2D Dam Failure Inundation Modeling

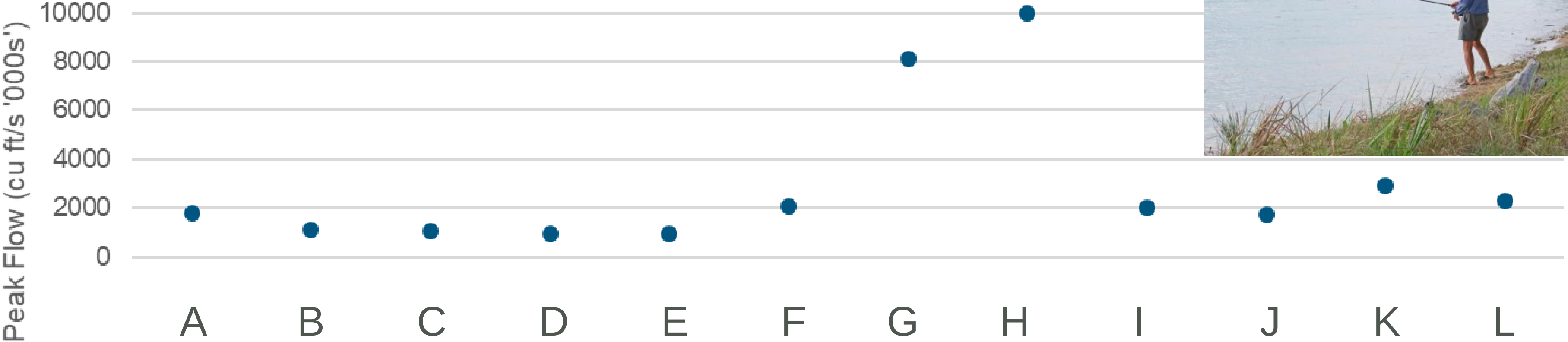
FMA 2018 Annual Conference
Reno, Nevada
Mitchell Smith

Overview

- Breach Formation
- Hydrograph Routing
- Physical and Empirical Methods
- Modeling Dam Break Dynamically in a 1D/2D Flood Model
- Learnings

Source: LA Times

But first two questions????



Dam Failure Inundation Modeling

Main components of dam failure:

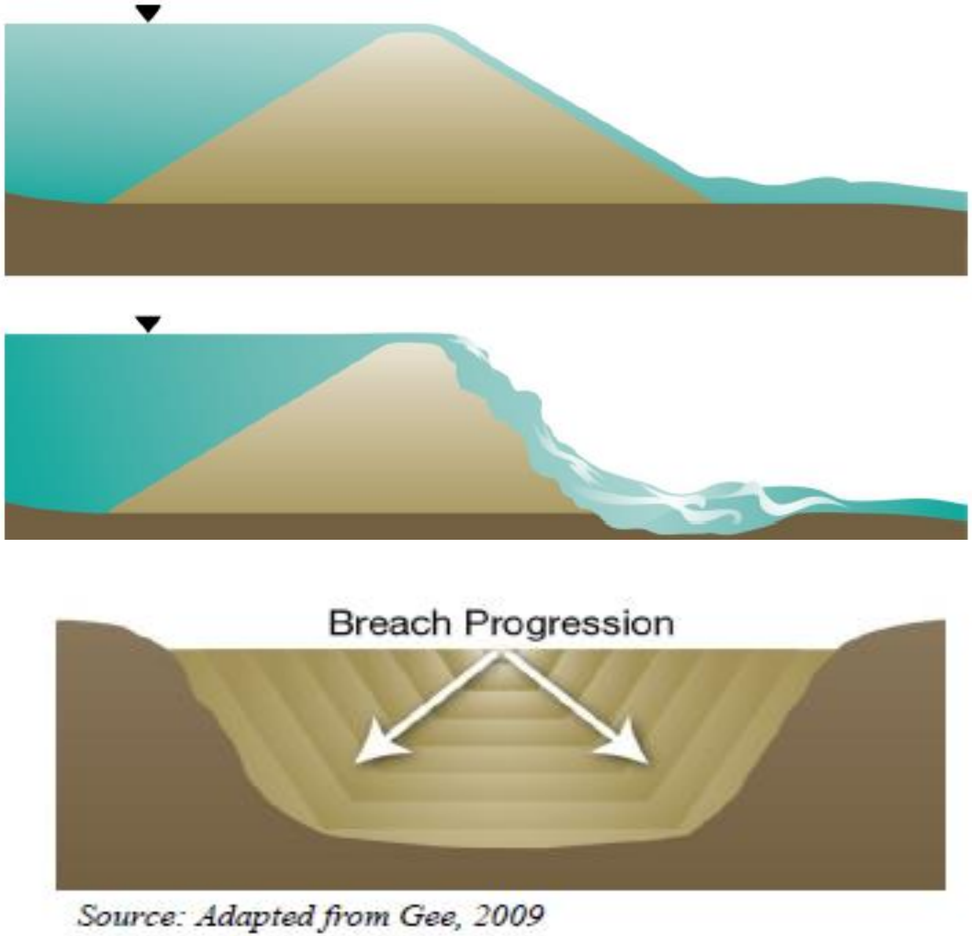
1. **Breach formation**
2. **Breach hydrograph estimation**
3. **Hydrograph routing downstream**

Level of rigor proportional to population, infrastructure and socio-environmentally sensitive areas at risk

Source: LA Times

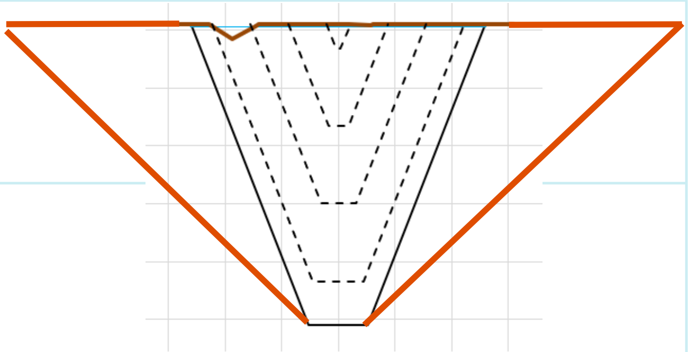
Breach Formation

- Uncertainty
- Breach size and shape
- Time for breach to full develop
- Piping failure
- Overtopping failure



Source: Springer, FEMA and USDA

Breach Shape and Timing Estimation



Physically-based (sediment transport and erosion)

Empirically-based

- Type of embankment
- Base width of breach
- Top width of breach
- Headwater depth
- Volume of material removed
- Storage volume in reservoir
- Side slope of breach
- Start time of breach
- Time for breach to fully develop
- Duration of breach

Investigator	Equation for predict t_f
MacDonald and Langridge-Monopolis [8]	$t_f = 0.0179 \times (V_{er})^{0.364}$
Froehlich (1995) [19]	$t_f = 0.00254 \times V_w \times 0.53 \times H_b{}^{-0.9}$
Reclamation [1]	$t_f = 0.011 \times B_{ave}$
Von Thun and Gillette (hard erosion) [13]	$t_f = 0.02 \times H_w + 0.25$
Von Thun and Gillette (easy erosion) [13]	$t_f = 0.015 \times H_w$
Froehlich (2008) [4]	$t_f = 63.2 \times (v_w / 9.81 \times H_b{}^2)^{0.5}$

Hydrograph Estimation and Downstream Routing

Dam Breach Hydrograph

- Assume peak flow from dam – Steady State
- Route hydrologically + dam breach
- Dynamically with 1D or 2D model

Downstream Routing

- Hydrologic model
- Dynamically route 1D
- Dynamically route 2D
- 1D and 2D models can allow you to model the impact on hydraulic structures

