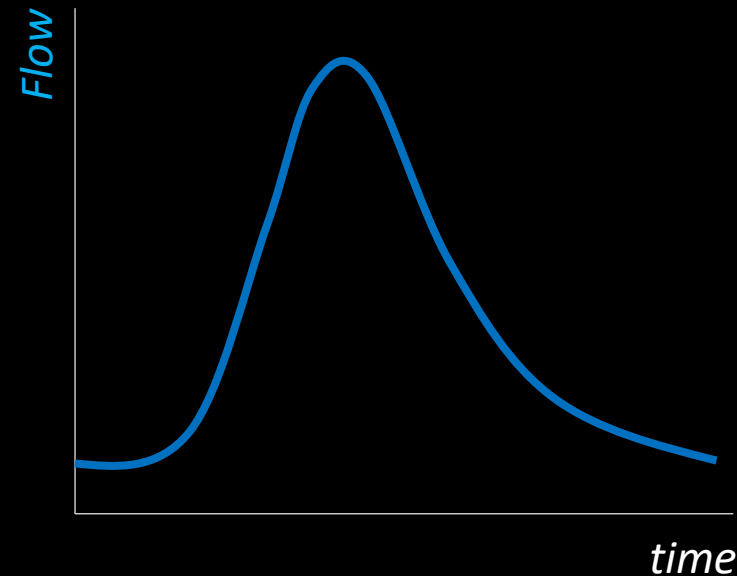


*changes gradually*

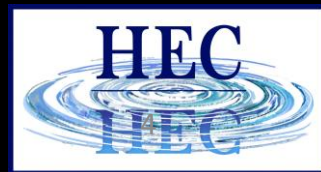
Flow ~~does not change~~ with time

## Unsteady Flow

$$Q(t)$$



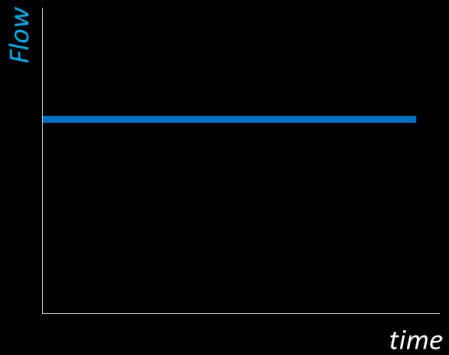
Flow changes with time



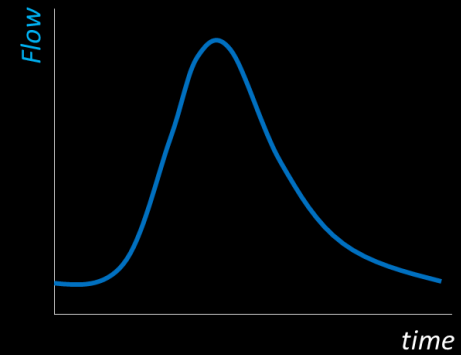
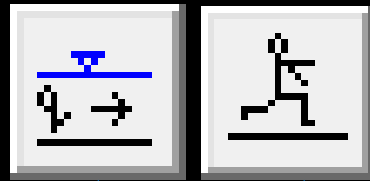
# 1. What is Unsteady Flow?

Steady Flow

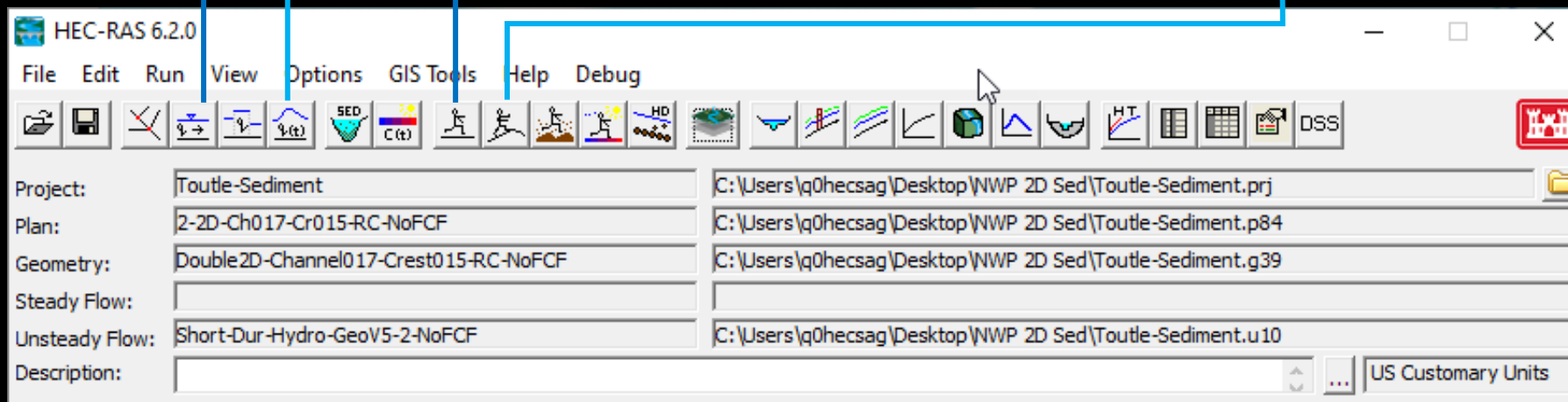
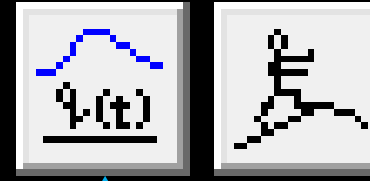
Unsteady Flow



$$Q(t)$$

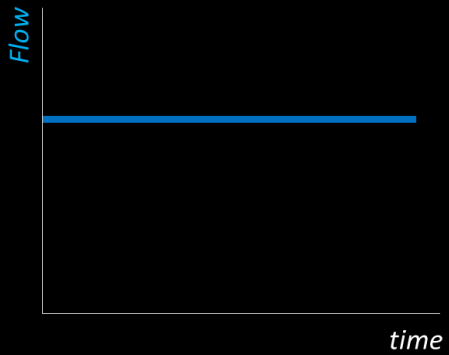


$$Q(t)$$

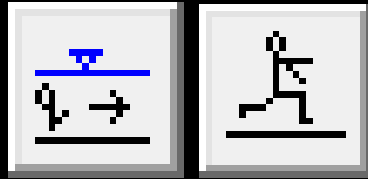


# 1. What is Unsteady Flow?

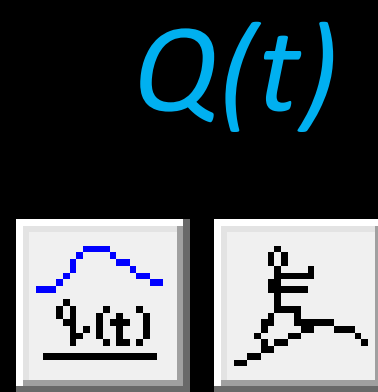
## Steady Flow



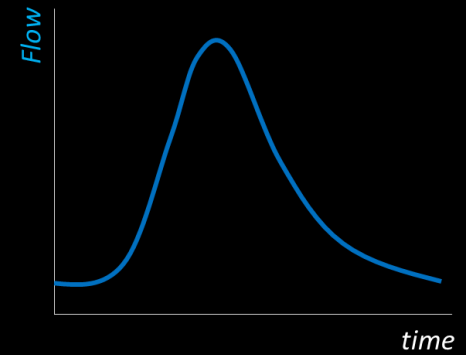
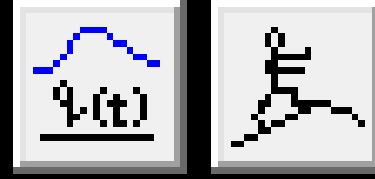
$$Q(\cancel{t})$$



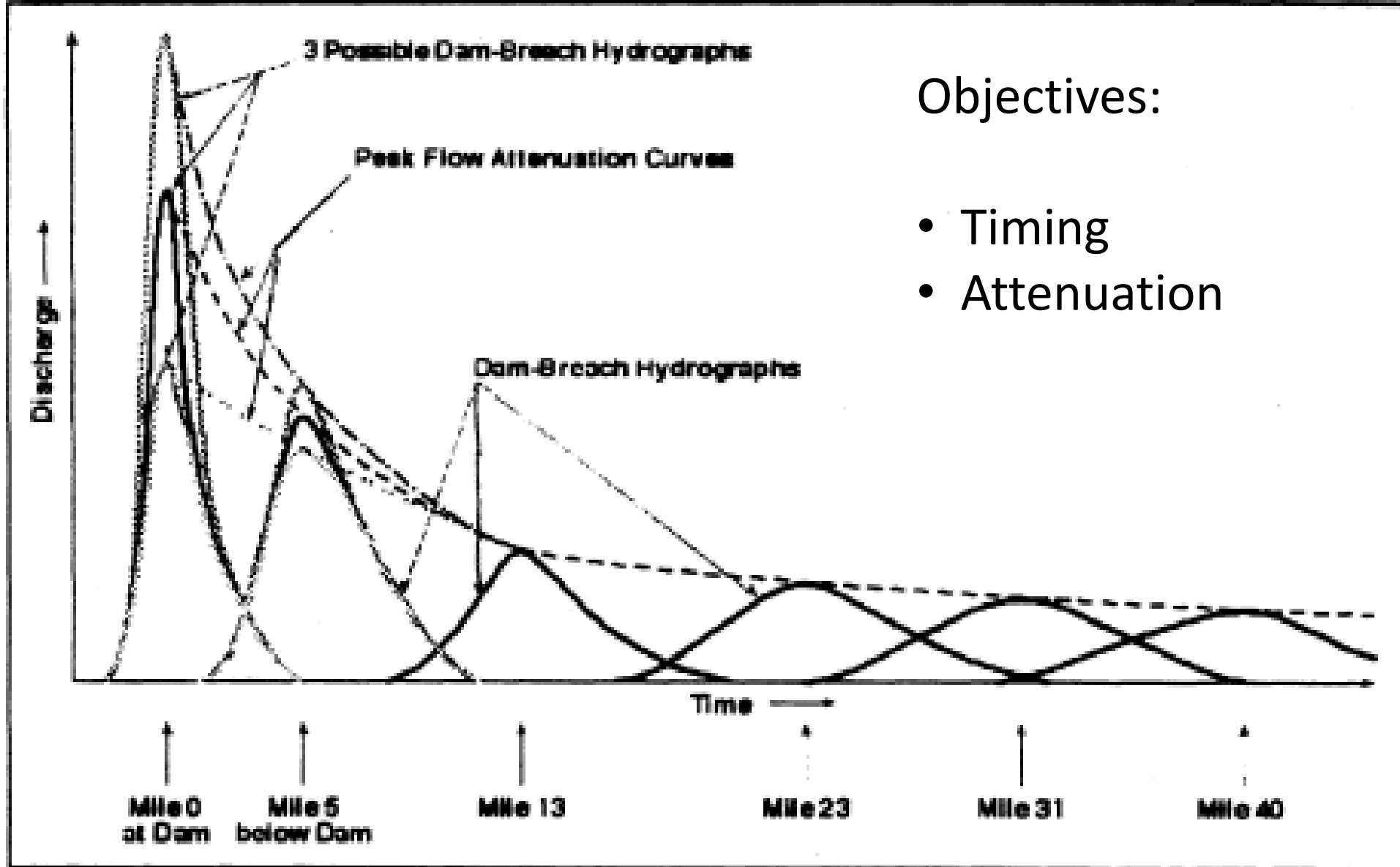
## Unsteady Flow



$$Q(t)$$



# Which do we use for Dam Breach?



Objectives:

- Timing
- Attenuation

# Shallow Water Flow Equations

$$\frac{\partial Q}{\partial x} + \frac{\partial s_c (A + A_o)}{\partial t} - q = 0 \quad (\text{Conservation of Mass})$$

$$\frac{\partial (s_m Q)}{\partial t} + \frac{\partial (\beta Q^2 / A)}{\partial x} + gA \left( \frac{\partial h}{\partial x} + S_f + S_{ec} + S_i \right) + L = 0 \quad (\text{Conservation of Momentum})$$

