# Overview of Unsteady Flow Modeling for Dam Breach Analysis

Stanford Gibson, PhD
Hydrologic Engineering Center

# Overview:

1. Overview of Unsteady Flow

2. Overview of Dam Breaches Options

3. Examples

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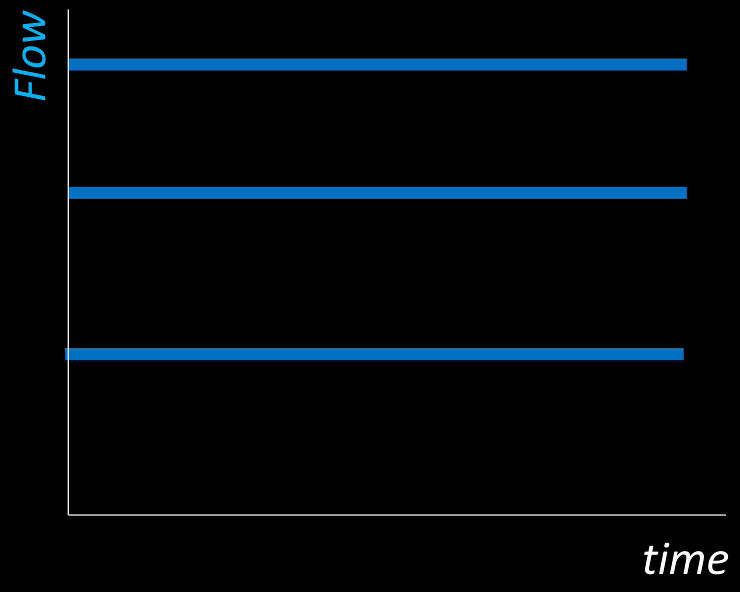
# 1. What is Unsteady Flow?

