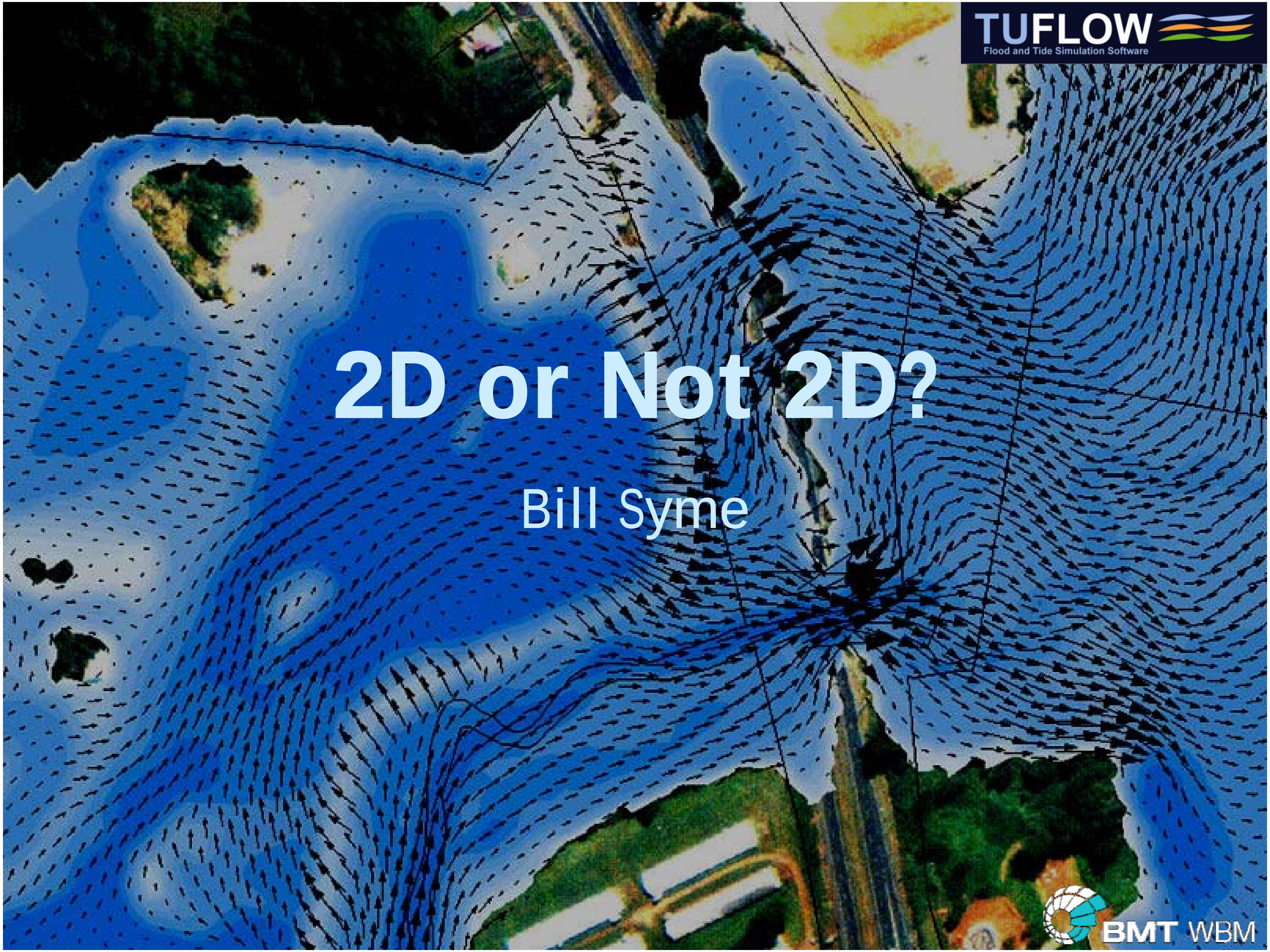


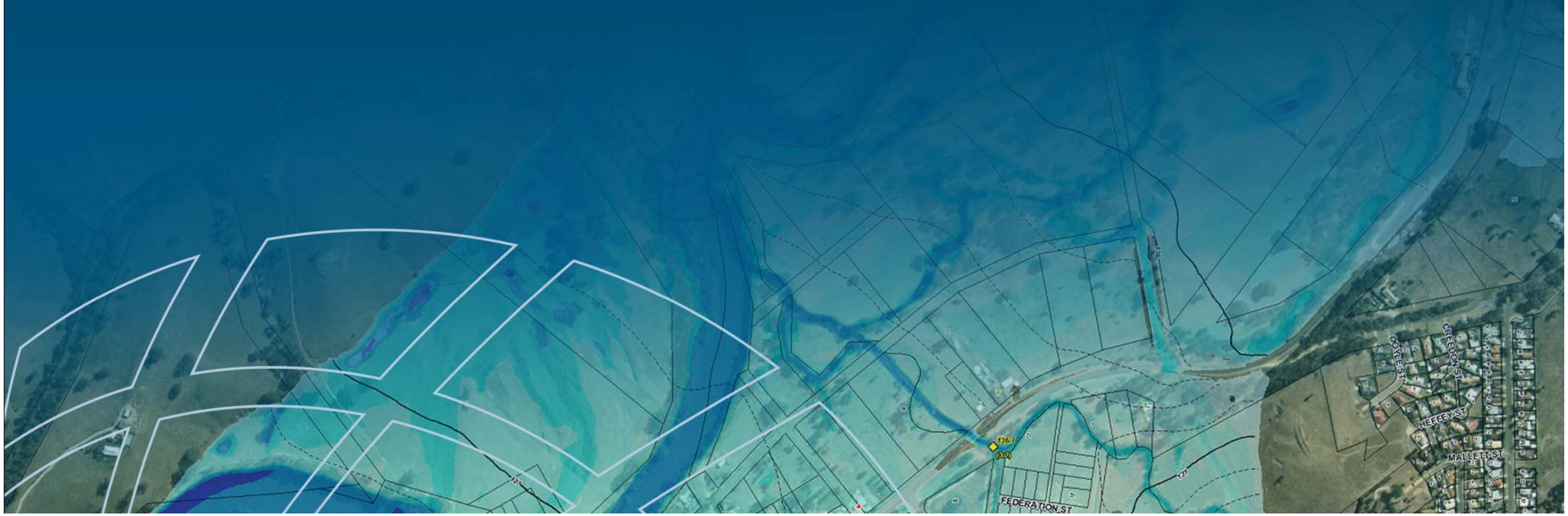
2D or Not 2D?

Bill Syme

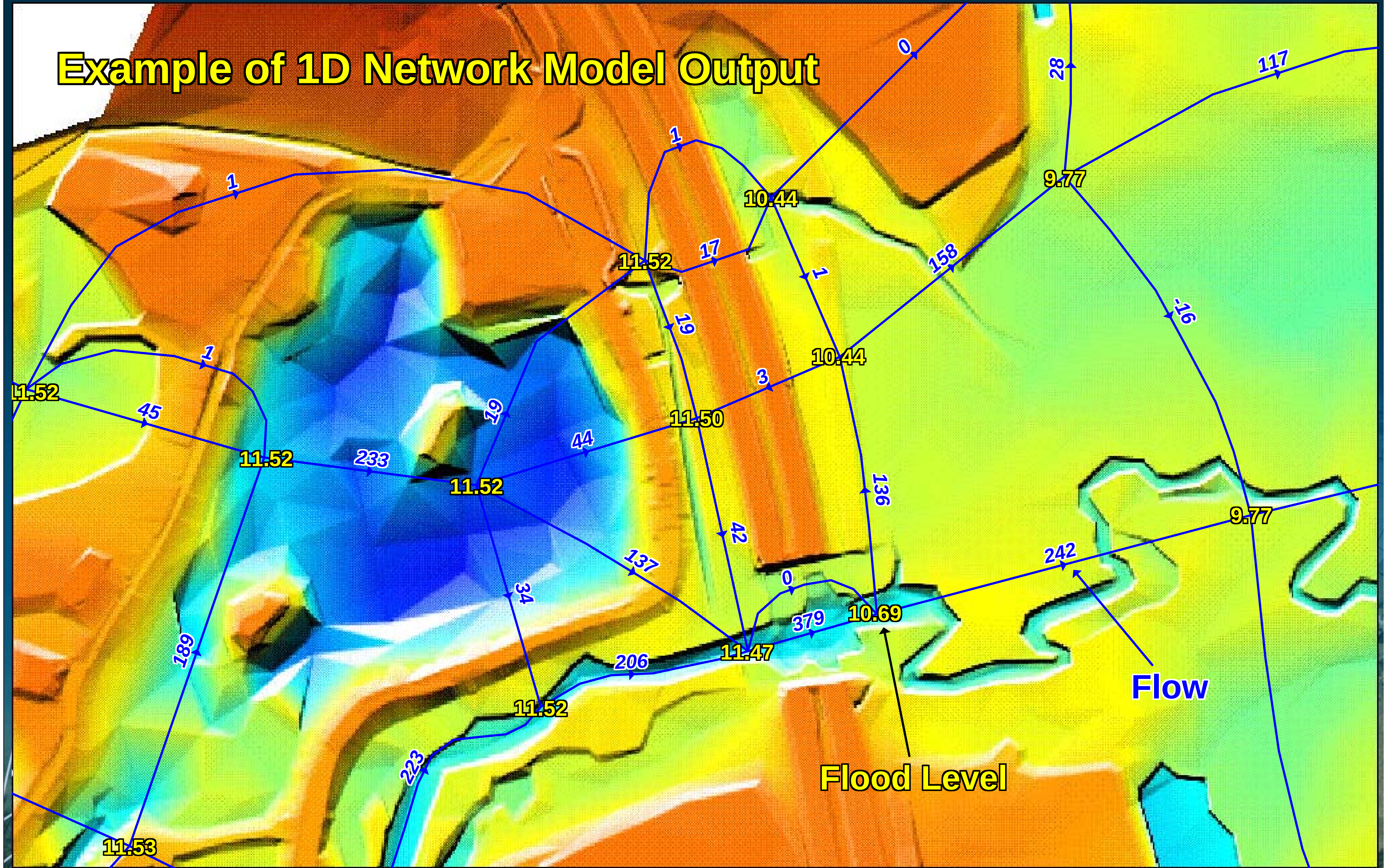
2D or Not 2D?

