Interpreting 2D Models

When is a Model Right and When is it Wrong?

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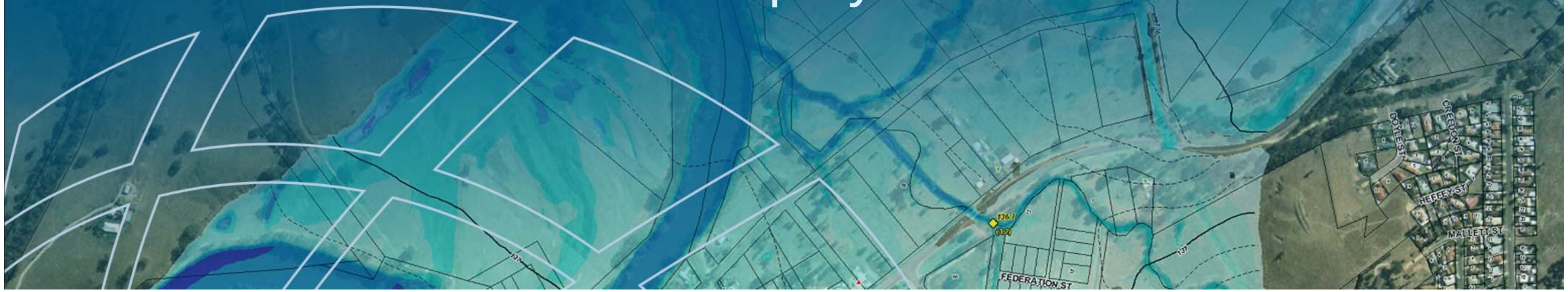

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Full 1D Equations (St Venant)

$$\frac{\partial h}{\partial t} + \frac{\partial (uA)}{W \partial x} = 0$$

Mass Balance

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial h}{\partial x} + k|u|u = 0$$

Momentum

Full 2D Equations (SWE)

$$\frac{\partial h}{\partial t} + \frac{\partial (Hu)}{\partial x} + \frac{\partial (Hv)}{\partial y} = 0$$

Mass Balance

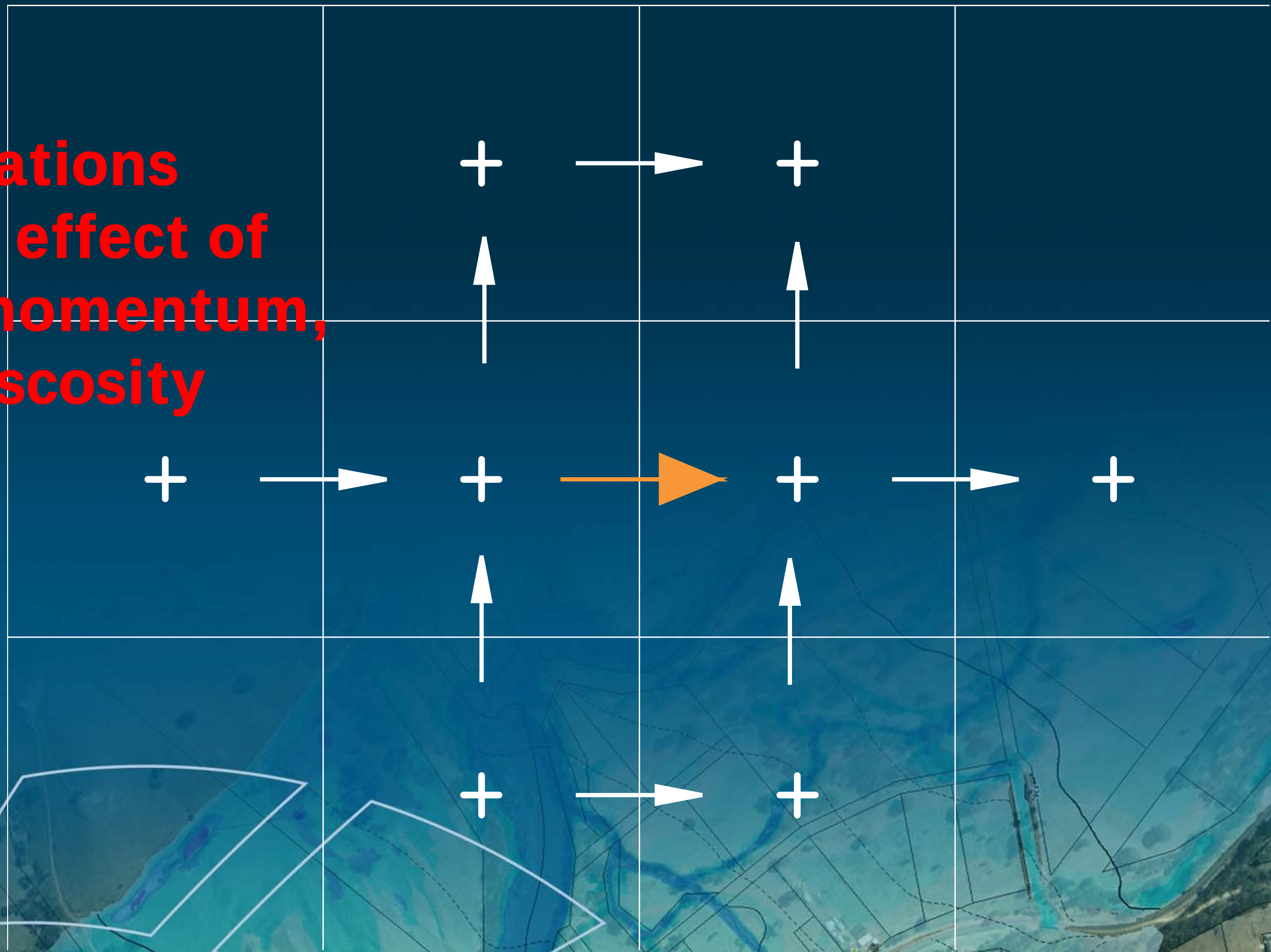
Momentum

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - c_f v + g\frac{\partial h}{\partial x} + g u\frac{\sqrt{u^2 + v^2}}{C^2 H} - \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \frac{1}{\rho}\frac{\partial p}{\partial x} = F_x$$

New terms introduced – cross momentum, sub-grid scale turbulence

Inside the Fully 2D Cell

2D equations include effect of cross-momentum, eddy viscosity



Inside the Fully 2D Cell

1D equations exclude these influences

The Assumptions – 1D

- Depth and width averaged
- Water surface is horizontal
- Flow follows a straight line
- Most model momentum (in a straight line)
- No cross-momentum
- No turbulence (eddy viscosity)
- Examples: HEC-RAS, MIKE 11, XP-SWMM, TUFLOW 1D

The Assumptions – Pseudo-2D

- Depth averaged
- Solves 1D equation over 2D grid/mesh
- Spreading model
- Diminished or no cross momentum
- No turbulence
- Simplistic representation of true 2D solution
- Can be used where friction dominates (eg. shallow flow)
- Velocity output not reliable
- Example: FLO-2D

The Assumptions – Fully 2D

- Depth averaged
- Some omit turbulence (eddy viscosity)
- Can omit Coriolis and atmospheric pressure
- Much closer to reality than 1D (where flow is not unidirectional) and Pseudo-2D (where friction doesn't dominate)
- Grid Examples: MIKE Flood, Sobek, TUFLOW
- Mesh Examples: ADH, FESWMS, InfoWorks, MIKE FM, RMA2, RiverFlo-2D, TUFLOW FV

Full 2D Equations

(Wave length much larger than depth, eg. floods)

How Velocity changes over time

Coriolis Force

Atmospheric Pressure

External Forces (Wind, Waves, ...)