## Steady Flow

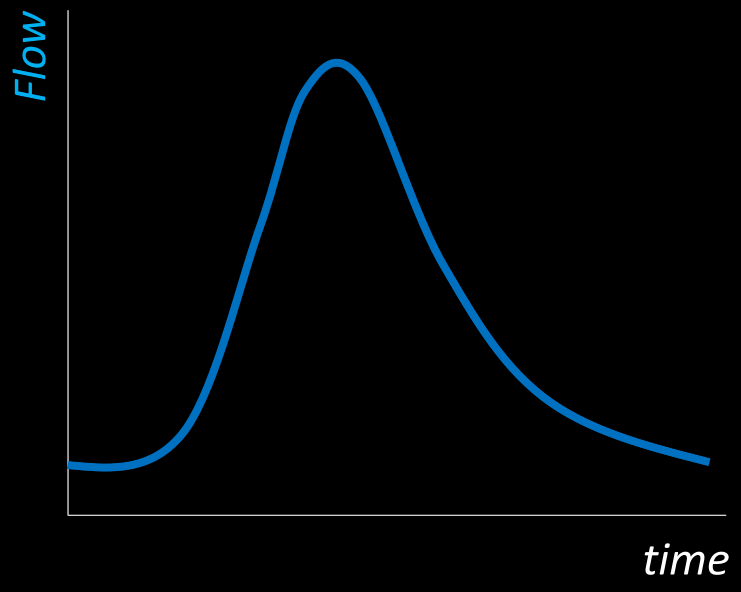
*Q(~~t~~)*




Flow ~~does not change~~ *changes gradually* with time

## Unsteady Flow

*Q(t)*

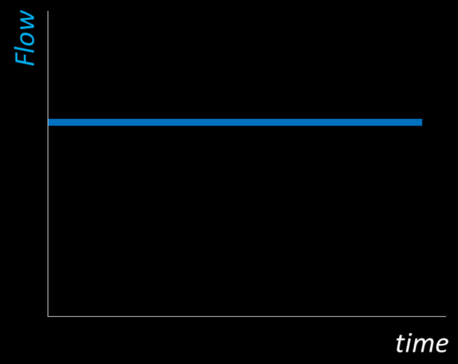



Flow changes with time

# 1. What is Unsteady Flow?

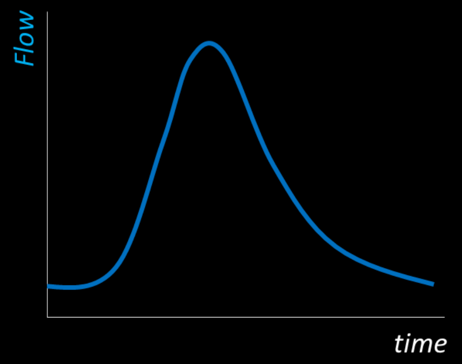
## Steady Flow

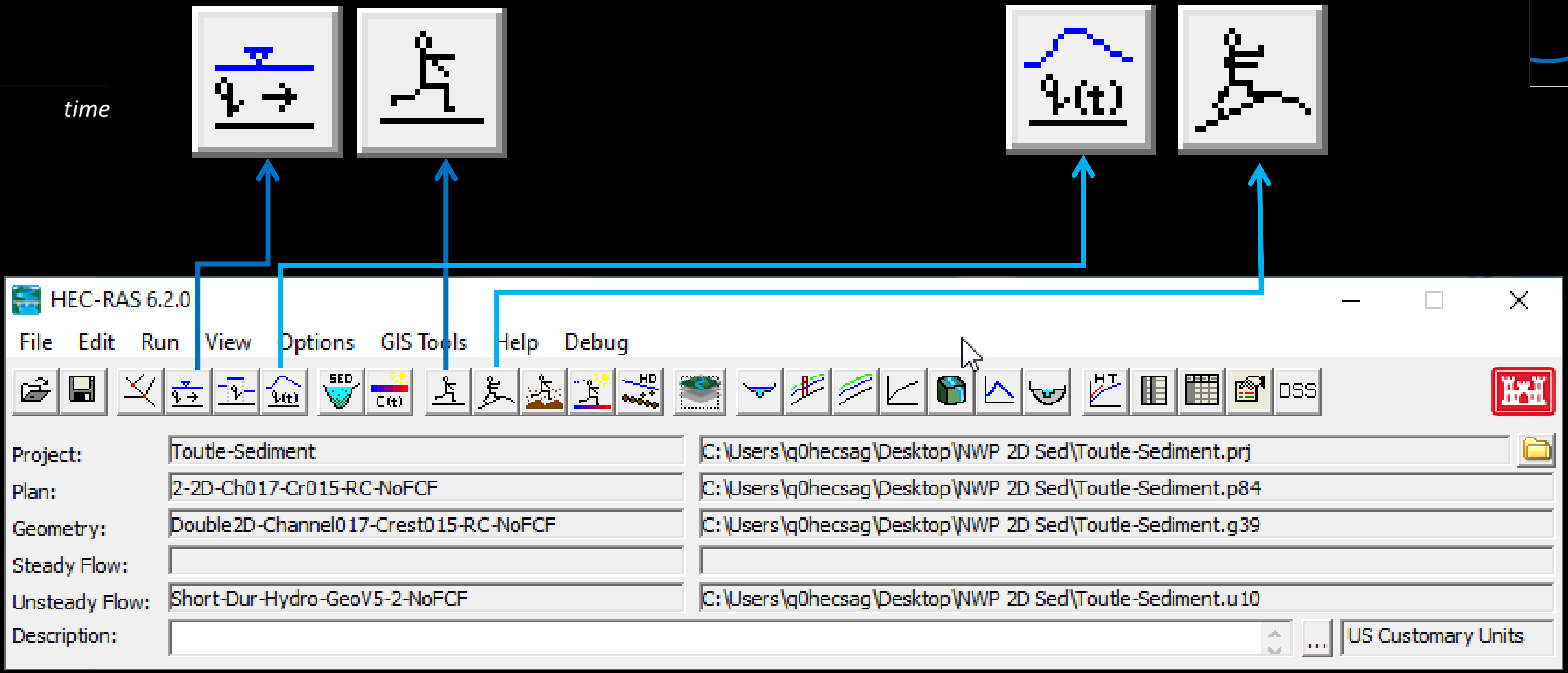
*Q(t)*




## Unsteady Flow

*Q(t)*

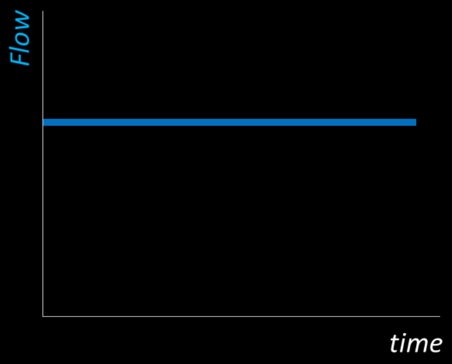


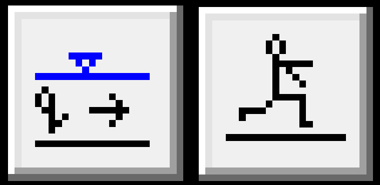



# 1. What is Unsteady Flow?

## Steady Flow

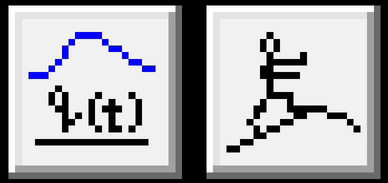
*Q(~~t~~)*

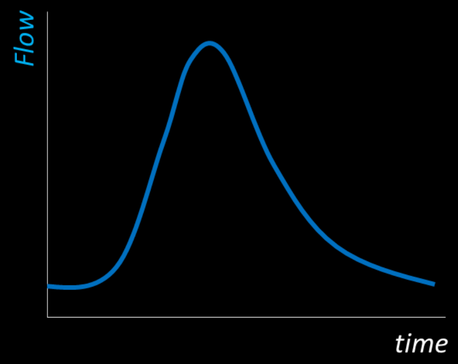


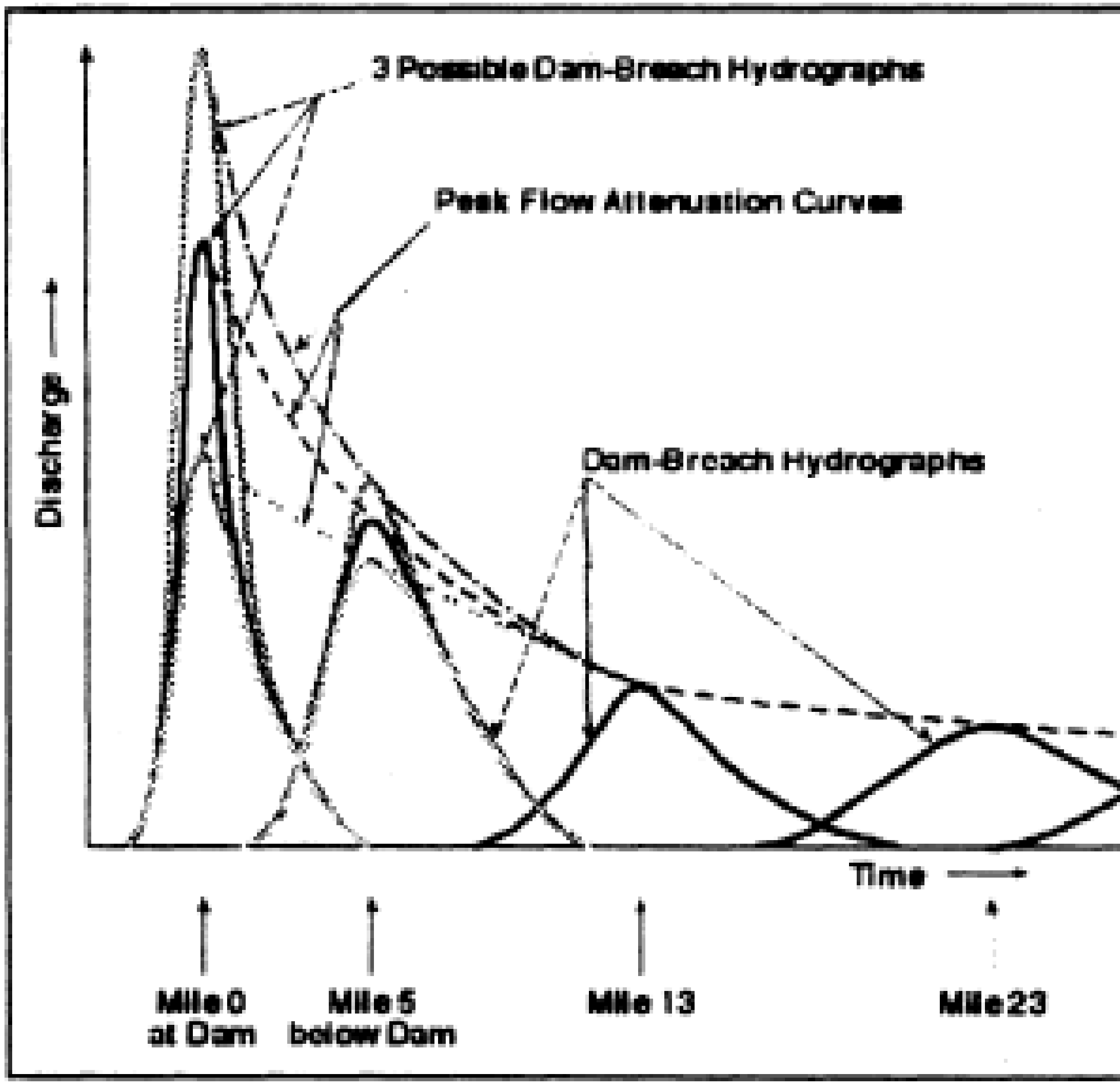
## Unsteady Flow

*Q(t)*






# Which do we use for Dam Breach?



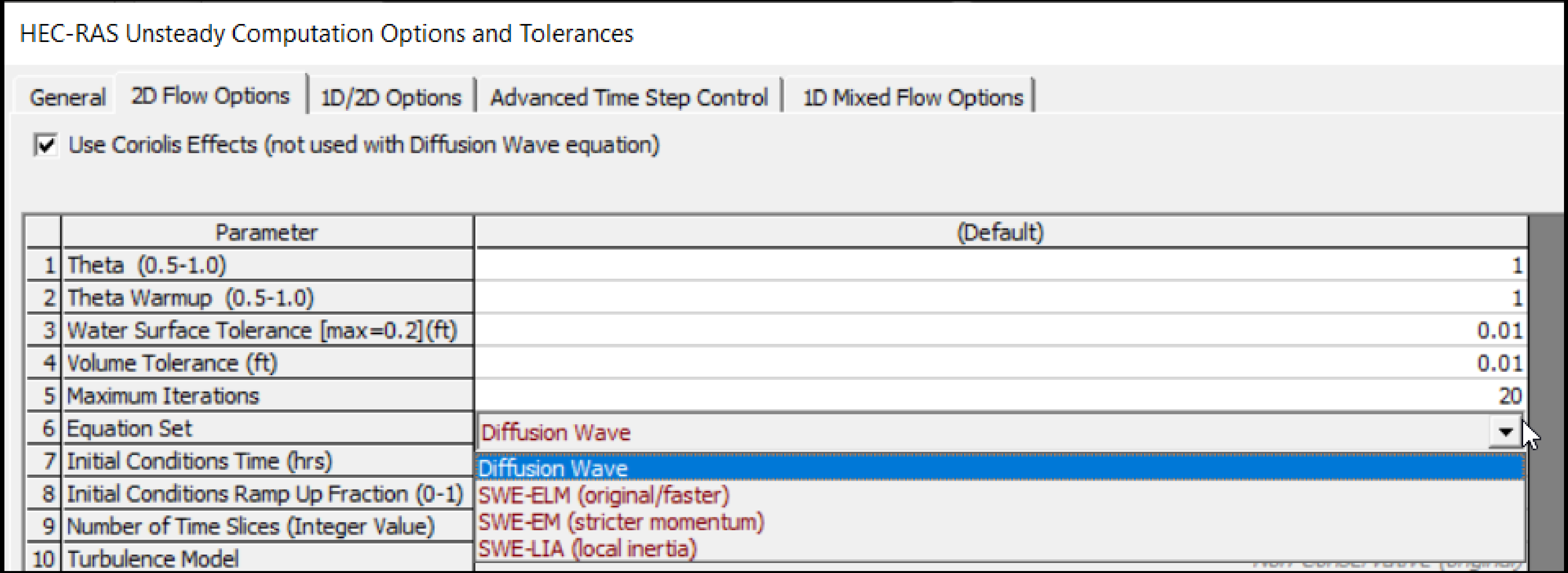

Objectives:

- Timing
- Attenuation

# Shallow Water Flow Equations

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

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

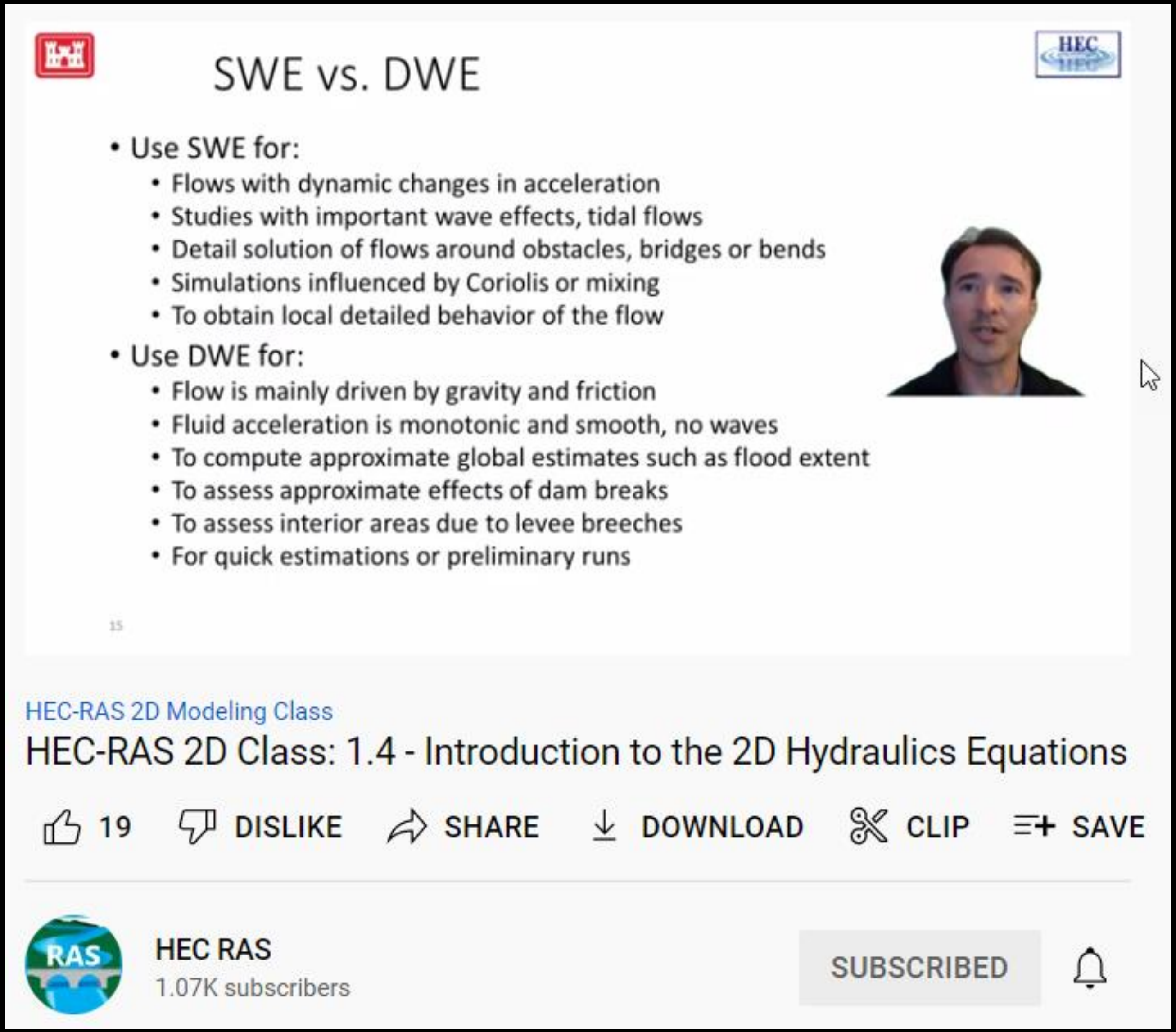


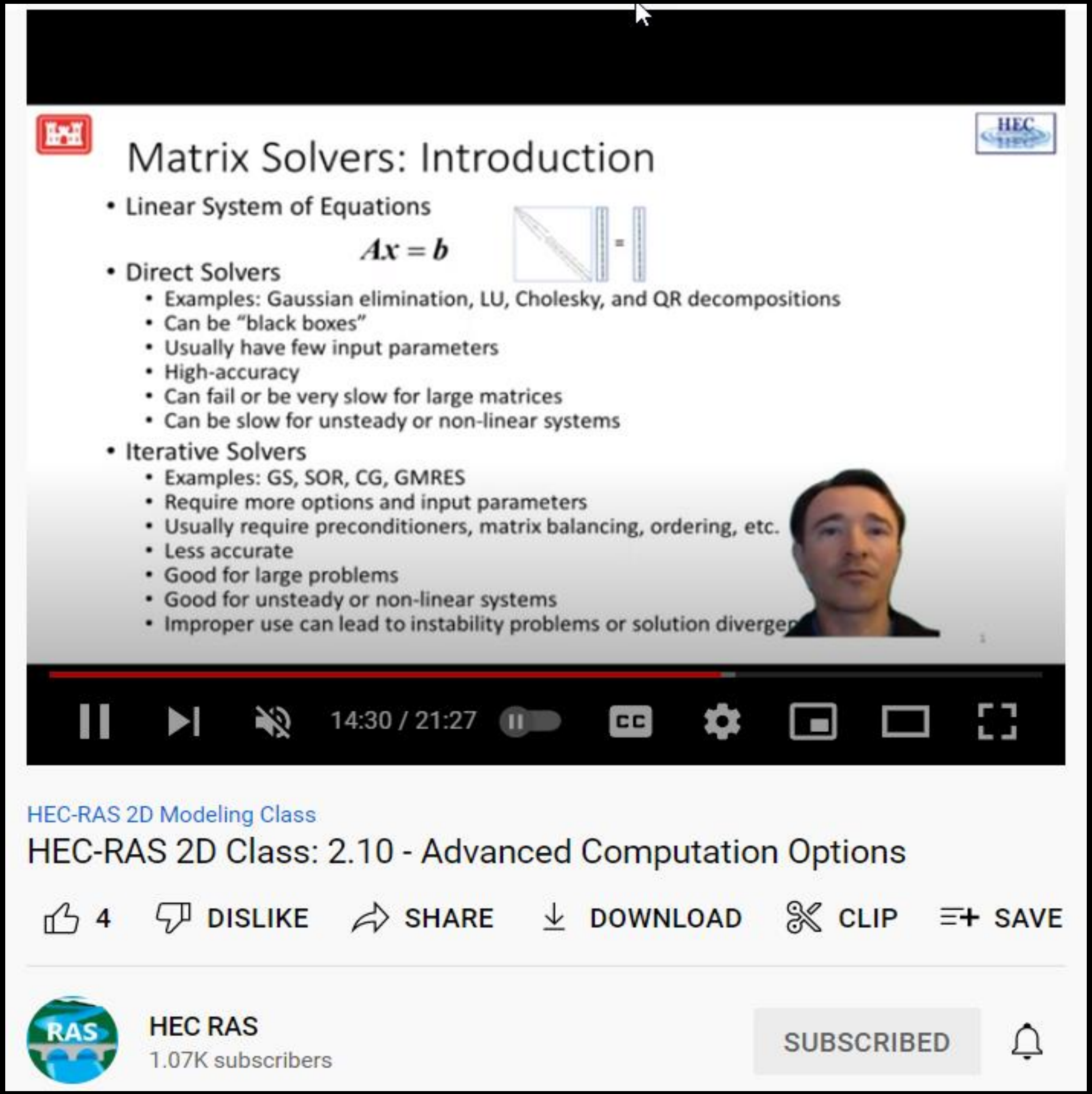
# Momentum Equation

$$\underbrace{\frac{\partial \boldsymbol{V}}{\partial t}}_{\text{Temporal}} + \underbrace{(\boldsymbol{V}\cdot\nabla)\boldsymbol{V}}_{\text{Advection}} + \underbrace{f_c \boldsymbol{k}\times\boldsymbol{V}}_{\text{Coriolis}} = -\underbrace{g\nabla z_s}_{\text{Pressure gradient}} + \underbrace{\frac{1}{h}\nabla\cdot\left(\boldsymbol{v}_t h \nabla \boldsymbol{V}\right)}_{\text{Diffusion}} - \frac{\boldsymbol{\tau}_b}{\underbrace{\rho R}_{\text{Bottom Friction}}} + \frac{\boldsymbol{\tau}_s}{\underbrace{\rho h}_{\text{Wind Stress}}}$$