- Mathematical Reasons

- Real-World Reasons



1D versus 2D



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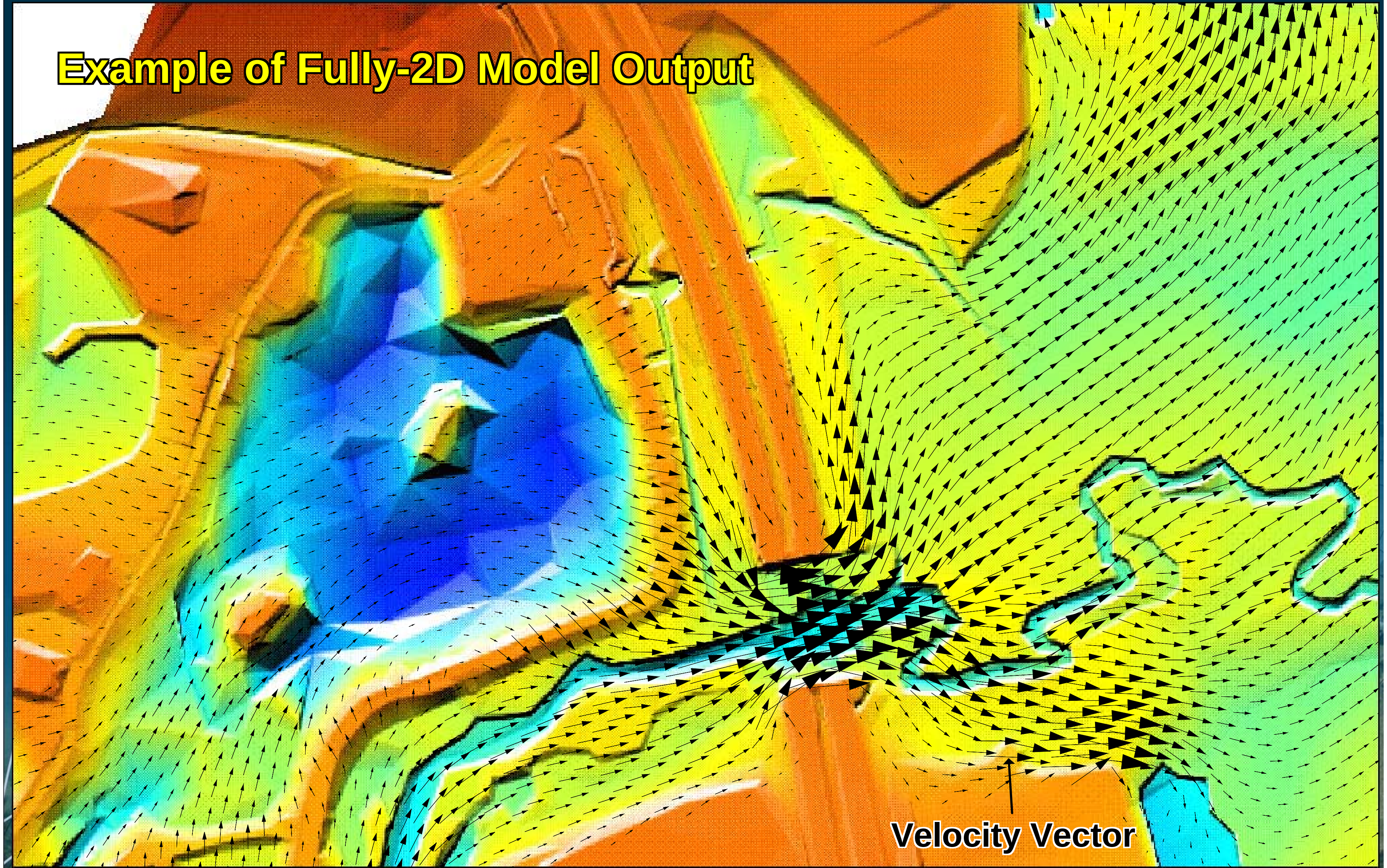
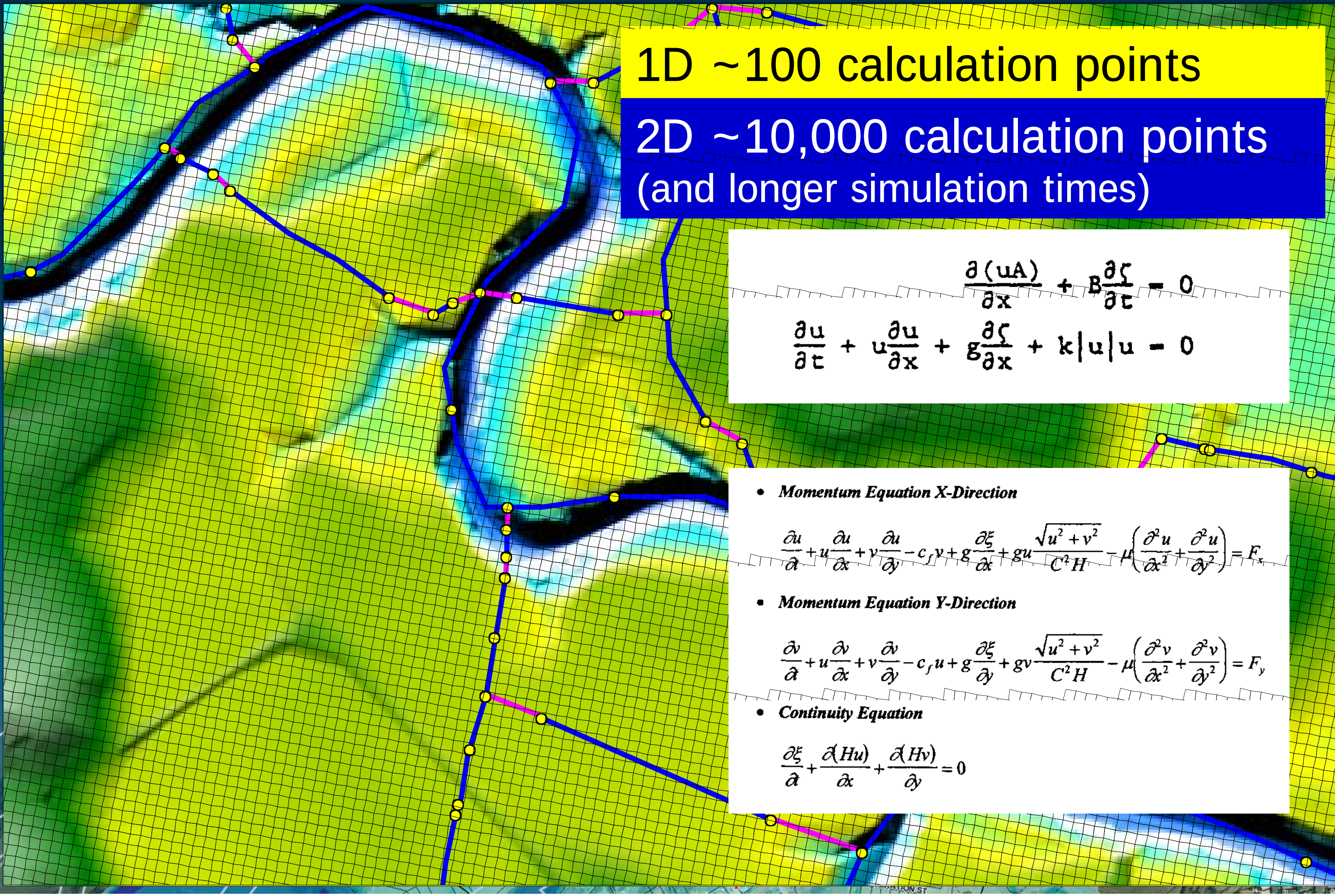
AQUAVEO Water Modeling Solutions
xpsoftware
XP 2D
SMS
TUFLOW Flood and Tide Simulation Software

1D versus 2D



1D versus 2D



1D ~100 calculation points

2D ~10,000 calculation points
(and longer simulation times)

$$\frac{\partial (uA)}{\partial x} + B\frac{\partial \zeta}{\partial t} = 0$$

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

- ***Momentum Equation X-Direction***

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

- ***Momentum Equation Y-Direction***

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} - c_f u + g\frac{\partial \xi}{\partial y} + gv\frac{\sqrt{u^2+v^2}}{C^2 H} - \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) = F_y$$

- ***Continuity Equation***

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

5

Key Physical Processes

(What does your 2D scheme solve?)

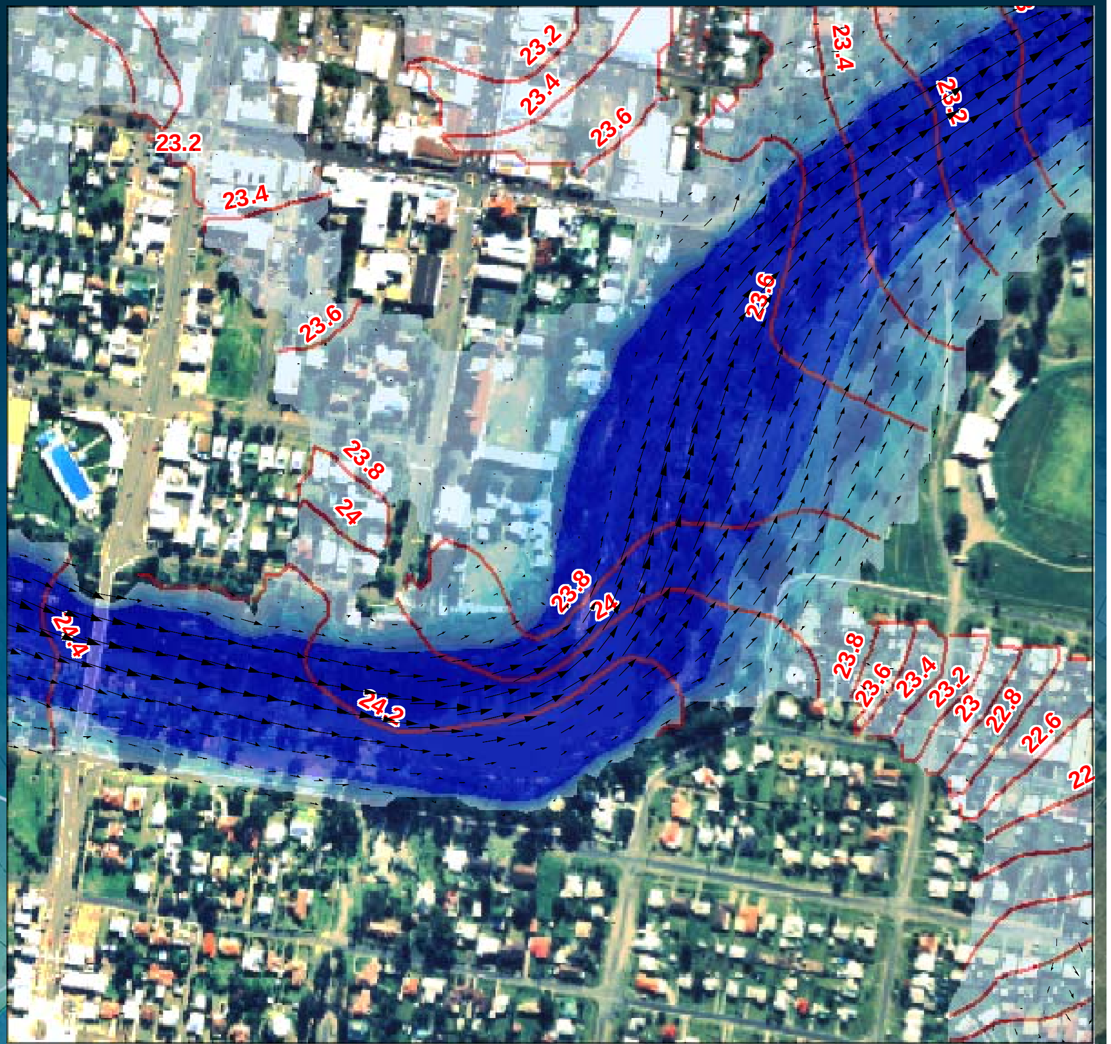
- How Velocity changes over time
- Inertia Term
- Coriolis Force
- Gravity
- Bed Resistance
- Atmospheric Pressure
- Viscosity (Turbulence)
- External Forces (Wind, Waves, ...)

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

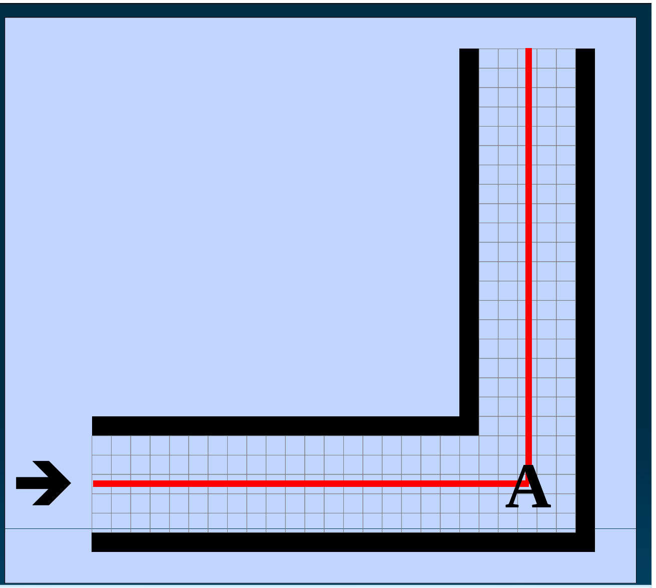
What does your 2D scheme need to solve?