Inertia Term

Gravity

Bed Resistance

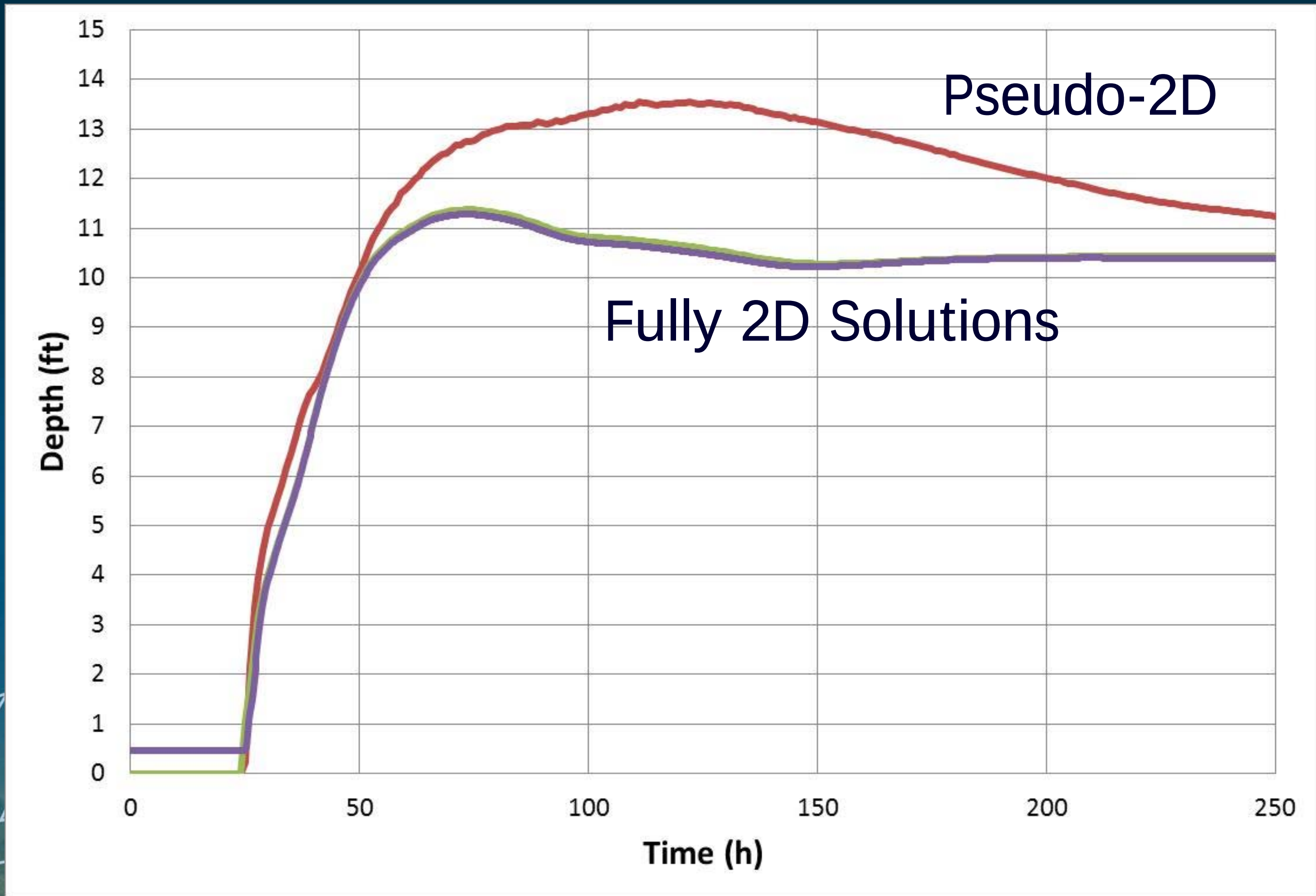
Viscosity (Turbulence)

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + c_f\, u + g\frac{\partial h}{\partial y} + g\, v\, n^2\frac{\sqrt{u^2+v^2}}{H^{4/3}} - \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + \frac{1}{\rho}\frac{\partial p}{\partial y} = F_y$$

Pseudo-2D vs Fully 2D

- UK EA 2D Benchmarking findings:
  - Pseudo-2D suitable for national, strategic, broad-scale assessments
  - Unsuitable for detailed flood hazard and impact assessments (Need to use Fully 2D)
  - Often no speed gains from using Pseudo-2D models

Accuracy Example



Key Physical Processes

How Velocity changes over time

~~Coriolis Force~~

~~Atmospheric Pressure~~

~~External Forces (Wind, Waves, …)~~

Inertia Term

Gravity

Bed Resistance

~~Viscosity (Turbulence)~~

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + c_f\, u + g\frac{\partial h}{\partial y} + g\, v\, n^2 \frac{\sqrt{u^2+v^2}}{H^{4/3}} - \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + \frac{1}{\rho}\frac{\partial p}{\partial y} = F_y$$

Understand what your 2D scheme needs to solve?

2D Grid or Flexible Mesh?

- Principal Grid Applications
  - Flood studies
  - Flood impact assessments
  - Floodplain management what-if scenarios
  - Whole of catchment modelling
- Principal Flexible Mesh Applications
  - Detailed, high resolution, analyses (eg. hydraulic structures)
  - Complex in-bank river flow patterns
  - Storm surge estuarine and coastal inundation

Grid Pros and Cons

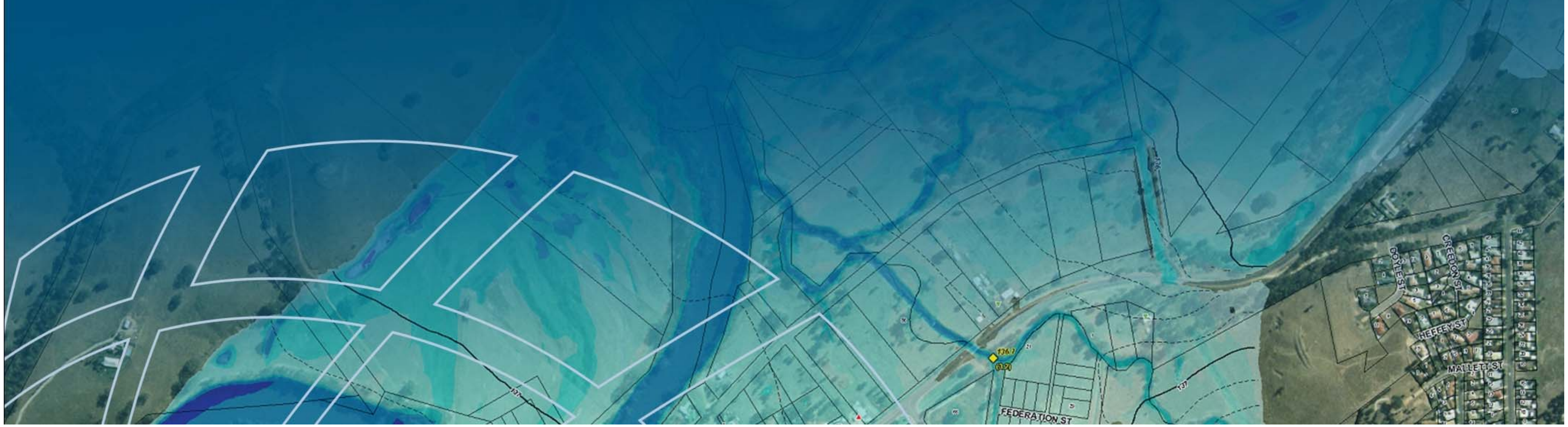
- Pros
  - Very quick to setup
  - Mesh remains unchanged (ie. base case results don't change)
  - Usually fixed timestep (good for flood impact assessments)
  - Faster (for same number of elements)
- Cons
  - Resolution too coarse in key areas (hydraulics not well resolved)
  - Resolution too fine (excessive amount of elements – long run times)
- Thus far, vast majority 2D flood models in Australia and UK grid based

Flexible Mesh Pros and Cons

- Pros
  - Element size reflects resolution needed to resolve hydraulics
  - Number of elements optimised to reduce run times
- Cons
  - Longer setup times and mesh refinement
  - Timestep reduced by very small elements
  - Changing mesh for what-if scenarios can change base case results (issue for BFE's and flood impact assessments)

2D Element Size
(Mesh Convergence)

- Cell/Element Size(s)
  - Small enough to meet hydraulic objectives
  - Large enough to minimise run-times
  - Coarser than DEM
- For a fixed grid model halving the cell size increases run-times by a factor of eight (8) – keep this in mind!