## HEC-RAS Unsteady Computation Options and Tolerances

General | 2D Flow Options | 1D/2D Options | Advanced Time Step Control | 1D Mixed Flow Options

Use Coriolis Effects (not used with Diffusion Wave equation)

	Parameter	(Default)
1	Theta (0.5-1.0)	1
2	Theta Warmup (0.5-1.0)	1
3	Water Surface Tolerance [max=0.2](ft)	0.01
4	Volume Tolerance (ft)	0.01
5	Maximum Iterations	20
6	Equation Set	Diffusion Wave
7	Initial Conditions Time (hrs)	Diffusion Wave
8	Initial Conditions Ramp Up Fraction (0-1)	SWE-ELM (original/faster)
9	Number of Time Slices (Integer Value)	SWE-EM (stricter momentum)
10	Turbulence Model	SWE-LIA (local inertia)



# Momentum Equation

$$\underbrace{\frac{\partial V}{\partial t}}_{\text{Temporal}} + \underbrace{(V \cdot \nabla)V}_{\text{Advection}} + \underbrace{f_c \mathbf{k} \times V}_{\text{Coriolis}} = - \underbrace{g \nabla z_s}_{\text{Pressure gradient}} + \underbrace{\frac{1}{h} \nabla \cdot (v_t h \nabla V)}_{\text{Diffusion}} - \underbrace{\frac{\tau_b}{\rho R}}_{\text{Bottom Friction}} + \underbrace{\frac{\tau_s}{\rho h}}_{\text{Wind Stress}}$$

# Diffusion Wave Equation

$$\cancel{\frac{\partial V}{\partial t}} + \cancel{(V \cdot \nabla)V} + \cancel{f_c \mathbf{k} \times V} = -g \nabla z_s + \cancel{\frac{1}{h} \nabla \cdot (v_t h \nabla V)} - \frac{\tau_b}{\rho R} + \frac{\tau_s}{\rho h}$$

*Note: In the Diffusion Wave Equation, the Temporal, Advection, Coriolis, and Diffusion terms are crossed out, leaving only the Pressure gradient, Bottom Friction, and Wind Stress terms.*



# SWE vs. DWE



- Use SWE for:
  - Flows with dynamic changes in acceleration
  - Studies with important wave effects, tidal flows
  - Detail solution of flows around obstacles, bridges or bends
  - Simulations influenced by Coriolis or mixing
  - To obtain local detailed behavior of the flow
- Use DWE for:
  - Flow is mainly driven by gravity and friction
  - Fluid acceleration is monotonic and smooth, no waves
  - To compute approximate global estimates such as flood extent
  - To assess approximate effects of dam breaks
  - To assess interior areas due to levee breaches
  - For quick estimations or preliminary runs



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HEC-RAS 2D Modeling Class

## HEC-RAS 2D Class: 1.4 - Introduction to the 2D Hydraulics Equations

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<https://youtu.be/nEr87YpHnzA>



# Matrix Solvers: Introduction



- Linear System of Equations  $Ax = b$
- Direct Solvers
  - Examples: Gaussian elimination, LU, Cholesky, and QR decompositions
  - Can be "black boxes"
  - Usually have few input parameters
  - High-accuracy
  - Can fail or be very slow for large matrices
  - Can be slow for unsteady or non-linear systems
- Iterative Solvers
  - Examples: GS, SOR, CG, GMRES
  - Require more options and input parameters
  - Usually require preconditioners, matrix balancing, ordering, etc.
  - Less accurate
  - Good for large problems
  - Good for unsteady or non-linear systems
  - Improper use can lead to instability problems or solution divergence



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HEC-RAS 2D Modeling Class

## HEC-RAS 2D Class: 2.10 - Advanced Computation Options

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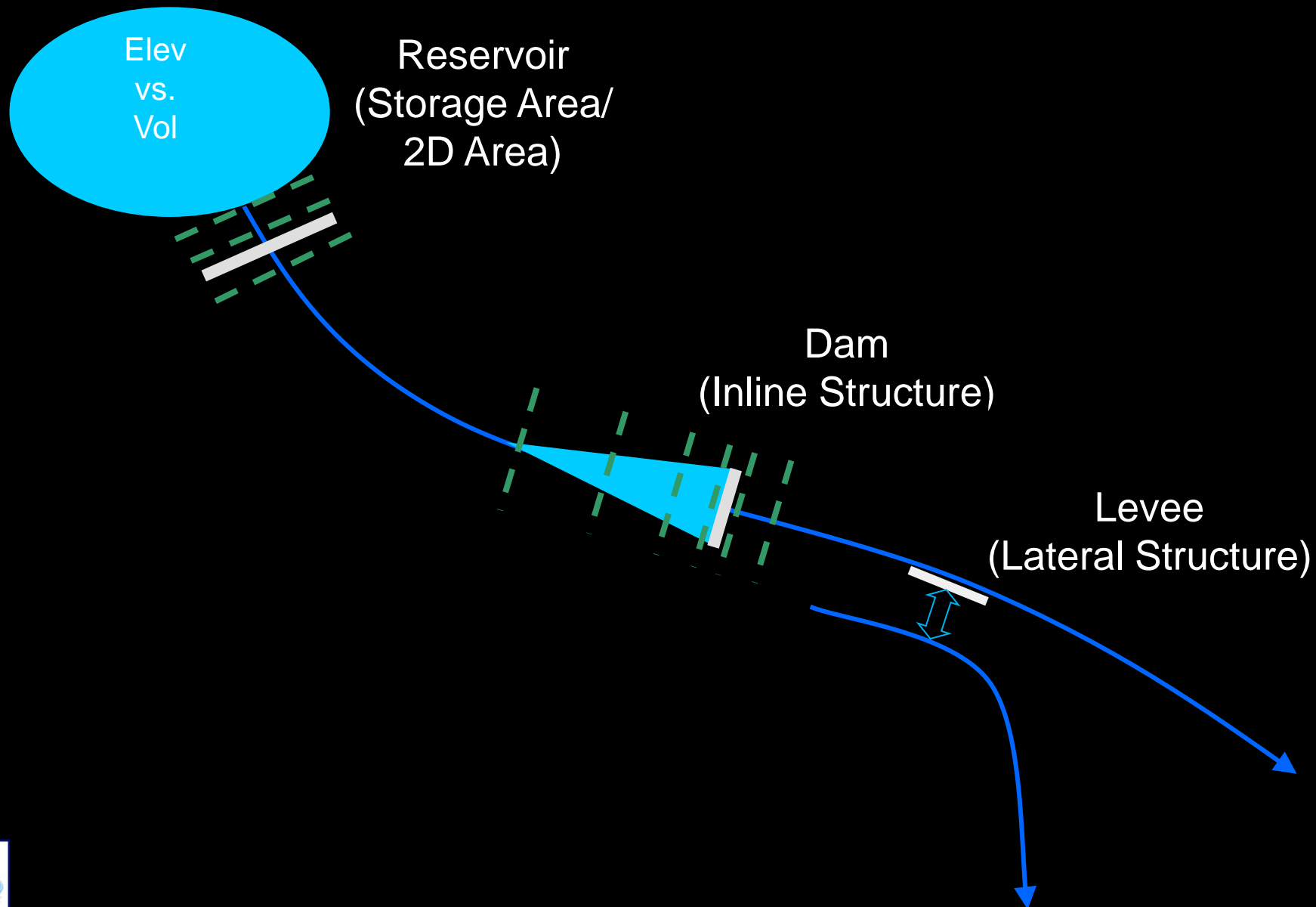


# Overview:

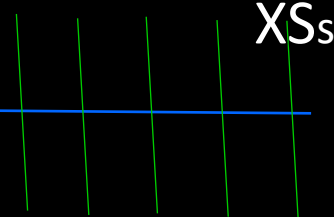

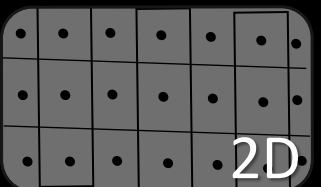
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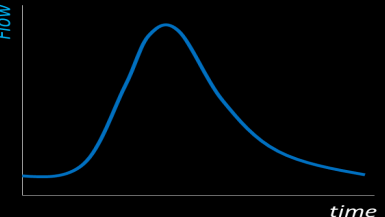
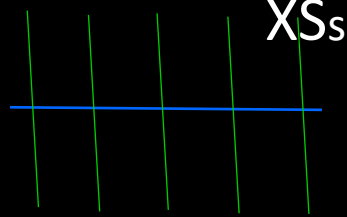

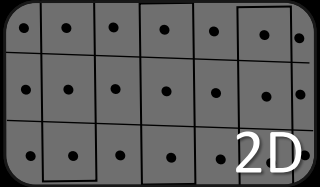
# HEC-RAS Breach Locations



# Downstream of Dam

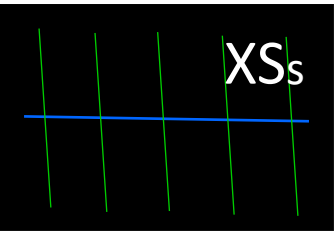
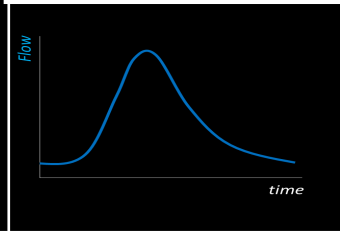
				
				
				

# Upstream of Dam

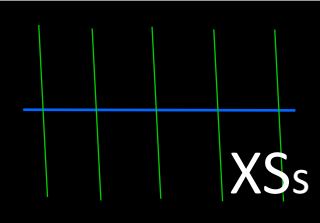
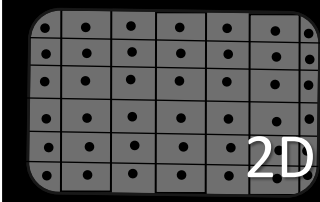
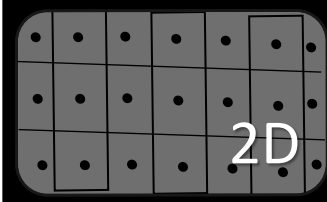
			
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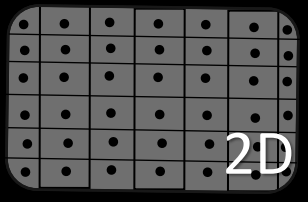
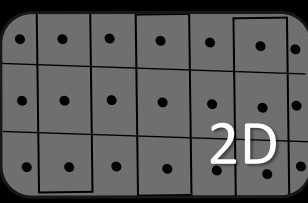
# Downstream of Dam