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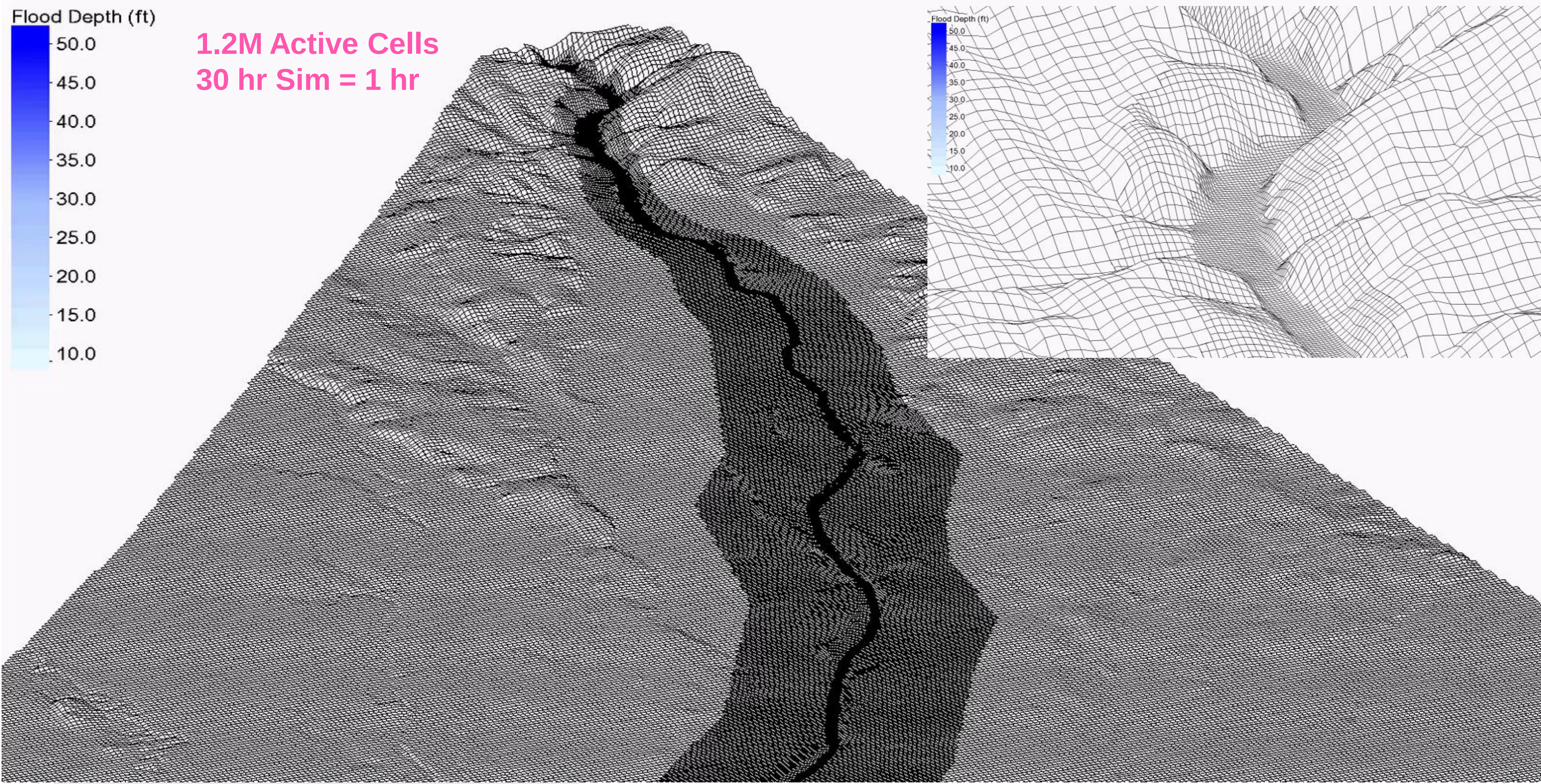
Camp Far West - California



Flood Depth (ft)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
1.2M Active Cells
30 hr Sim = 1 hr
Flood Depth (ft)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0

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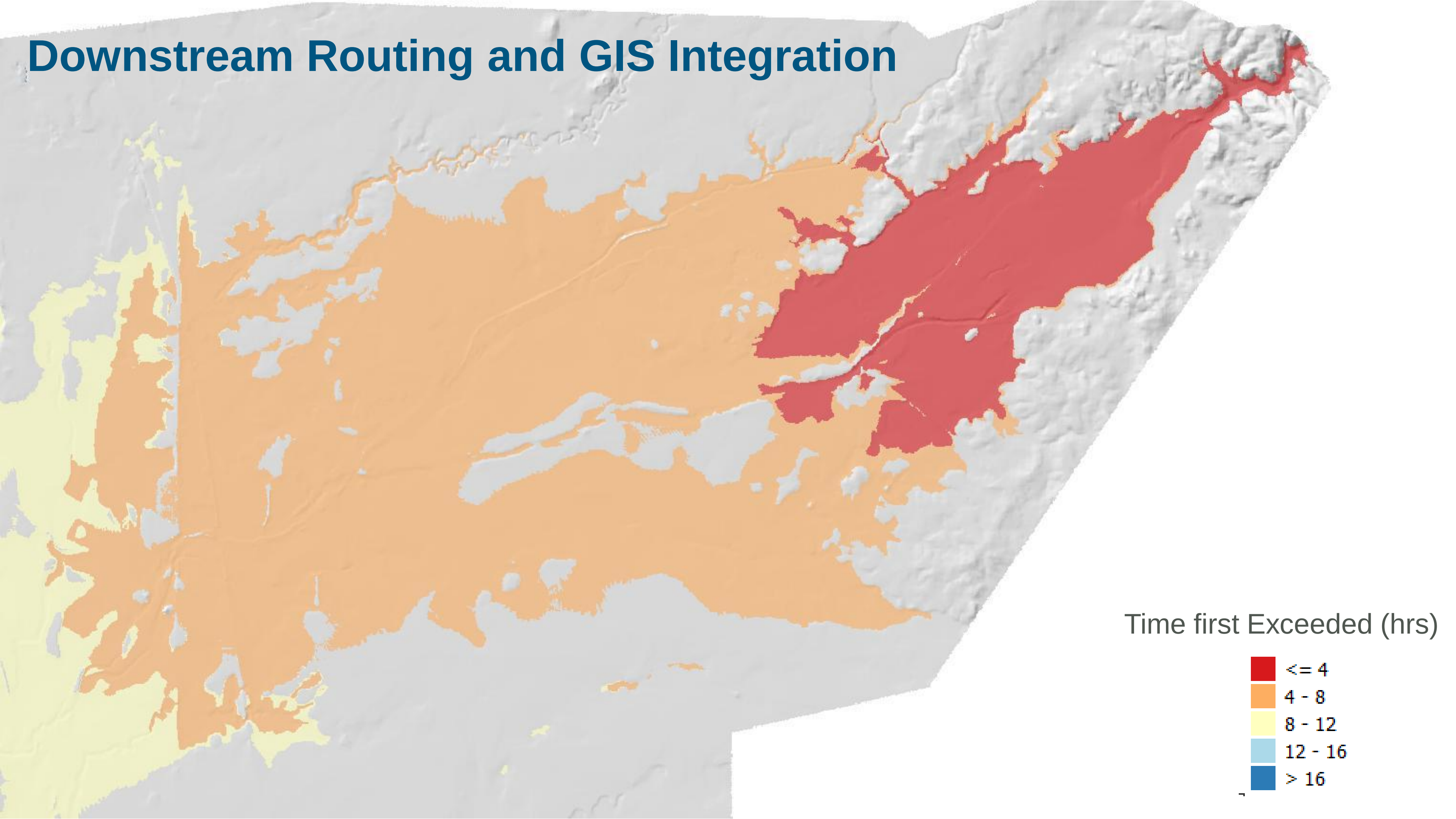
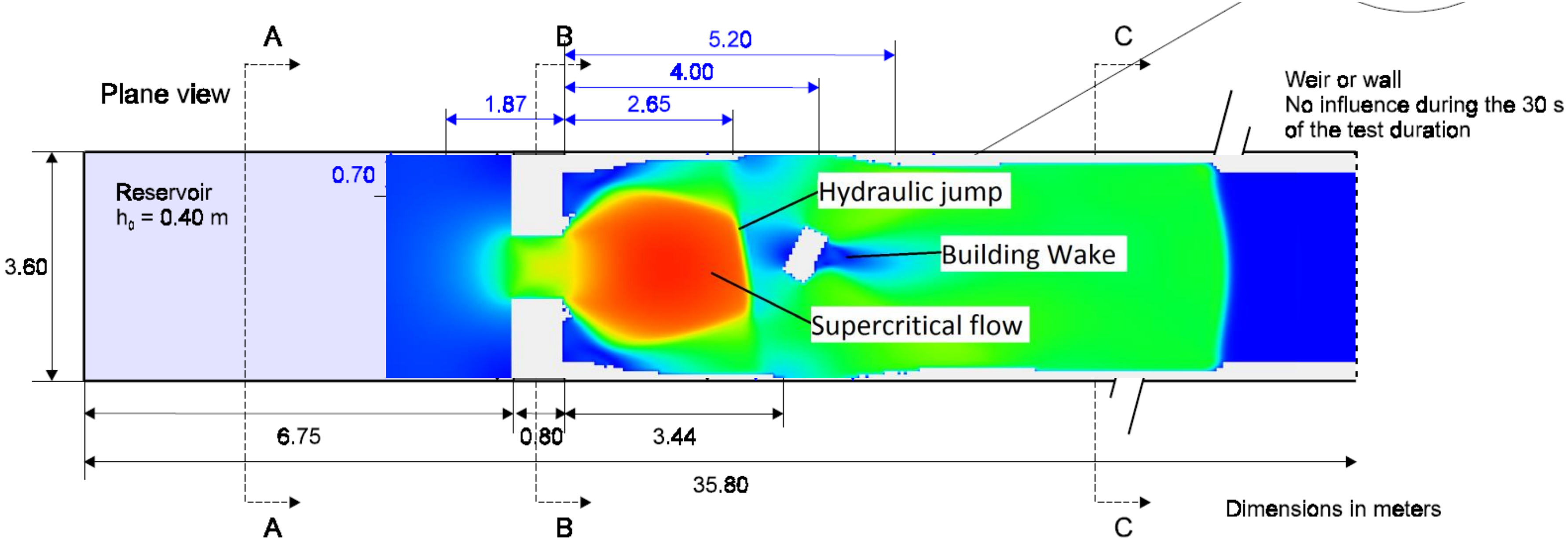
Downstream Routing and GIS Integration