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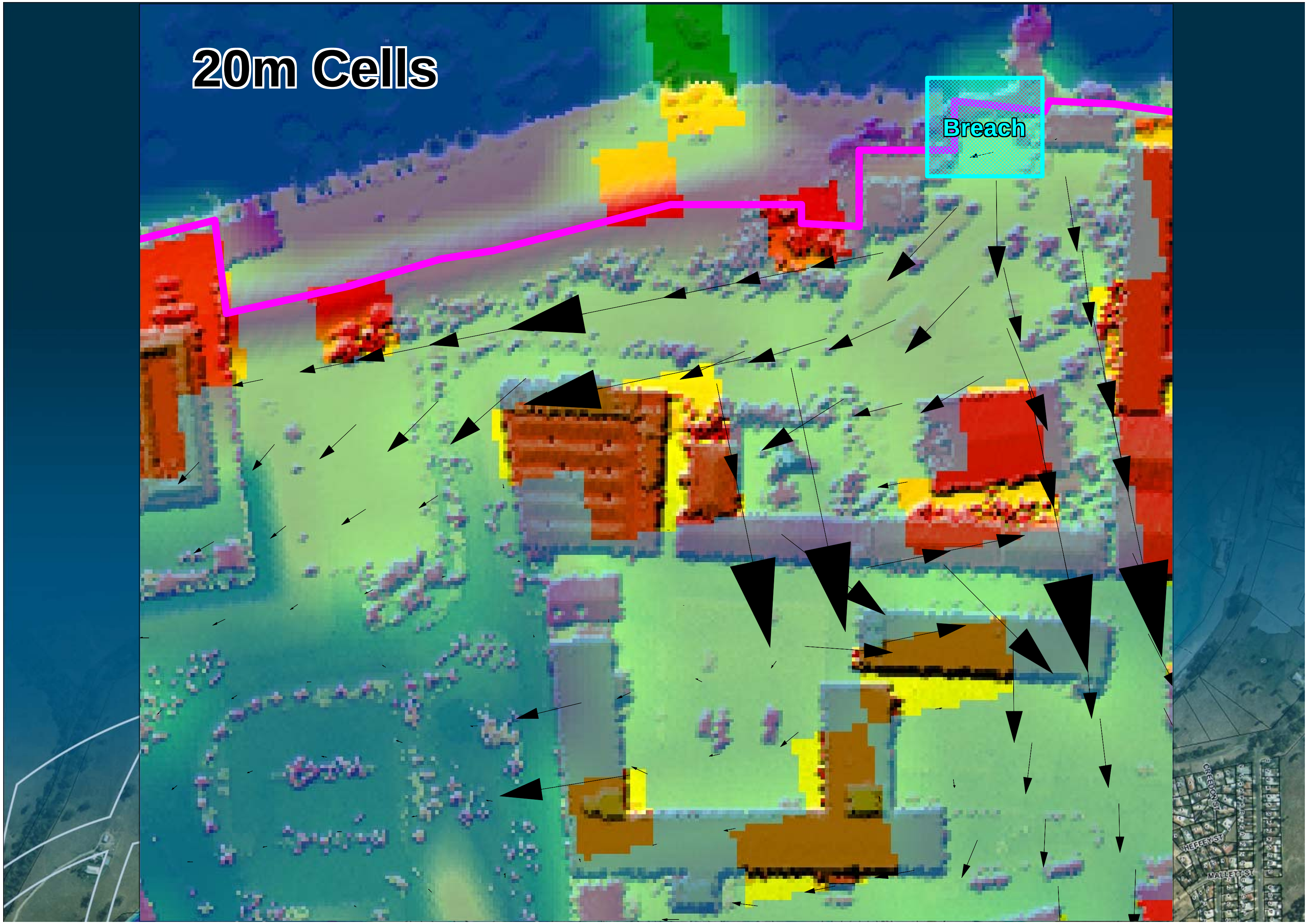
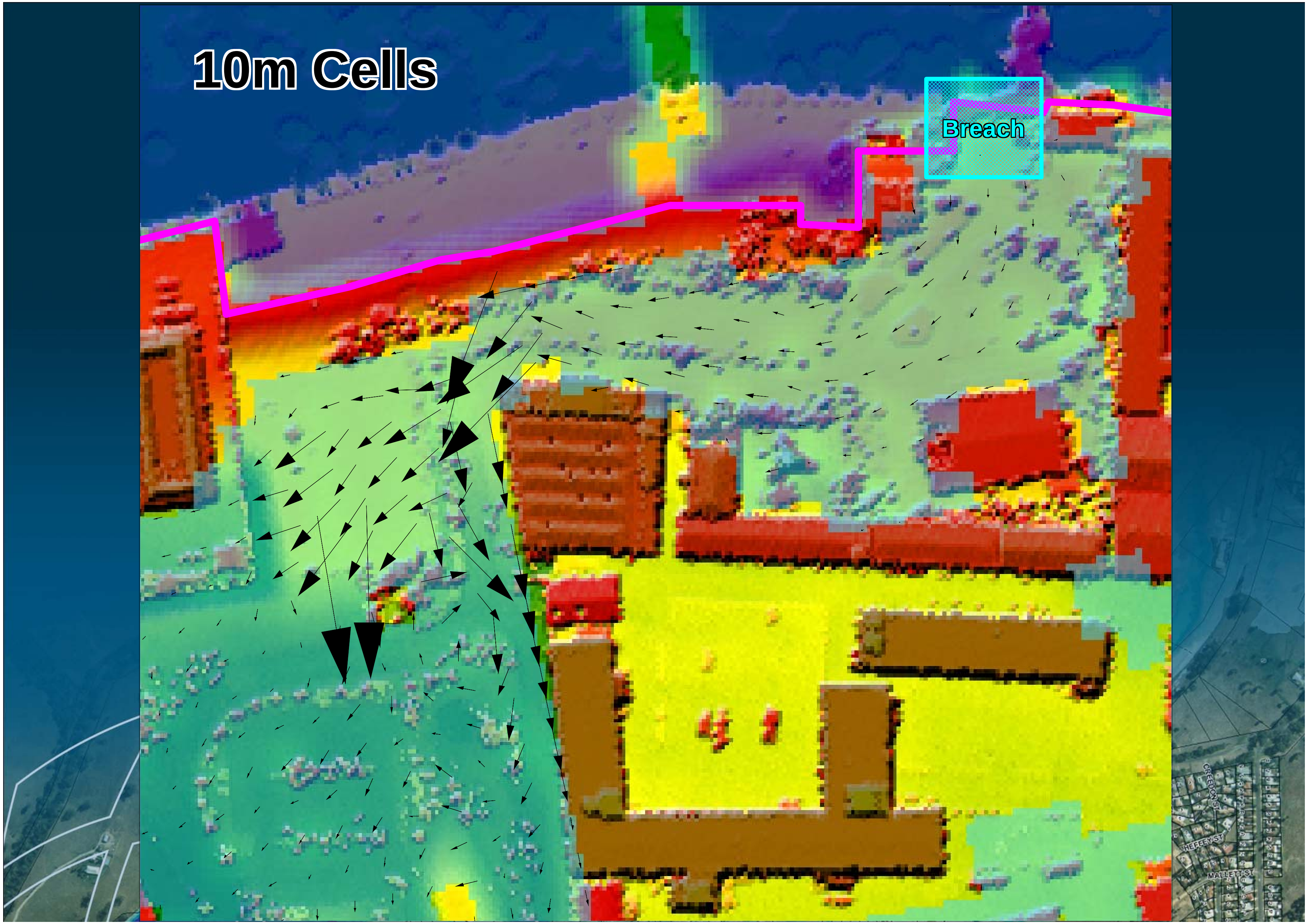

20m Cells
Breach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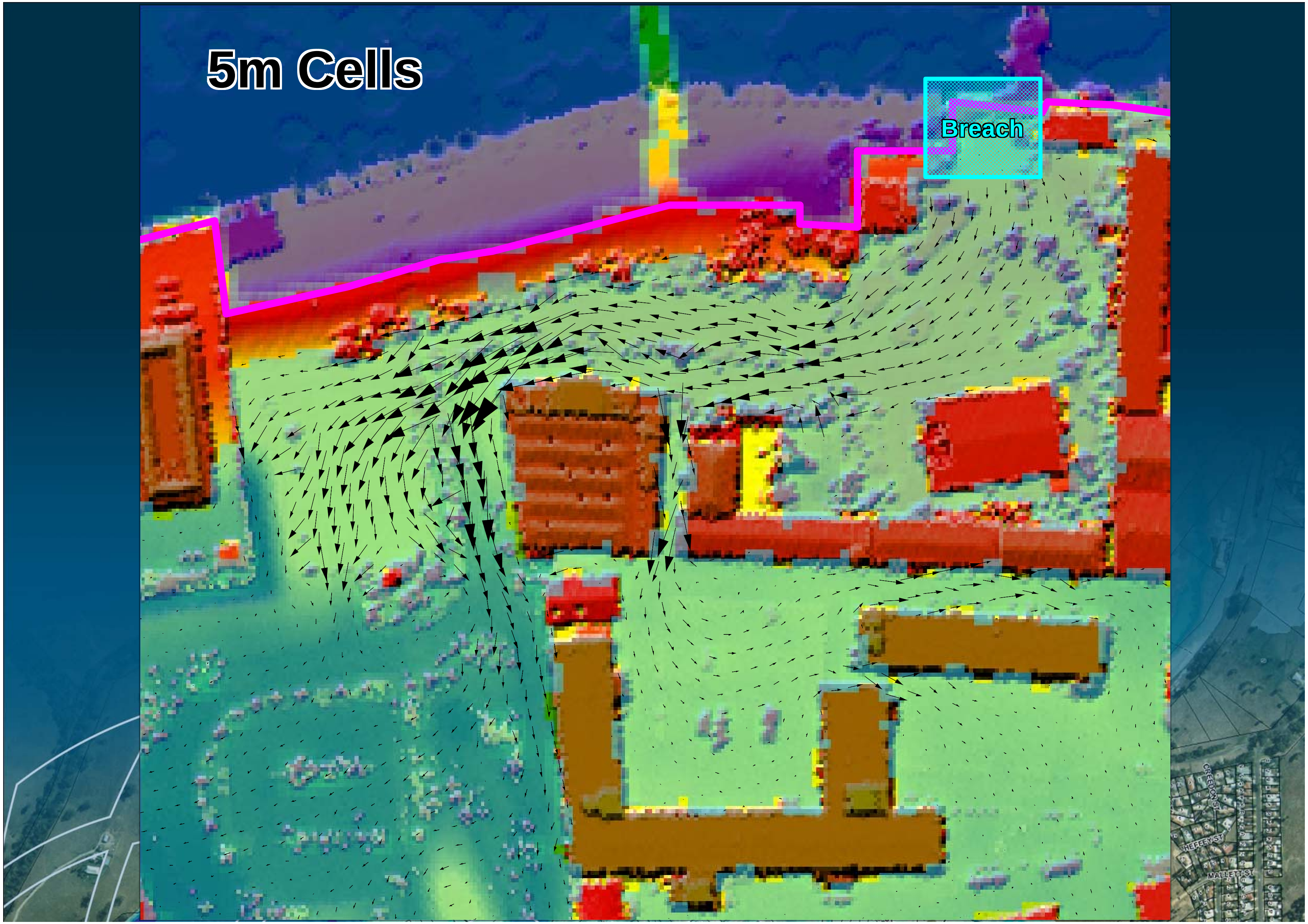
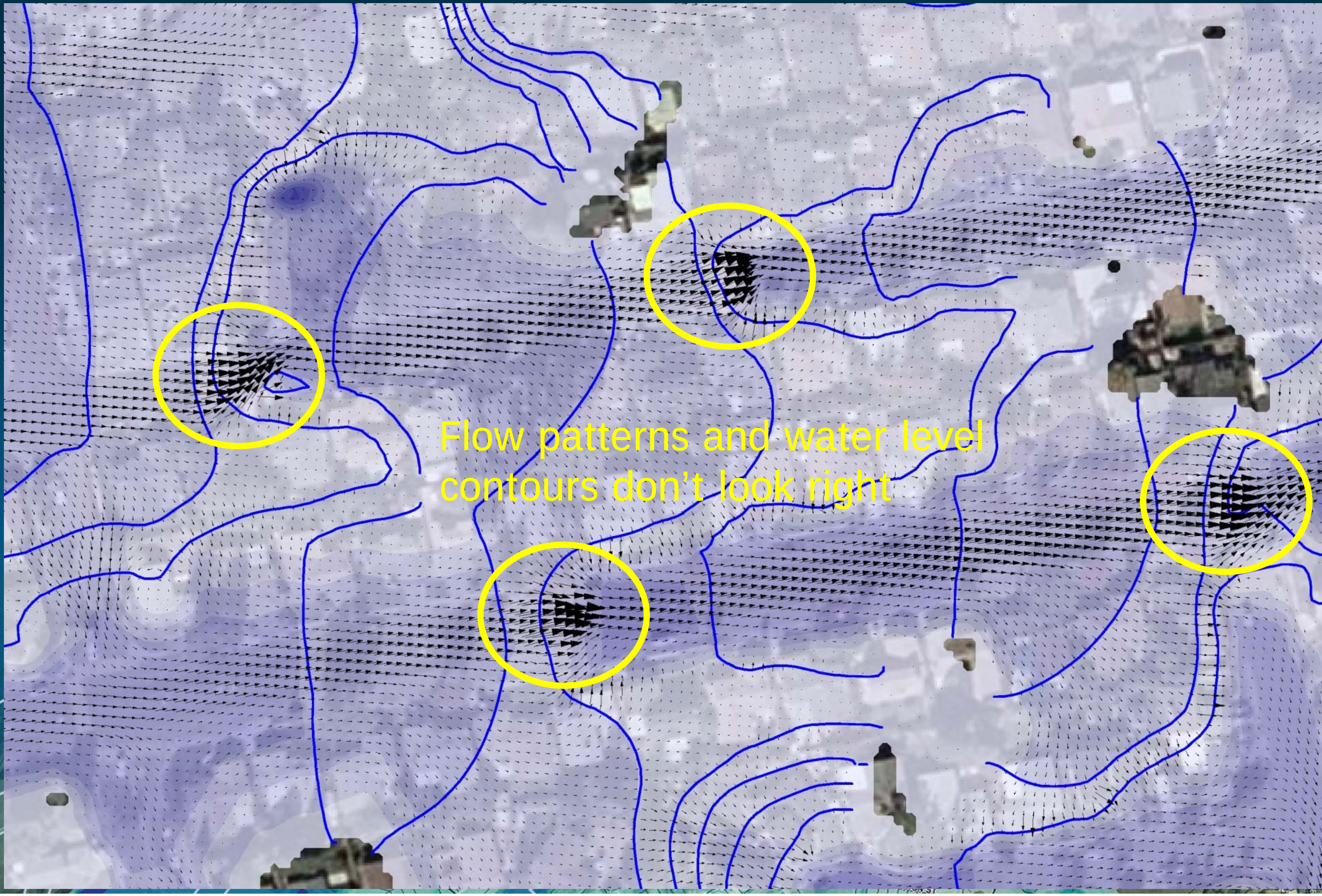
Breach