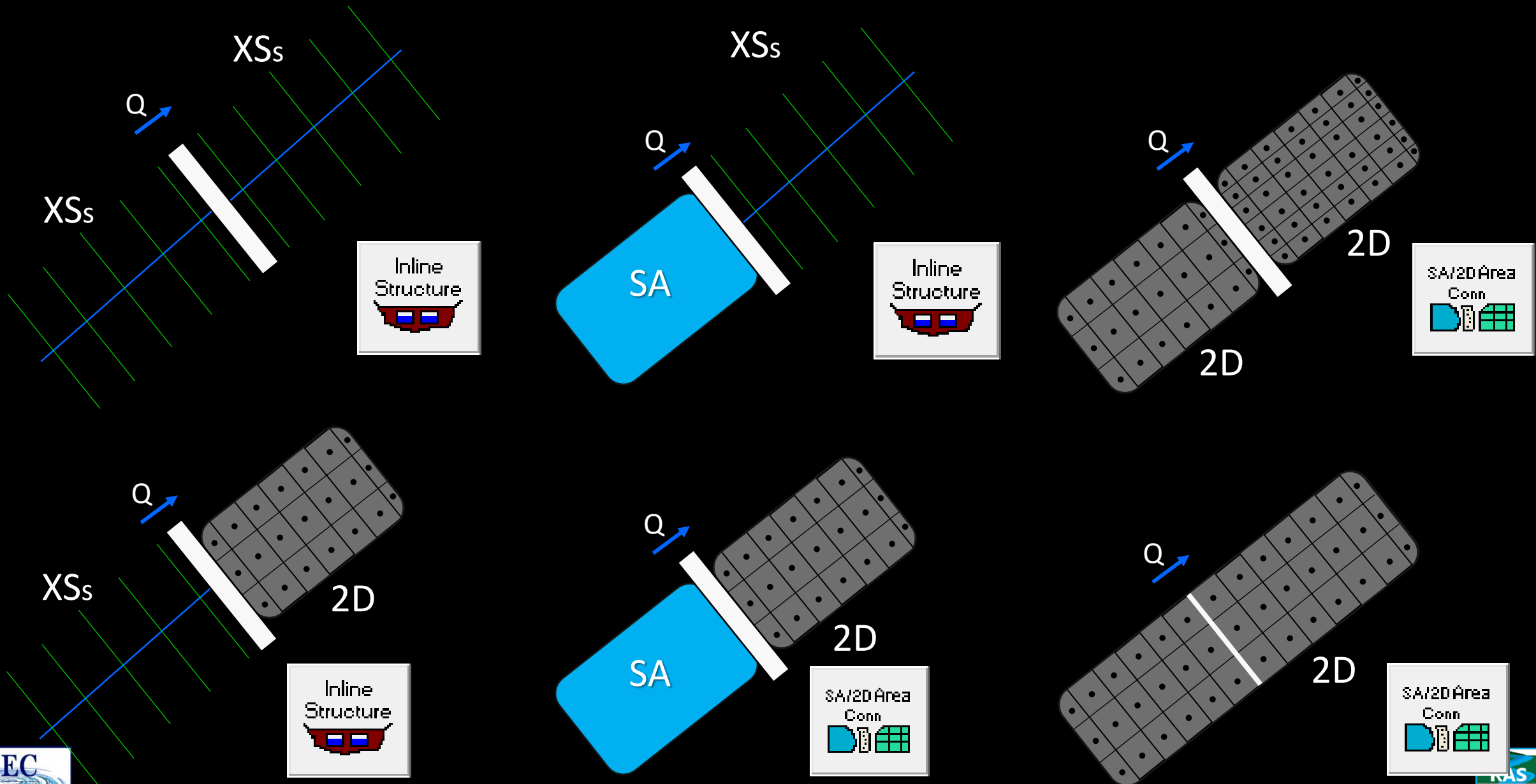
SA



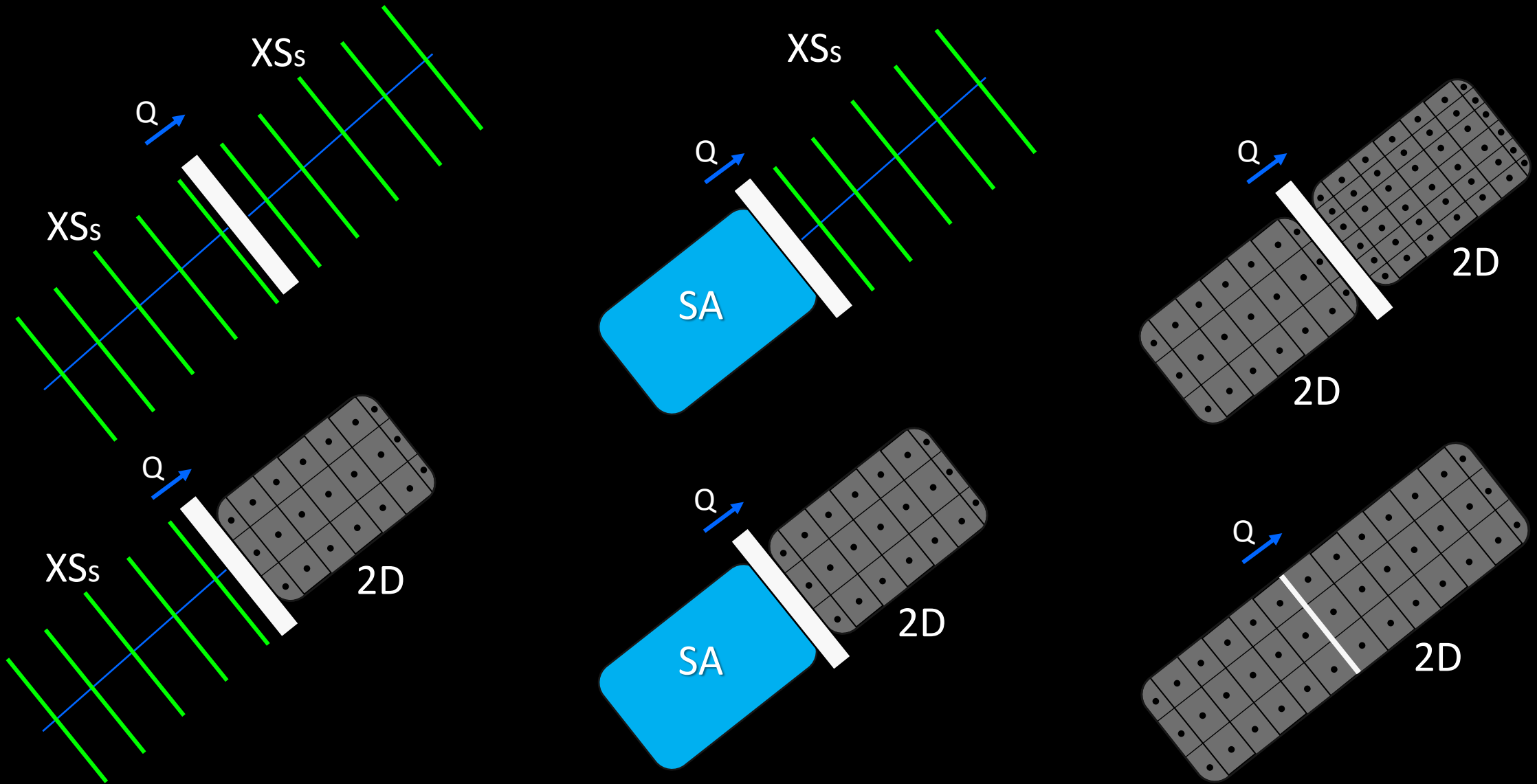
SA



# Breach Model Configuration Options



# Breach Model Configuration Options



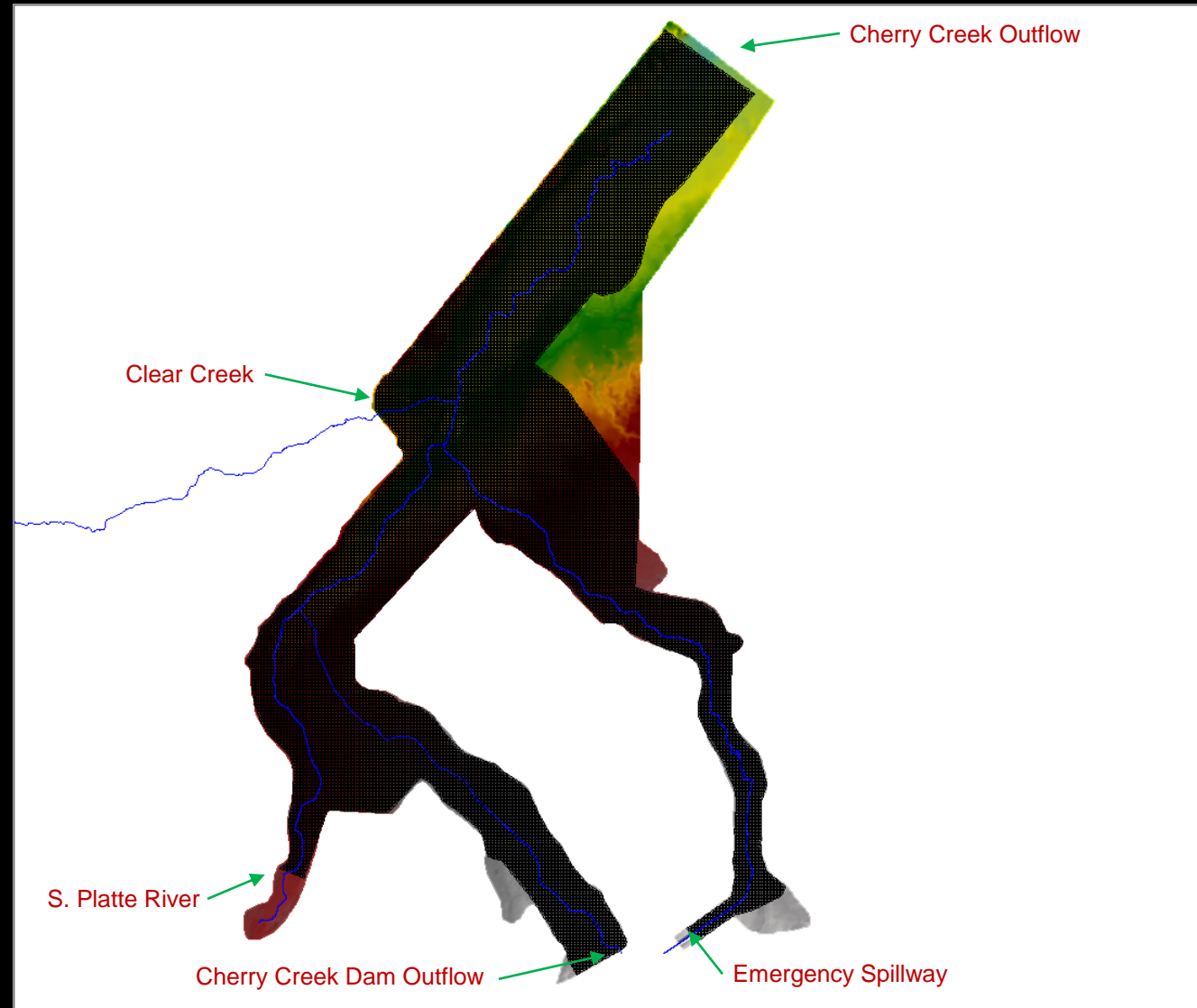


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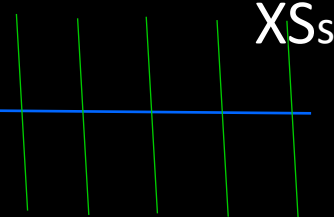

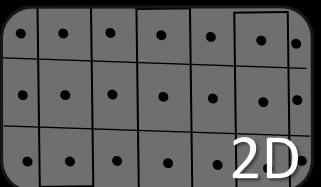
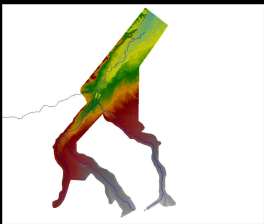
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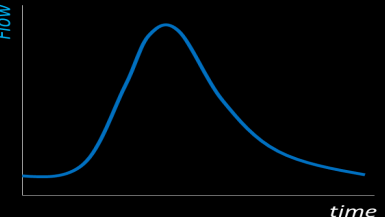
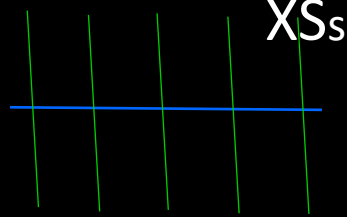

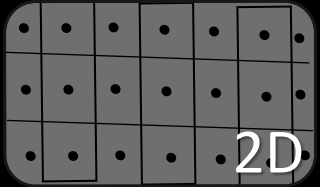
# Single 2D Area with Boundary Conditions