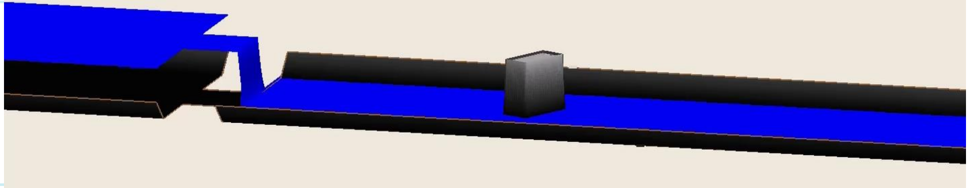
Benchmarking
Test Case 6A – UK EA



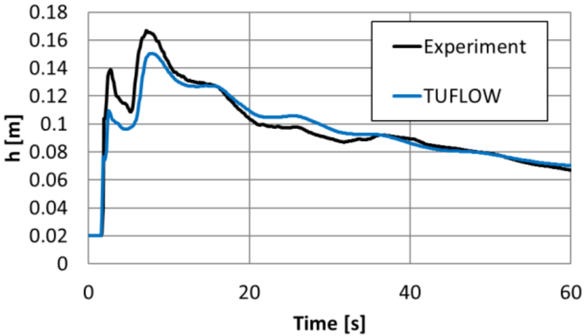
Bed friction coefficient : Manning n = 0.01 s $m^{-1/3}$
Test duration : 30 s

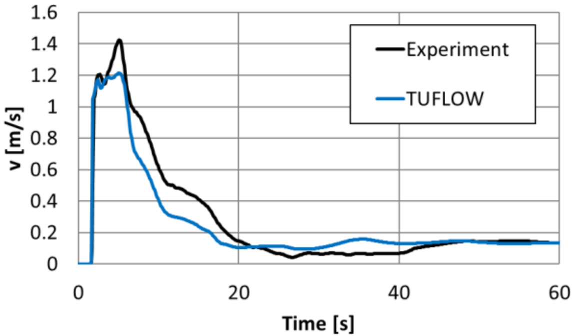
Flume experiment
(Soares Frazao, Noel, Spinewine & Zech, UCL, Belgium)

Benchmarking TUFLOW HPC
Test Case 6A – UK EA

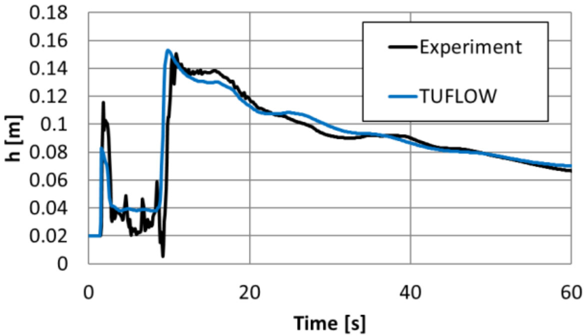


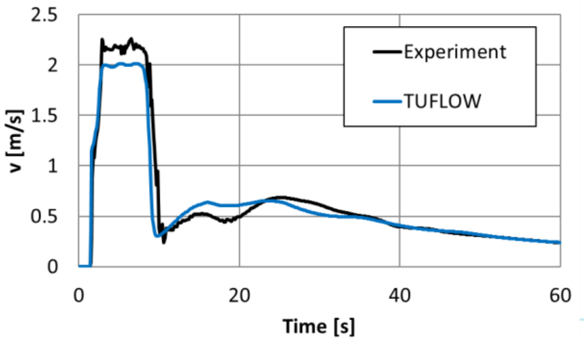
Location 1



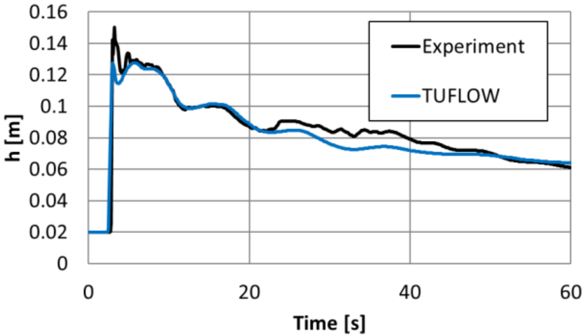


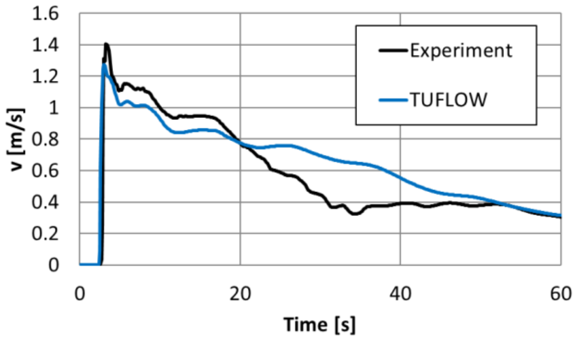
Location 2





Location 3





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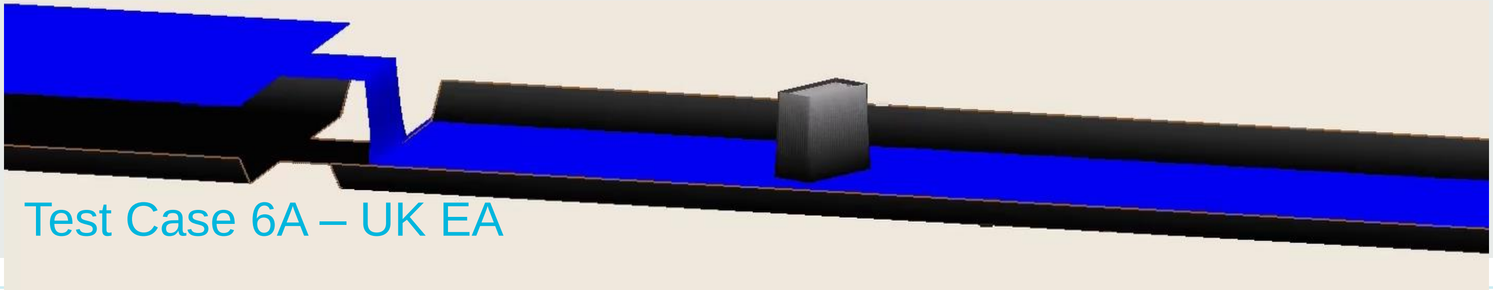
TUFLOW HPC

1. Extremely fast – Realistic modelling time for a *large downstream catchment*, *extreme dam failure velocities,* and *inclusion of dam bathymetry*
2. Dam wall can be modified during a simulation to emulate a dam failure
3. Improved estimation of flood wave dynamics for both in channel, the reservoir and on the floodplain
4. Outputs can be visualised and reported easily (inundation extents, and population at risk and potential loss of life estimates)