5m Cells
Breach

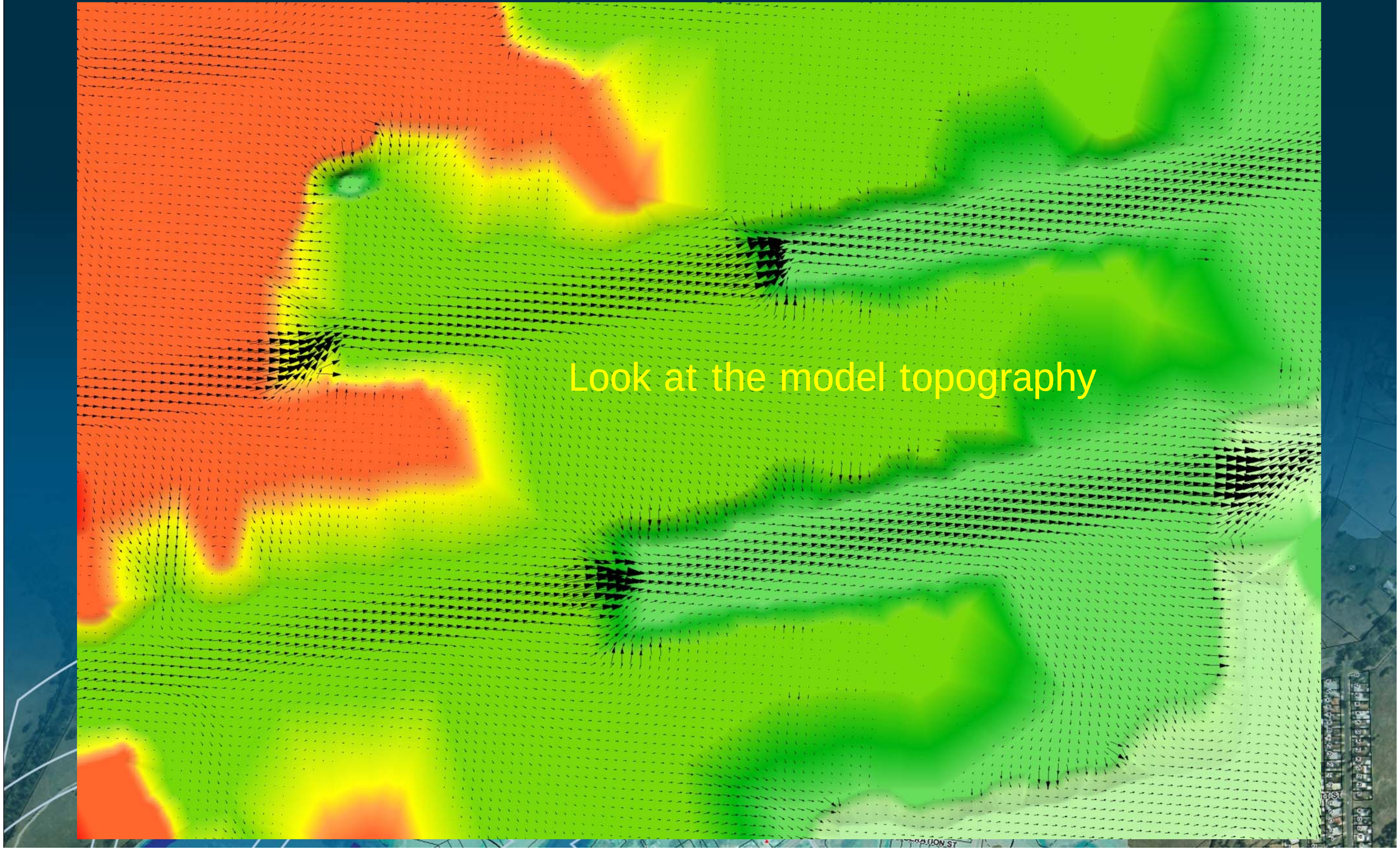
Proofing a Model

- Look at the results!
  - Velocities / flow patterns
  - Water levels
  - Energy always reduces downstream