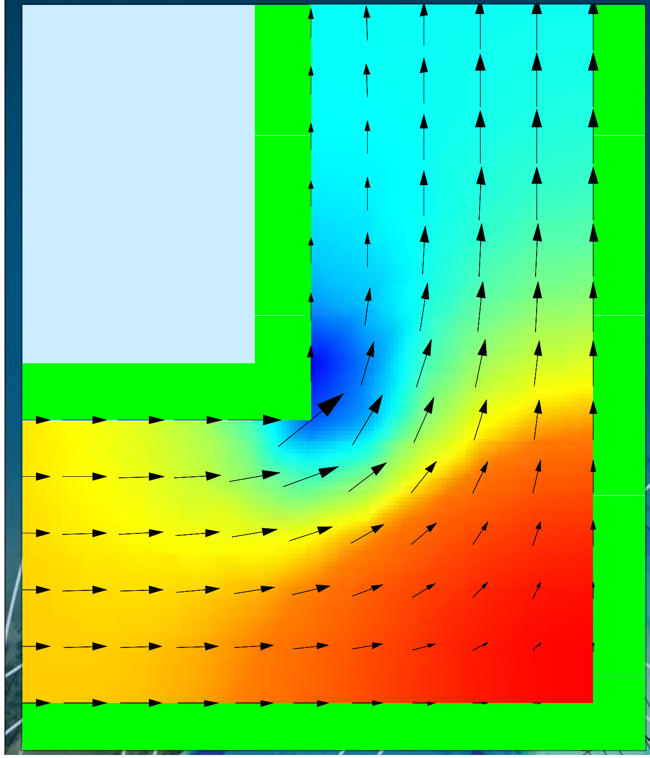
Inertia

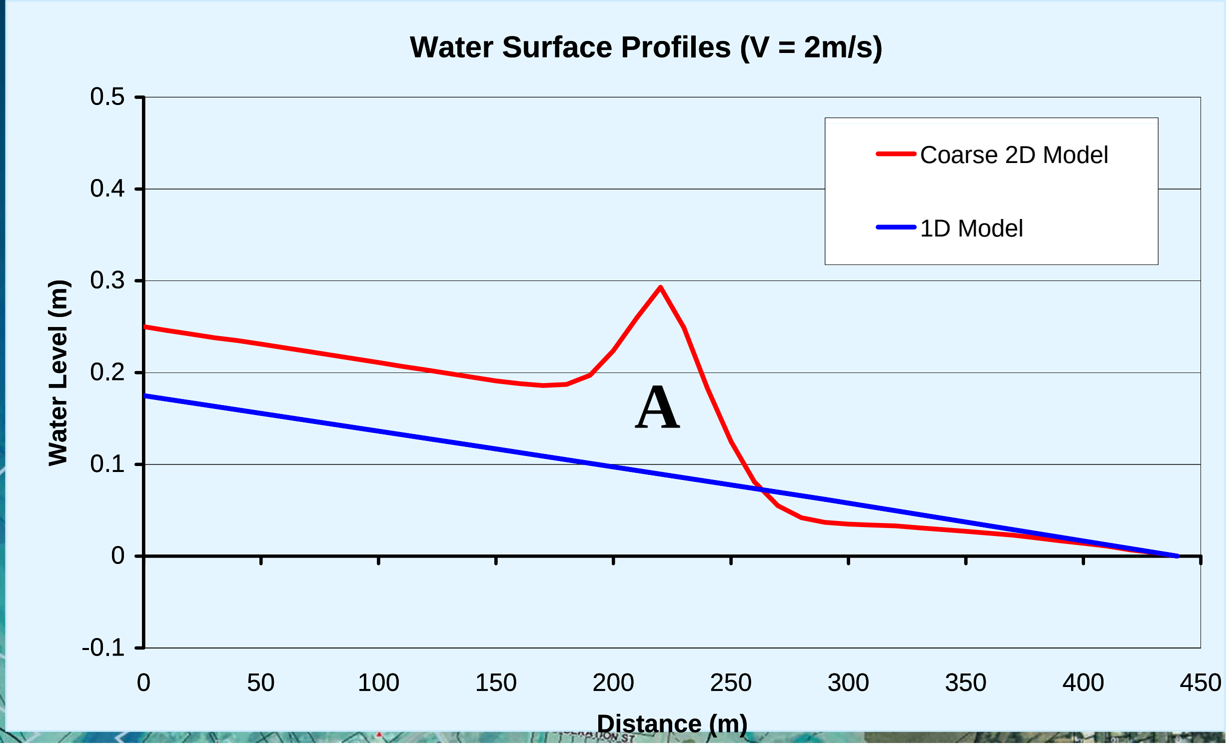
- Very important where velocity
  - Speeds up or slows down
  - Changes direction
- Essential at structures and bends



Right-Angled Bend 1D vs 2D

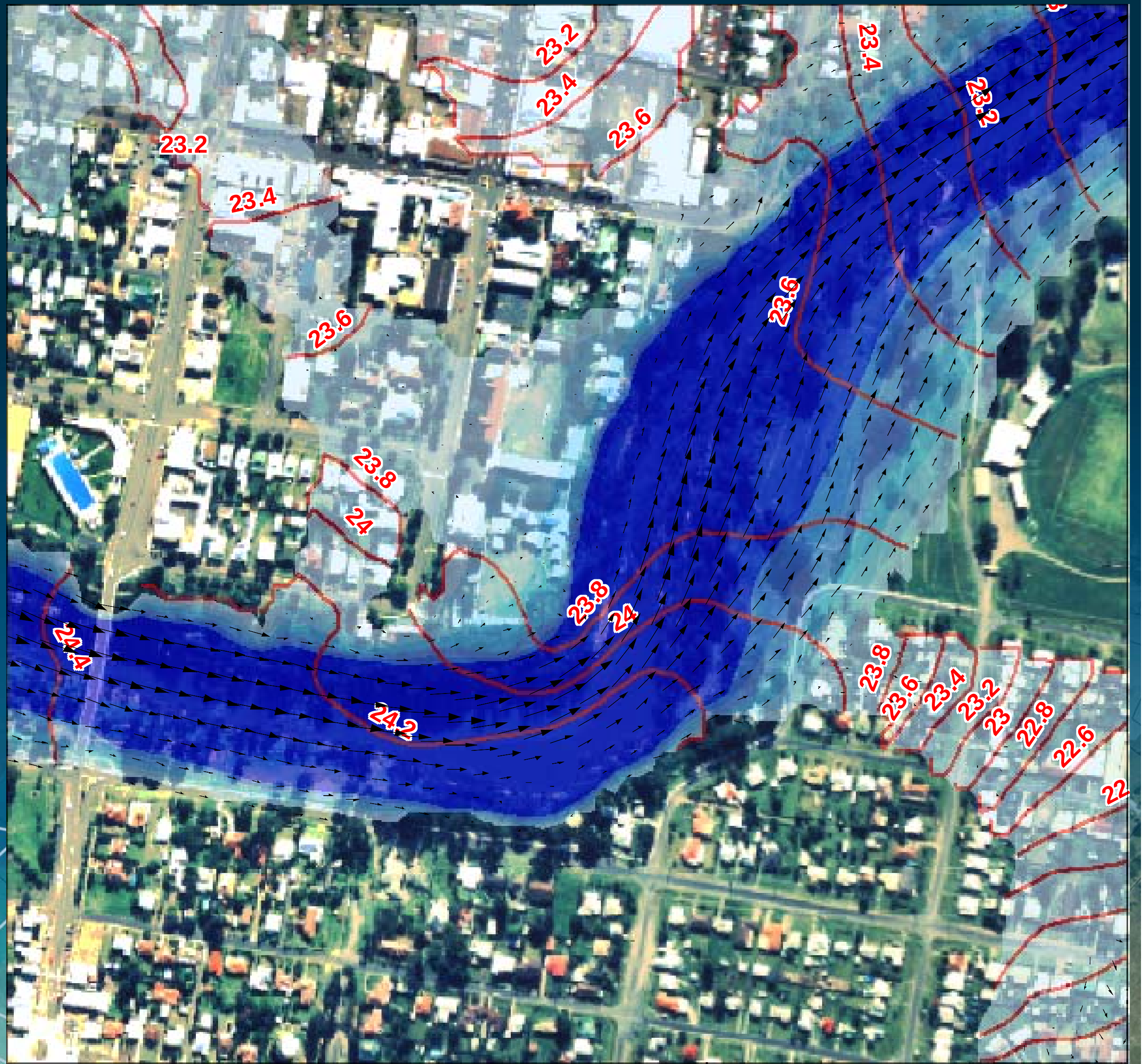






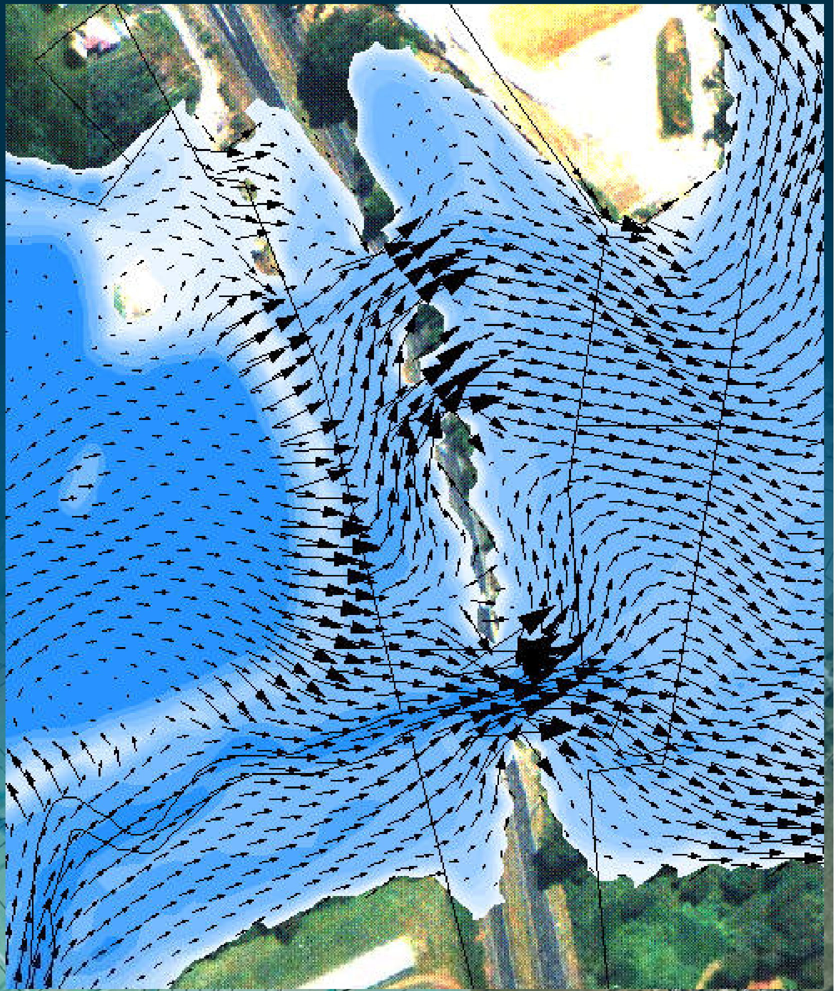
River Bends

- 4 m/s
- 20 m deep
- 0.4m superelevation
- 1D:
  - Need additional losses
  - No superelevation