Case Study – Tasty Crocodile Dam

Catchment Details

- 1,800 sq mi
- 500 sq mi upstream of wall
- 50 mi to ocean

Dam Details

- Dam height 163 ft
- Capacity 890,000 ac ft
- Earth-fill embankment with central clay core
- Uncontrolled Ogee Spillway

Case Study – Tasty Crocodile Dam

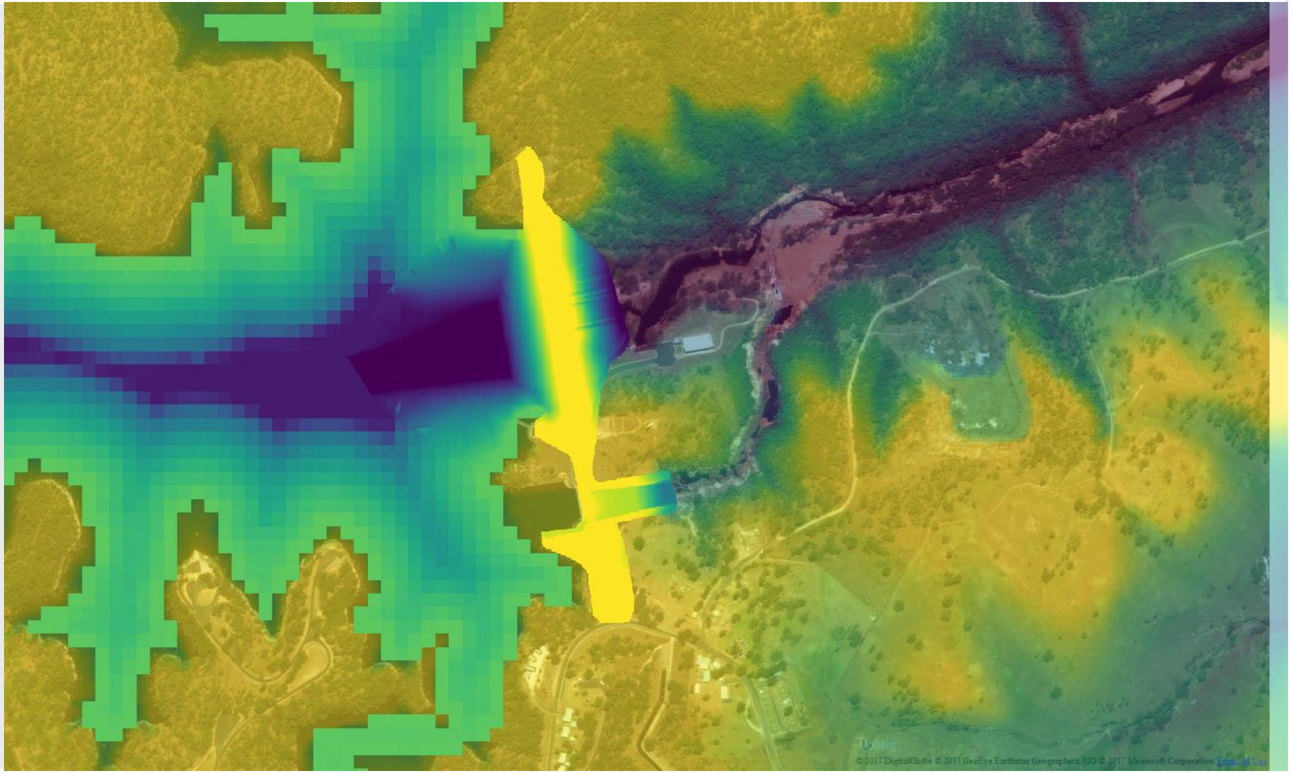
- PMF + overtopping breach
- Use two differing methods to apply the dam breach hydrograph
- Investigate the impact on peak flows, timing and water levels downstream

Two Failure Modeling Approaches

Model Feature	1. FULLY DYNAMIC	2. "LUMPED"
Breach Parameters	Spreadsheet derivation of breach shape and time	
Downstream Routing	Dynamically modelled in 1D/2D Flood Model	
Inflows	PMF Hydrograph	
Dam Breach Hydrograph	Generated by 1D/2D Model Topography	Spreadsheet Model (Level Pool). Applied downstream of dam.
Reservoir Routing	All within 1D/2D Flood Model	Spreadsheet Model (Level Pool)

Case Study – Tasty Crocodile Dam

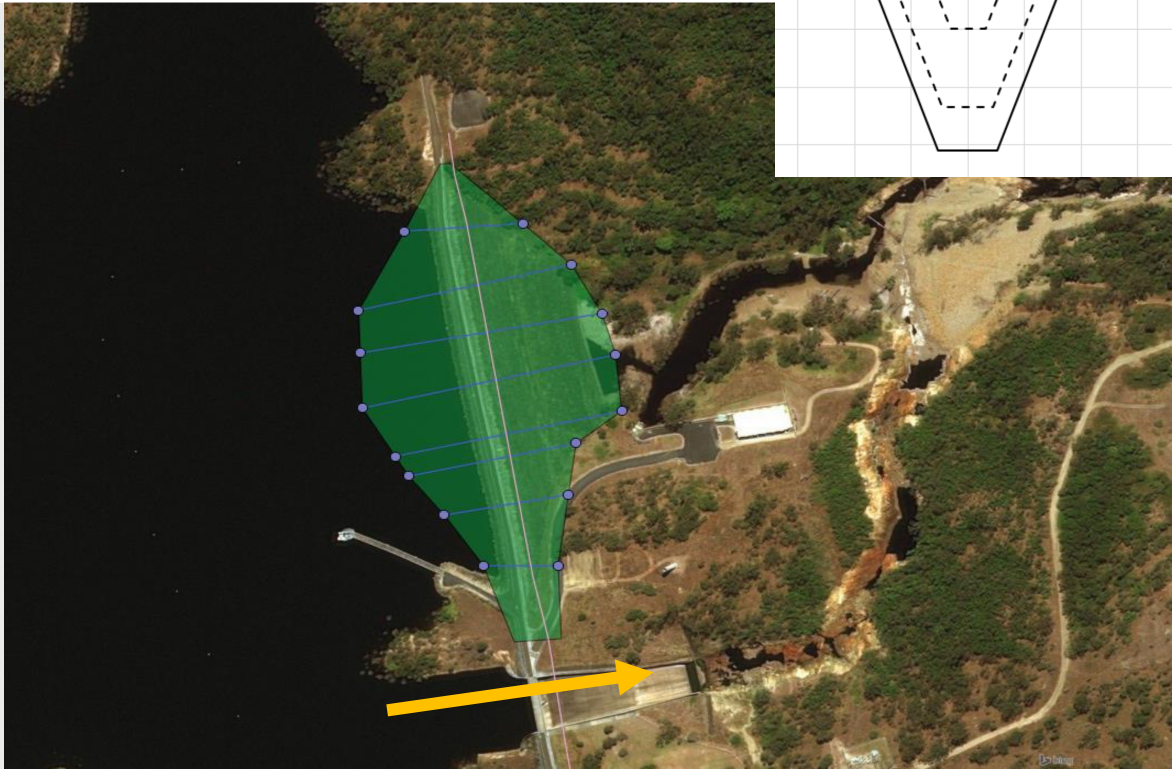
- **LIDAR**
- **Detailed survey**
- **Crest and spillway**
- **Bathymetry**

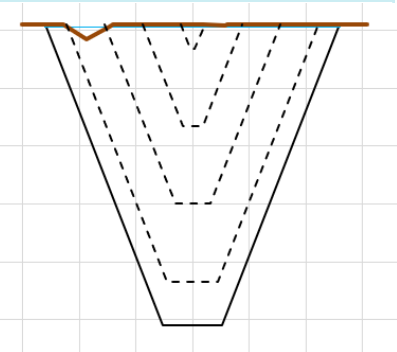


Approach 1 - Fully Dynamic Breach

Variable geometry

- Dynamically breach dam during simulation
- Triggered by water level in reservoir
- Spillway discharge curve in 1D/2D