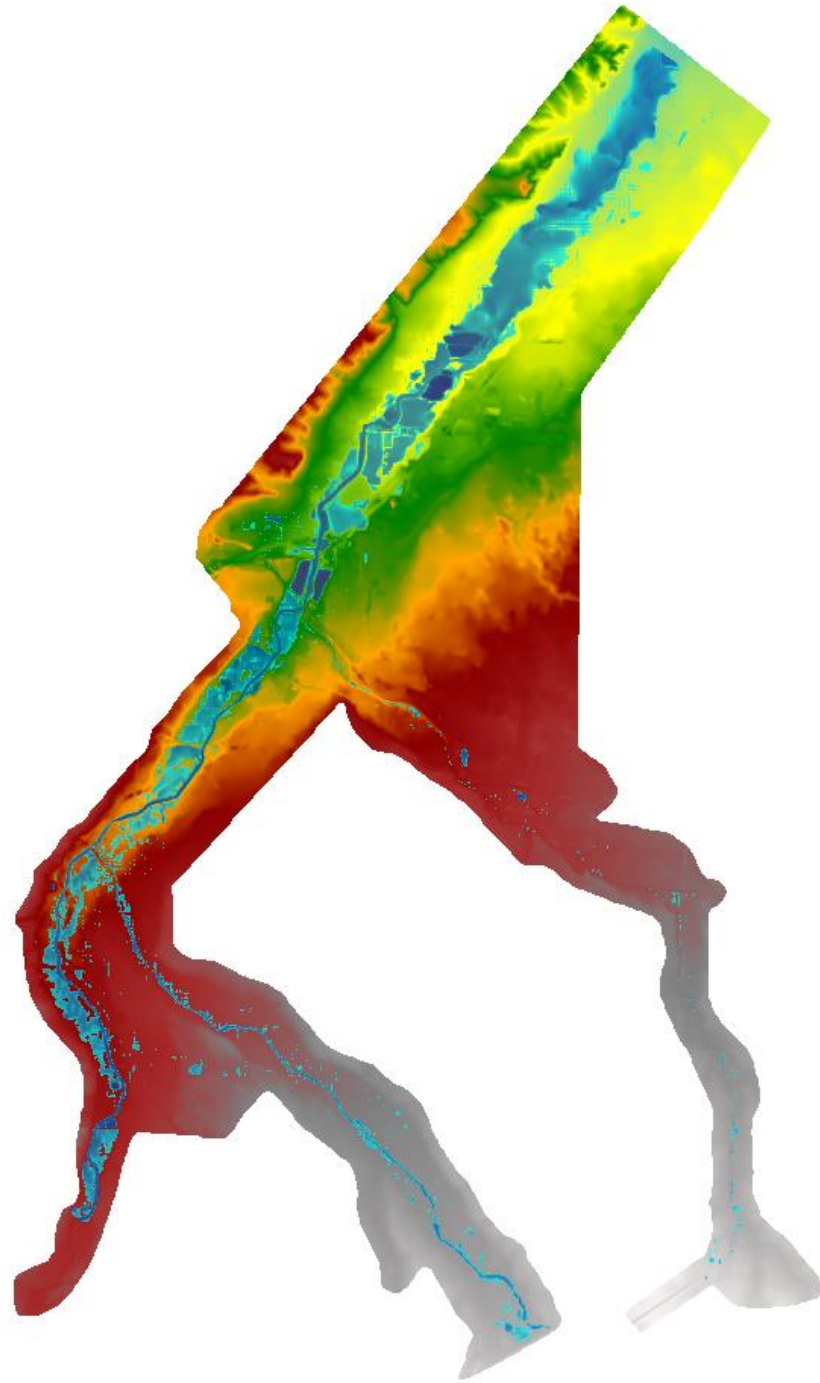
# Downstream of Dam

 XSs				
 SA				
 2D				

# Upstream of Dam

 Flow time	 XSs	 SA	 2D
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# Cherry Creek



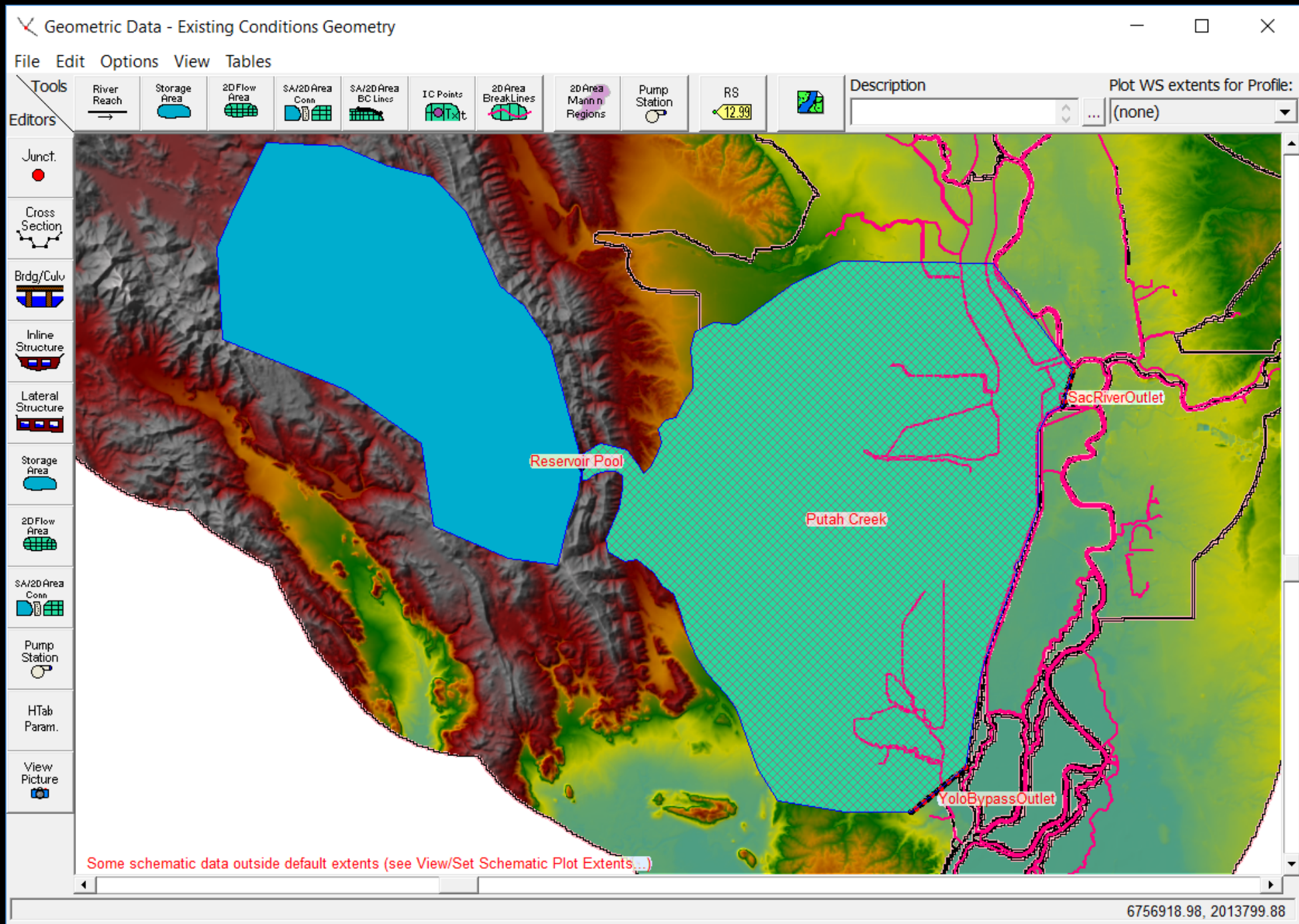


# Cherry Creek

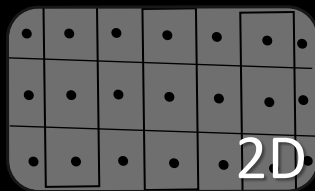
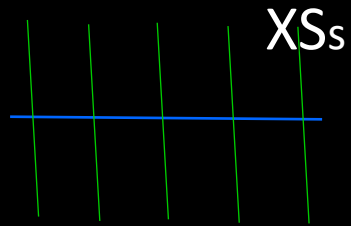




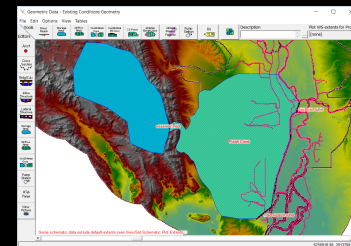
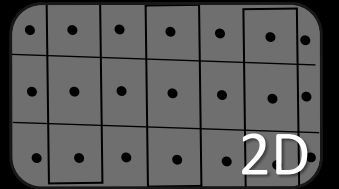
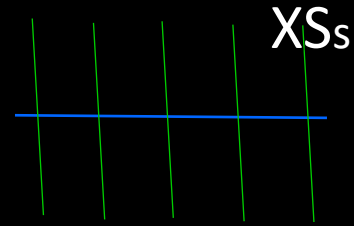
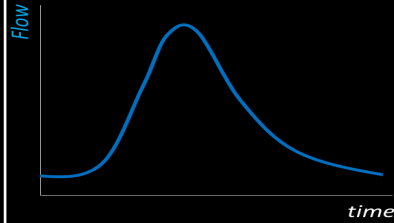
# Monticello Dam Breach