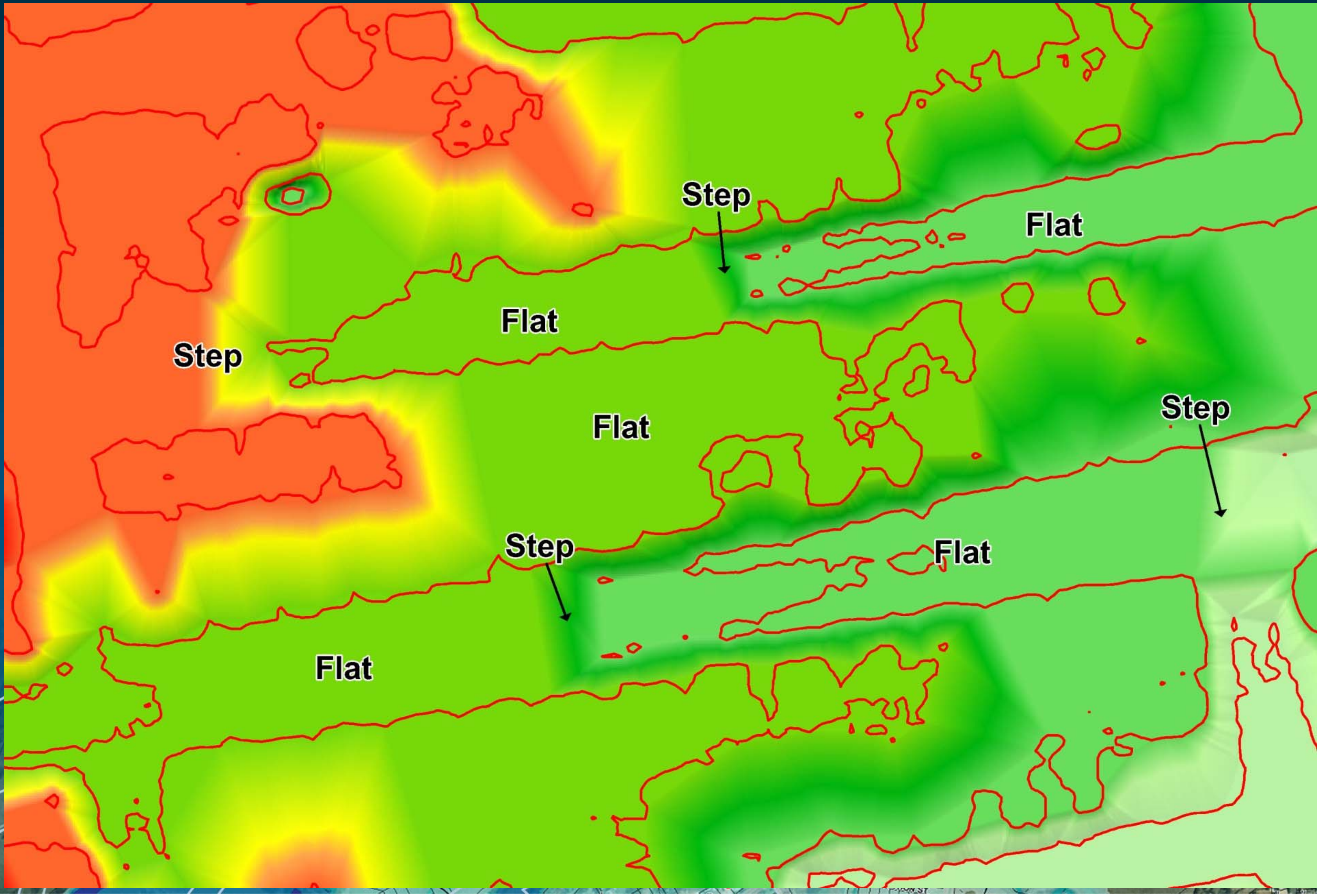
Challenge 1



Challenge 1



Challenge 1



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Mass Error – Solution Convergence

- Less than 1% a good benchmark for adequate convergence

2010 UK EA 2D Benchmarking:

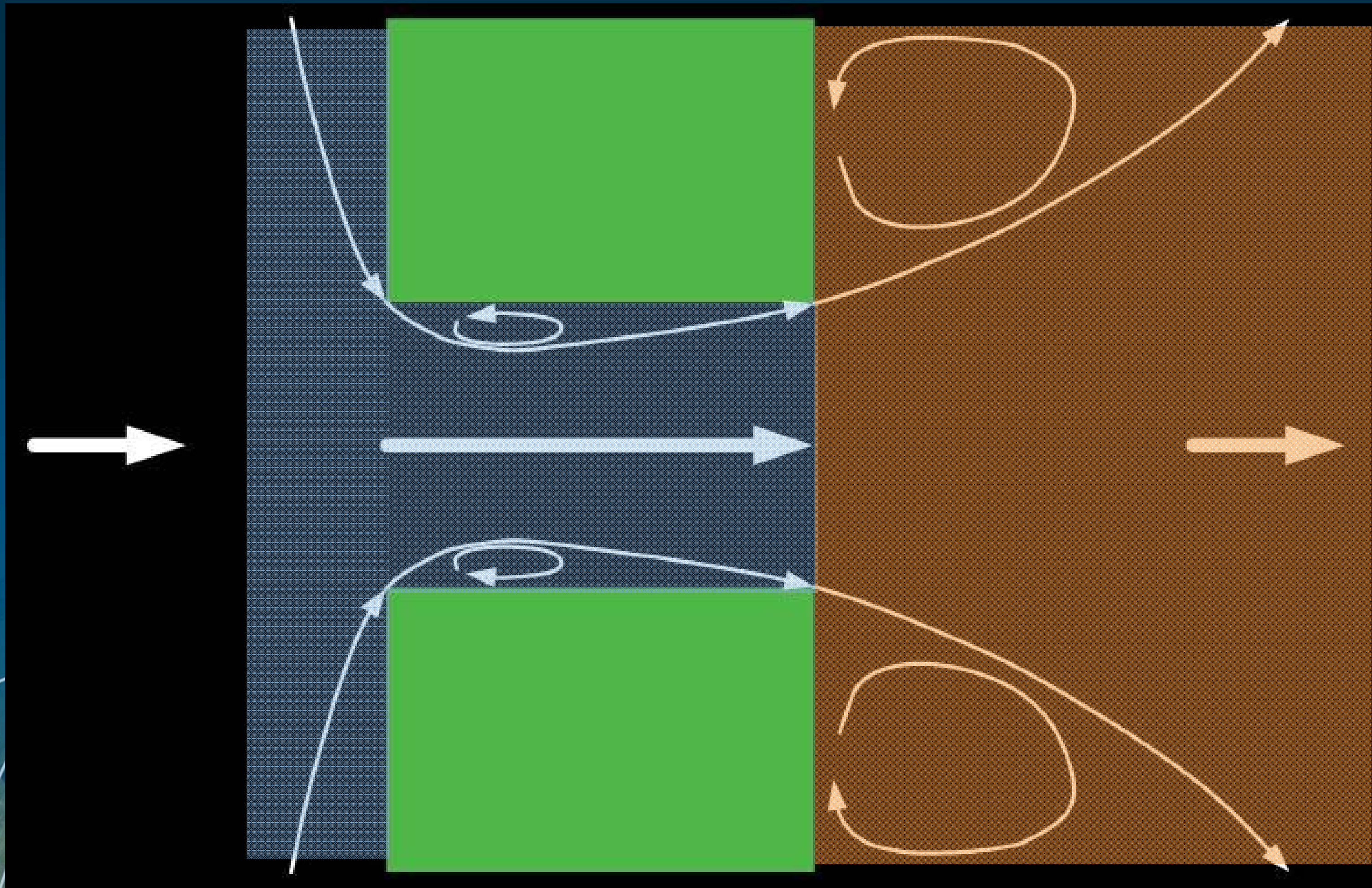
“The largest volume change reported is a 1.4% volume loss. This did not have any identifiable consequence in the results, and the effect of model choice was clearly more significant than a lack of volume conservation of this magnitude.”

Acceptable n Values

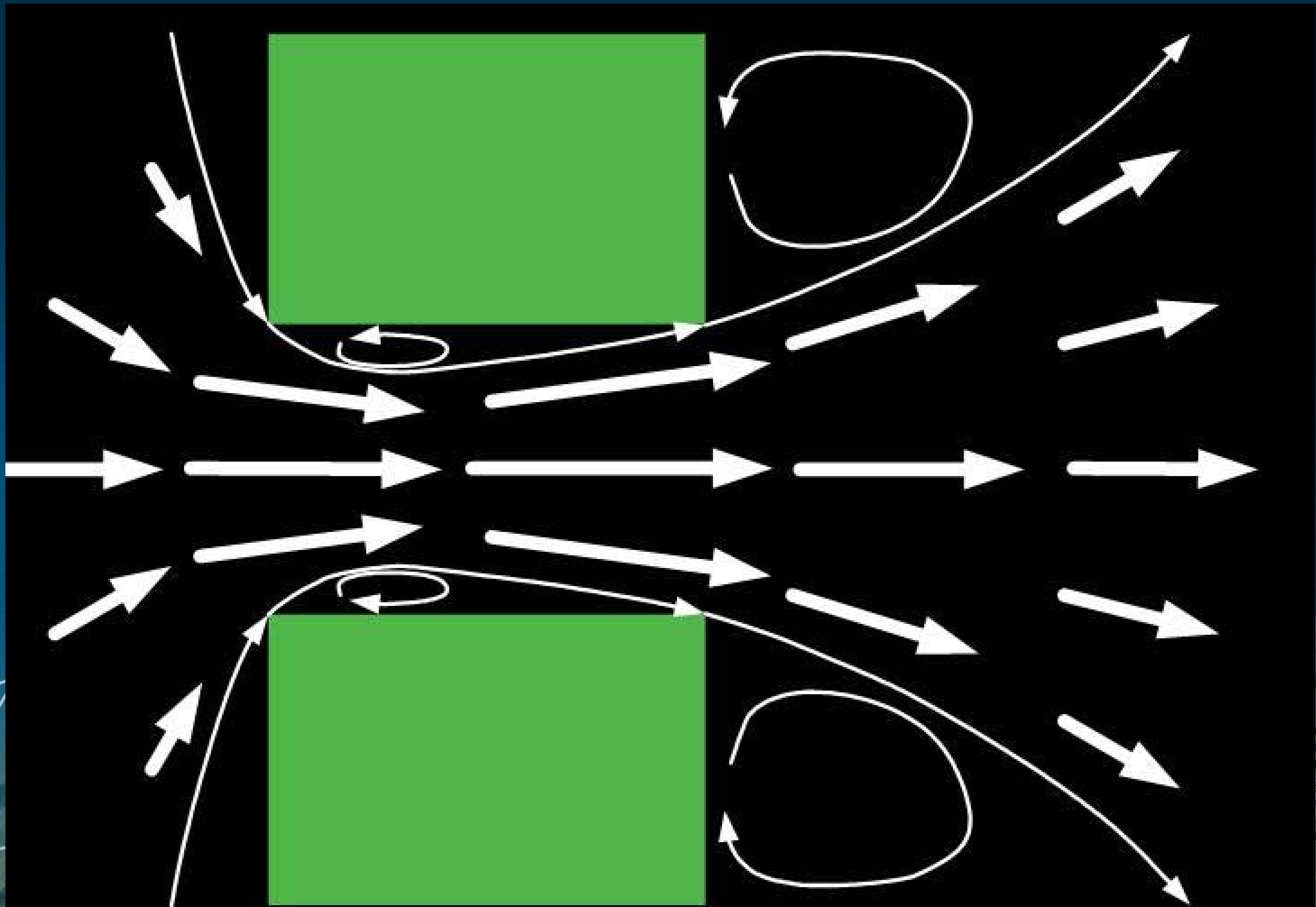
Are Manning's n Values the same for 1D and 2D models?