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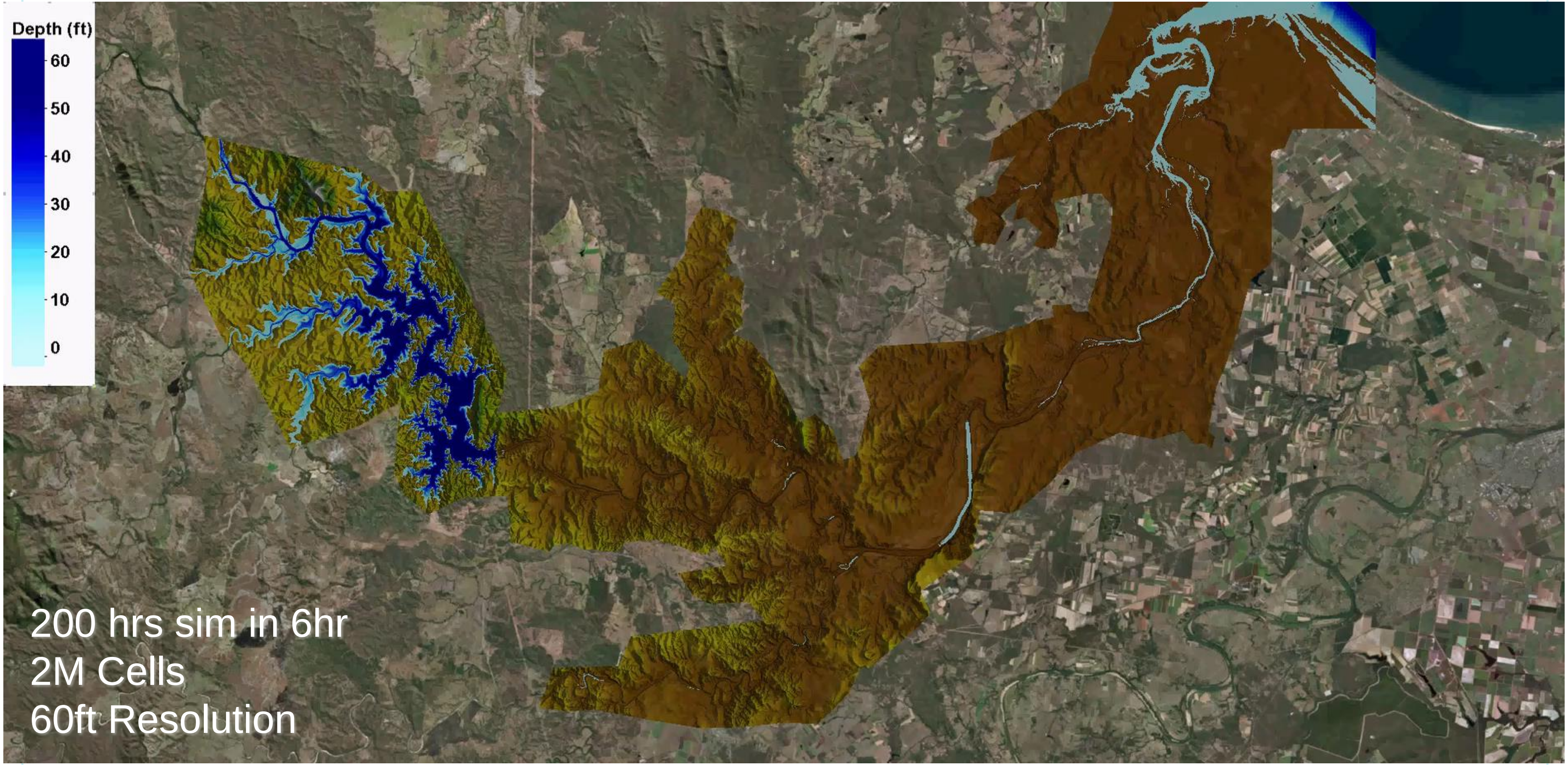
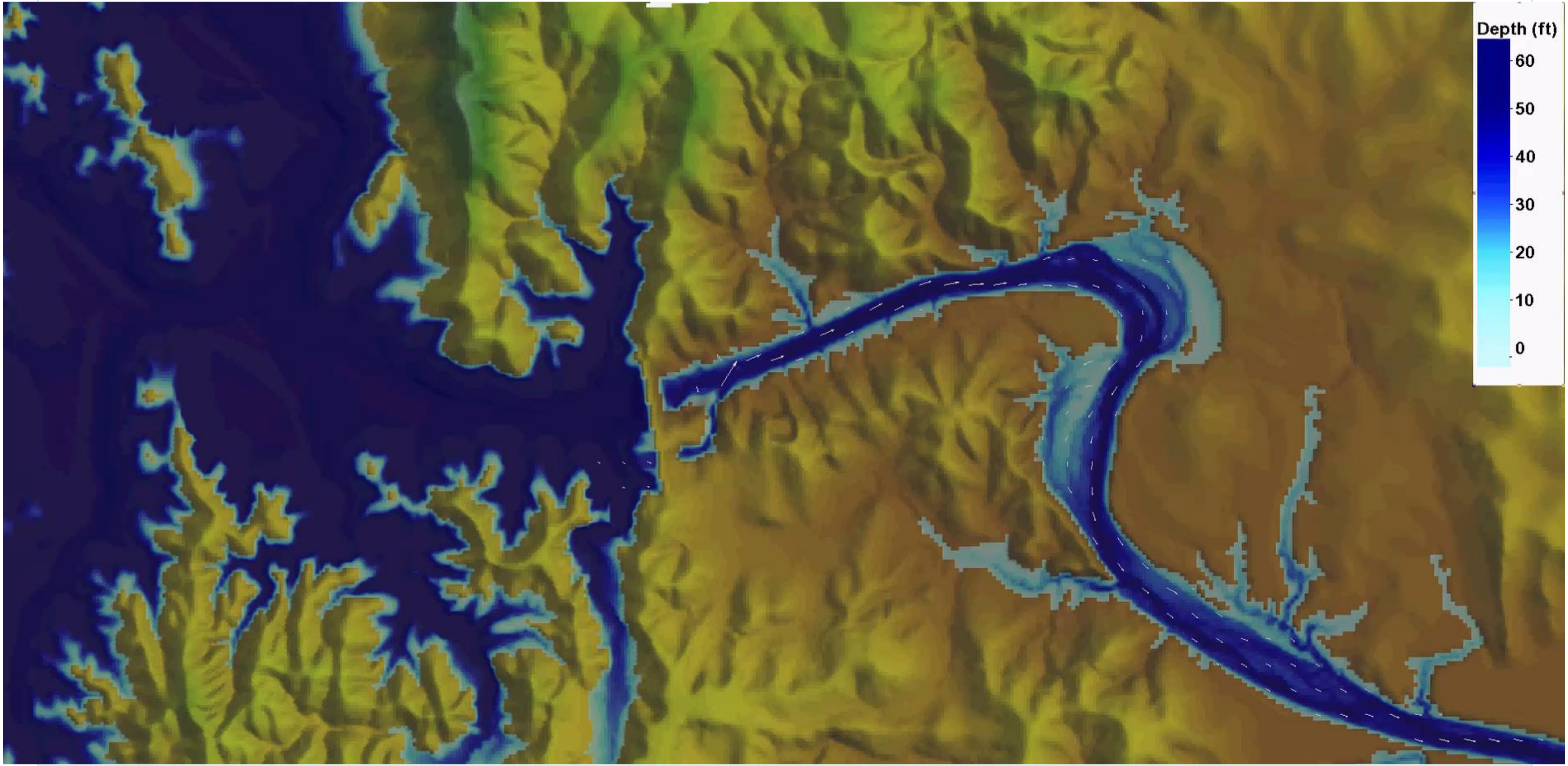
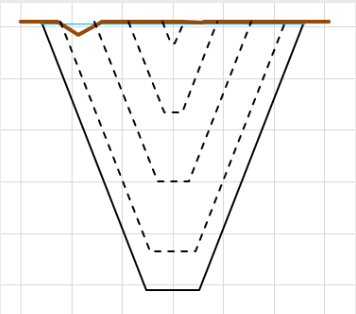
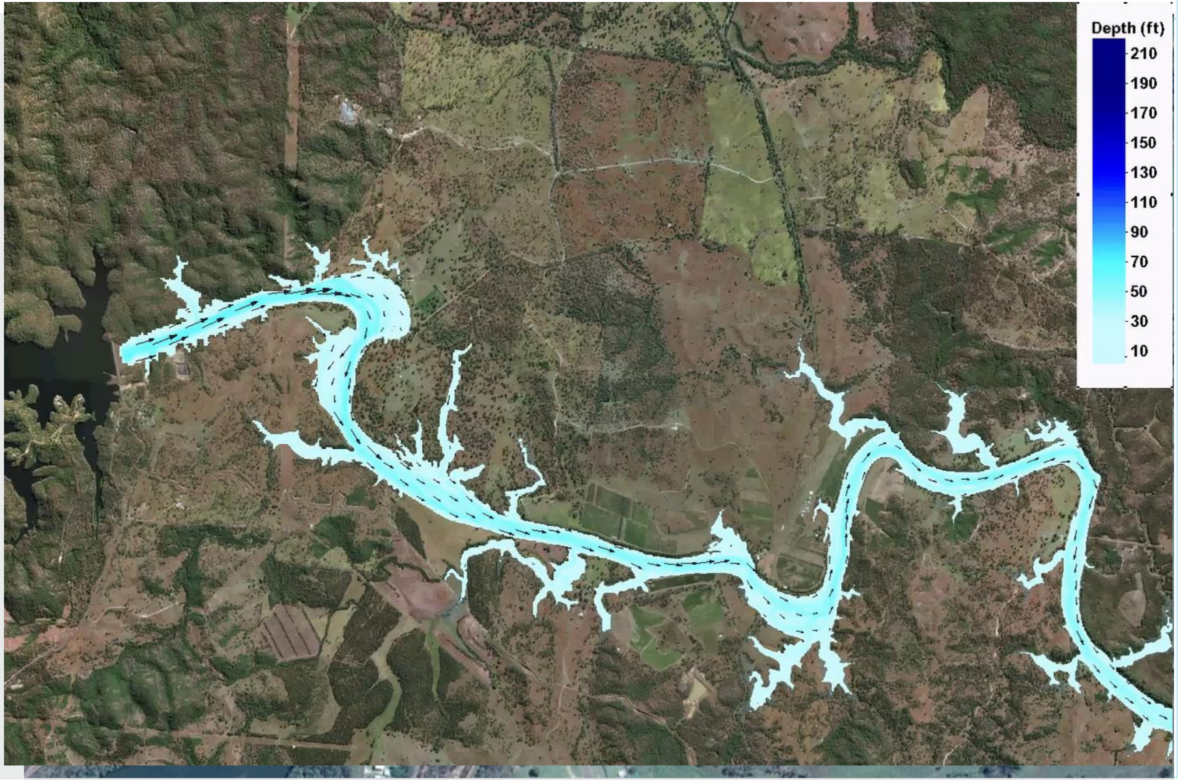