# Downstream of Dam

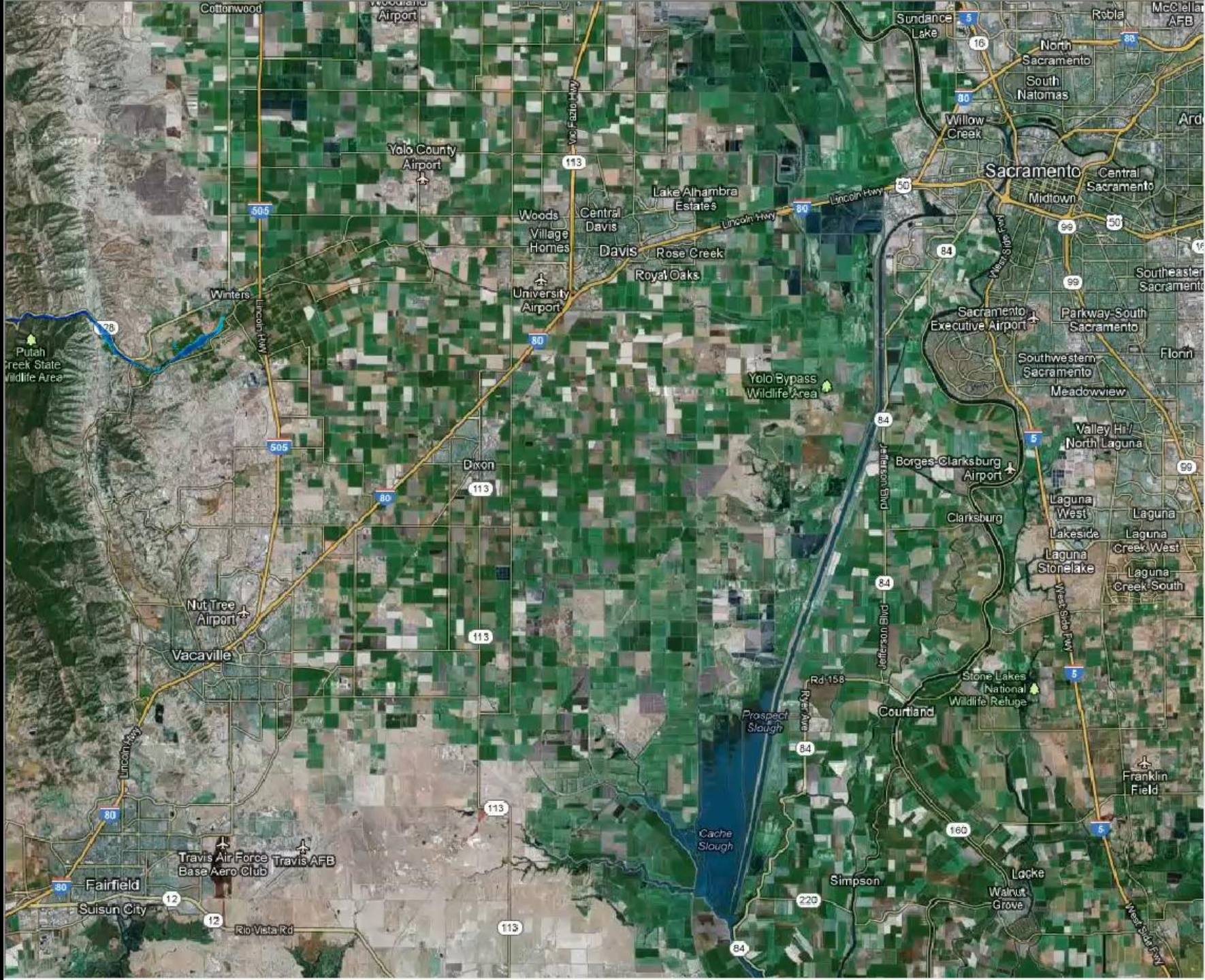


# Upstream of Dam



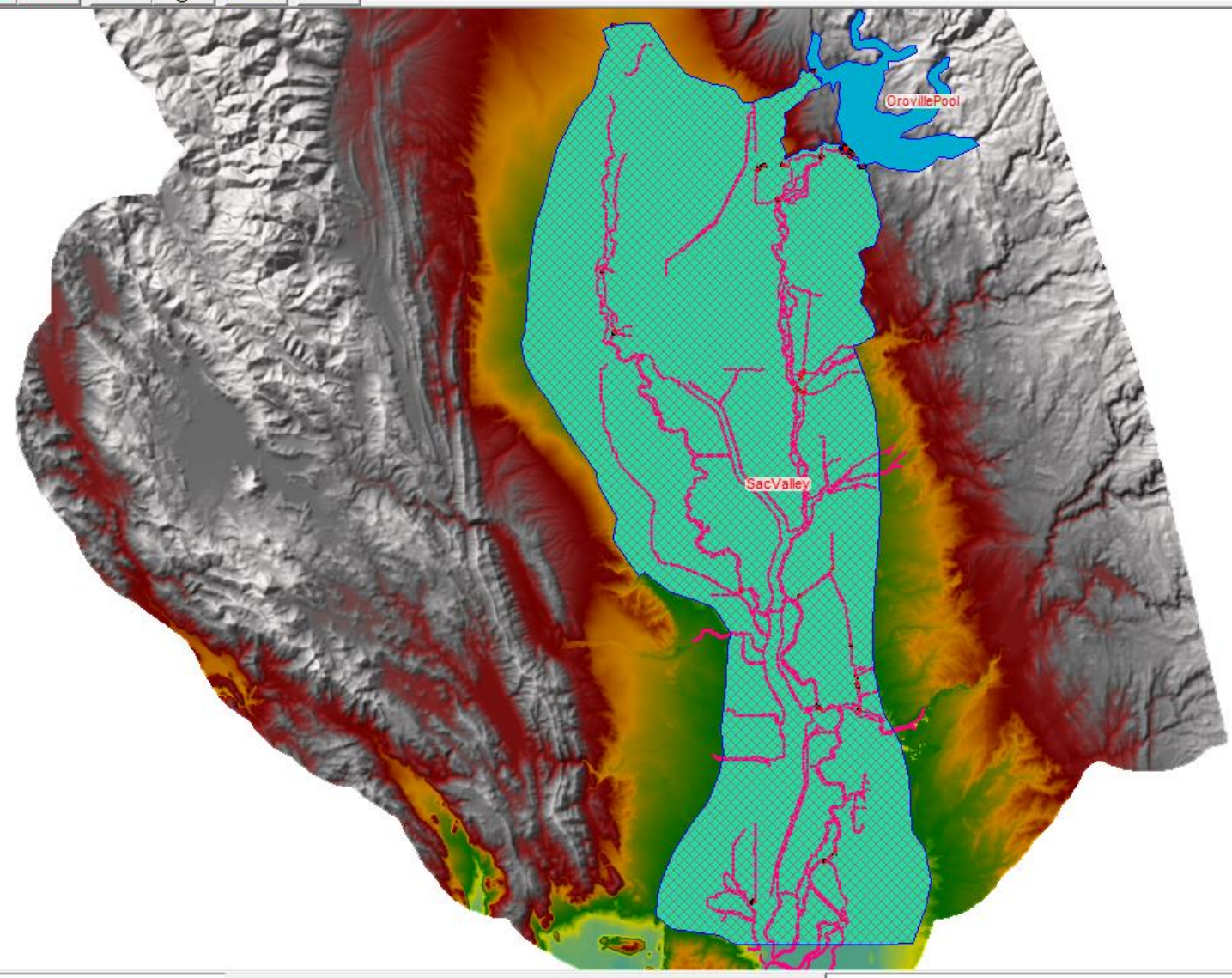


# Monticello Dam Breach





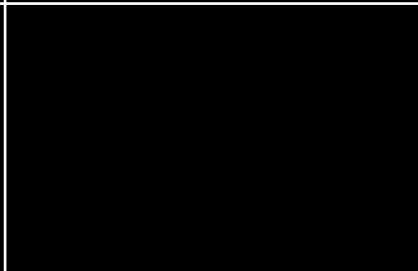
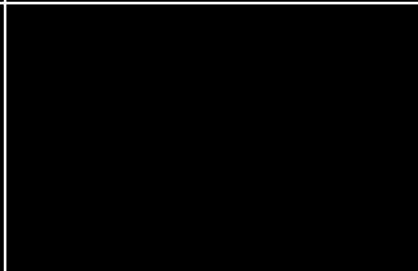
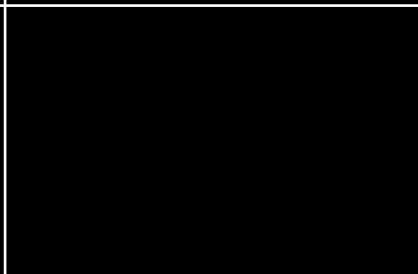
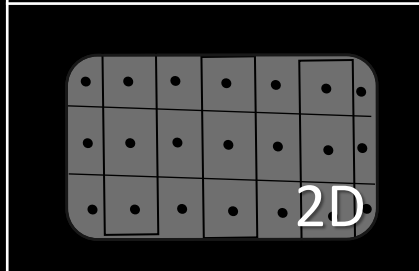
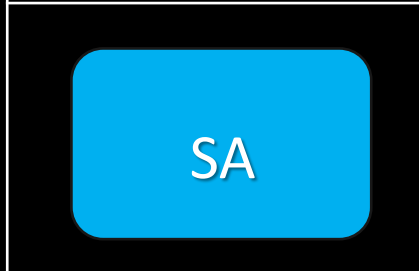
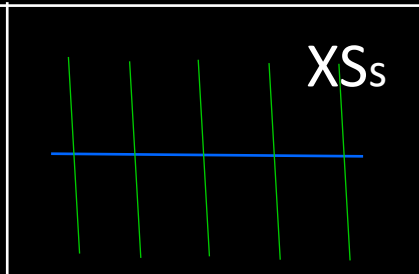
- Junct.
- Cross Section
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- Lateral Structure
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- SA/2D Area Conn
- Pump Station
- HTab Param.
- View Picture



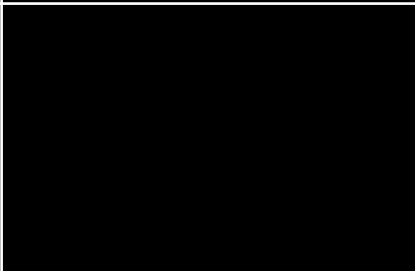
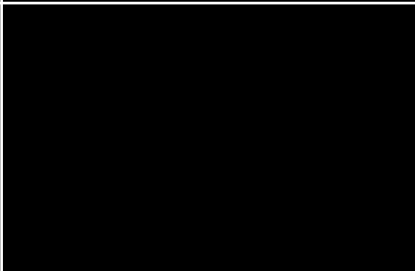
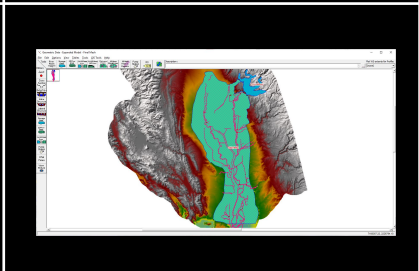
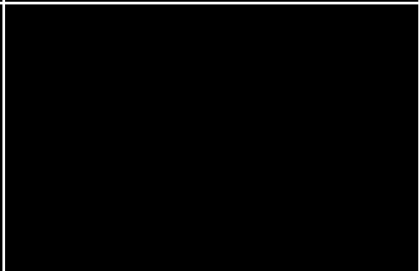
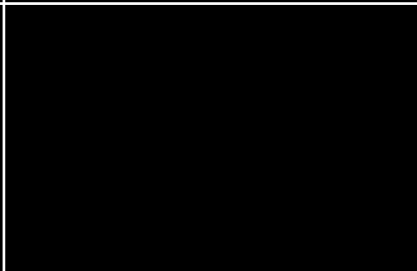
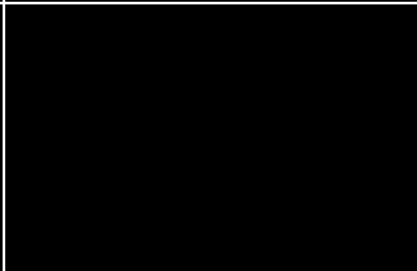
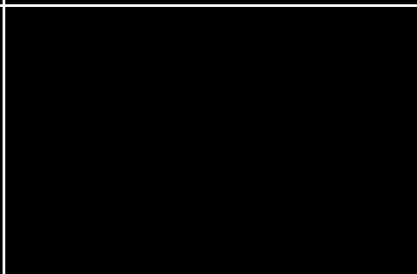
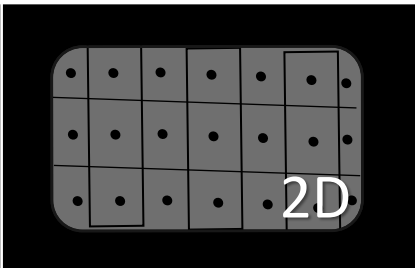
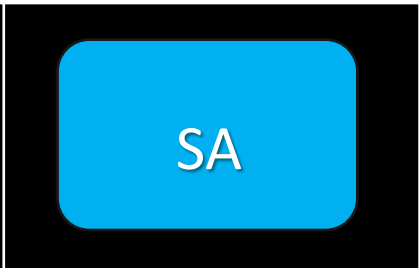
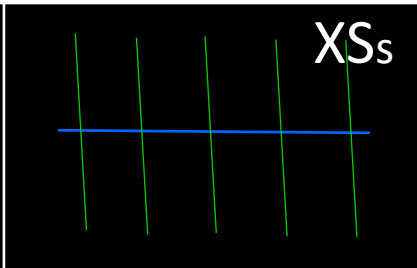
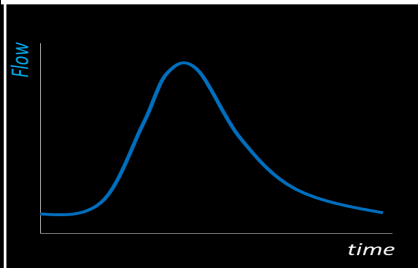
# Oroville Dam