# Diffusion Wave Equation

$$\underbrace{\cancel{\frac{\partial \boldsymbol{V}}{\partial t}}}_{\text{Temporal}} + \underbrace{\cancel{(\boldsymbol{V}\cdot\nabla)\boldsymbol{V}}}_{\text{Advection}} + \underbrace{\cancel{f_c \boldsymbol{k}\times\boldsymbol{V}}}_{\text{Coriolis}} = -\underbrace{g\nabla z_s}_{\text{Pressure gradient}} + \underbrace{\cancel{\frac{1}{h}\nabla\cdot\left(\boldsymbol{v}_t h \nabla \boldsymbol{V}\right)}}_{\text{Diffusion}} - \frac{\boldsymbol{\tau}_b}{\underbrace{\rho R}_{\text{Bottom Friction}}} + \underbrace{\cancel{\frac{\boldsymbol{\tau}_s}{\rho h}}}_{\text{Wind Stress}}$$




https://youtu.be/nEr87YpHnzA

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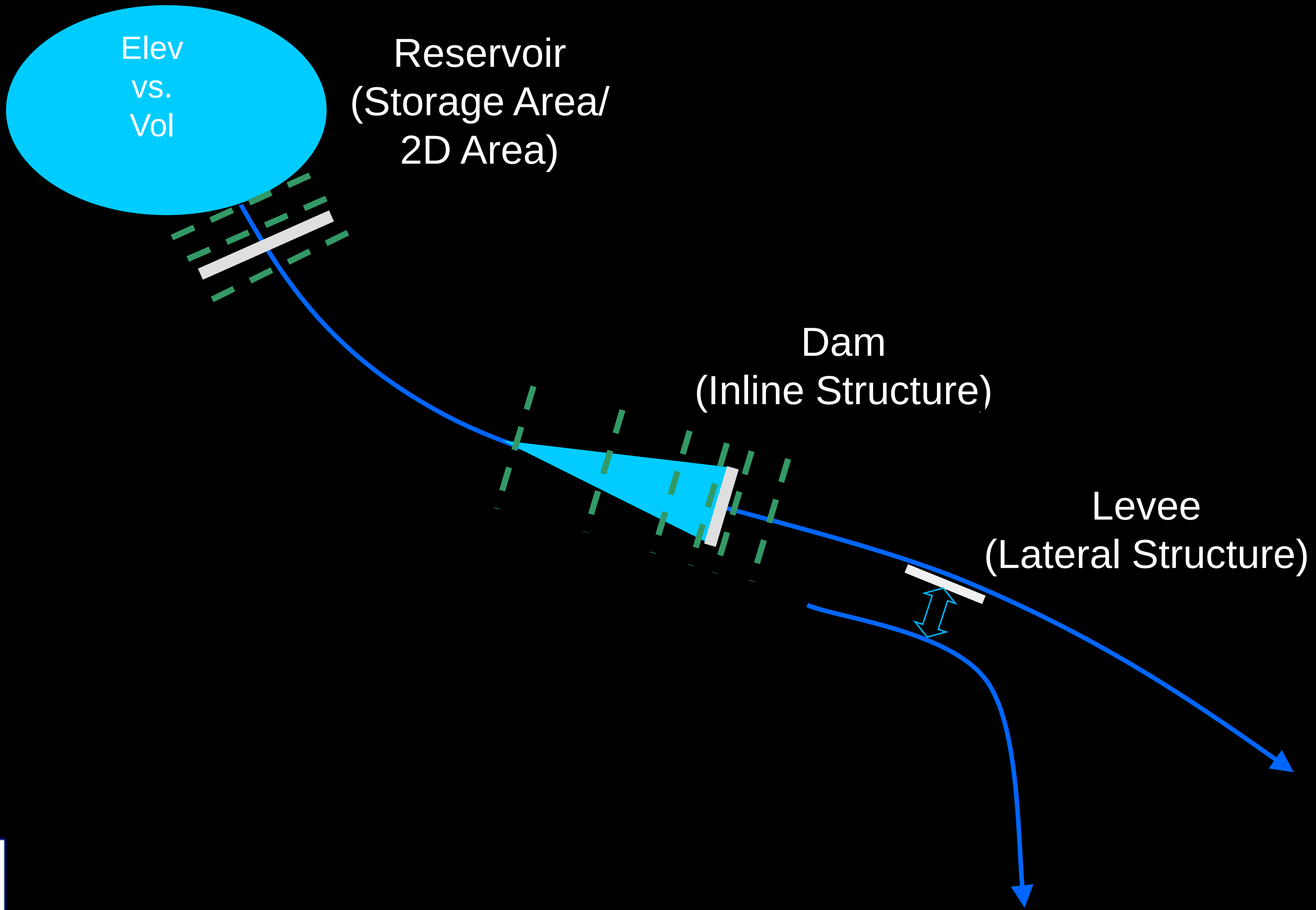
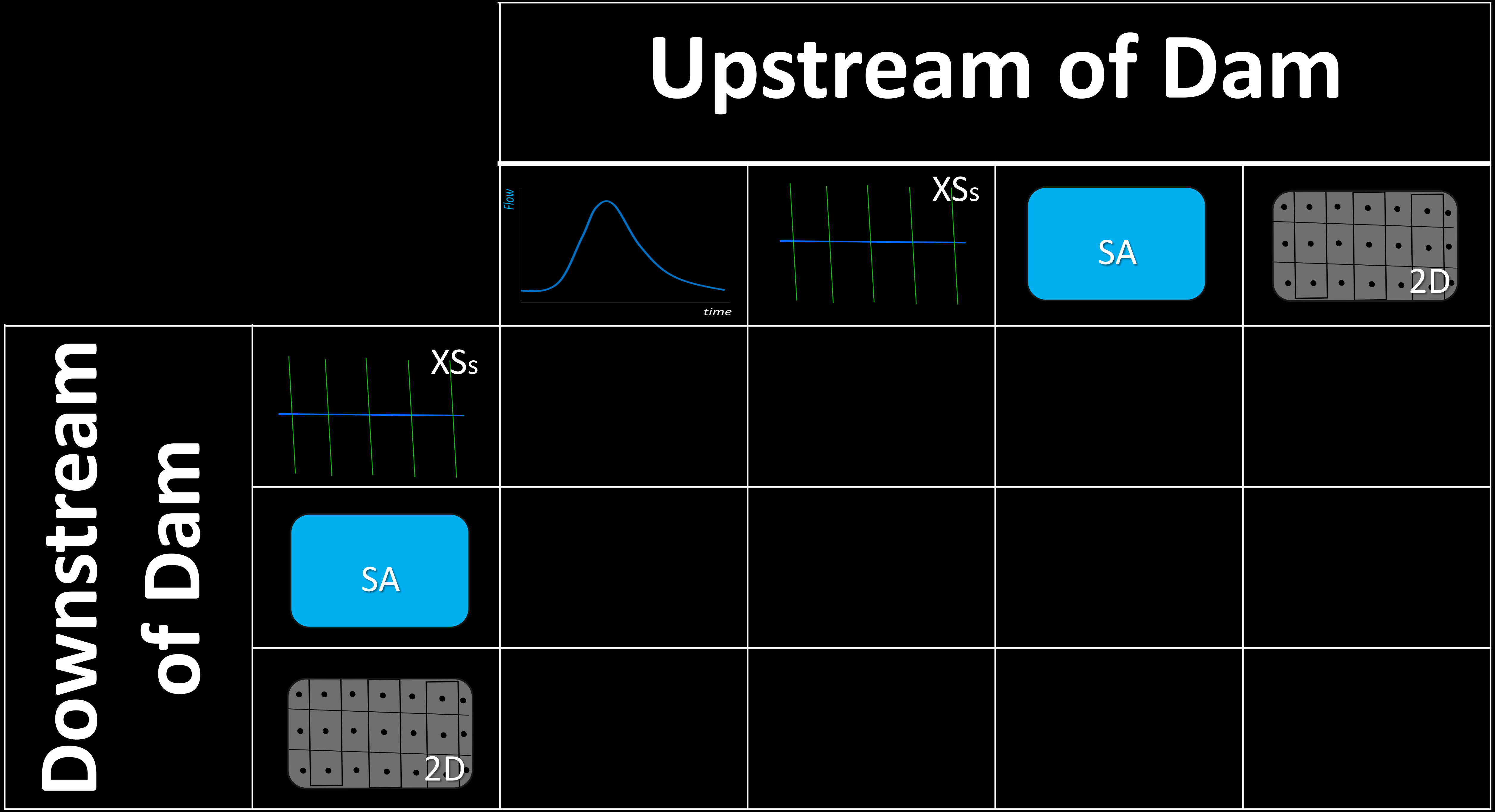
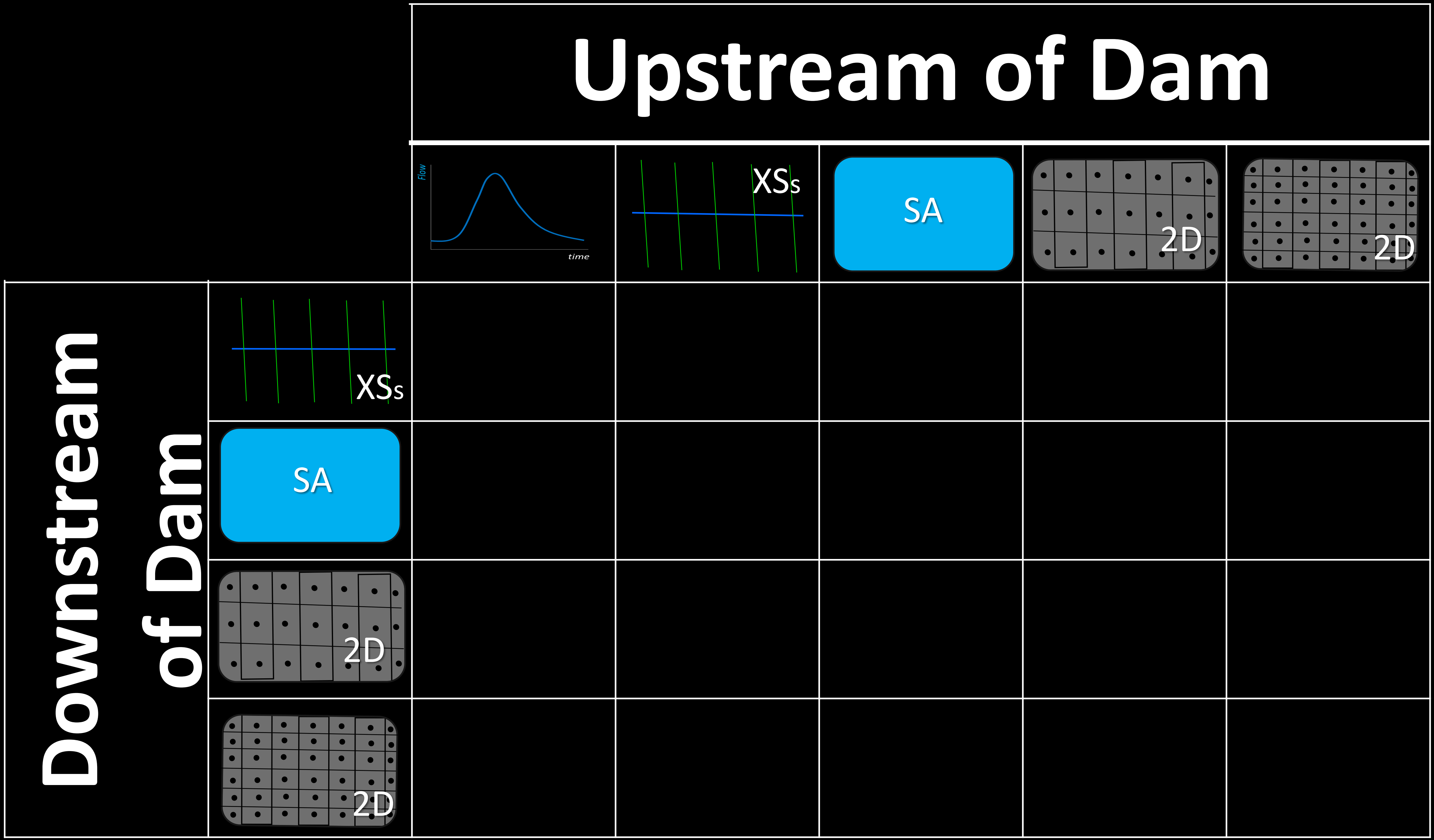
# HEC-RAS Breach Locations