Depth (ft)
60
50
40
30
20
10
0
200 hrs sim in 6hr
2M Cells
60ft Resolution


Depth (ft)
60
50
40
30
20
10
0

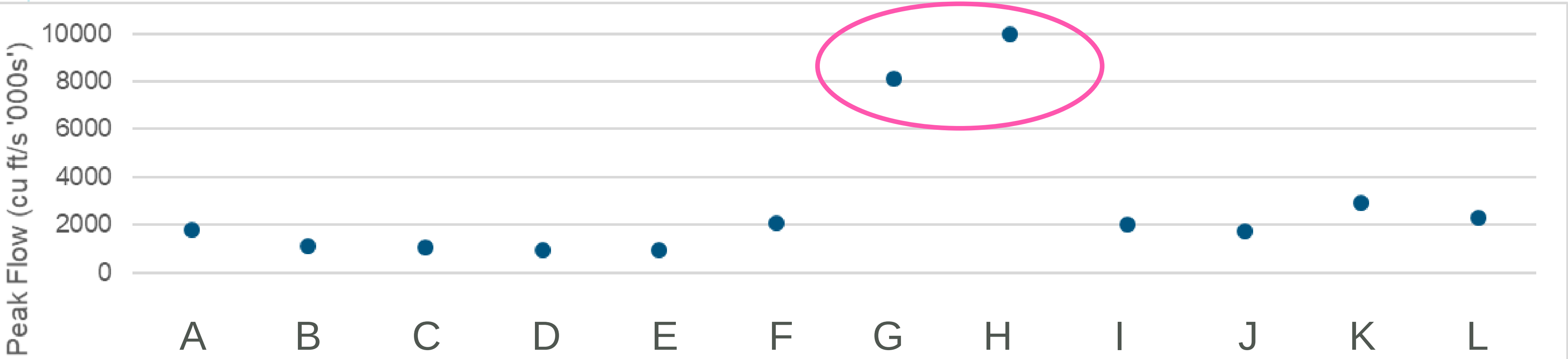
Approach 2 Lumped Breach

- Spreadsheet routing of dam
- Spillway + breach + overtopping lumped
- Consistent breach shape and timing

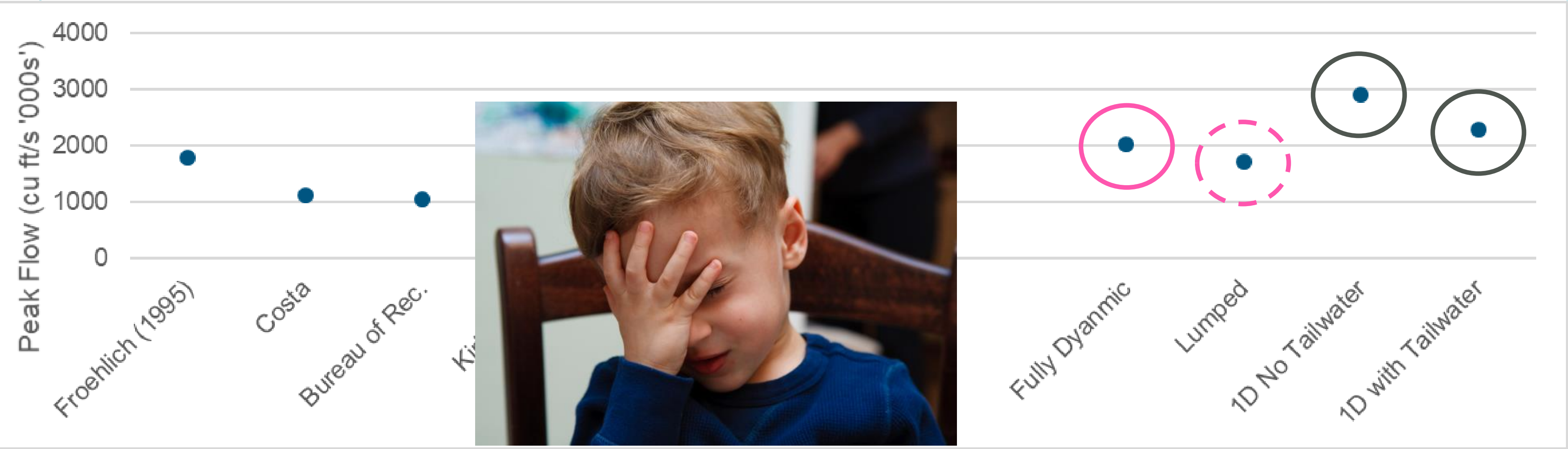




So Question 1???? Which is the ‘right’ answer….