# Downstream of Dam

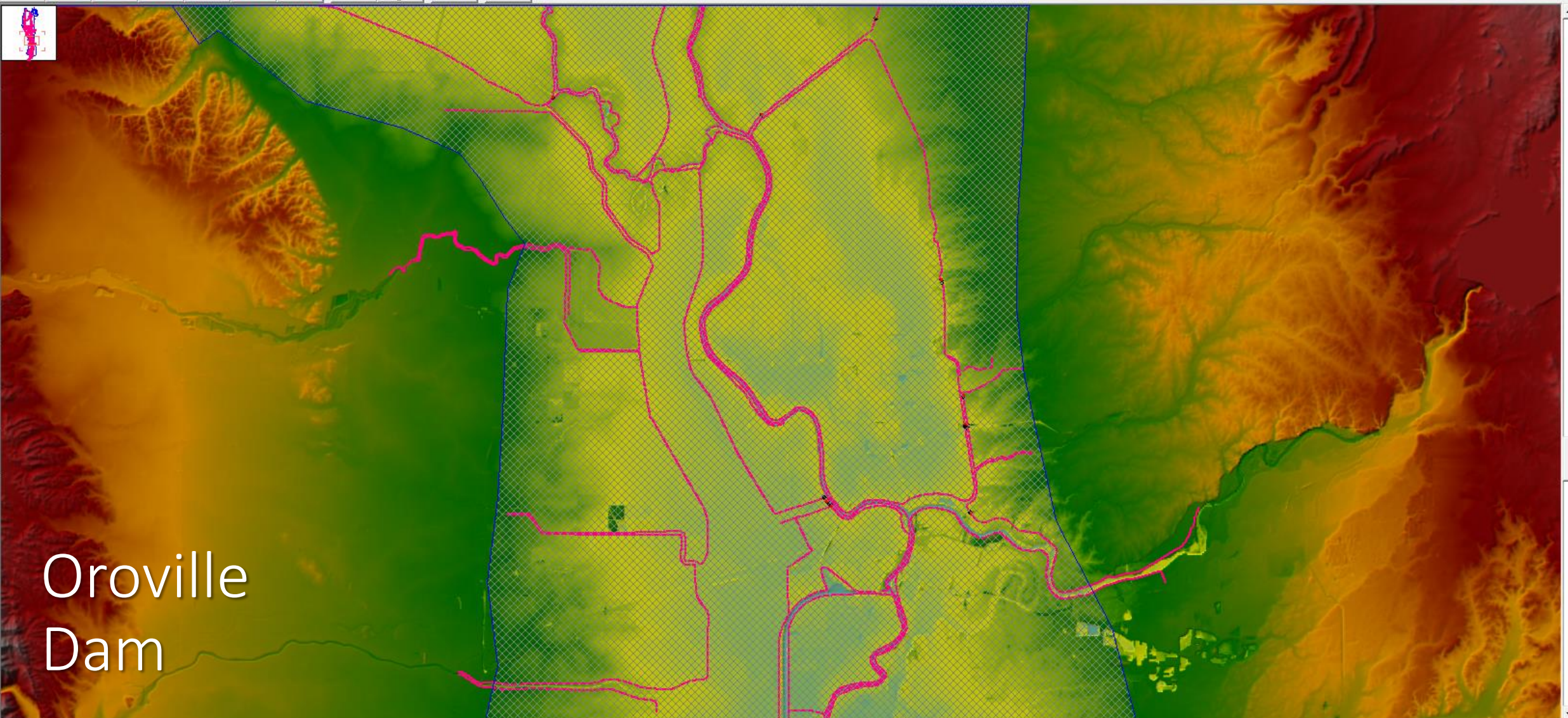


# Upstream of Dam





- Junct.
- Cross Section
- Brdg/Culv
- Inline Structure
- Lateral Structure
- Storage Area
- 2D Flow Area
- SA/2D Area Conn
- Pump Station
- HTab Param.
- View Picture

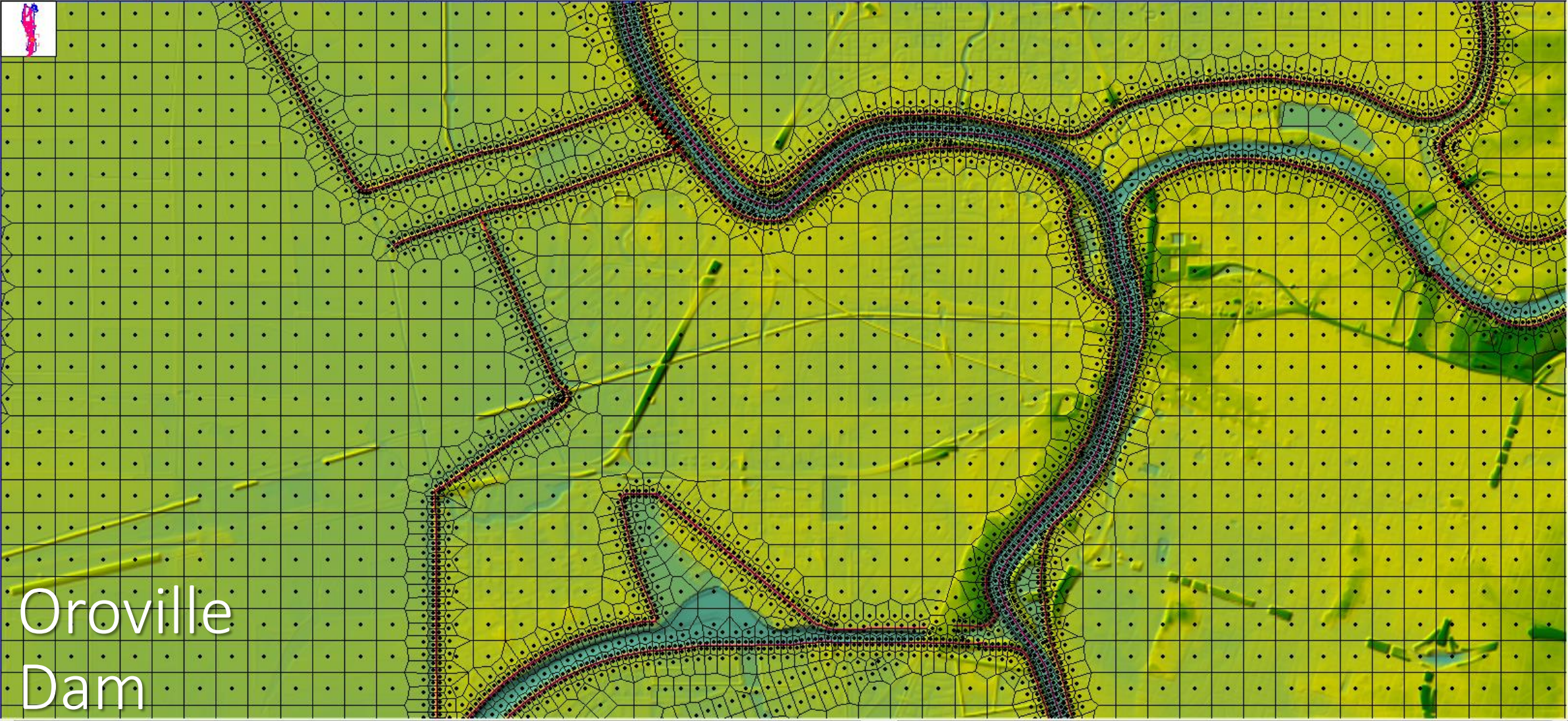


Oroville  
Dam





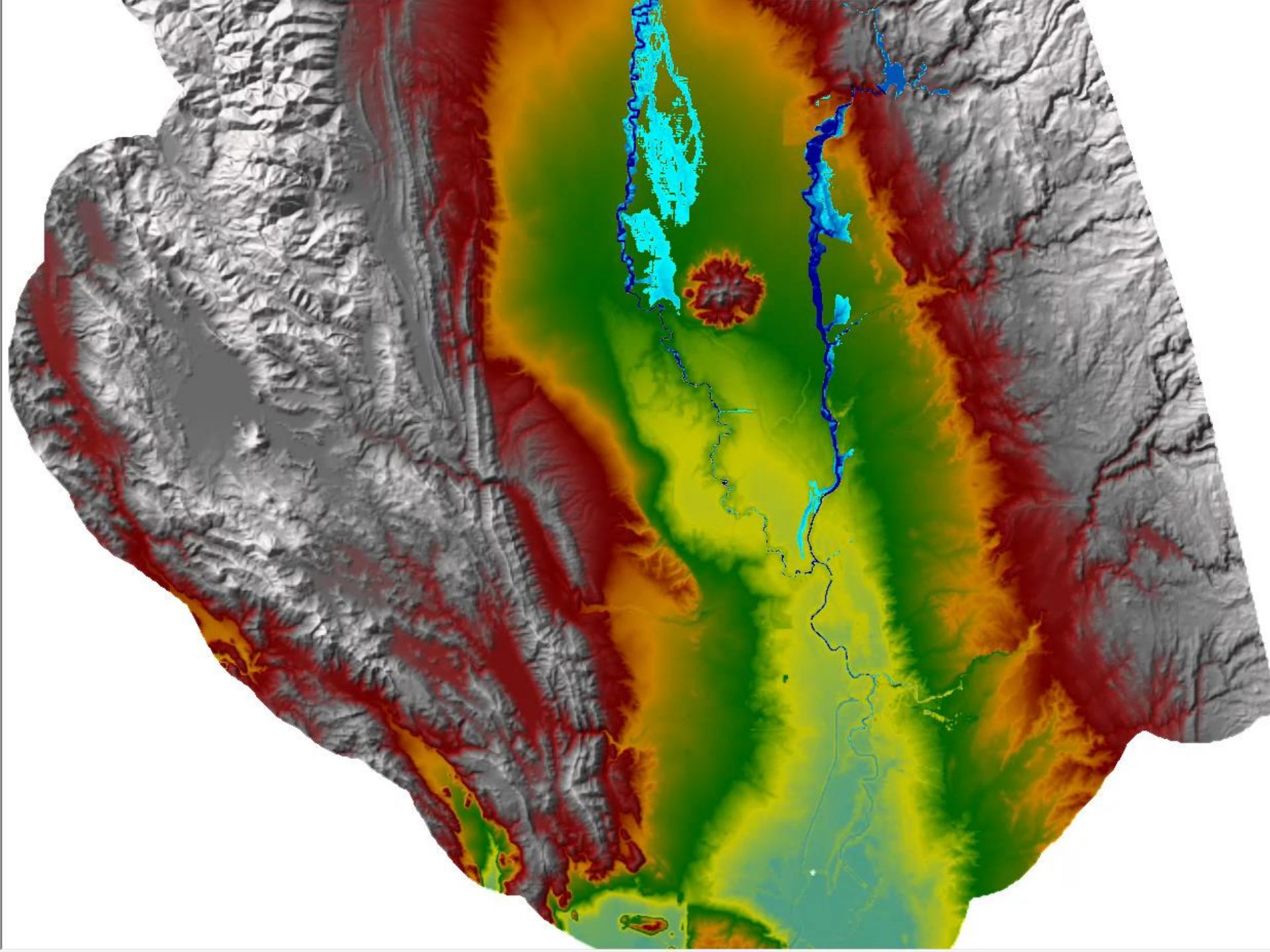
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Oroville  
Dam

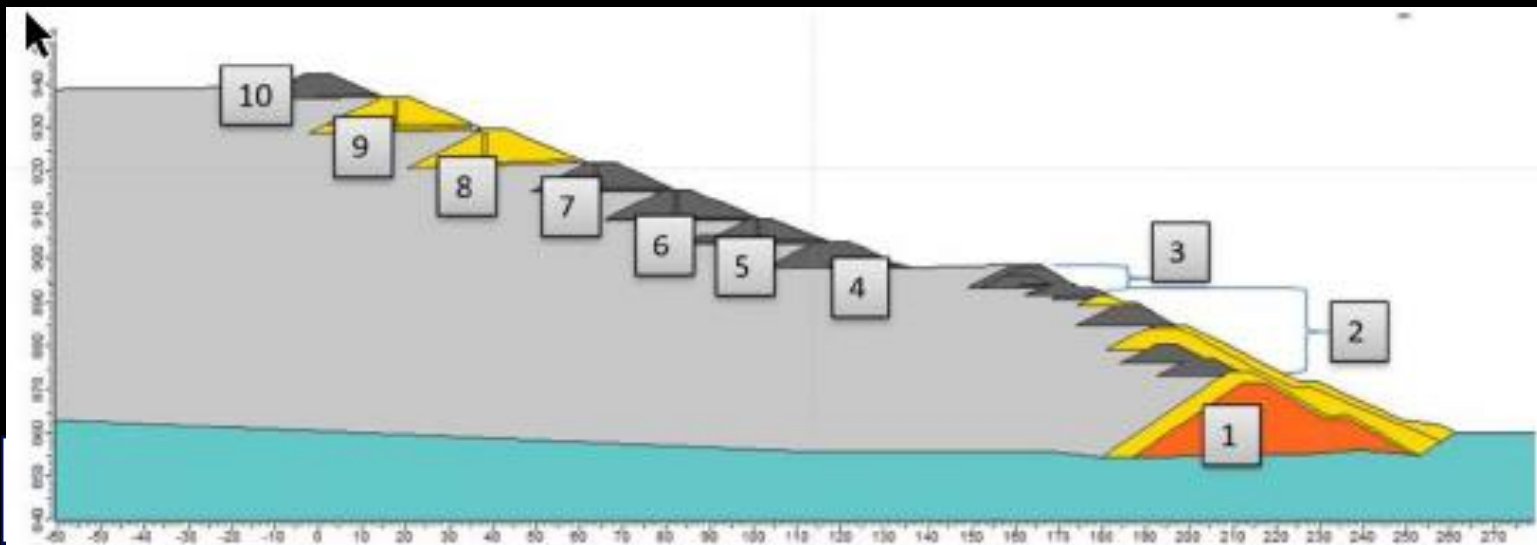






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# Mine Tailings Dam Failures