Viscosity
Sub-Grid Scale Turbulence

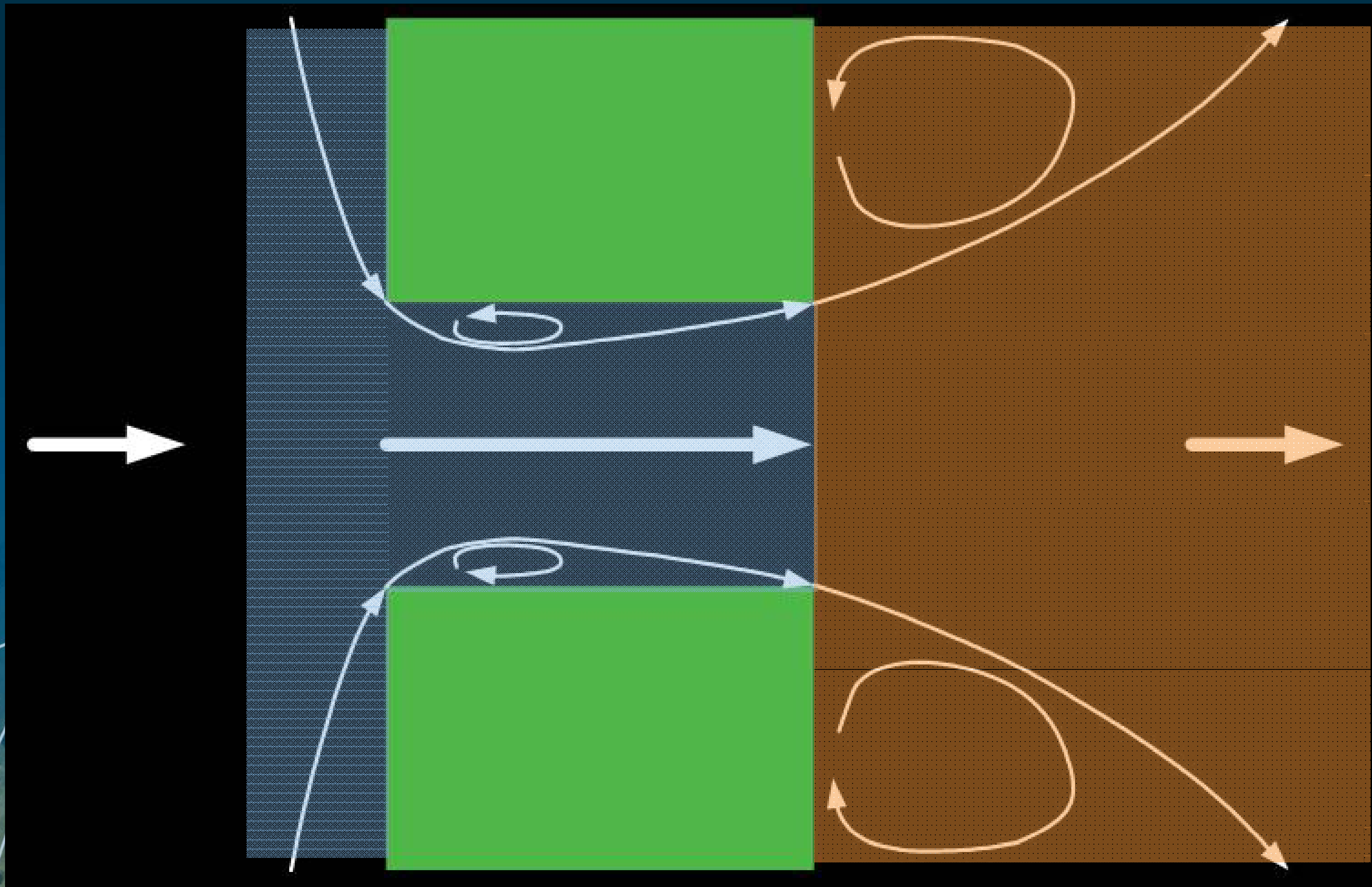
- Important where bed resistance term not dominant and/or rapid changes in velocity gradient
  - Low Manning's n values and/or deep water
  - Flow constrictions
- Smagorinsky formula preferred (varies coefficient based on velocity gradient)
- Many 2D schemes omit this term (Computationally intensive and difficult to solve)
- Don't artificially increase viscosity to stabilise models – distorts results



1D Structures

Contraction/Expansion Losses

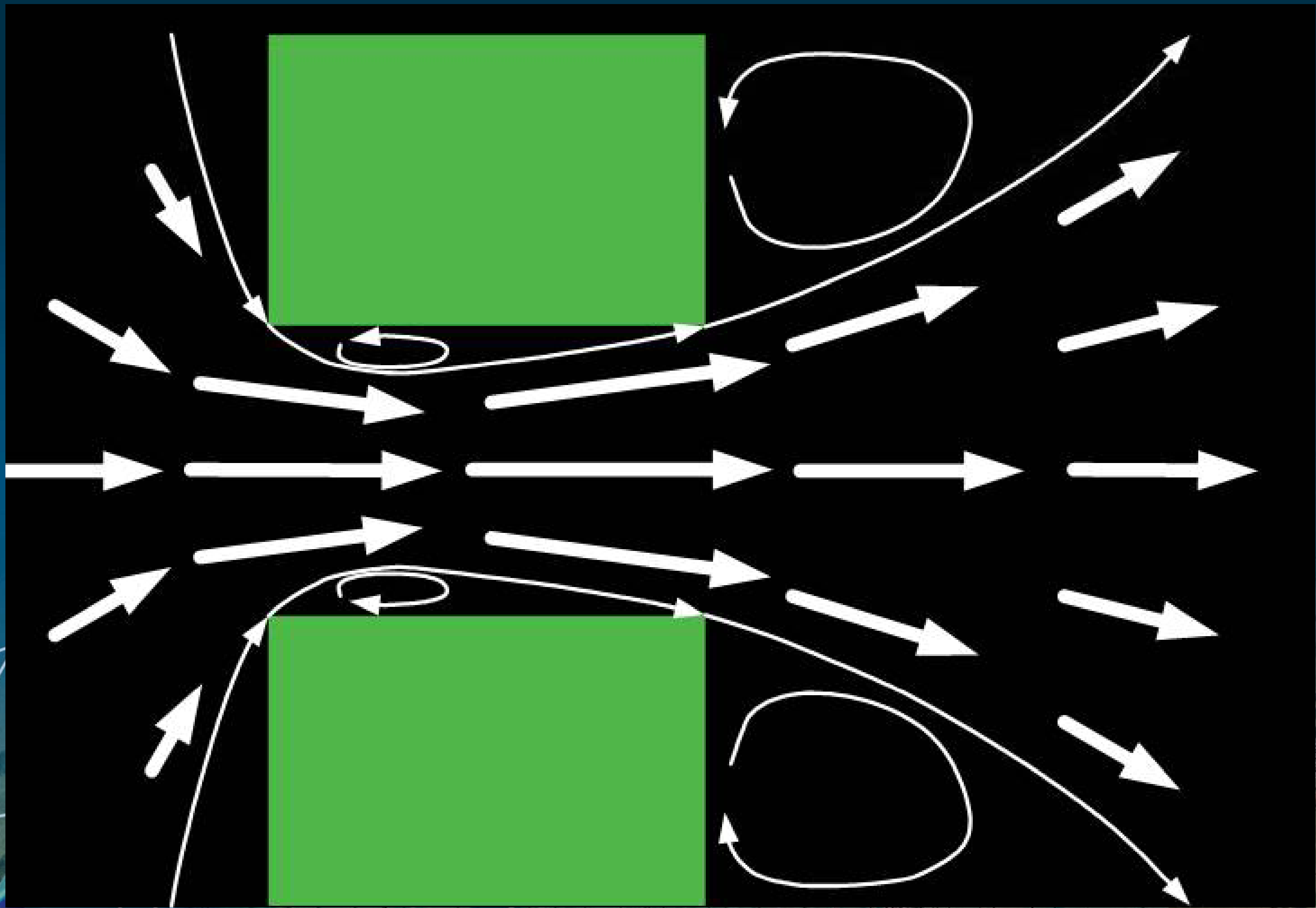
Simplified representation of complex flows



2D Structures

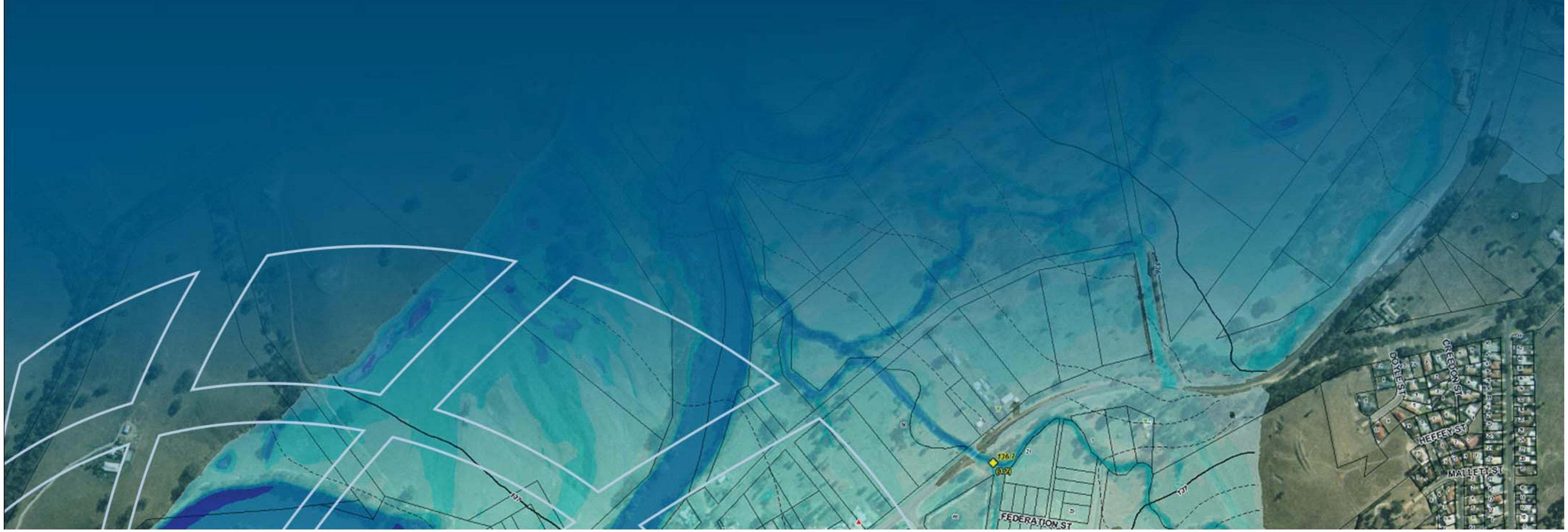
No Contraction/Expansion Losses

But need inertia/viscosity, ability to add fine-scale losses for bridge piers, etc



Real-World

- In Australia and UK
  2D or 1D/2D modelling now standard
- Three pivotal studies…