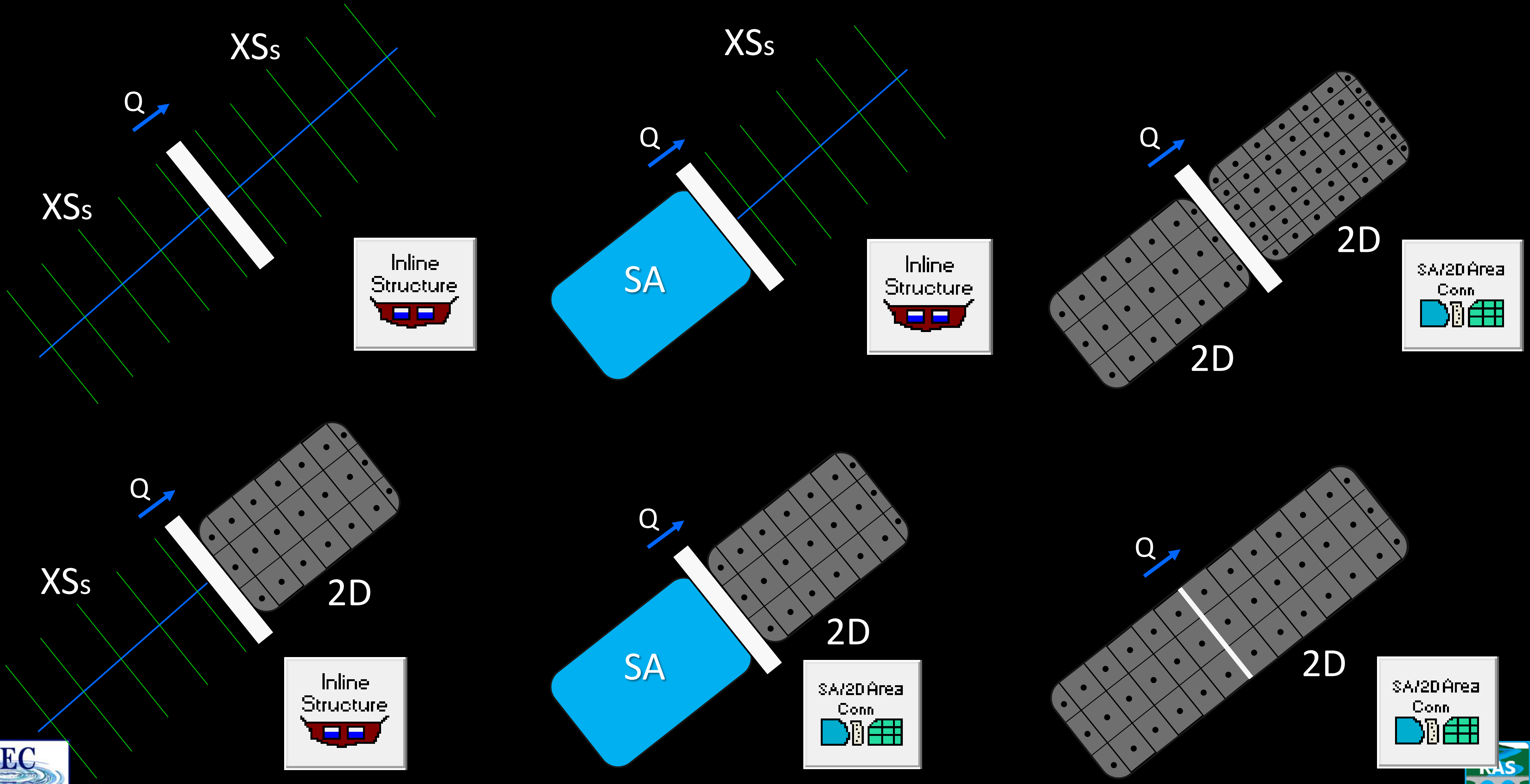




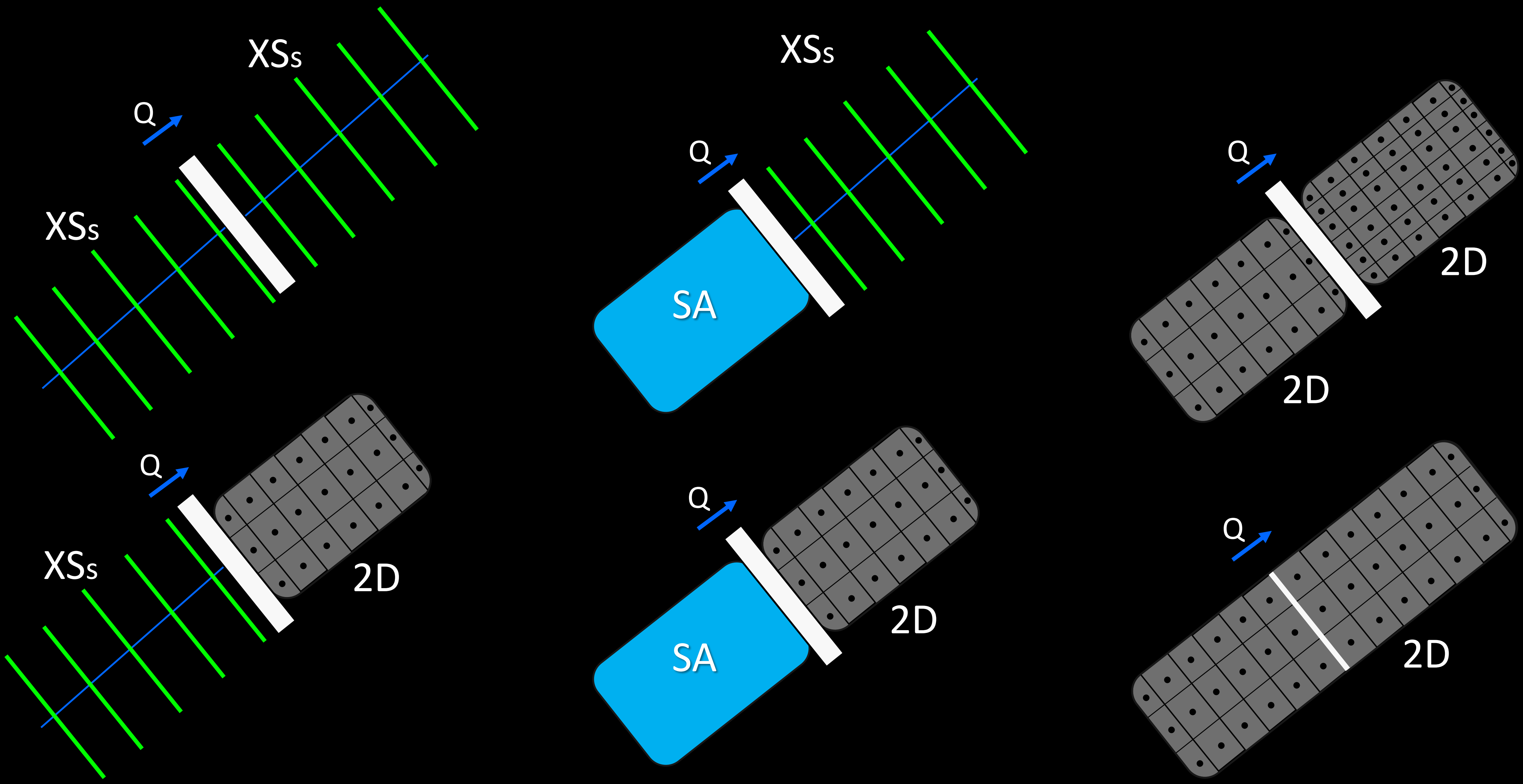
Upstream of Dam
Flow
time
XSs
SA
2D
Downstream of Dam
XSs
SA
2D


Upstream of Dam
Flow
time
XSs
SA
2D
2D
Downstream of Dam
XSs
SA
2D
2D

# Breach Model Configuration Options



# Breach Model Configuration Options



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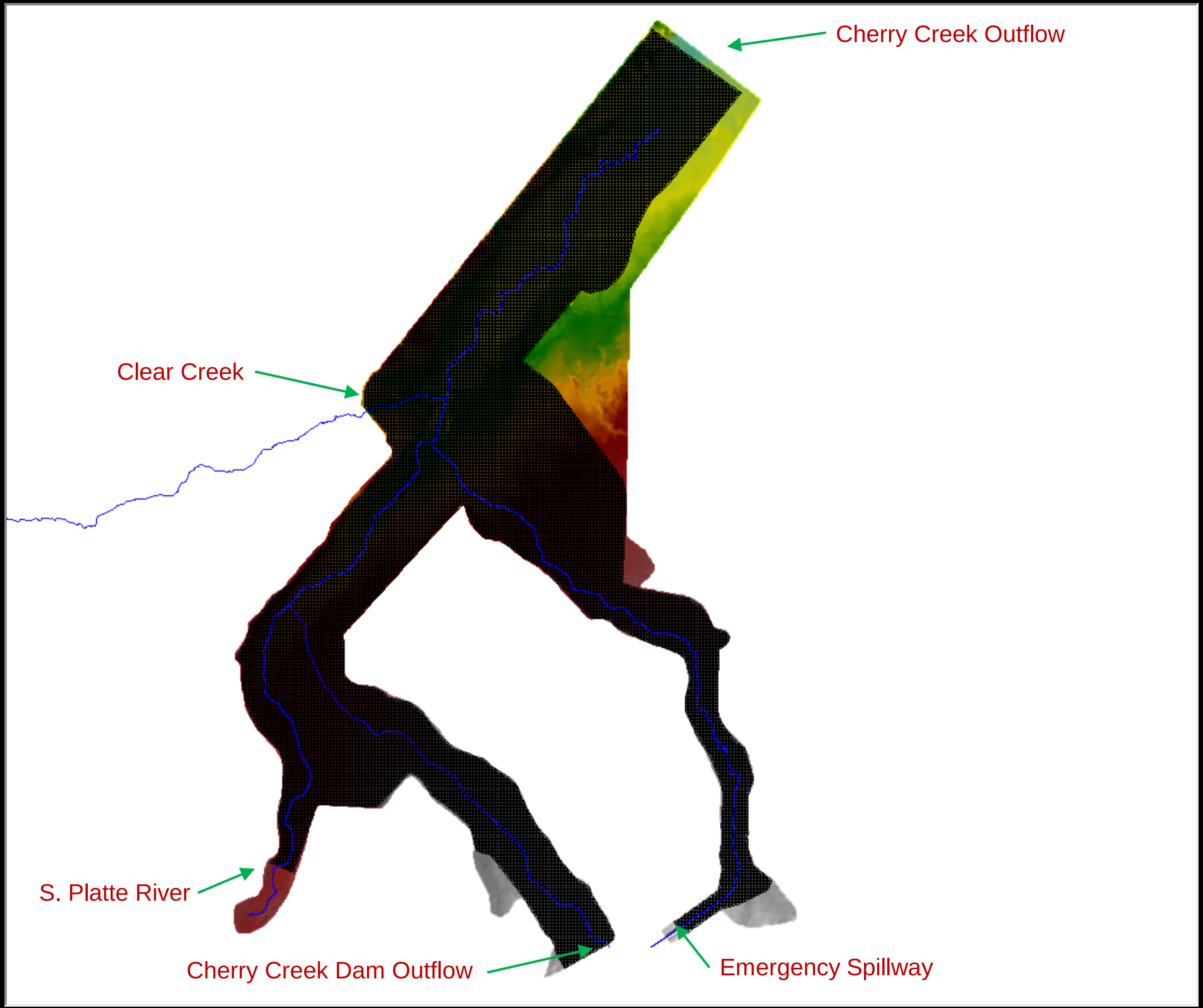
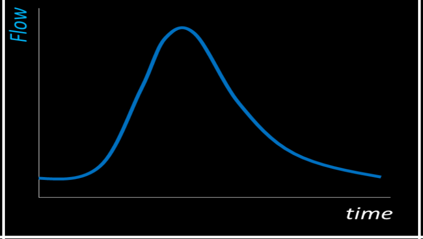
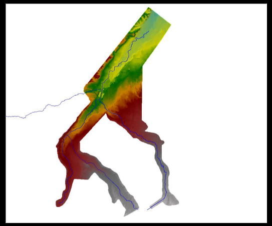
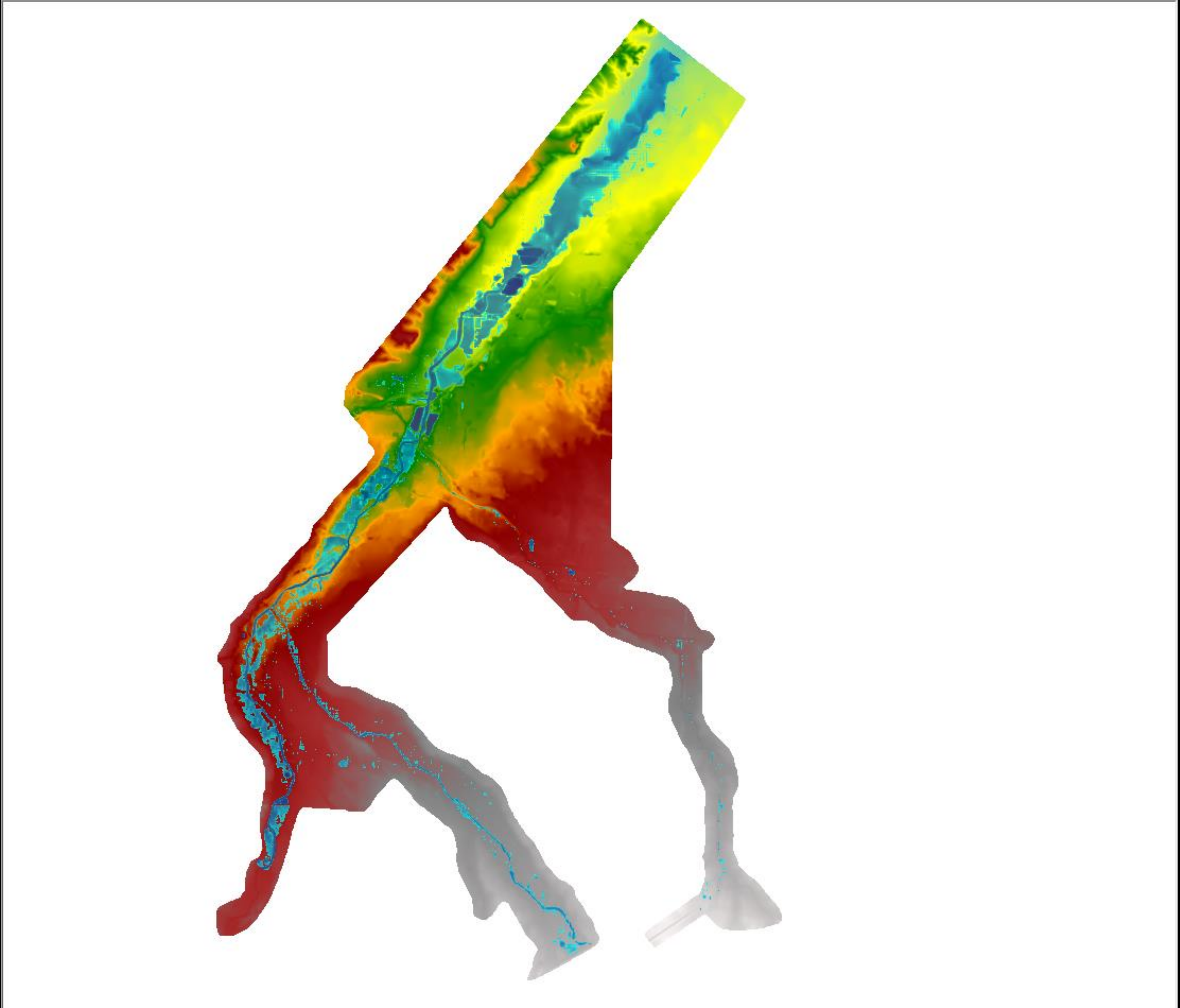
# Single 2D Area with Boundary Conditions