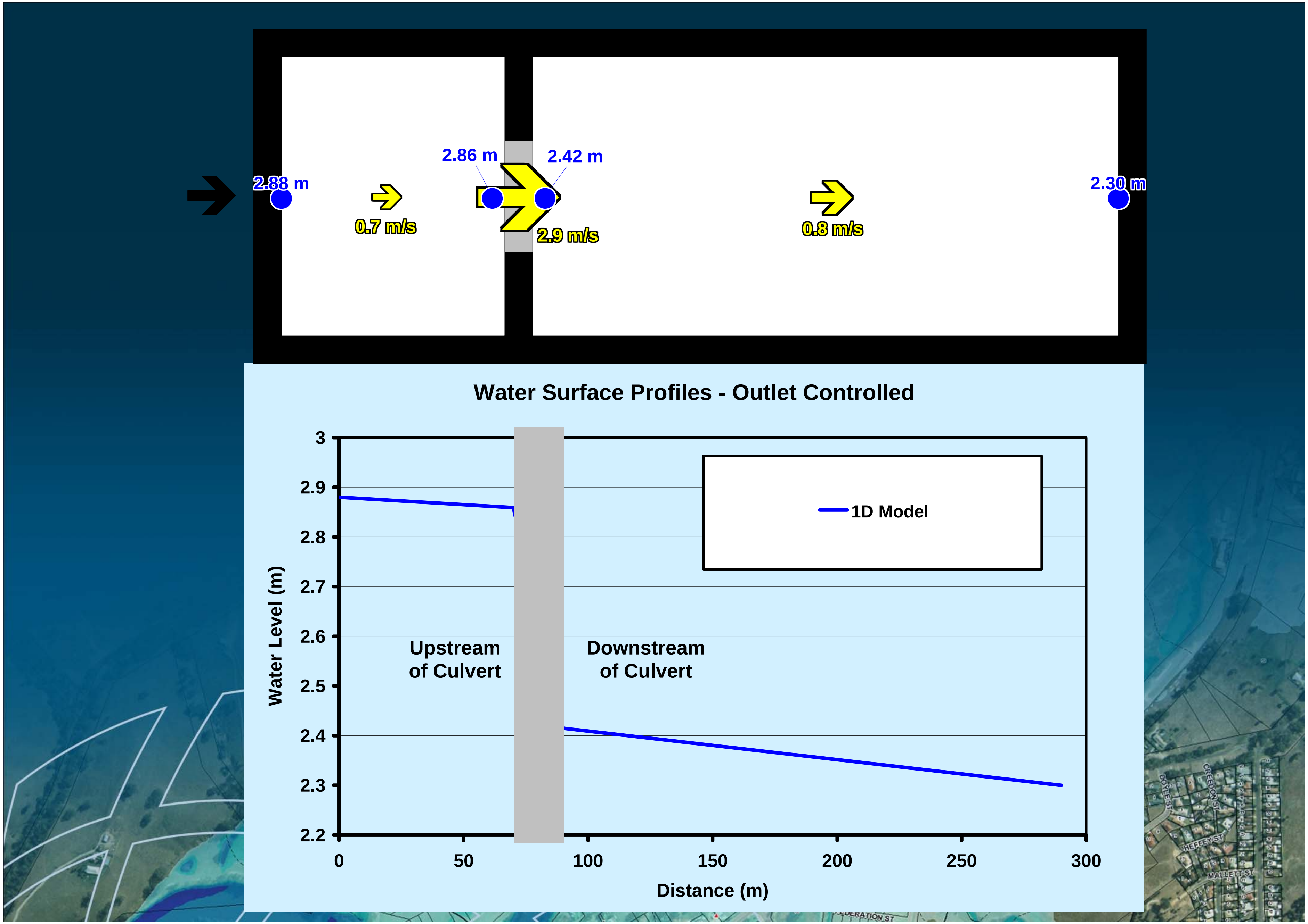
- Generally, Manning's n values are usually very similar for 1D and 2D schemes, except:
- Rapid changes in flow direction and magnitude
  (eg. at a structure, sharp bend or embankment opening)
  - Fully 2D schemes simulate energy losses associated with water changing flow direction and magnitude
    (may need some minor additional energy loss for fine-scale and/or 3D effects)
  - 1D schemes require: (a) a structure with energy losses;
    (b) artificially high Manning's n; or (c) an additional energy loss
- 2D schemes typically apply no side wall friction
  - Where there is significant wall friction a 2D scheme may require a slightly higher Manning's n than a 1D scheme