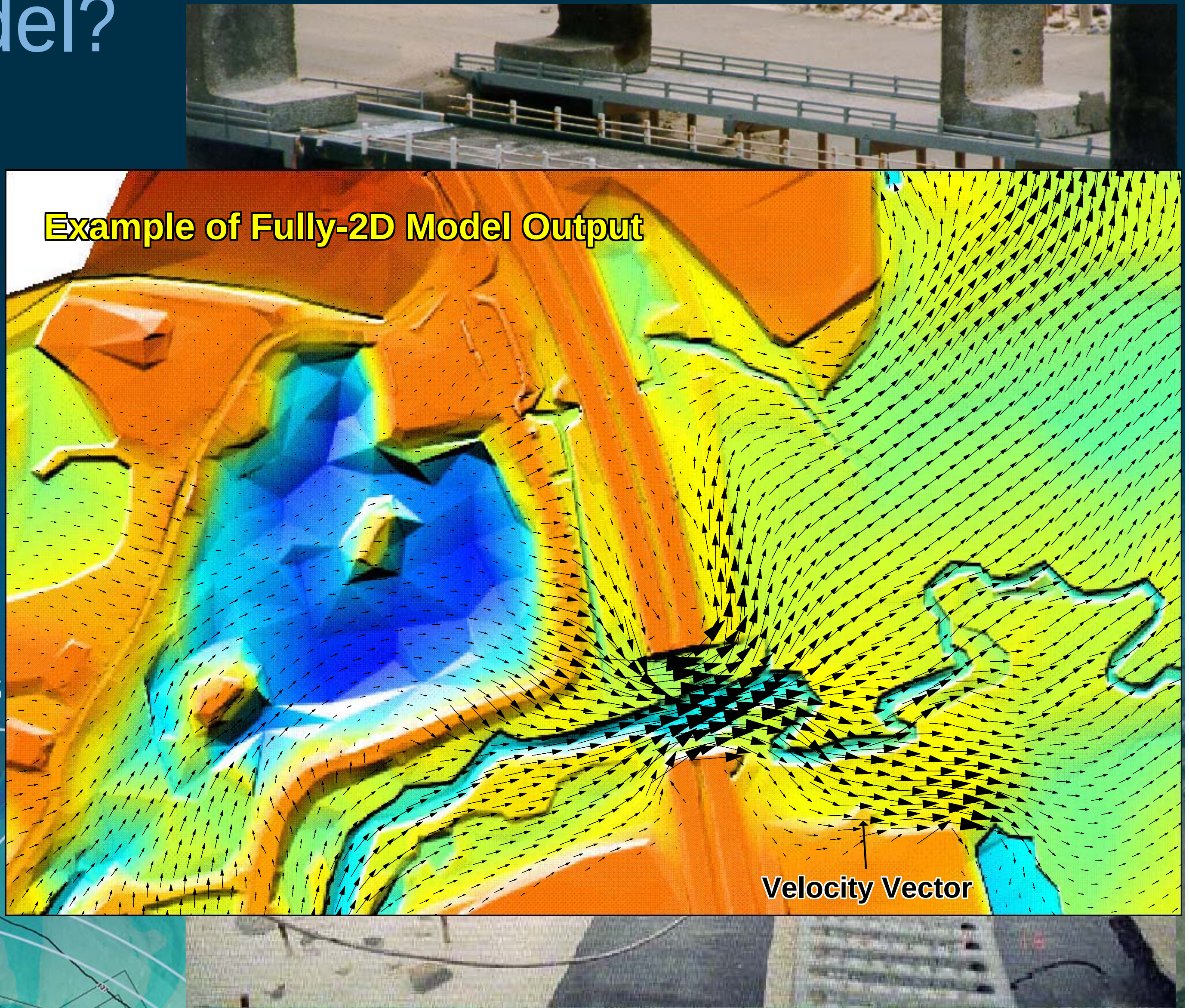


13

Eudlo Creek Hydraulic Investigations, Qld, 1998-2003

Which Model?

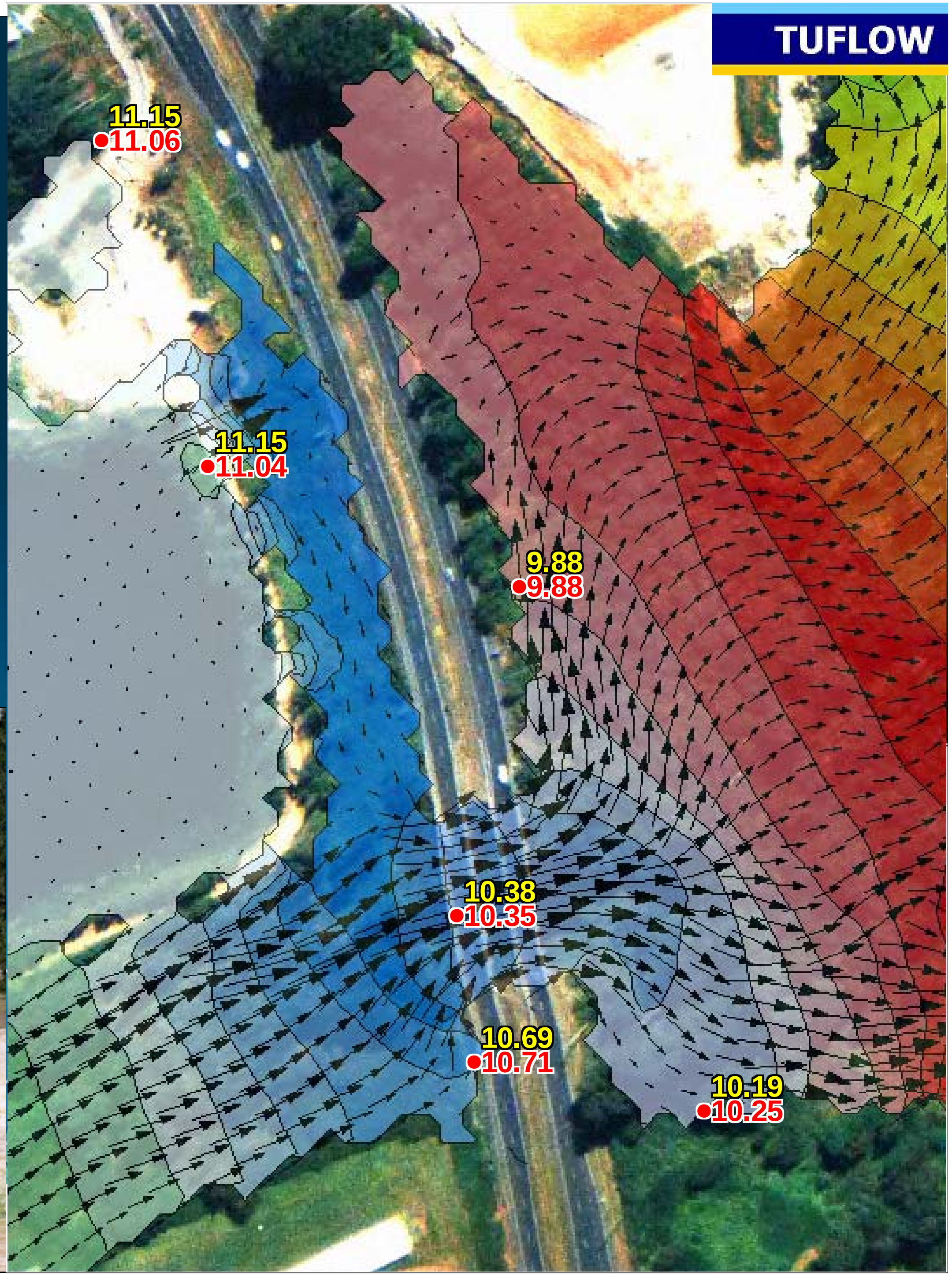
- Exhaustive Investigations
- $4m damages claim
- Physical Model
- Four 1D Models
- Three 2D Models