# Brumadinho Dam Failure

## 25 January 2019

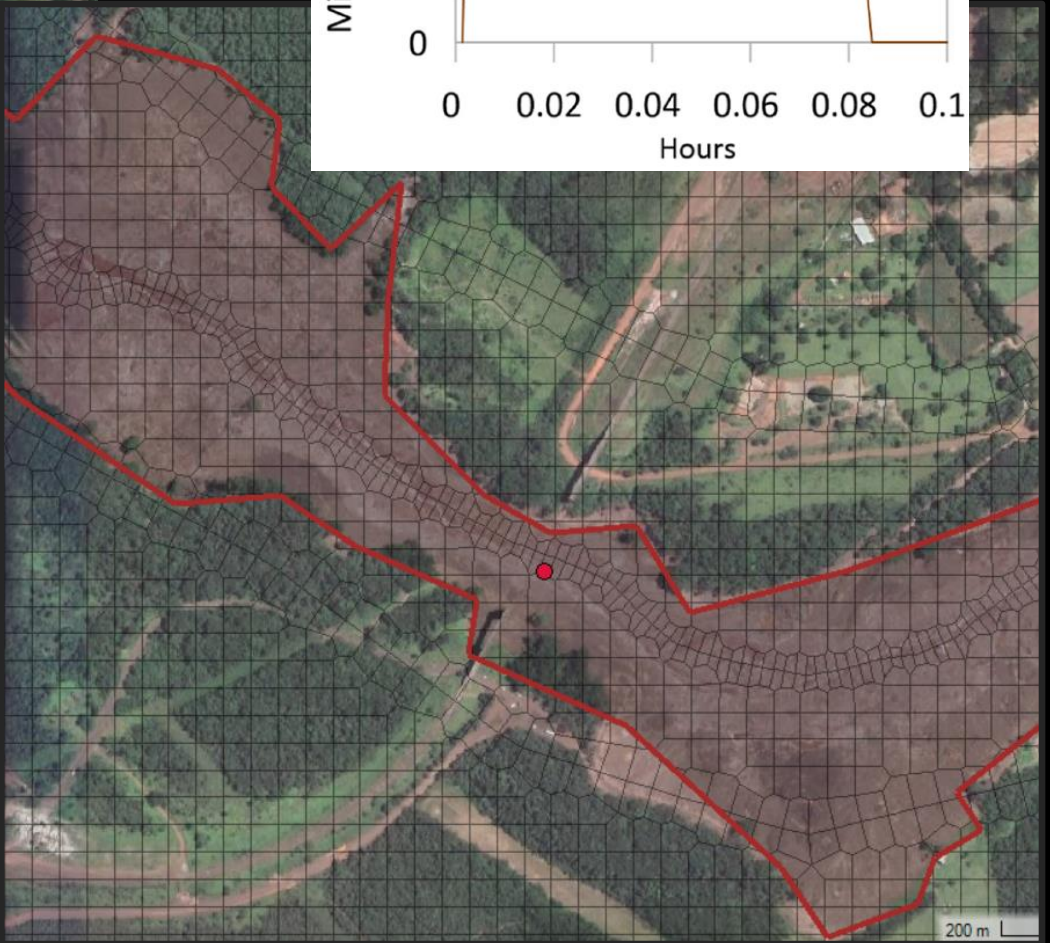
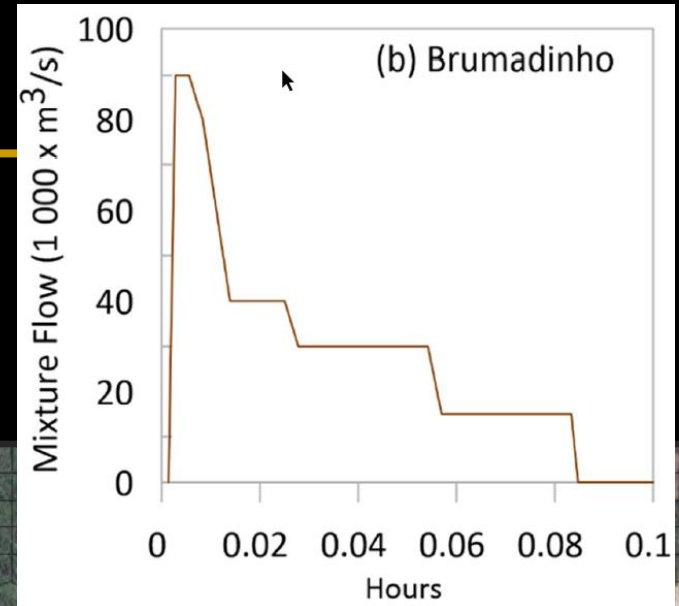
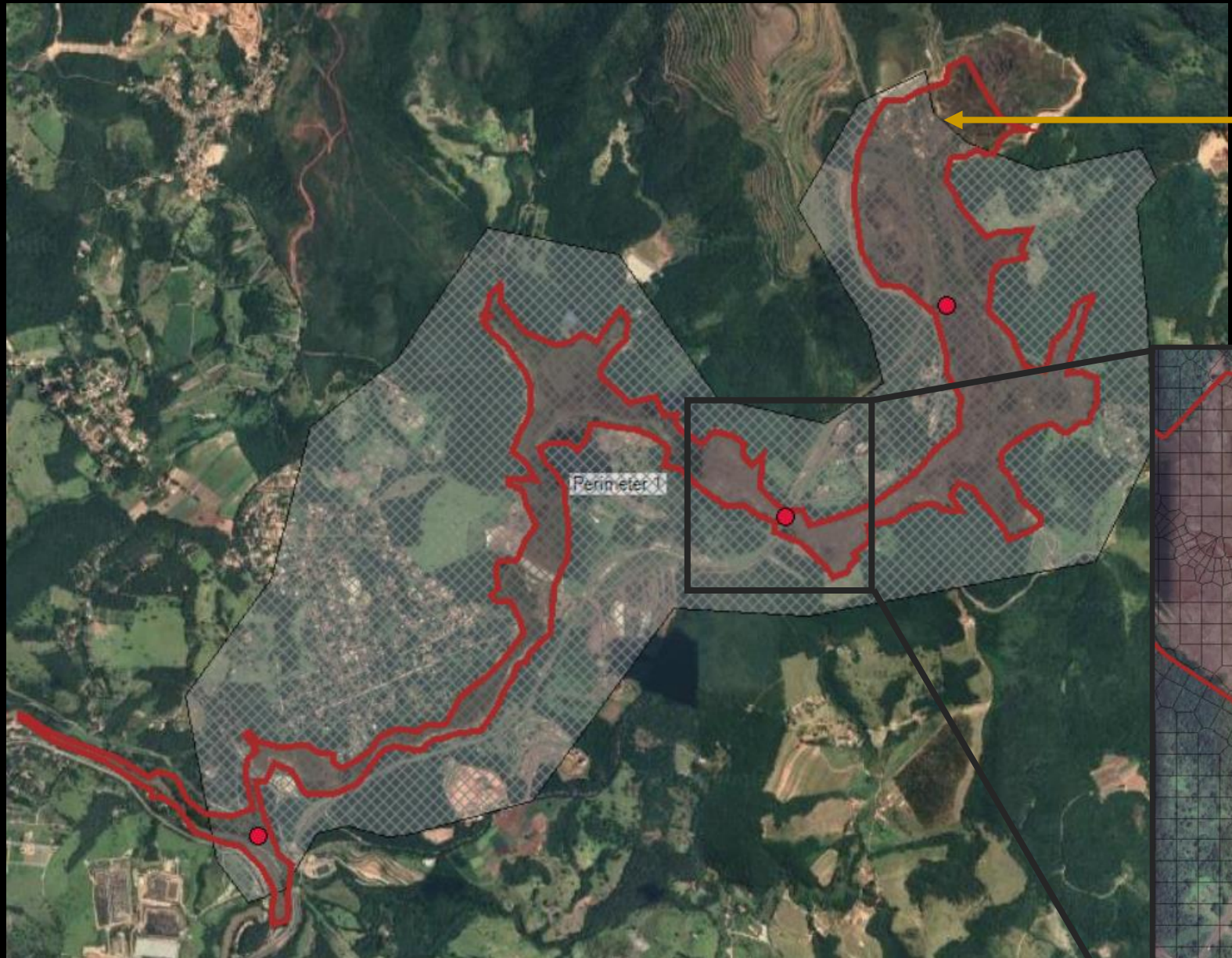


- 270 Deaths
- 3 Years After Mariana Failure
- Released 12 Million m<sup>3</sup>

Images from dw



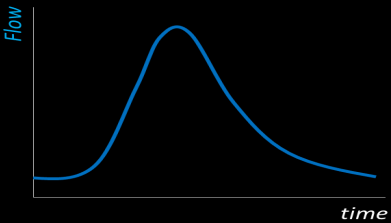
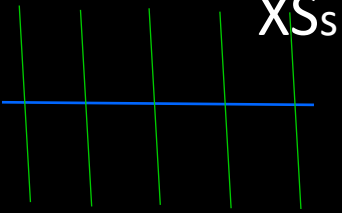

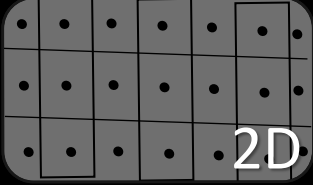




# Downstream of Dam

 <p>XSs</p>				
 <p>SA</p>				
 <p>2D</p>				

# Upstream of Dam

 <p>Flow</p> <p>time</p>	 <p>XSs</p>	 <p>SA</p>	 <p>2D</p>
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Selected: 'Depth'

25JAN2019 12:28:00





Shear Component

$$\tau = \tau_{yield} + \tau_{viscous} + \tau_{turbulent} + \tau_{dispersive} + \tau_{Mohr-Coulomb}$$

Flow Type

Hyperconcentrated

Mudflow

Grain Flow  
Collision Dominated

Debris Flow  
Friction Dominated

Internal Loss Mechanism

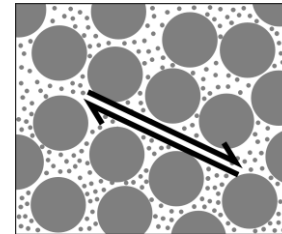
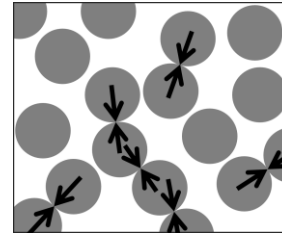
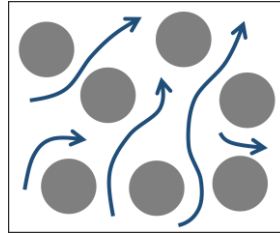
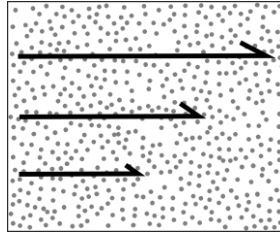
Viscous