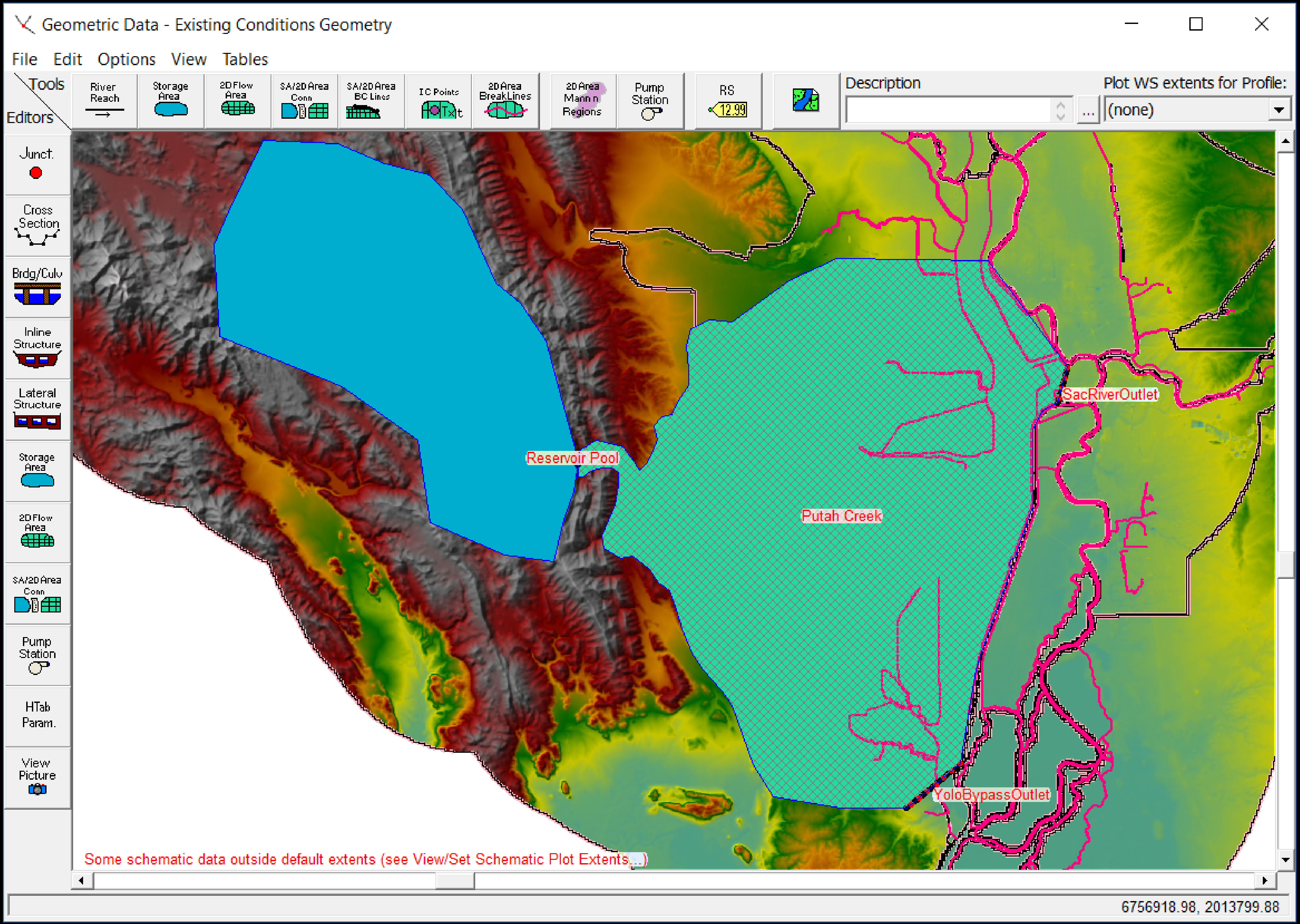
| | | Upstream of Dam | | | |
|---|---|---|---|---|---|
| | |  | XSs | SA | 2D |
| Downstream of Dam | XSs | | | | |
| | SA | | | | |
| | 2D |  | | | |