1D: Traditional Approach
Uses Contraction/Expansion Losses

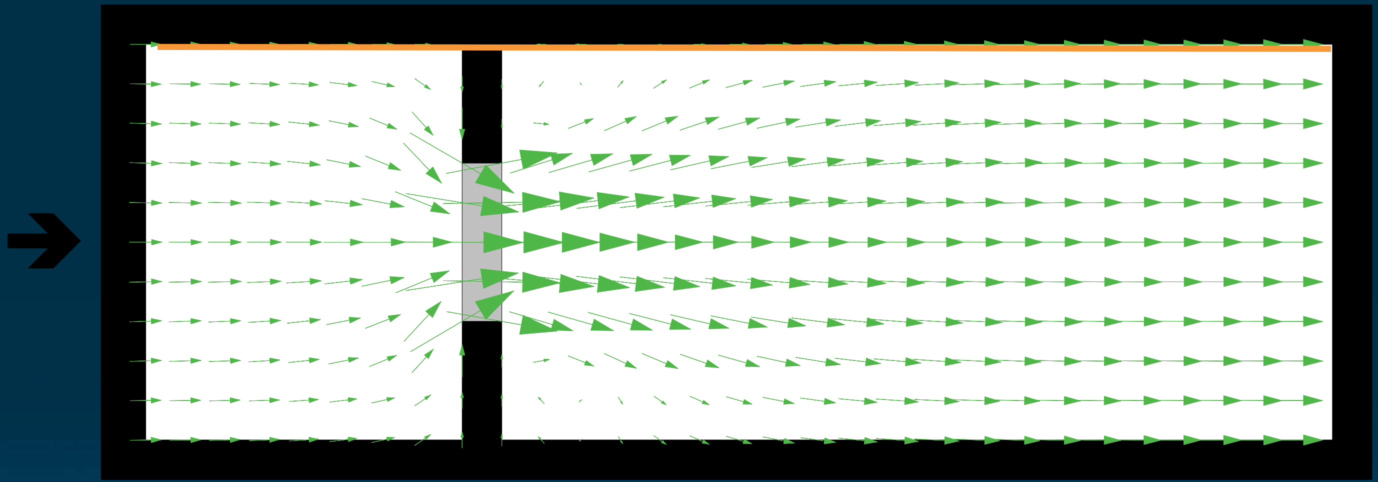


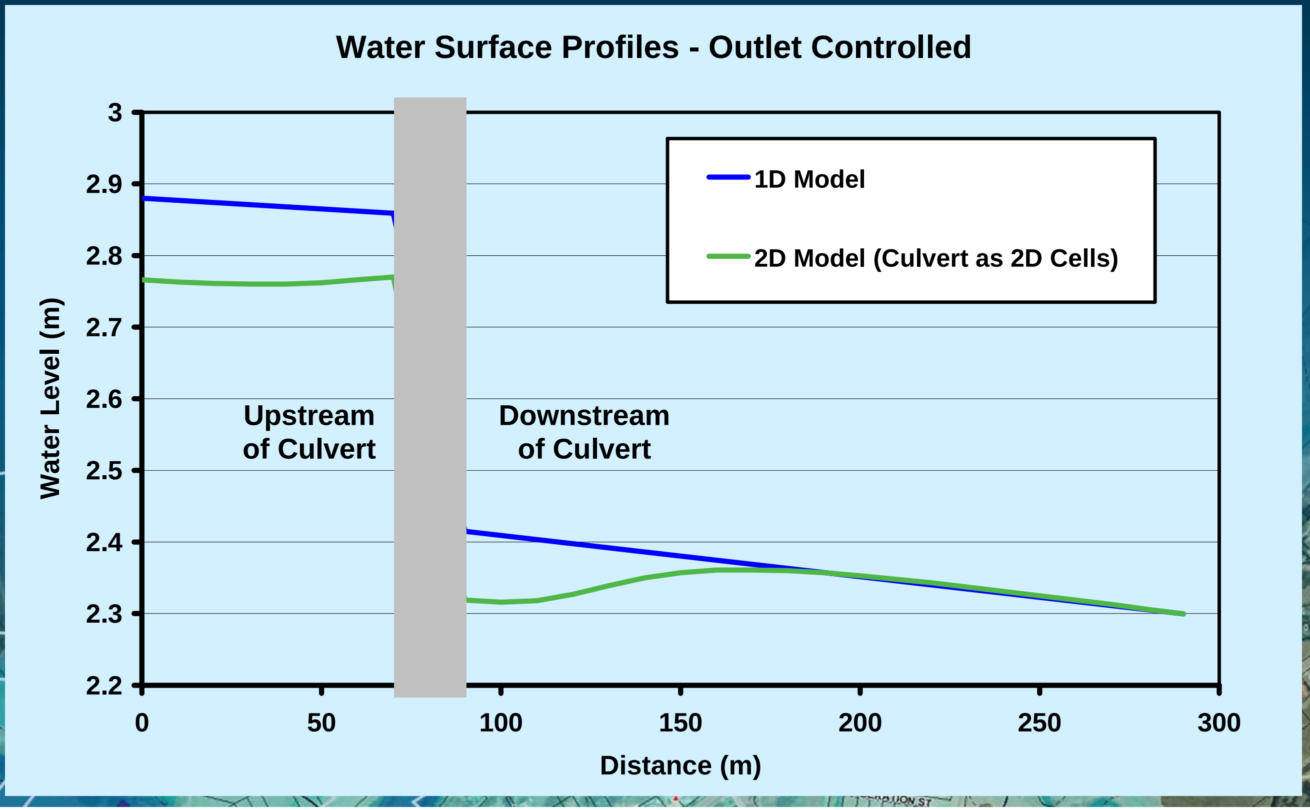
2D: No Contraction/Expansion Losses?





2.88 m
0.7 m/s
2.86 m
2.42 m
2.9 m/s
0.8 m/s
2.30 m
Water Surface Profiles - Outlet Controlled
Water Level (m)
Distance (m)
1D Model
Upstream of Culvert
Downstream of Culvert
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
0
50
100
150
200
250
300




Water Surface Profiles - Outlet Controlled
Water Level (m)
3
2.9
2.8
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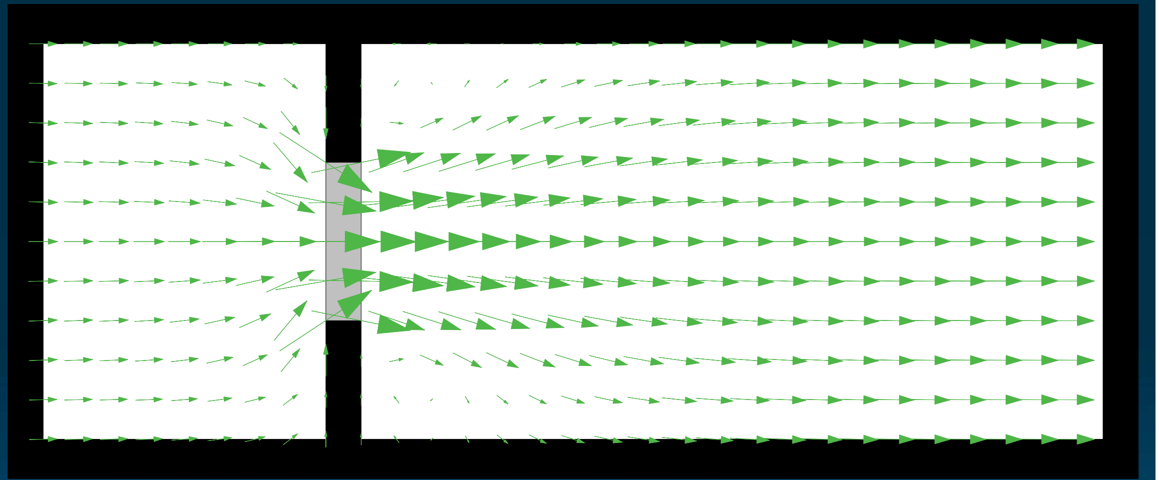
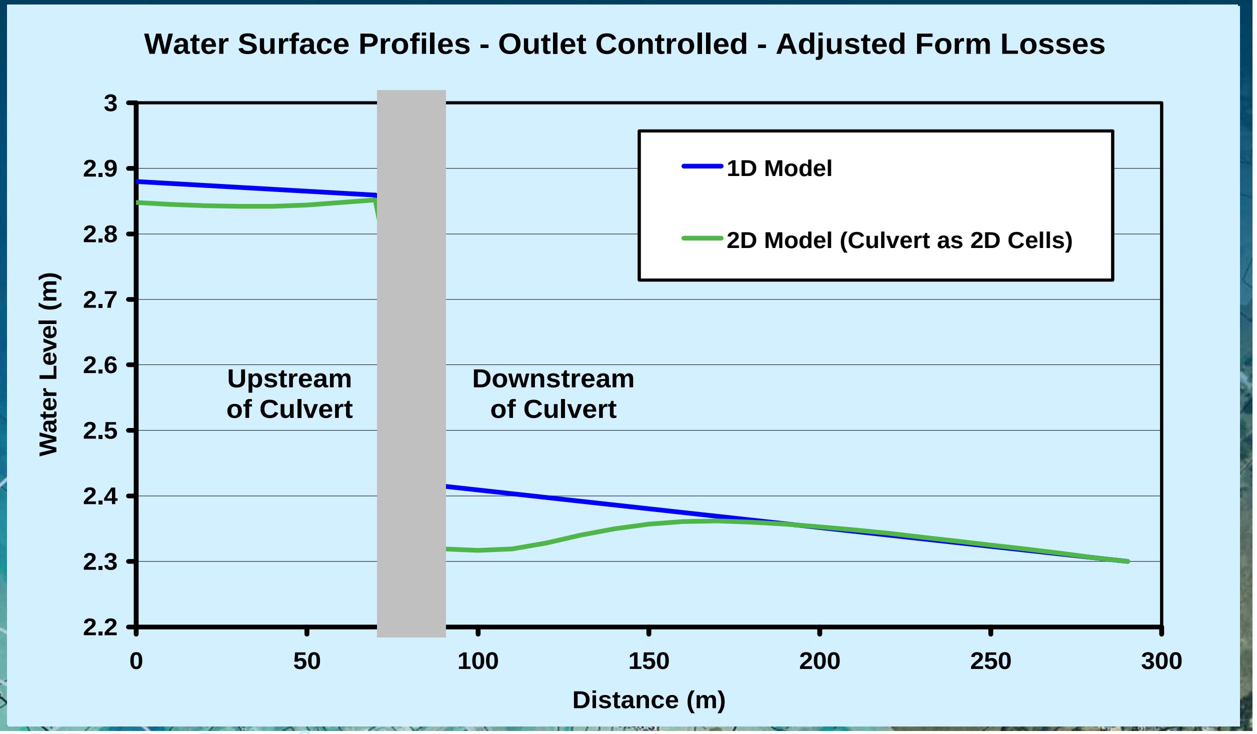
2.3
2.2
0
50
100
150
200
250
300
Distance (m)
1D Model
2D Model (Culvert as 2D Cells)
Upstream of Culvert
Downstream of Culvert

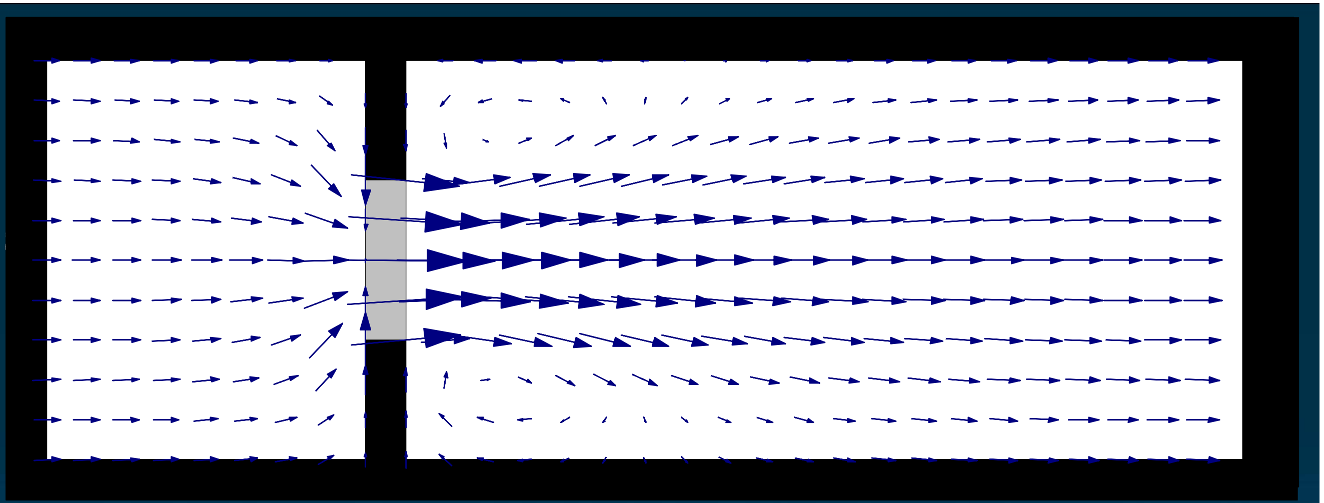
“Calibrating” 2D Structures

- For example, adding 0.2 energy loss, ie. add $0.2*V^2/2g$ compensates for energy losses not modeled