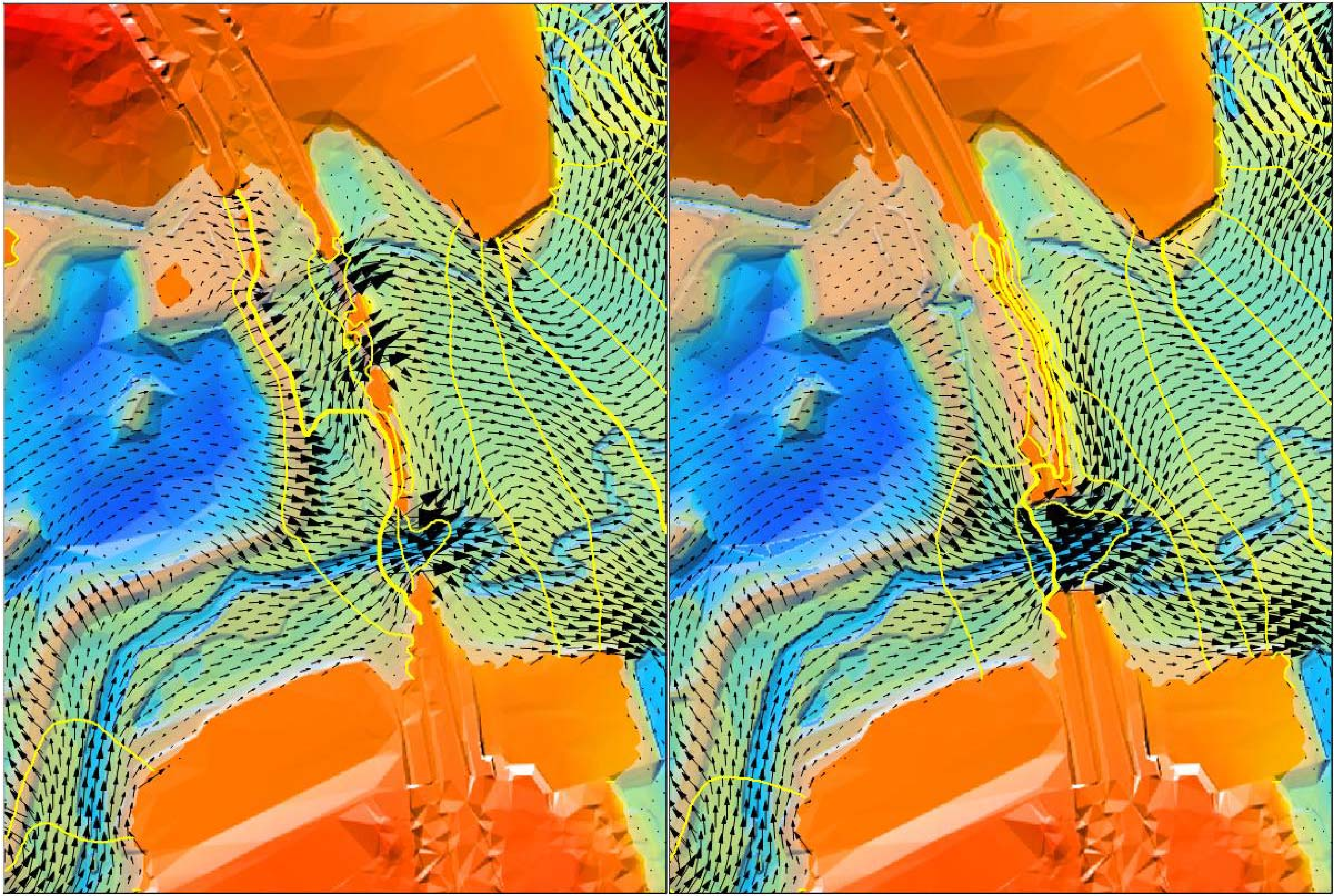
Eudlo Creek, Qld, 1998-2003

Calibration

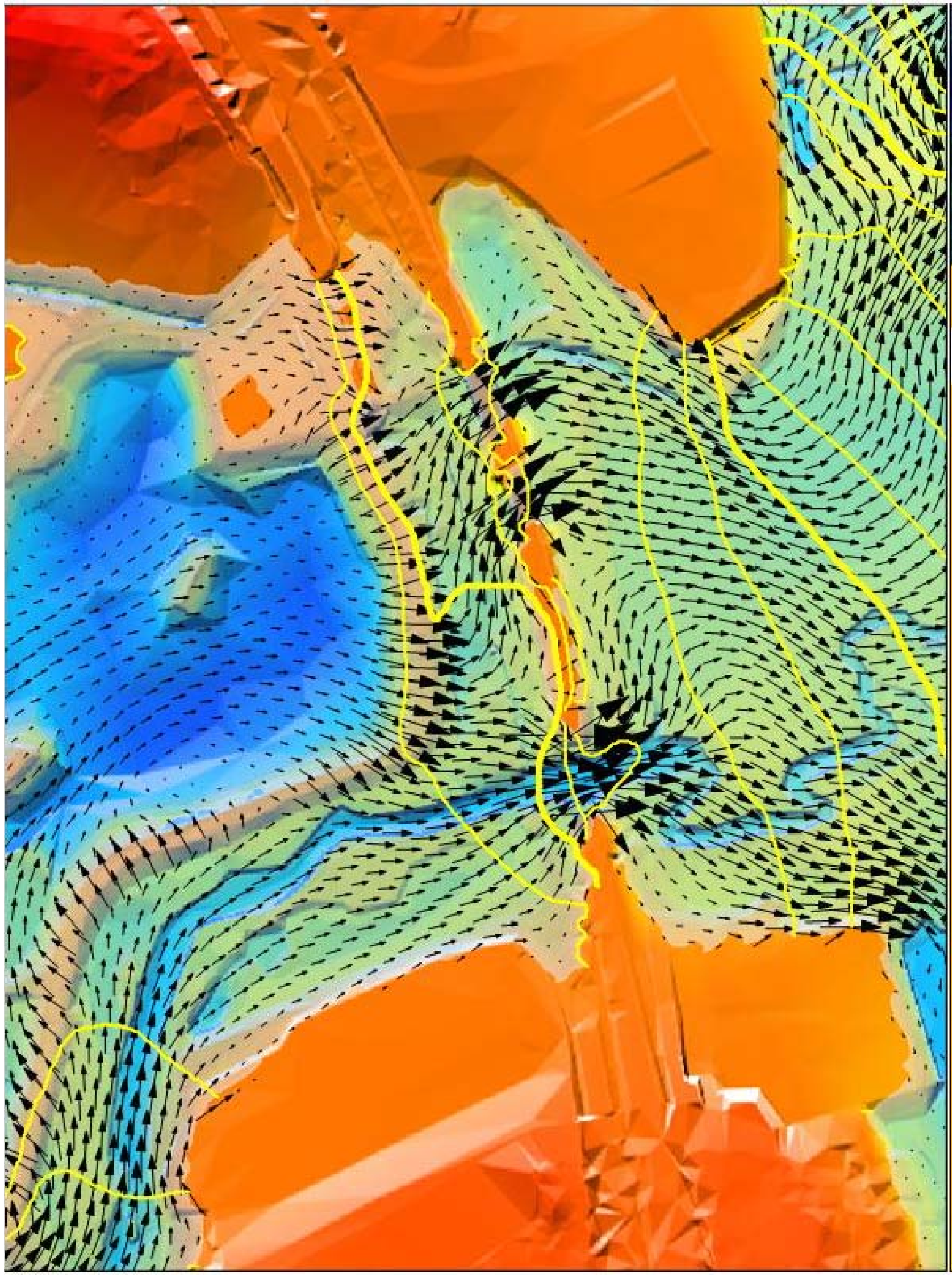
- Three floods
  - 1983, 1992, 1999
  - One during study
- Good data sets