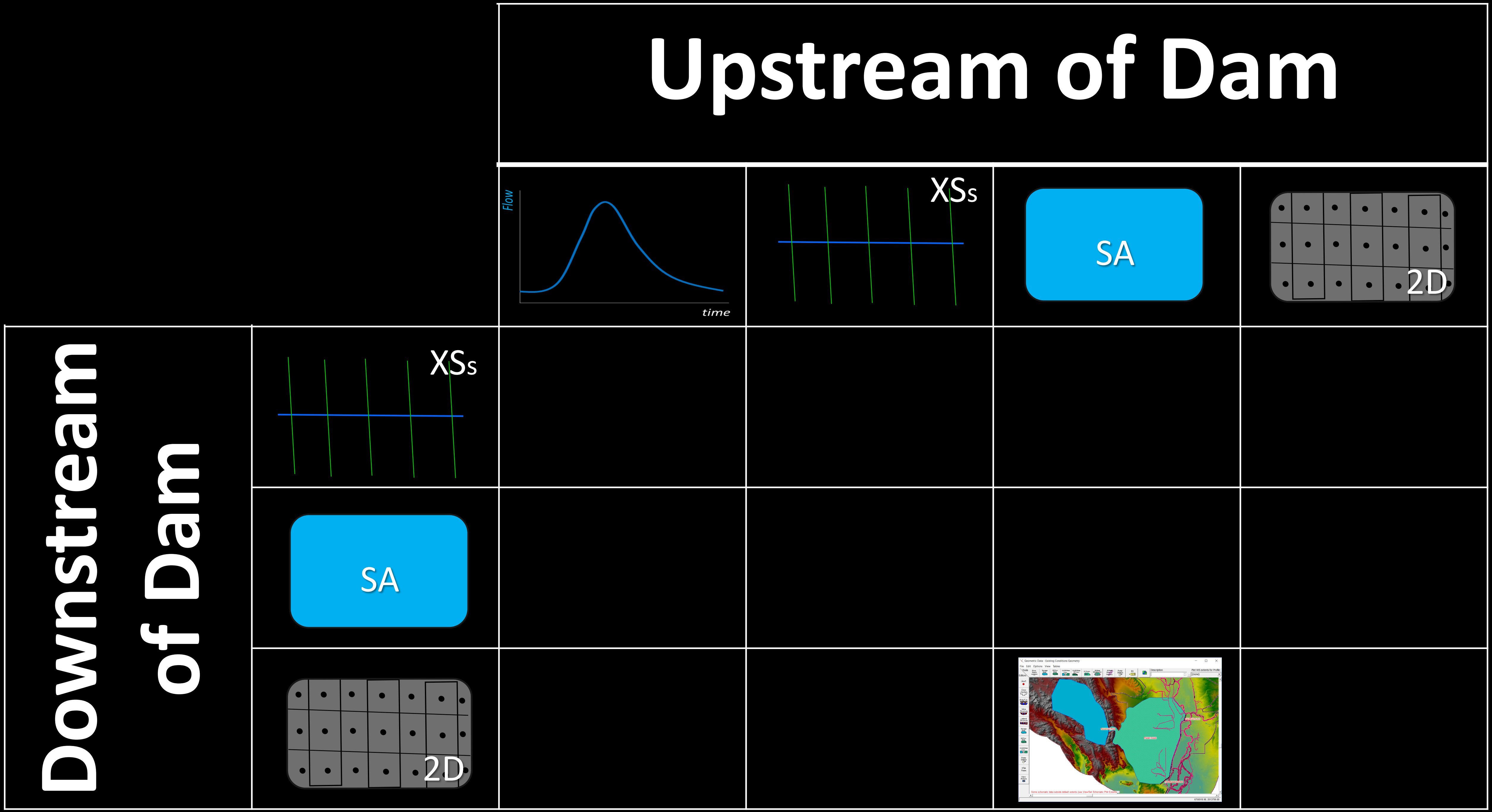
# Cherry Creek



# Cherry Creek

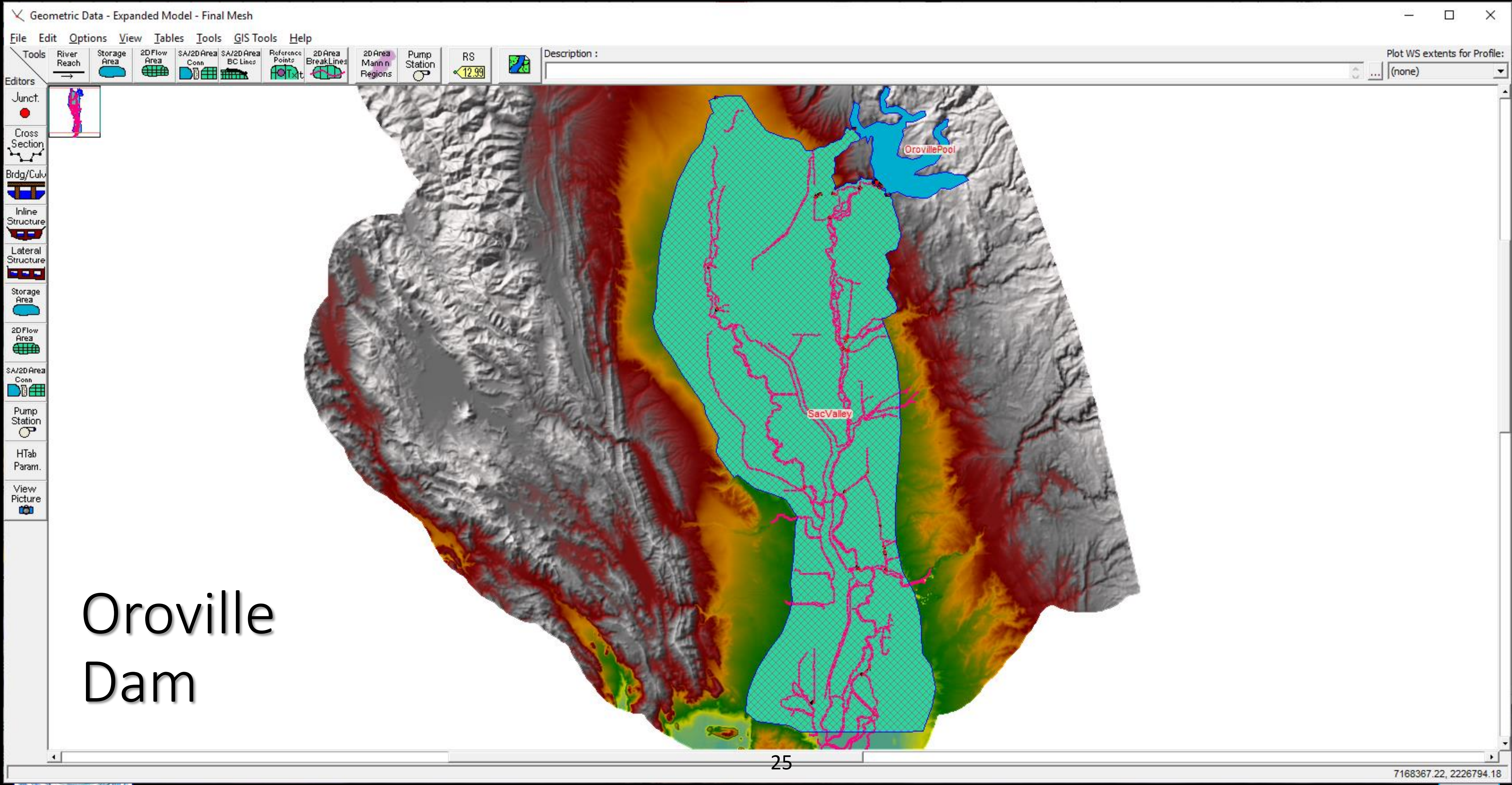
# Monticello Dam Breach



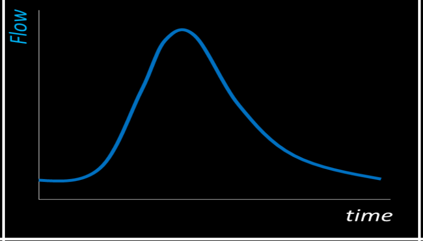
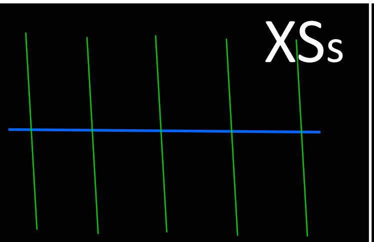
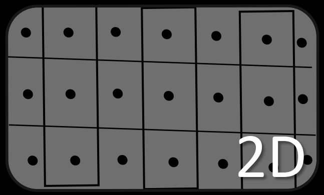
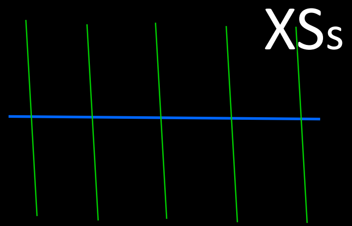
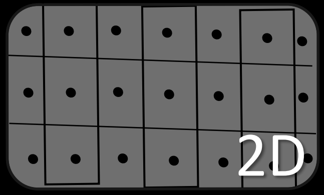
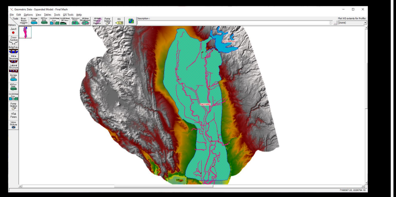


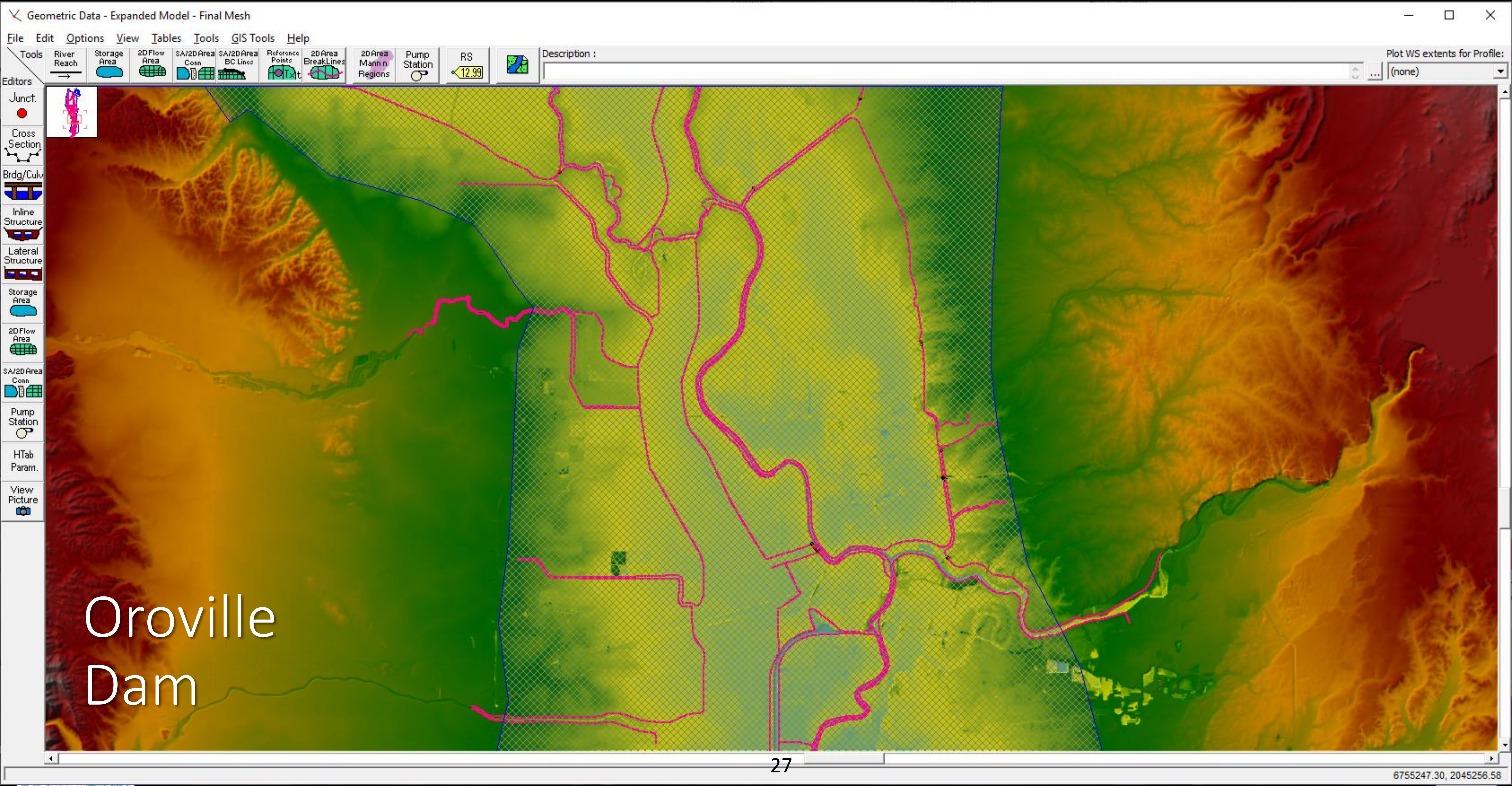
Upstream of Dam
Flow
time
XSs
SA
2D
Downstream of Dam
XSs
SA
2D

# Monticello Dam Breach




# Oroville Dam

| Downstream of Dam | Upstream of Dam | | | |
|---|---|---|---|---|
| |  |  | SA |  |
|  | | | | |
| SA | | | | |
|  | | |  | |




# Oroville Dam

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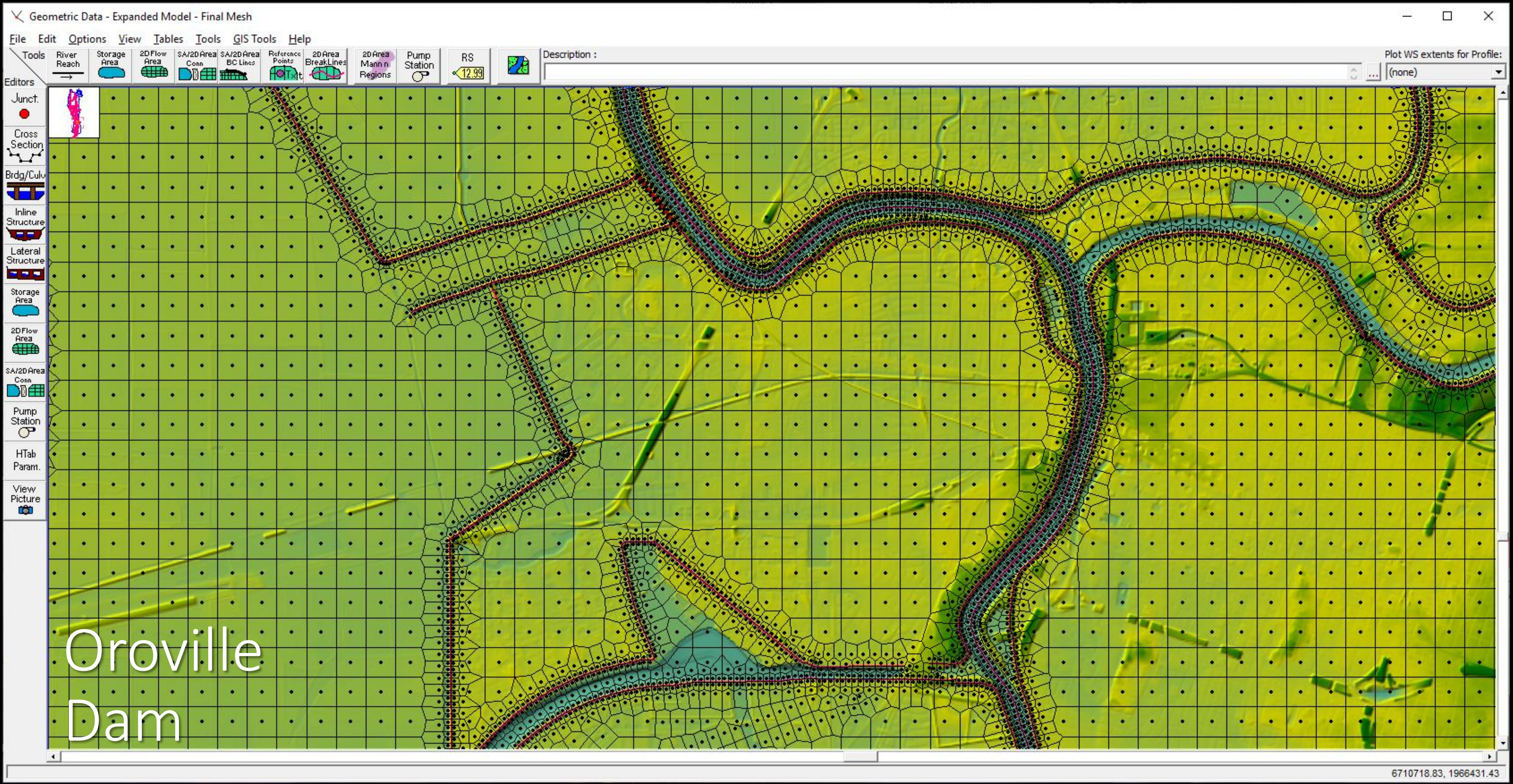
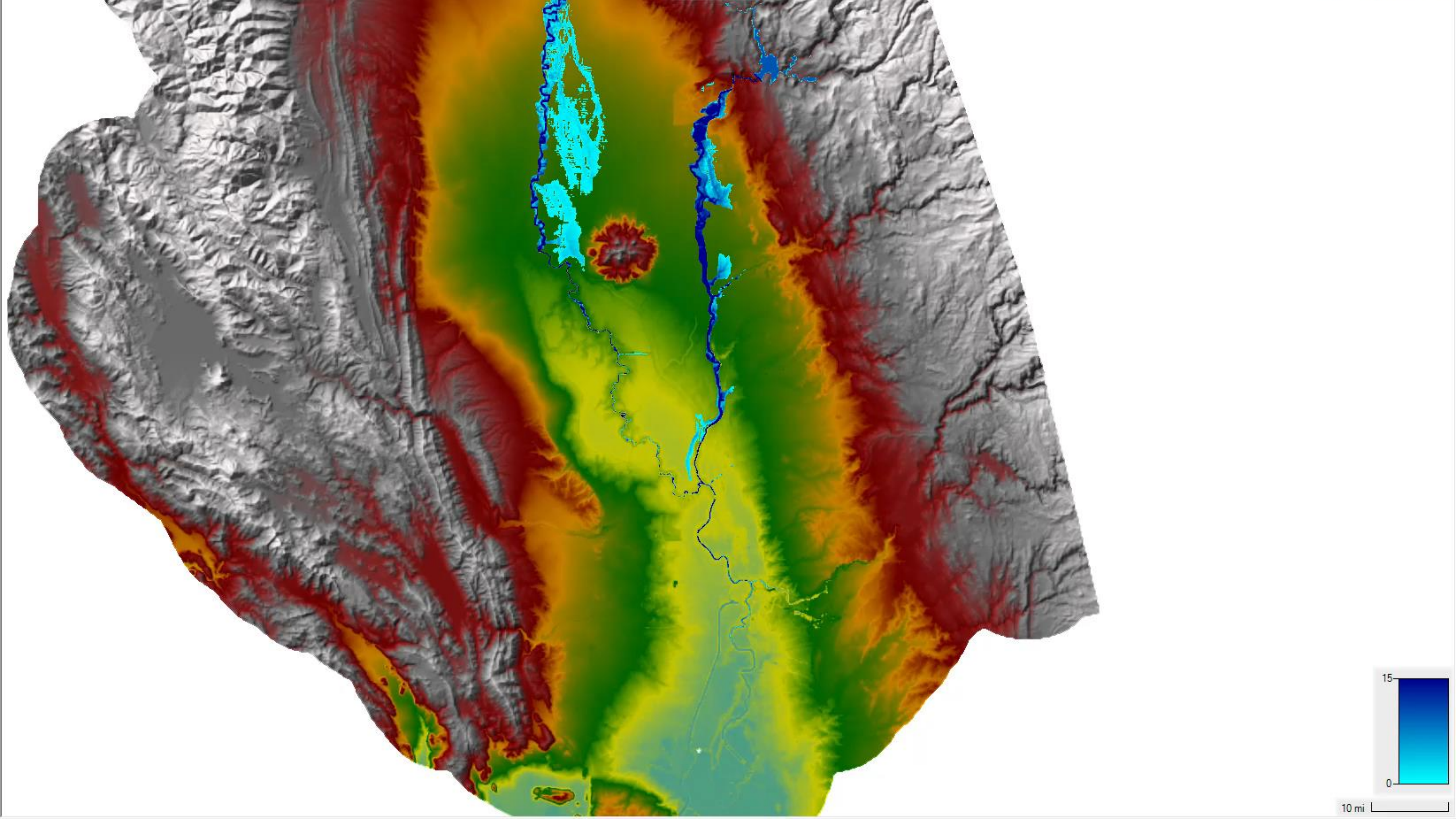
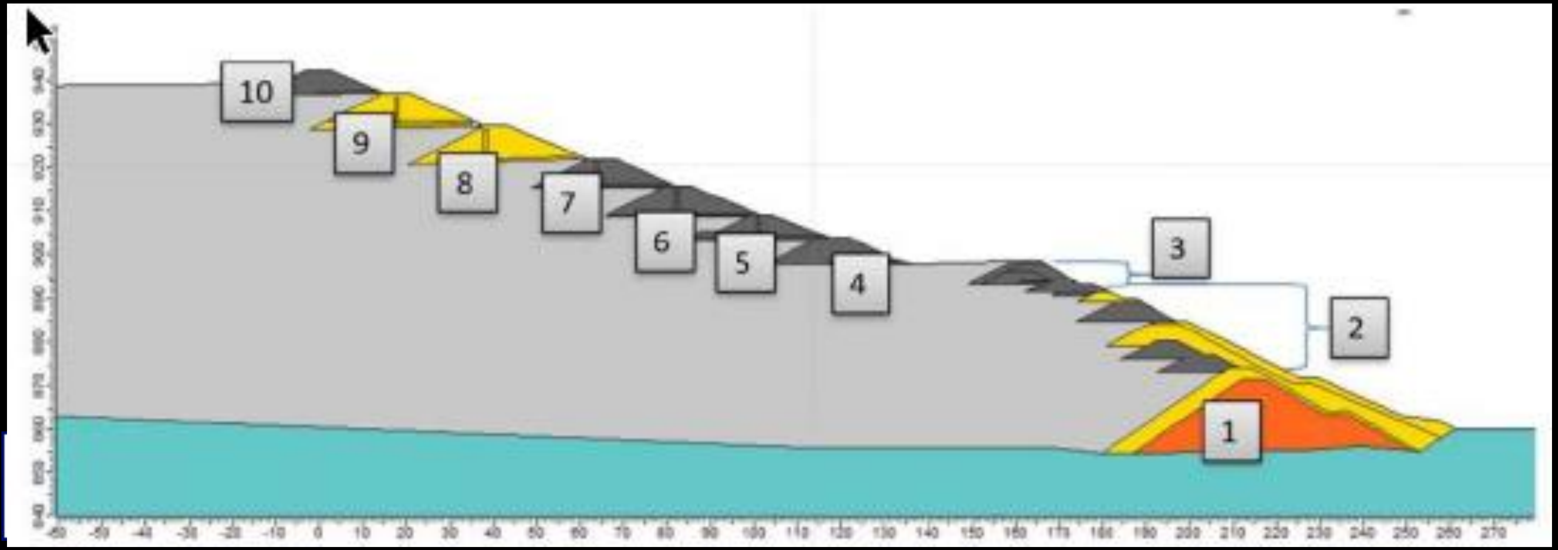