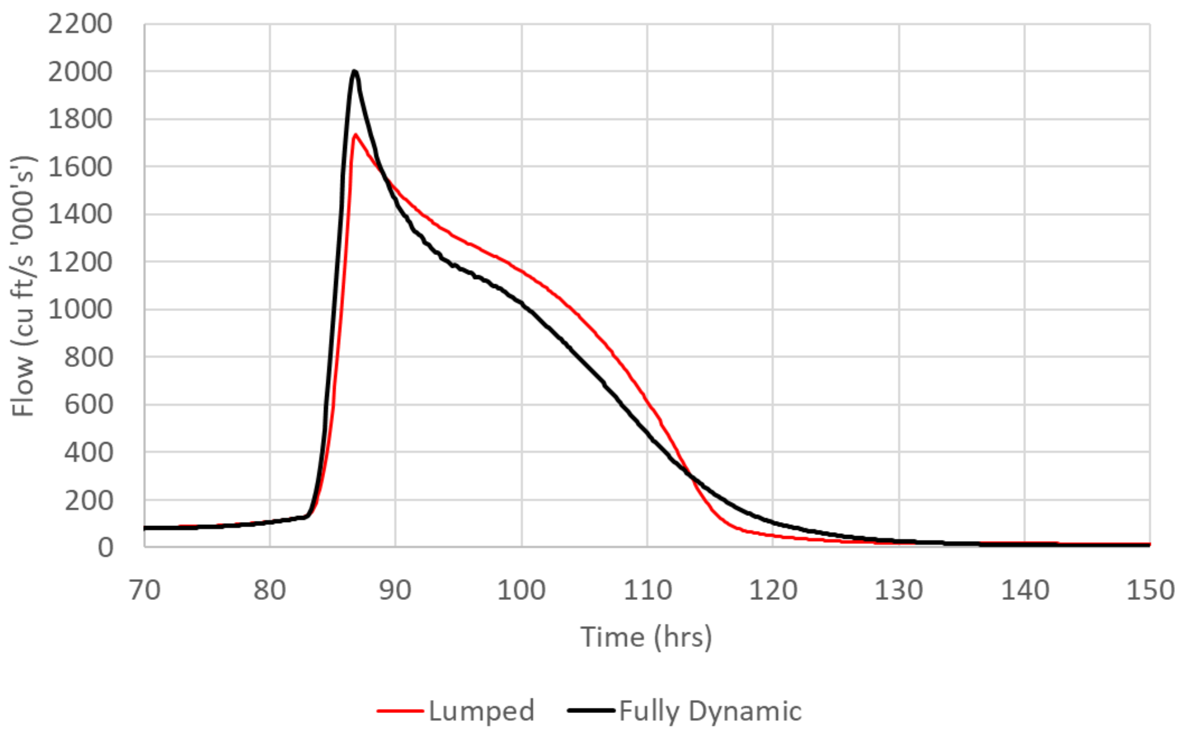
So Question 1???? Which is the ‘right’ answer….



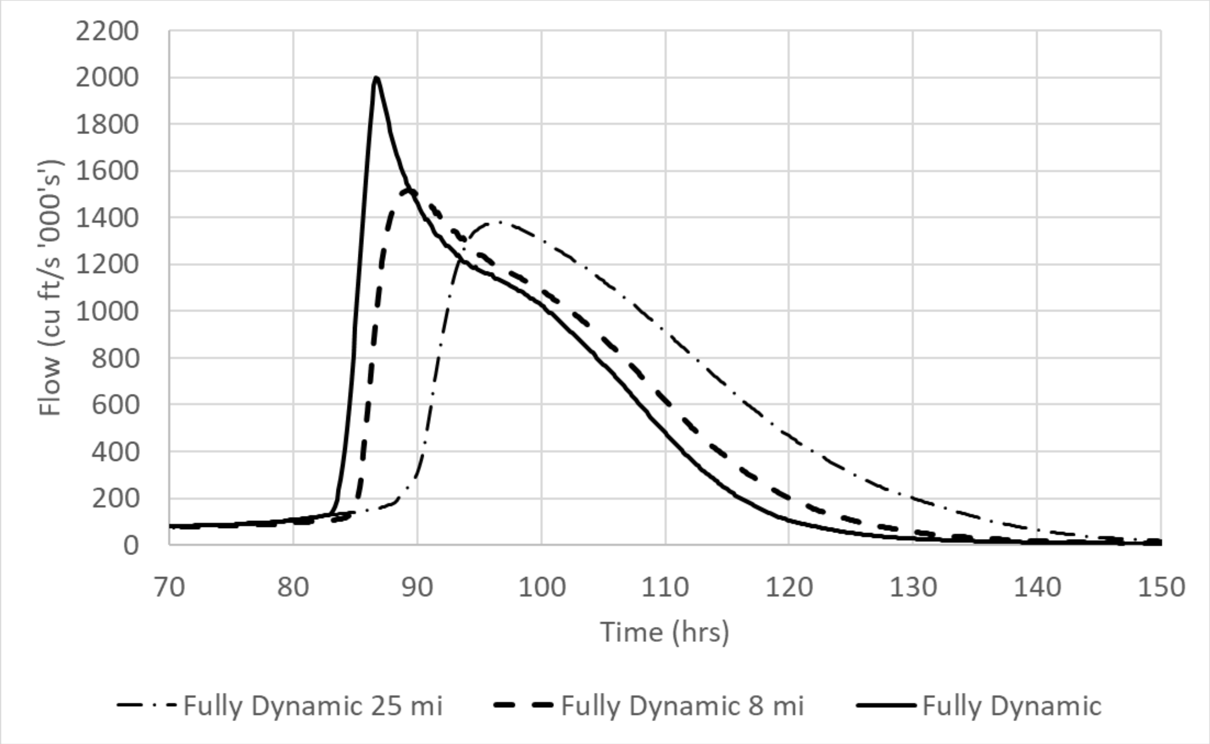
Which is ‘right’??? Good question…..

Comparison of Breach Hydrographs – Interesting…

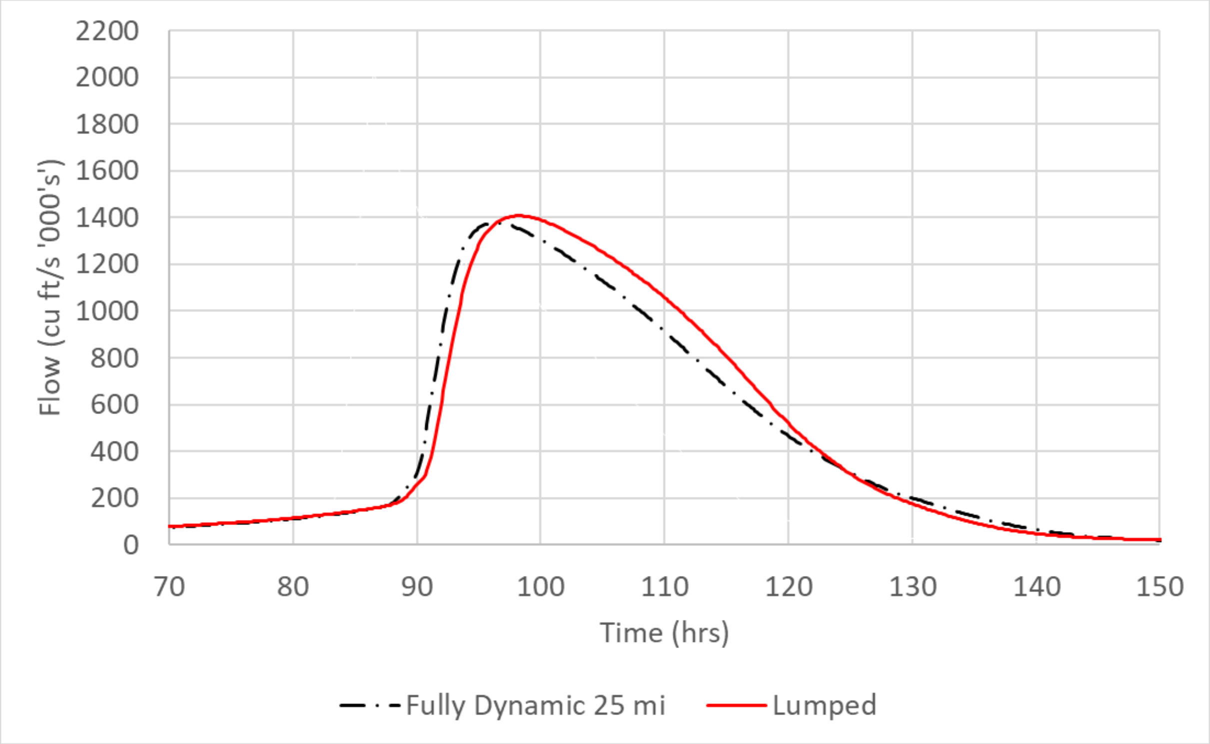
- **Breach in spreadsheet and model slightly different**
- **Routing through the reservoir**
- **Not still pool routing (gradient in reservoir)**
- **Tailwater effects?**