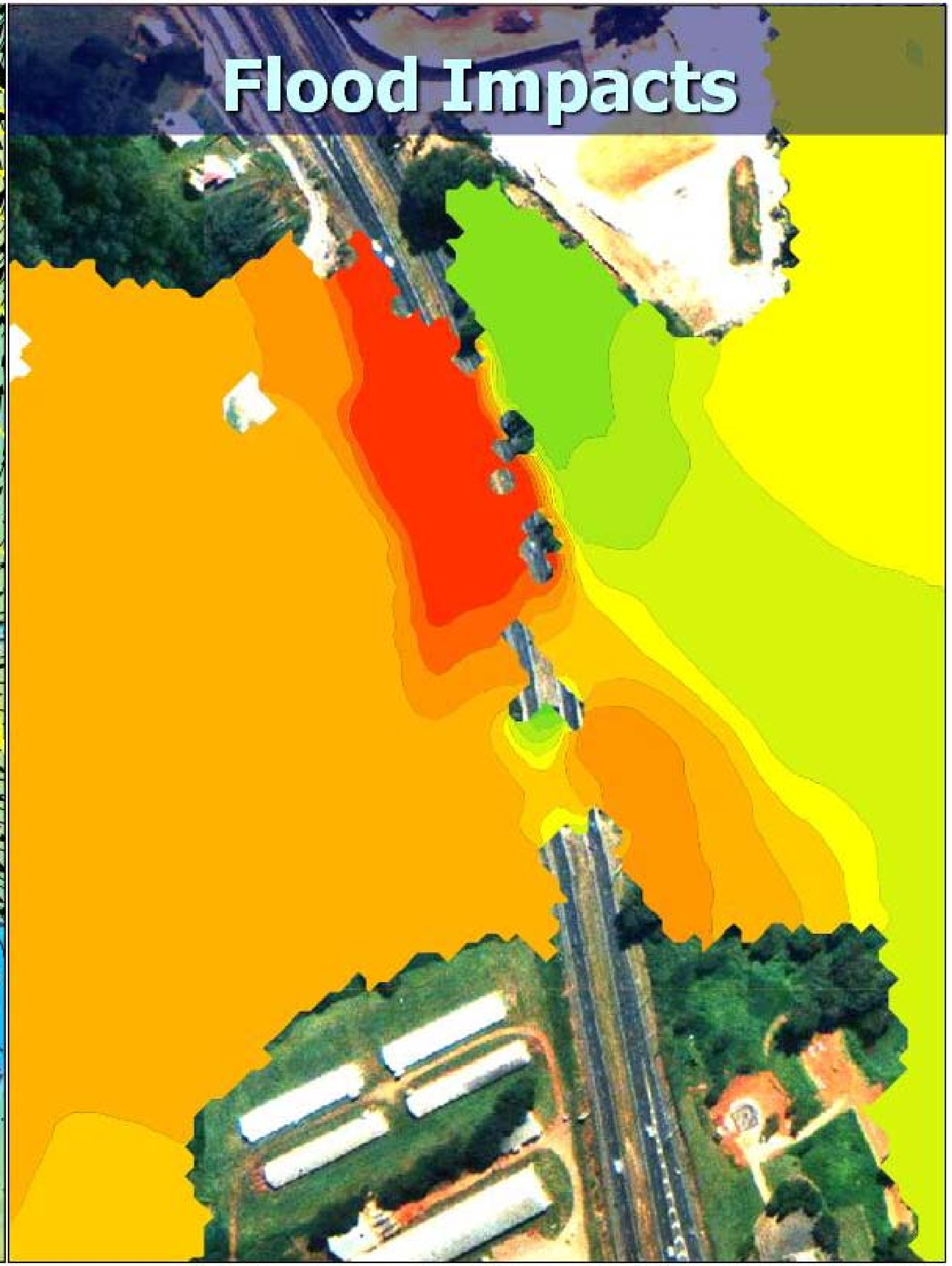


Pre-Duplication Post-Duplication



Pre-Duplication	Post-Duplication

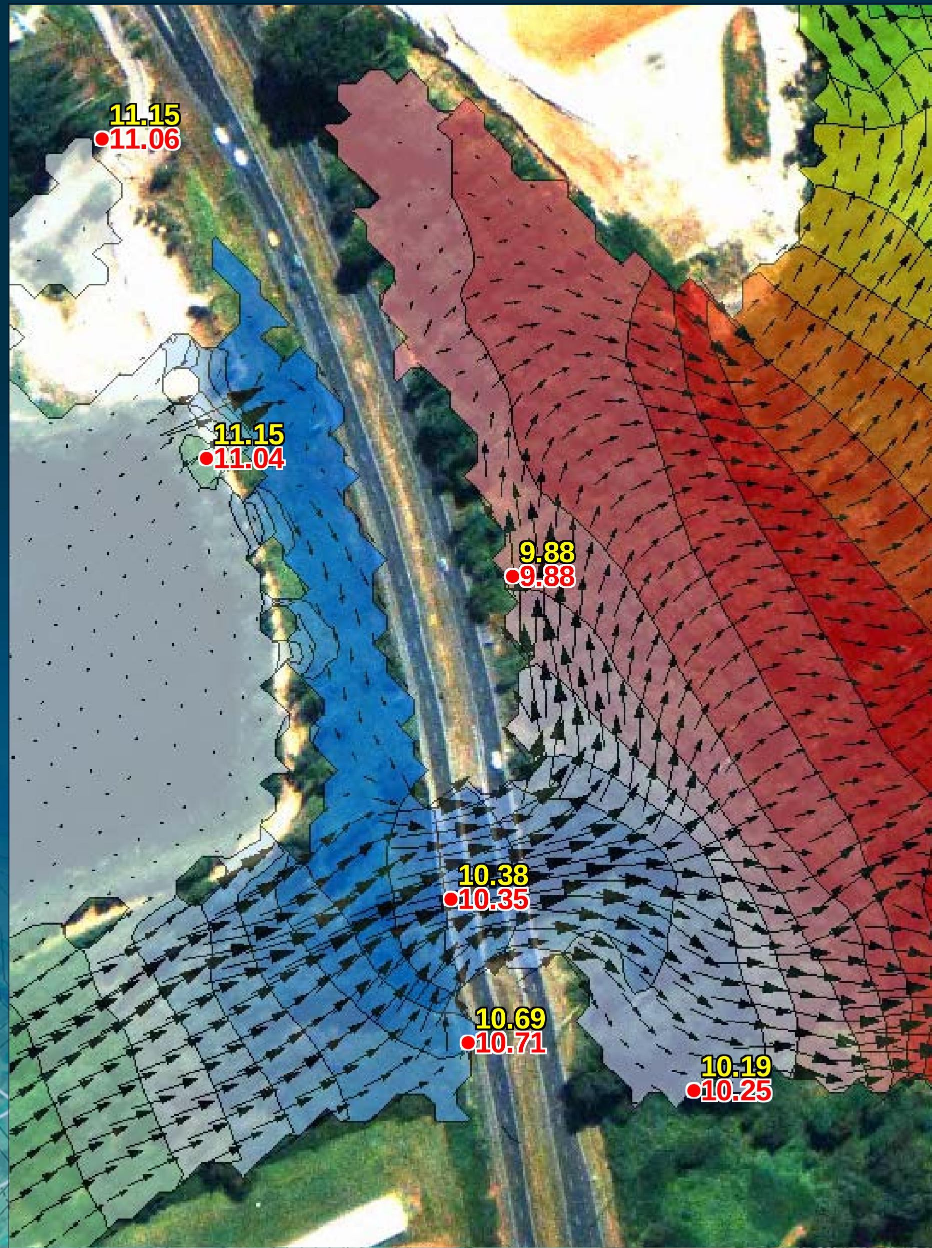




Eudlo Creek, Qld, 1998-2003

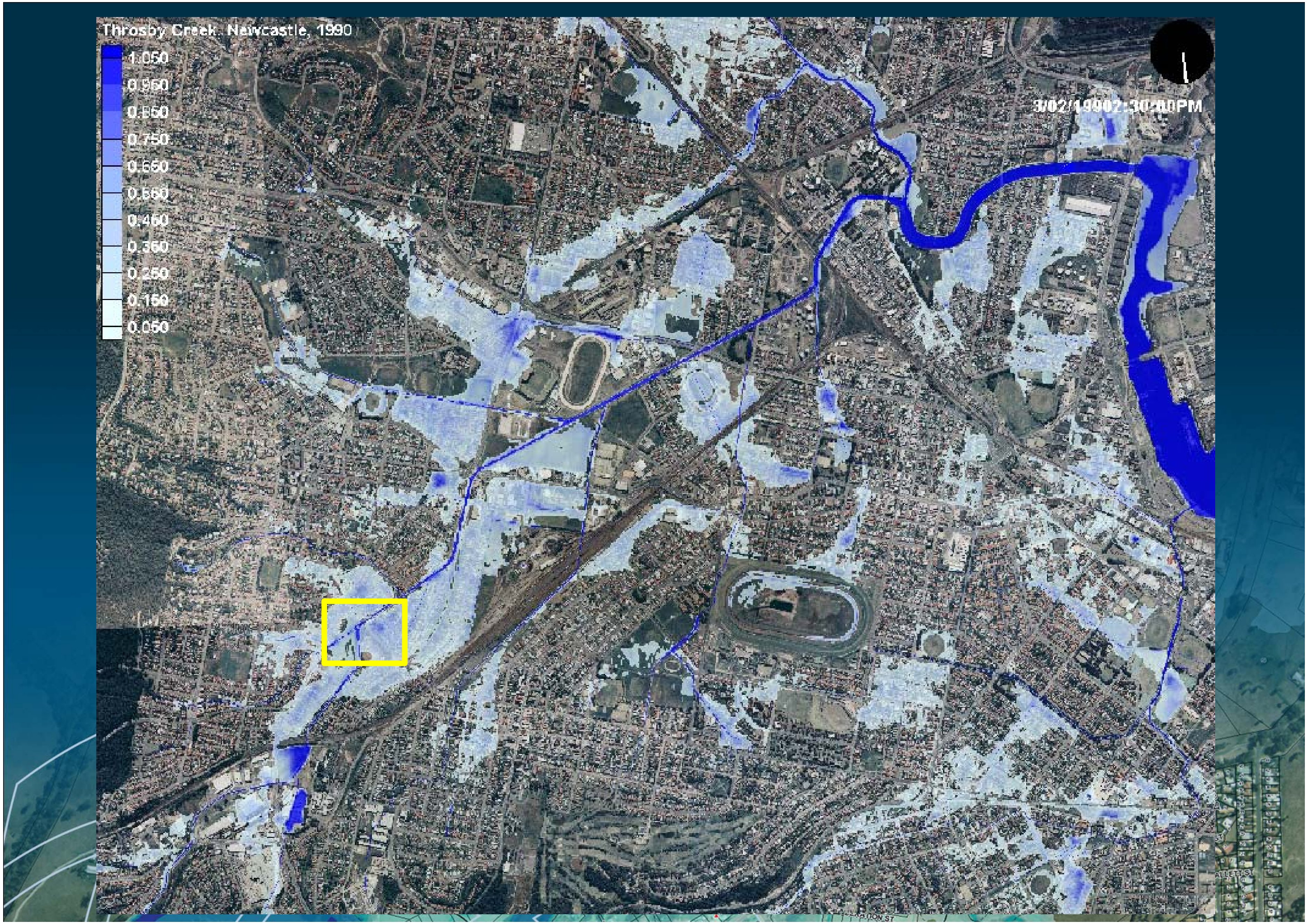
Key Findings

- 1D models very poor
  (Could not reproduce recorded affluxes using standard parameters – did not dissipate enough energy)
- 2D models performed well
  (Calibration data helped fine-tune models)
- Physical Model
  (once “rough” enough, ie. calibrated)
  performed well



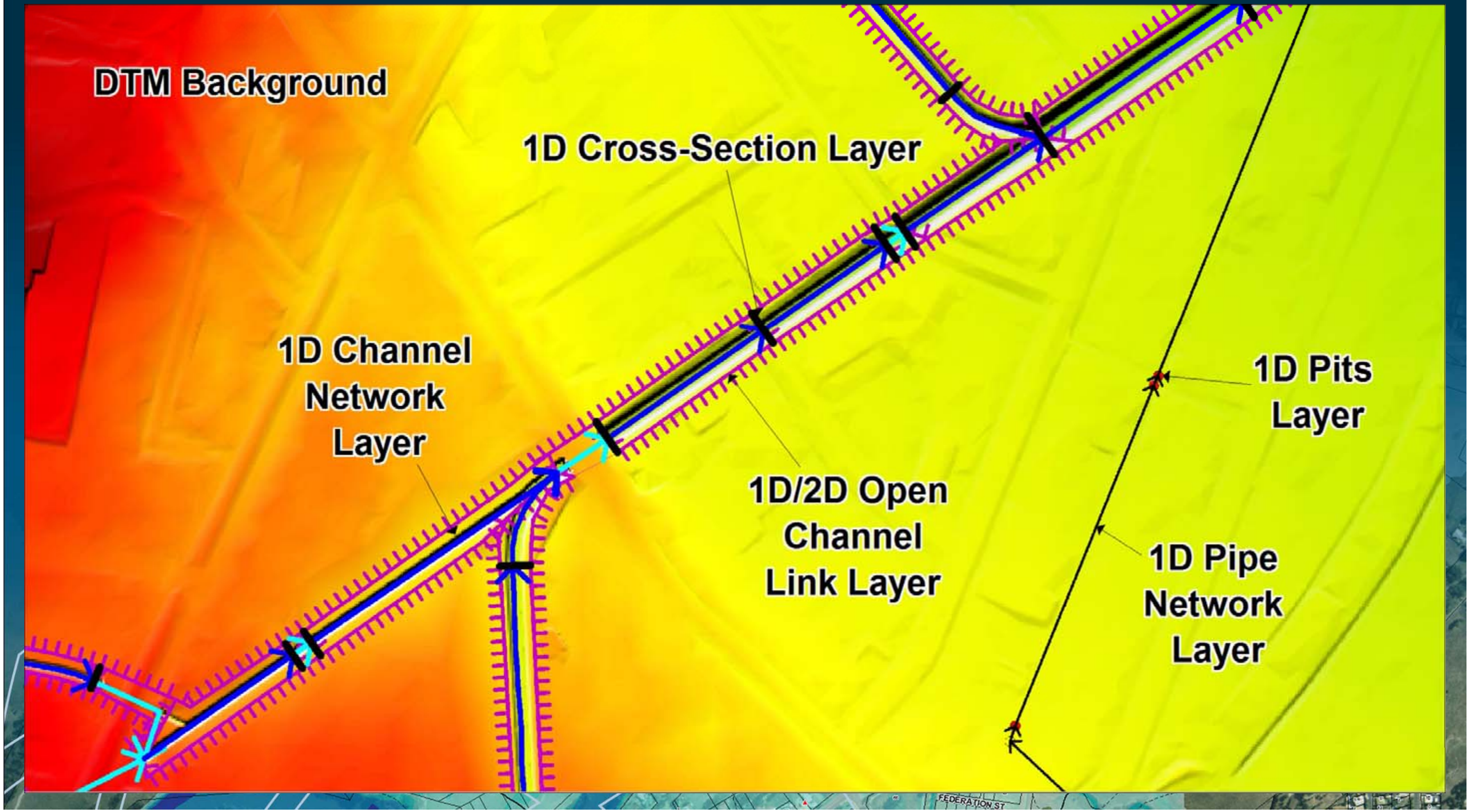
Throsby Creek Newcastle (2006)

- 1D
  - Sub and super critical flow
  - 700 structures
  - Major pipes, pits, manholes
- 2D
  - Complex overland flows


Throsby Creek, Newcastle, 1990
1.050
0.950
0.850
0.750
0.650
0.550
0.450
0.350
0.250
0.150
0.050
3/02/1990 2:30:00PM