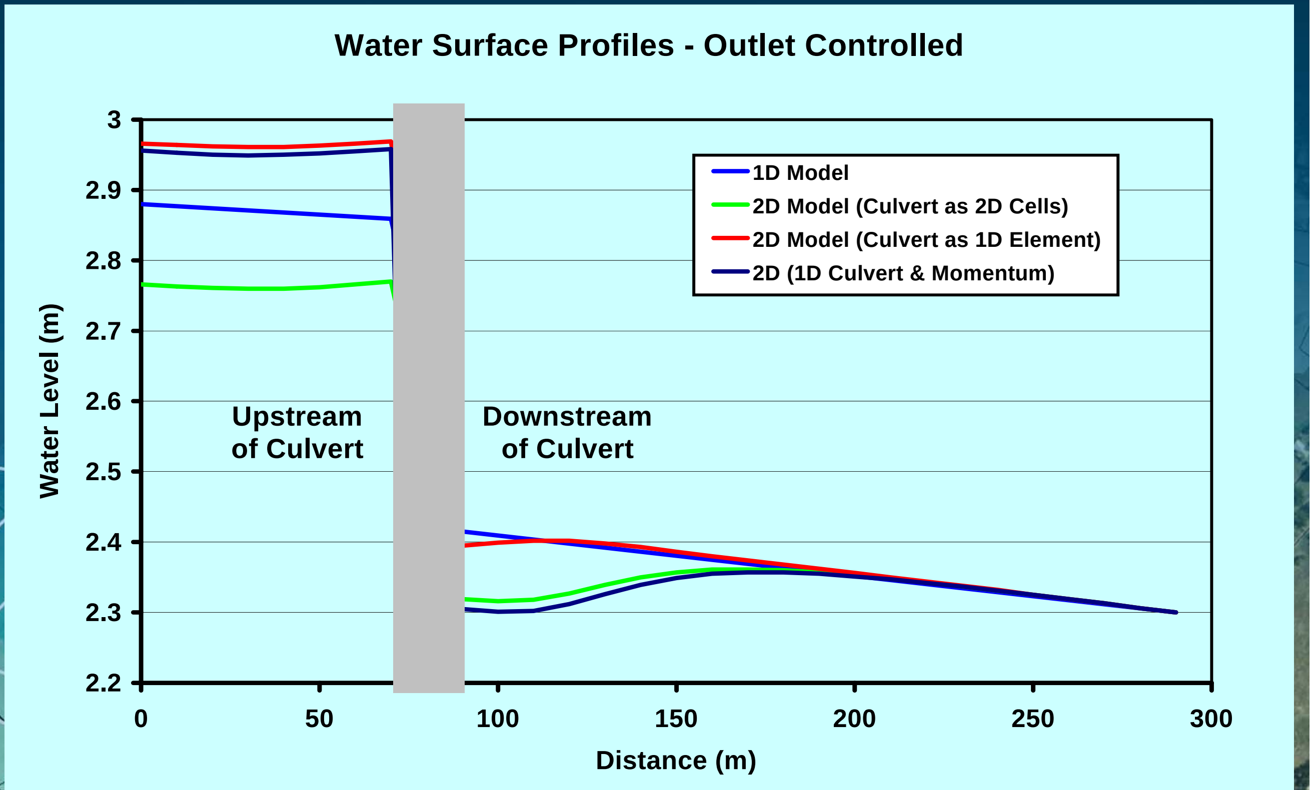




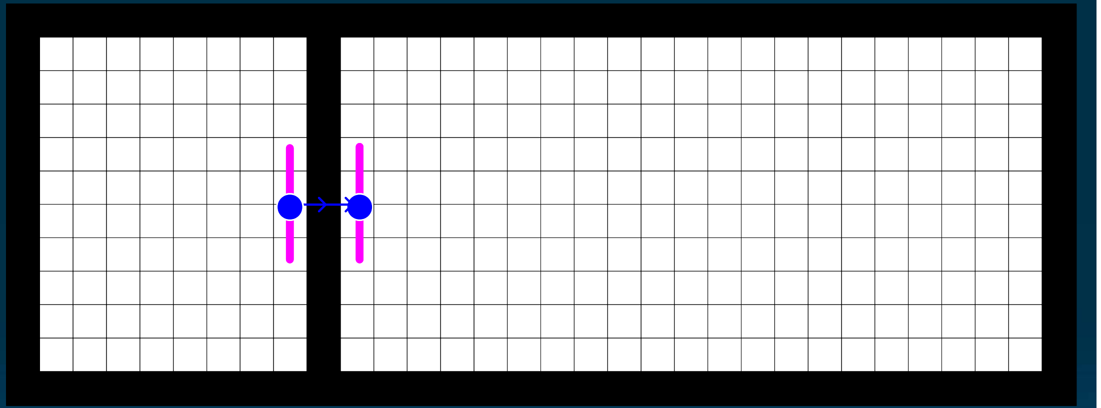
1D/2D Link Options



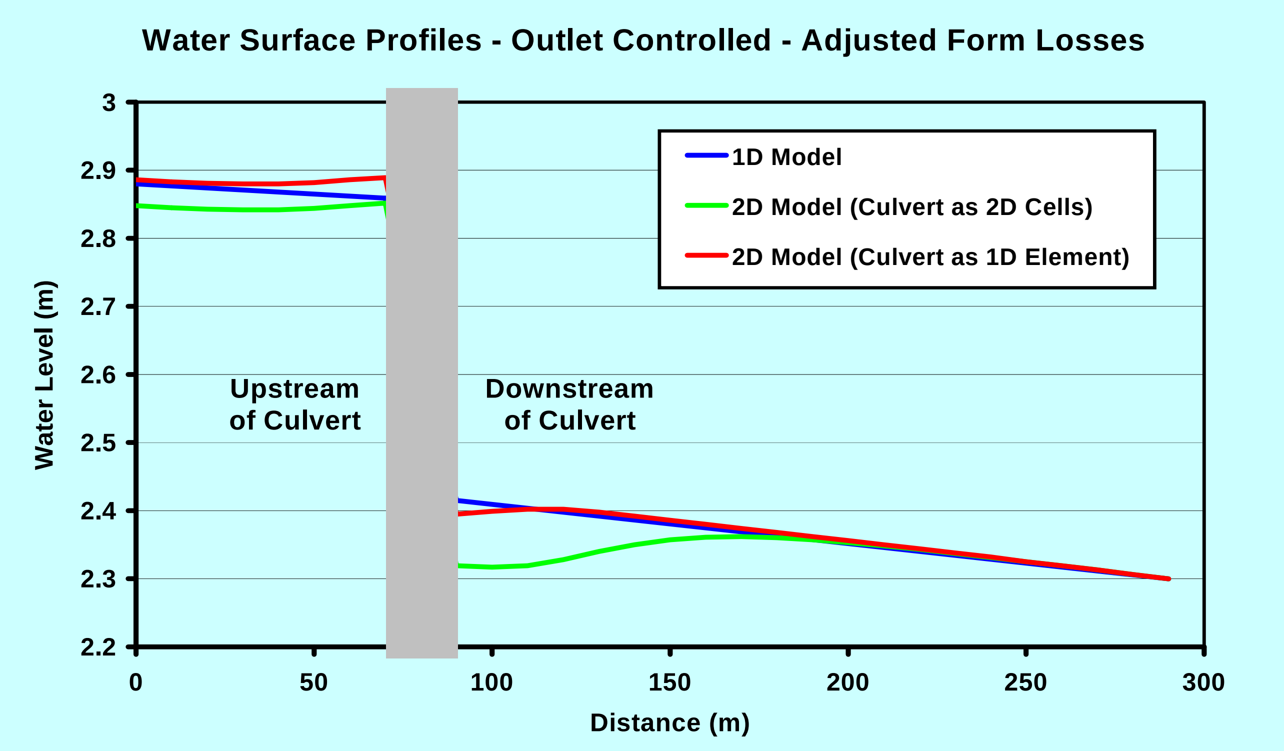
- SX Link (momentum not transferred)
- HX Link (preserves momentum)



“Calibrating” 1D Culvert Linked to 2D



- Culvert as 1D Element
  - Reduce Outlet Loss Coefficient by (0.2 in this case) to correct for duplicated losses



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Summary

- Full 2D equations significant step closer to reality where horizontal flow patterns are complex
- Pseudo-2D schemes useful but should only be used where bed friction dominates
  (ie. cross-momentum, turbulence not relevant)
- 2D models are NOT exact
  - Still need to scrutinise, still need to calibrate
- Check and understand your results!

thank you