15
0
10 mi

# Mine Tailings Dam Failures

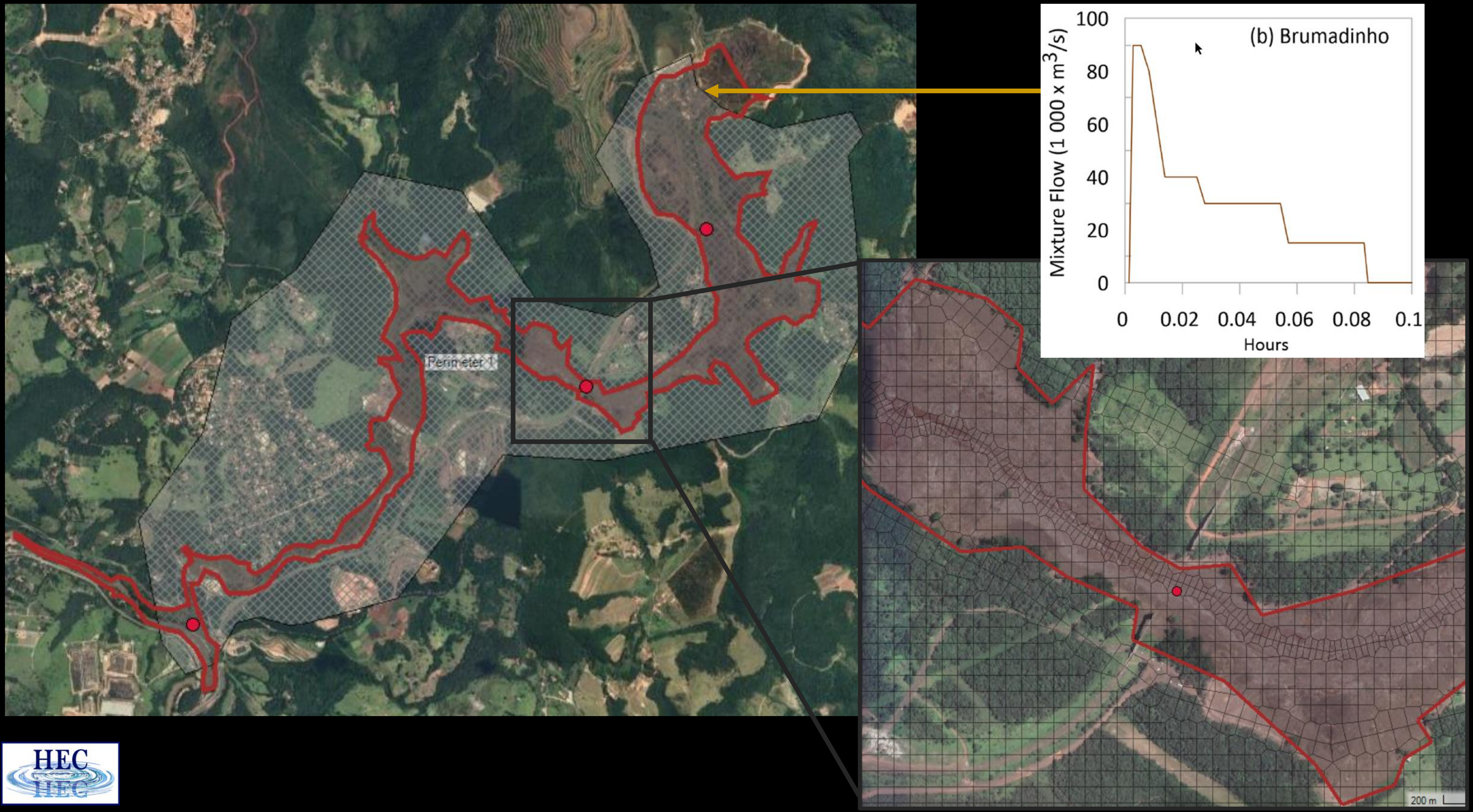



# Brumadinho Dam Failure
# 25 January 2019

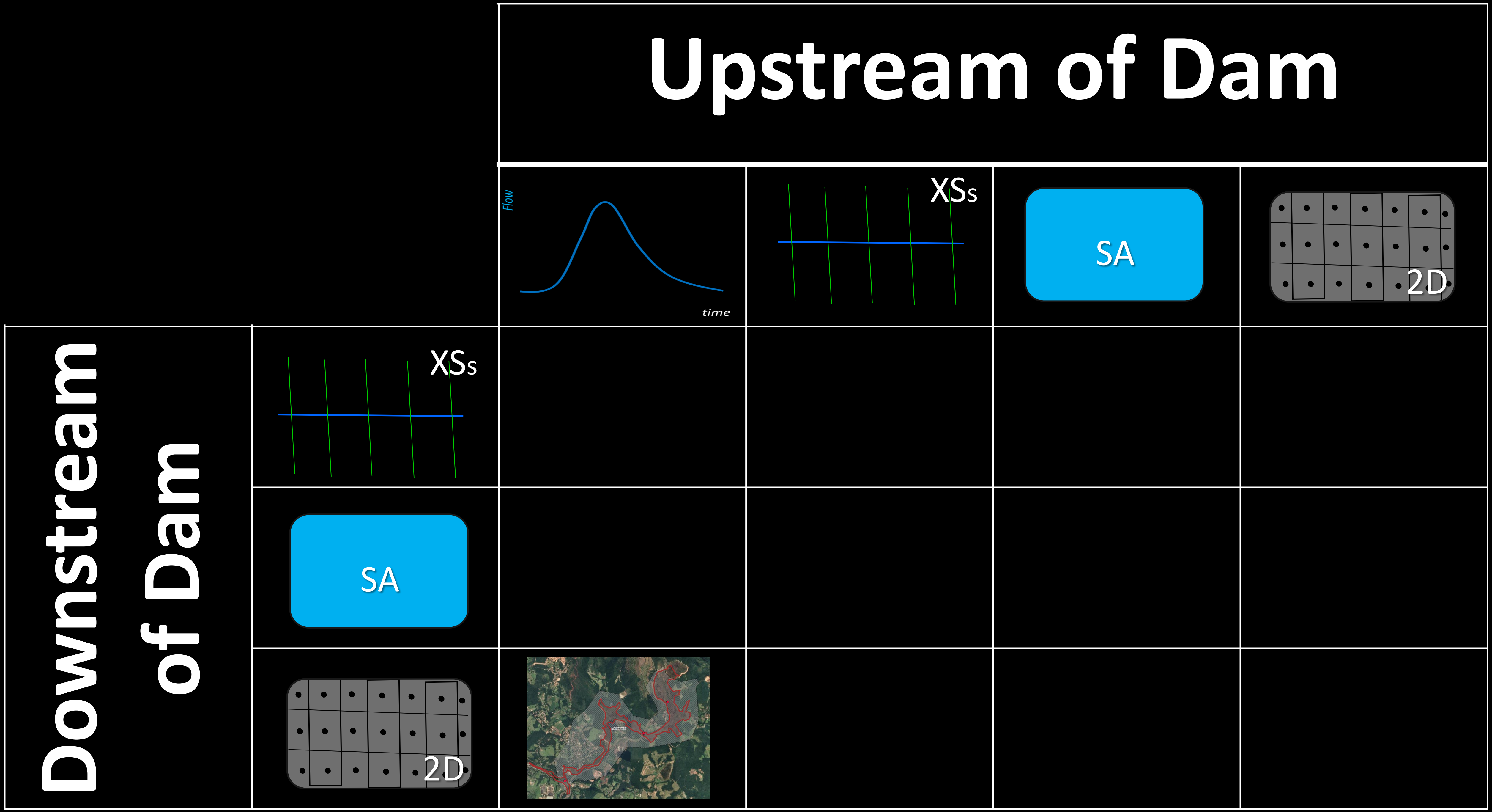


- 270 Deaths
- 3 Years After
  Mariana Failure
- Released 12 Million $m^3$

Images from dw



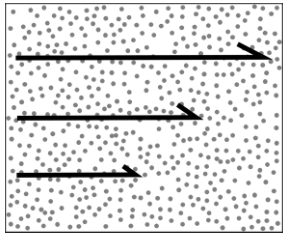
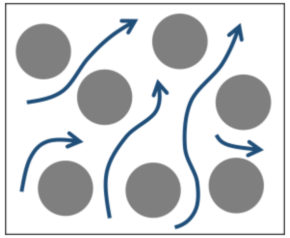
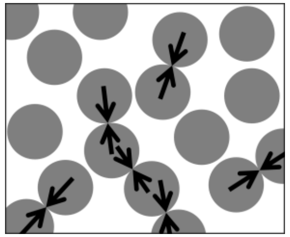
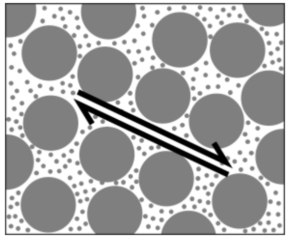
Perimeter 1
(b) Brumadinho
Mixture Flow (1 000 x m3/s)
100
80
60
40
20
0
0
0.02
0.04
0.06
0.08
0.1
Hours
200 m