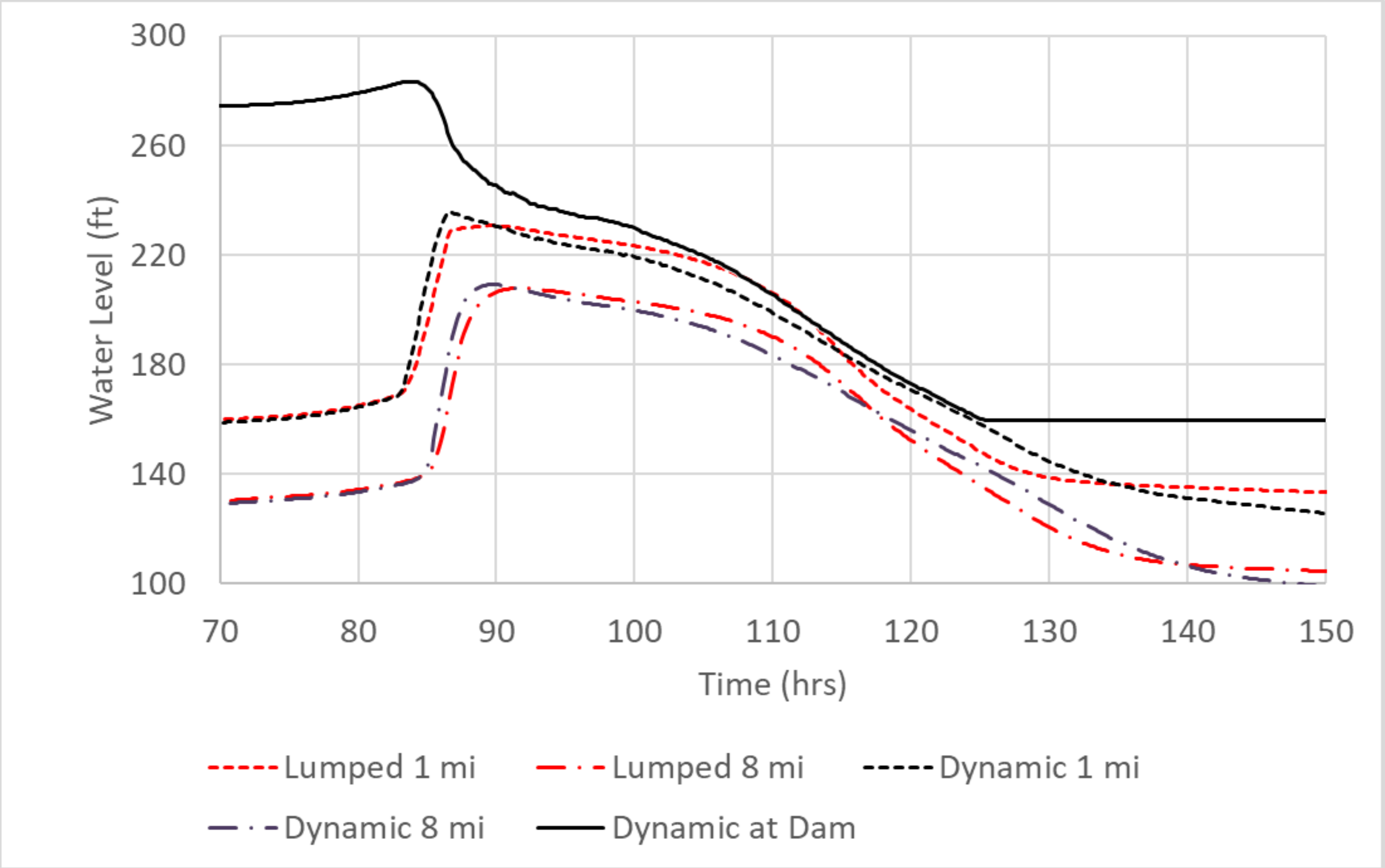
Flow Attenuation – 1, 8 and 25 Miles Downstream

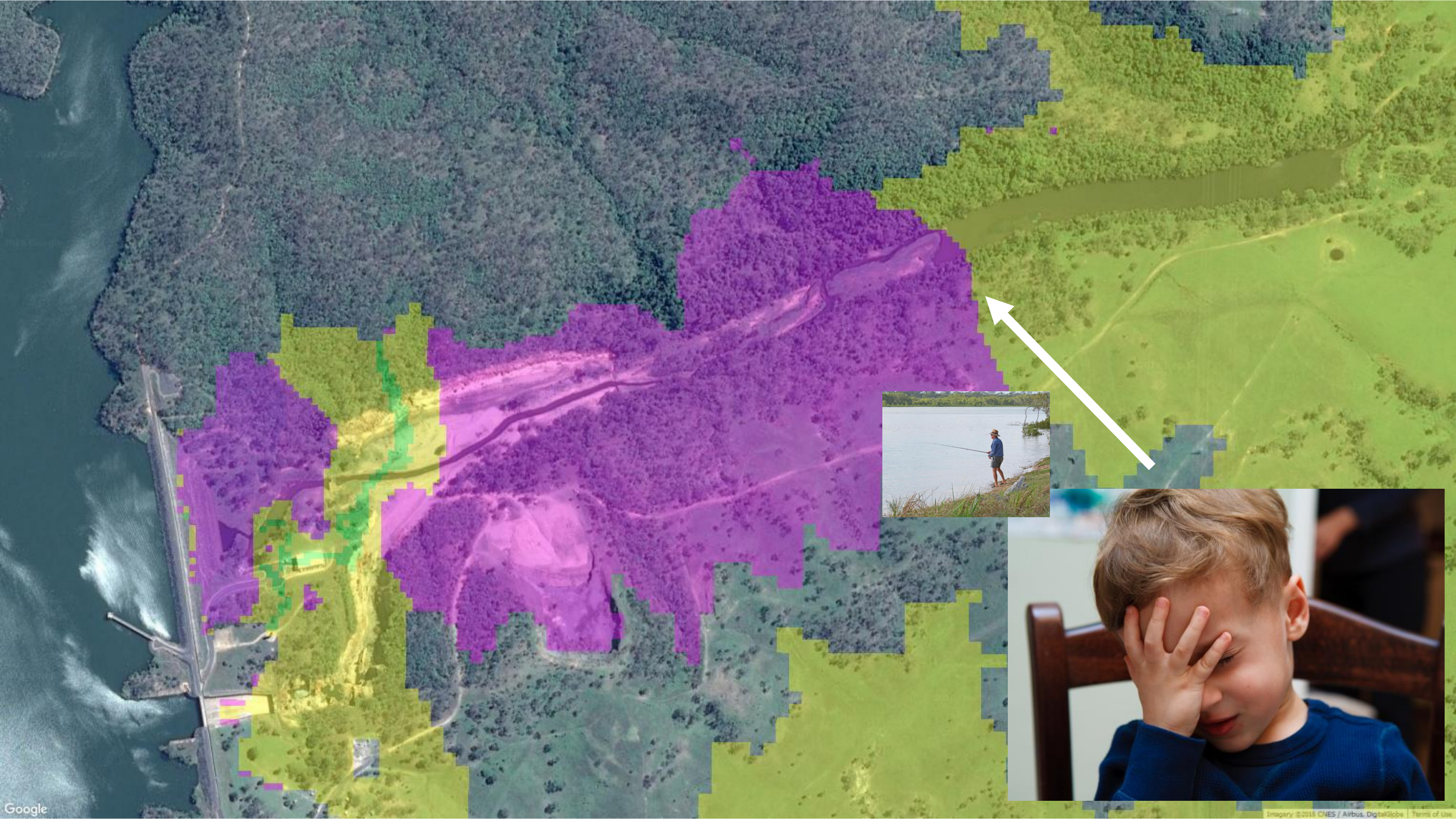


Flow Attenuation – Both Runs – 25 Miles Downstream



Wate


300
260
220
180
140
100
Water Level (ft)
70
80
90
100
110
120
130
140
150
Time (hrs)
Lumped 1 mi
Lumped 8 mi
Dynamic 1 mi
Dynamic 8 mi
Dynamic at Dam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Learnings…

Hydrograph shape and peakedness differ between methods which may be due to dynamic effects during drawdown

However… Presence of a constriction in the floodplain is the control under extreme flows

This won't exist for all models though…

Would I have saved some time by firstly running a series of extreme flows through the model and comparing the water level, velocity and discharge results downstream?

Shows the importance of hydraulic routing on attenuating the breach hydrograph and the influence of tailwater

Knowledge gained by sensitivity testing will usually save you in the long run…

Conclusion

- Breach formation and timing remains a major uncertainty
- Peak flows from ‘lumped’ and ‘dynamic’ models are in the same ball park.
- Very interesting differences in shape between the two hydrographs
- Downstream effects cannot be ignored
- Sensitivity testing - Fast and accurate 2D flood models of the catchment downstream can allow you to concentrate your energy on what matters
- To be continued…

Thank you. Any Questions???