Turbulence

Grain Collision

Matrix Strength

Support Schematic



Rheological Model

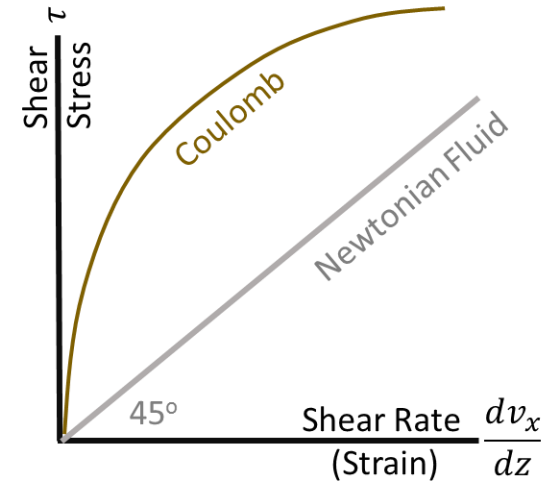
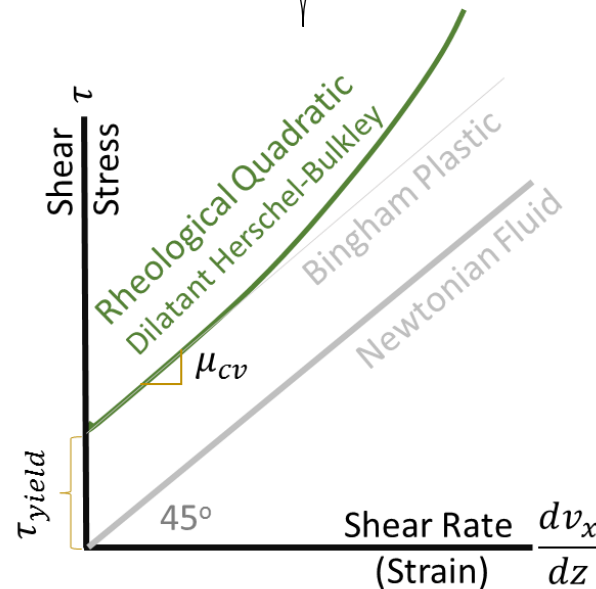
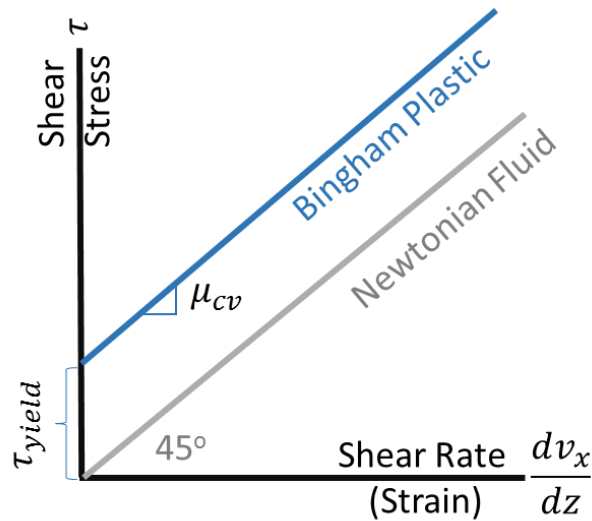
Bingham Plastic  
(First Order)

Turbulent  
(Quadratic)

Turbulent-Dispersive  
(Quadratic)

Coulomb  
(Geotechnical)

Rheological Model



Article

# Prototype Scale Evaluation of Non-Newtonian Algorithms in HEC-RAS: Mud and Debris Flow Case Studies of Santa Barbara and Brumadinho

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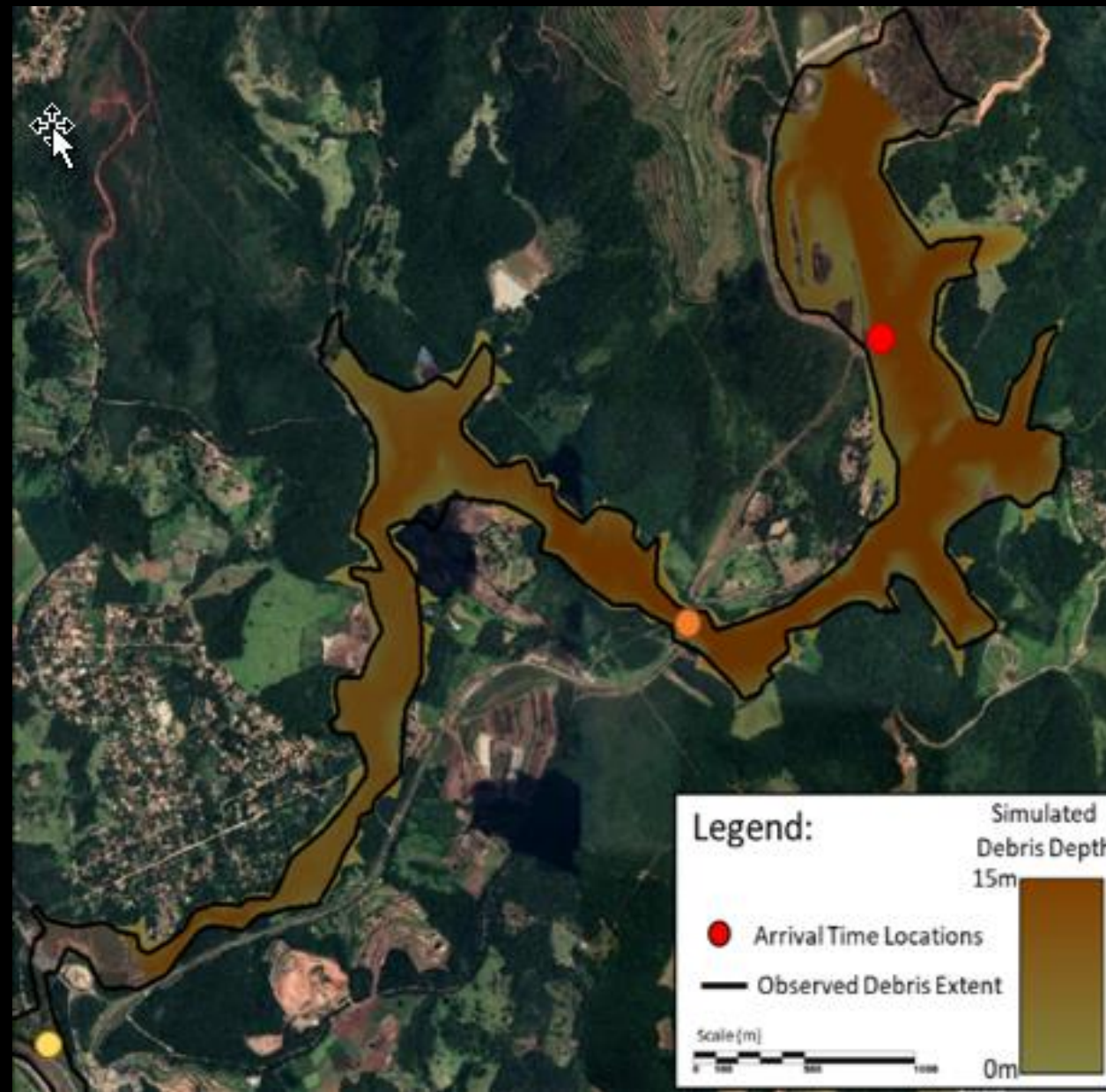
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**Abstract:** The Santa Barbara post-wildfire debris flows and the Brumadinho tailing-dam failure were two of the most catastrophic flood events of the late 2010s. Both these events carried so much solid-phase material, that classic, clear-water, flood risk approaches cannot replicate them, or forecast other events like them. This case study applied the new non-Newtonian features in HEC-RAS 6.1 to these two events, testing the most widely used flood risk model on the two most common mud and debris flow hazards (post-wildfire floods and mine tailing dam failures). HEC-RAS reproduced the inundation boundaries and the event timing (where available) for both events. The ratio between the largest debris flow clasts and the channel size, parametric trade-offs, the “convex” alluvial plain topography, and the stochasticity introduced by urban infrastructure made the Santa Barbara modeling more difficult and less precise than Brumadinho. Despite these challenges, the results provide prototype scale validation and verification of these new tools in this widely applied flood risk model.

**Keywords:** debris flow; mudflow; non-Newtonian; Santa Barbara; Brumadinho; HEC-RAS

Location	Observed Mudflow Front Time (hh:mm:ss)	HEC-RAS Simulated Time (hh:mm:ss)	Error
Canteen	00:01:30	00:01:30	0%
Railway Bridge	00:09:10	00:09:15	0.9%
Paraopeba River	01:26:05	01:27:45	1.9%





# SWE vs DW

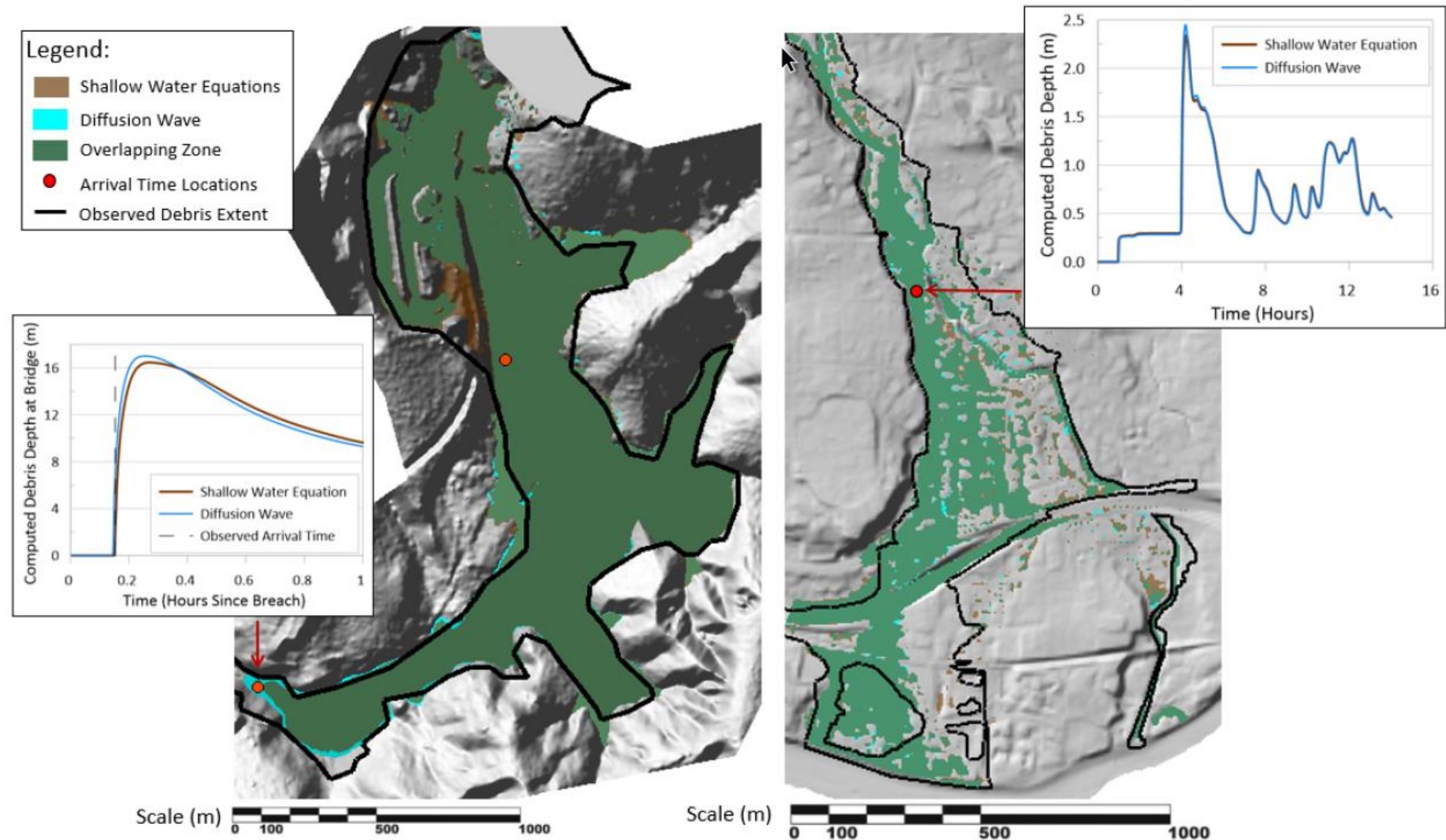


Figure 11. Brumadinho and Montecito model results with SWE and DW equations. The DW models did not differ substantially from the SWE simulations.