Upstream of Dam
Downstream of Dam
Flow
time
XSs
SA
2D
XSs
SA
2D

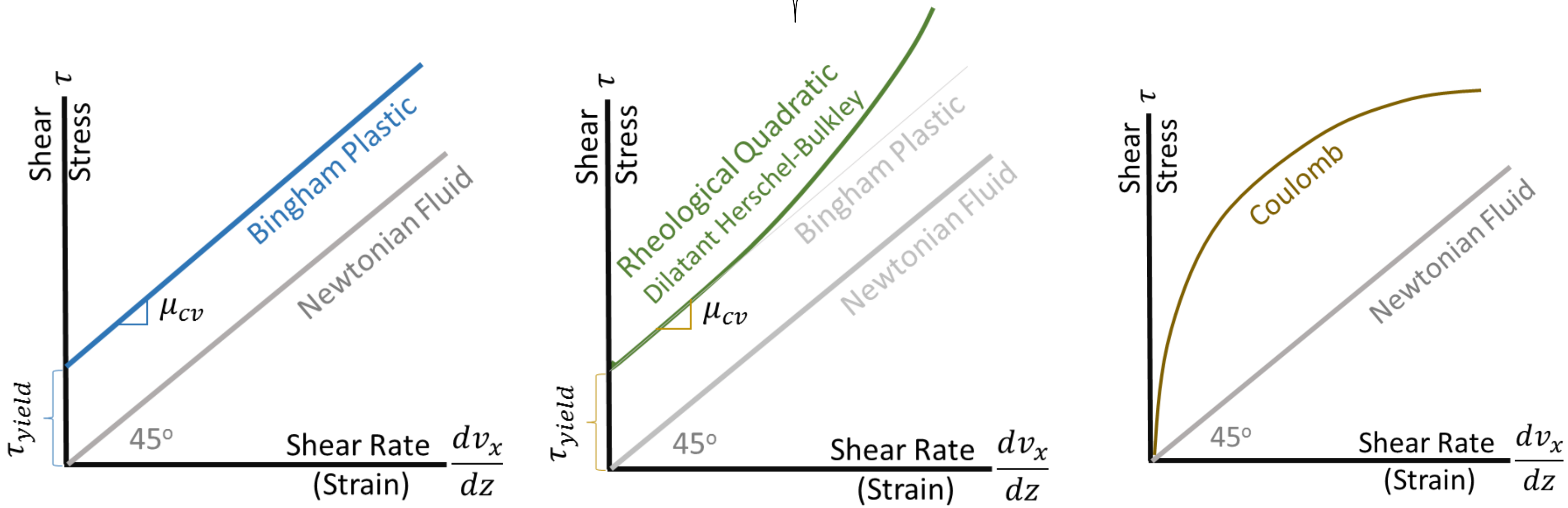

HEC

RAS

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

| Shear Component | $\tau_{yield} + \tau_{viscous}$ | $\tau_{turbulent}$ | $\tau_{dispersive}$ | $\tau_{Mohr-Coulomb}$ |
|---|---|---|---|---|
| Flow Type | Hyperconcentrated | Mudflow | Grain Flow<br>Collision Dominated | Debris Flow<br>Friction Dominated |
| Internal Loss Mechanism | Viscous | Turbulence | Grain Collison | Matrix Strength |
| Support Schematic |  |  |  |  |
| Rheological Model | Bingham Plastic<br>(First Order) | Turbulent<br>(Quadratic) | Turbulent-Dispersive<br>(Quadratic) | Coulomb<br>(Geotechnical) |

Rheological Model



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Article

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

Stanford Gibson [1,*], Leonardo Zandonadi Moura [2,3], Cameron Ackerman [1], Nikolas Ortman [4,5], Renato Amorim [6,7], Ian Floyd [8], Moosub Eom [4], Calvin Creech [9] and Alejandro Sánchez [1]

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5 Morrison-Maierle, Missoula, MT 59801, USA
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7 Department of Civil and Environmental Engineering, University of Iowa, Iowa, IA 52242, USA
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check for updates

Citation: Gibson, S.; Moura, L.Z.; Ackerman, C.; Ortman, N.; Amorim, R.; Floyd, I.; Eom, M.; Creech, C.; Sánchez, A. Prototype Scale Evaluation of Non-Newtonian Algorithms in HEC-RAS: Mud and Debris Flow Case Studies of Santa Barbara and Brumadinho. *Geosciences* **2022**, 12, 134. https://doi.org/10.3390/geosciences12030134

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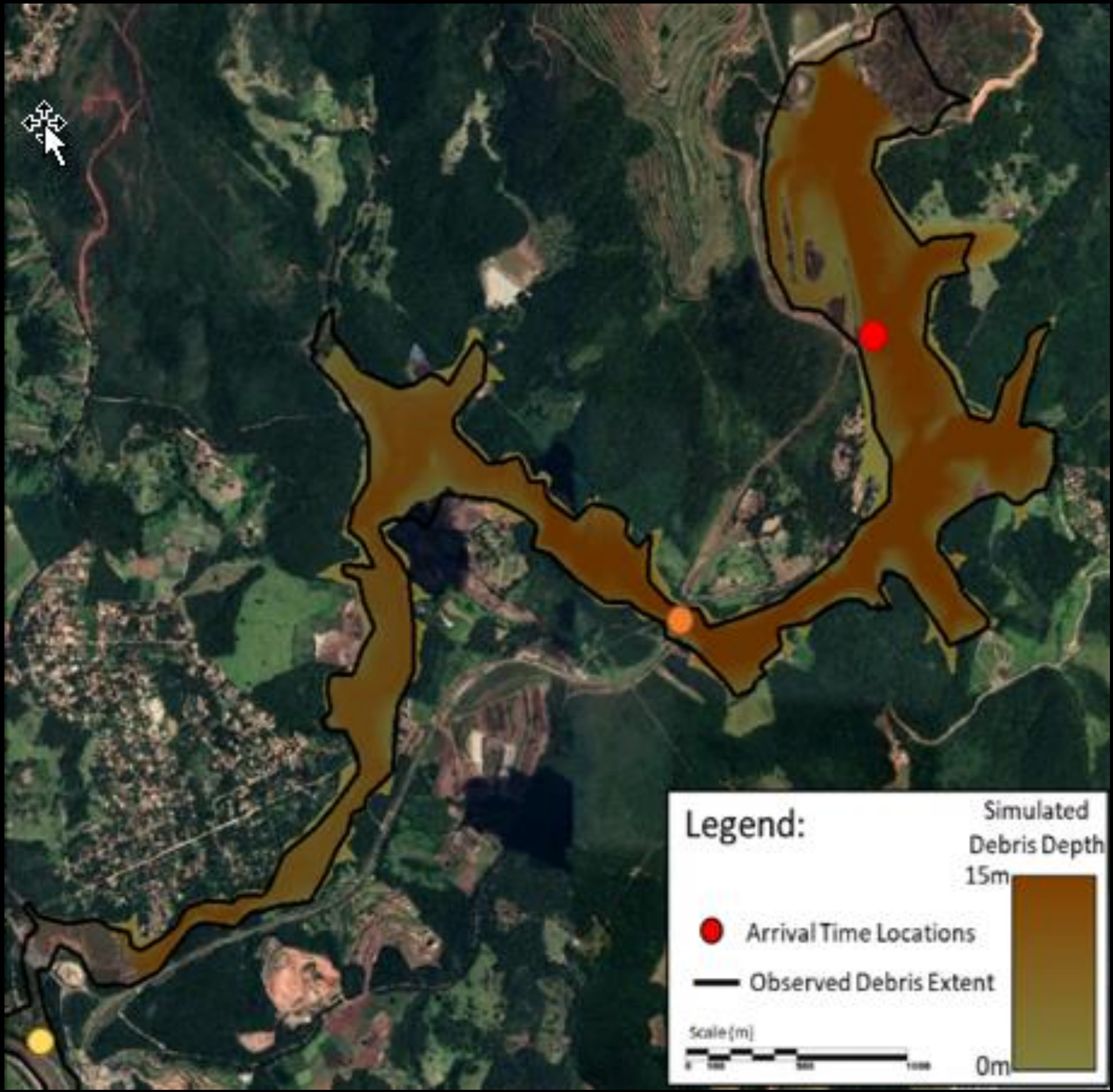
**Abstract:** The Santa Barbara post-wildfire debris flows and the Brumadinho tailing-dam failure were two of the most catastrophic flood events of the late 2010s. Both these events carried so much solid-phase material, that classic, clear-water, flood risk approaches cannot replicate them, or forecast 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 | ● (red) | 0% |
| Railway Bridge | 00:09:10 | 00:09:15 | ● (orange) | 0.9% |
| Paraopeba River | 01:26:05 | 01:27:45 | ● (yellow) | 1.9% |




https://www.mdpi.com/2076-3263/12/3/134

# SWE vs DW

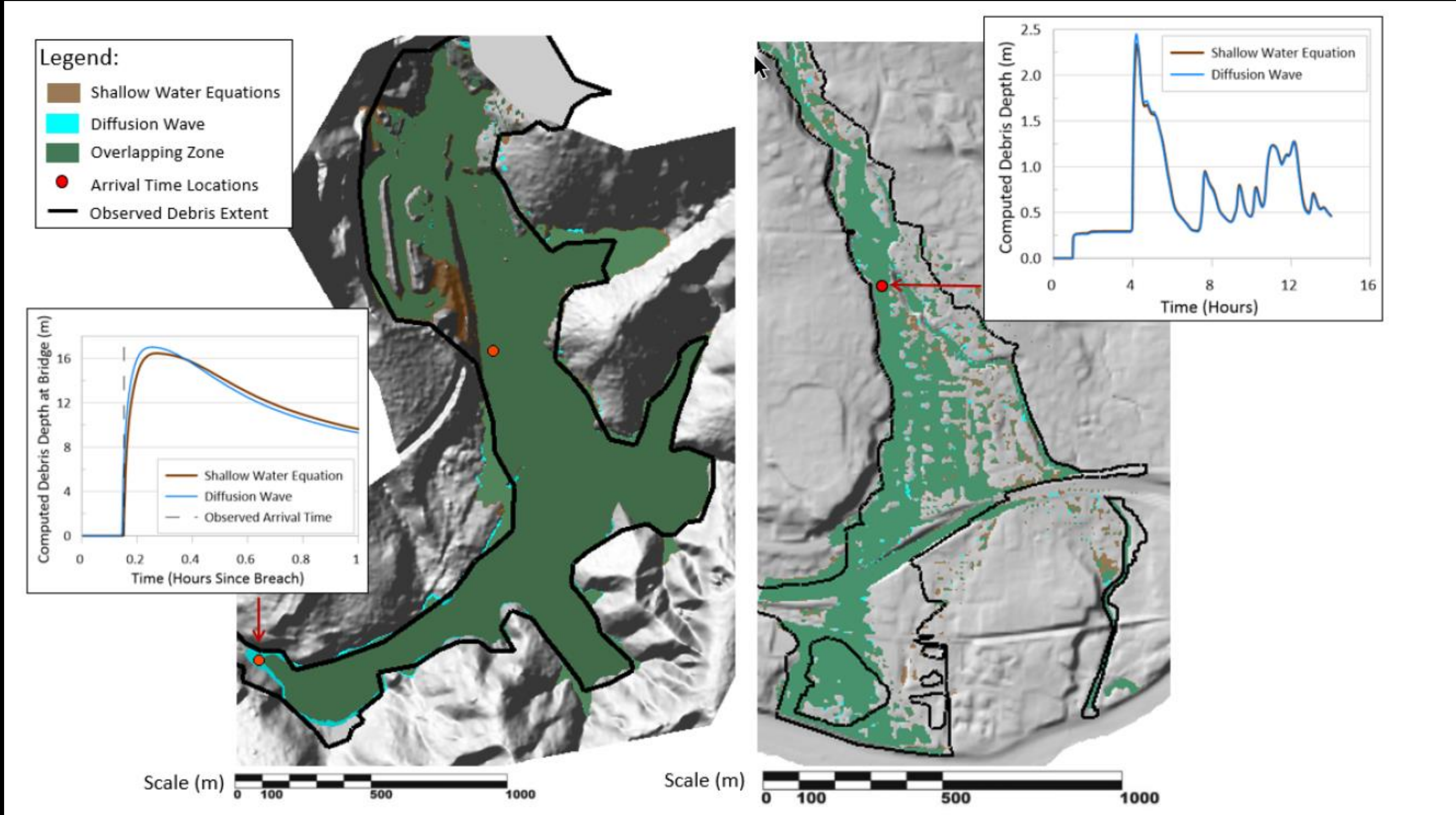



**Figure 11.** Brumadinho and Montecito model results with SWE and DW equations. The DW models did not differ substantially from the SWE simulations.