Throsby Creek, NSW, 2006 - 2007

1D/2D Model Development



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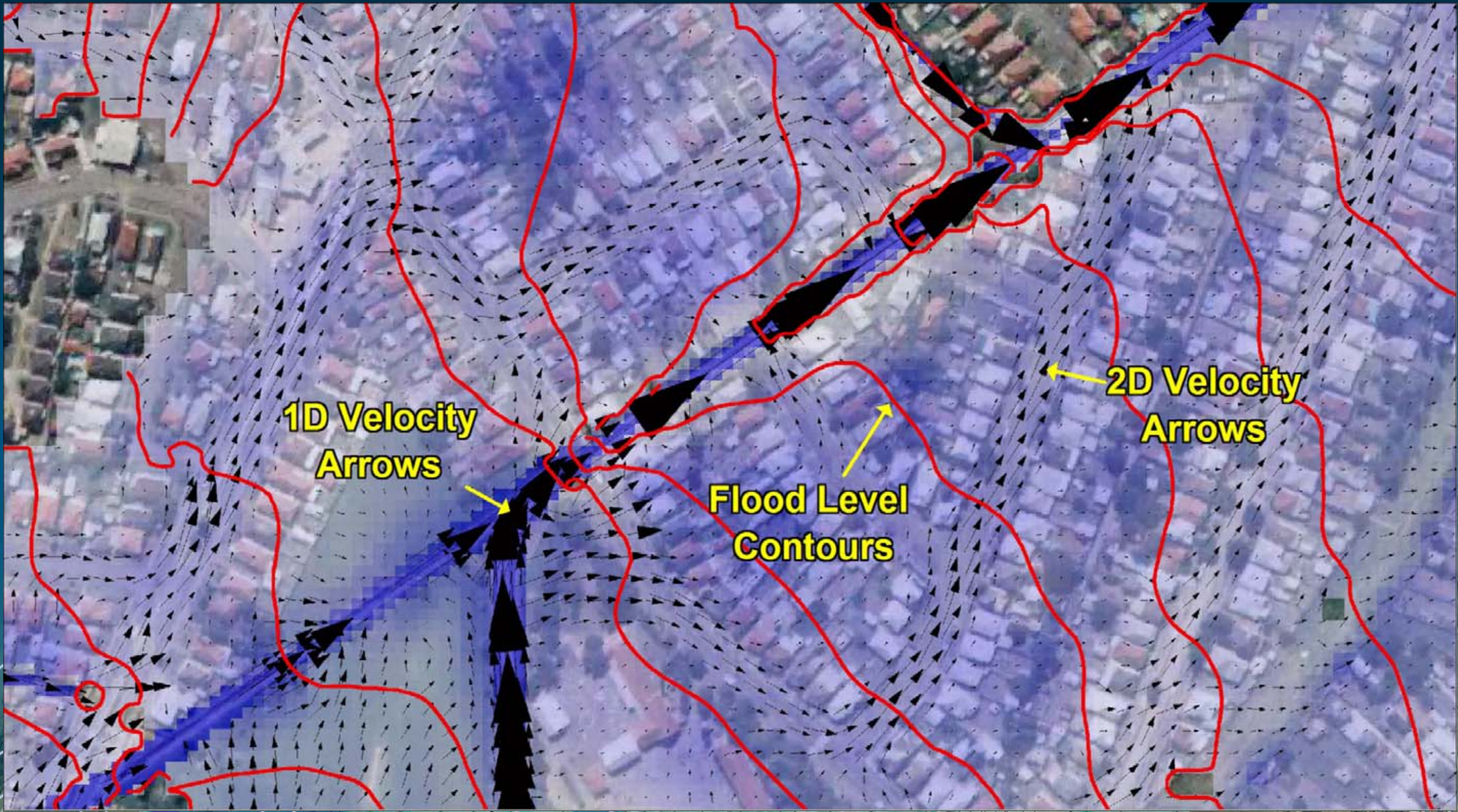
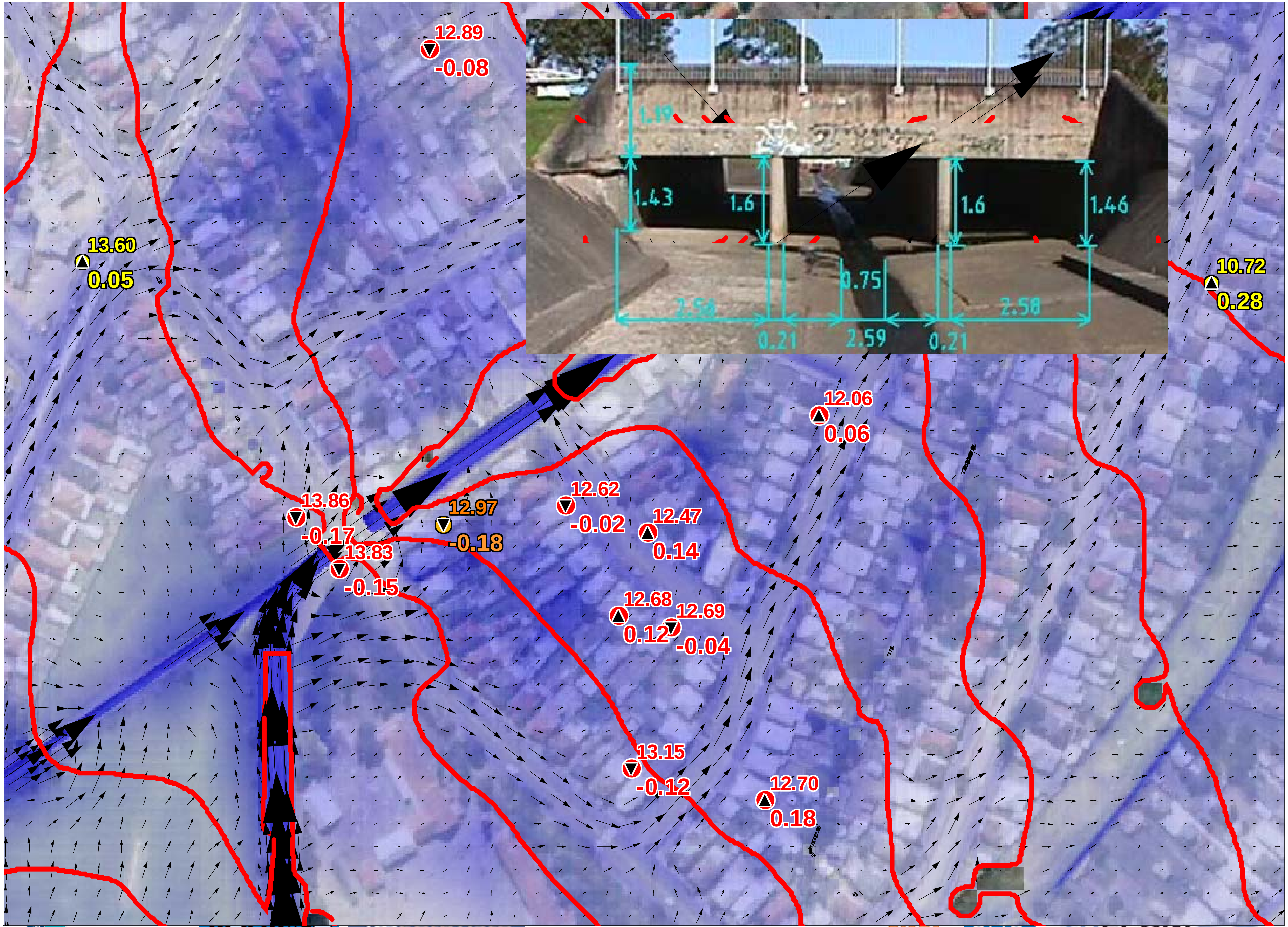
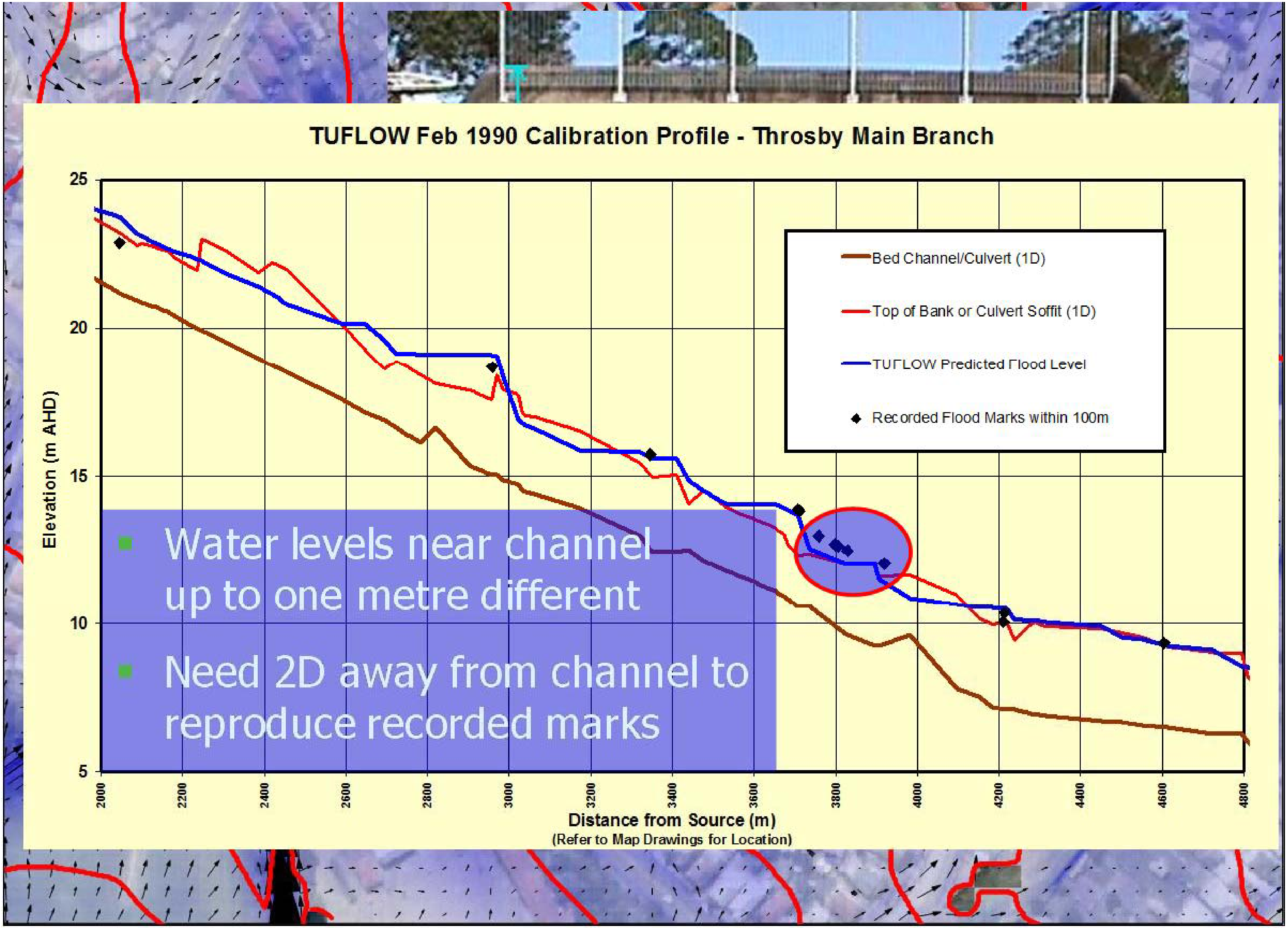
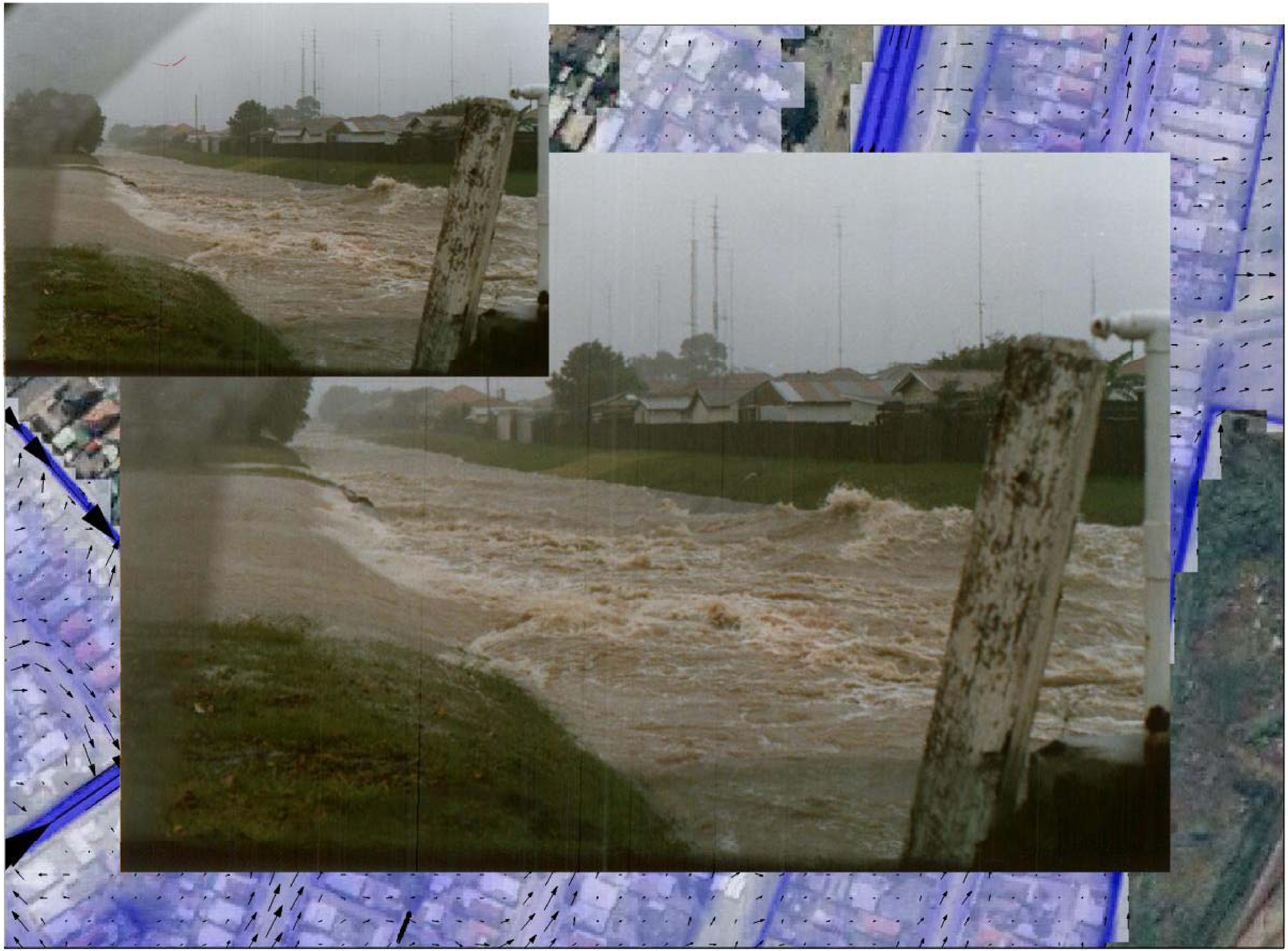
Throsby Creek, NSW, 2006 - 2007

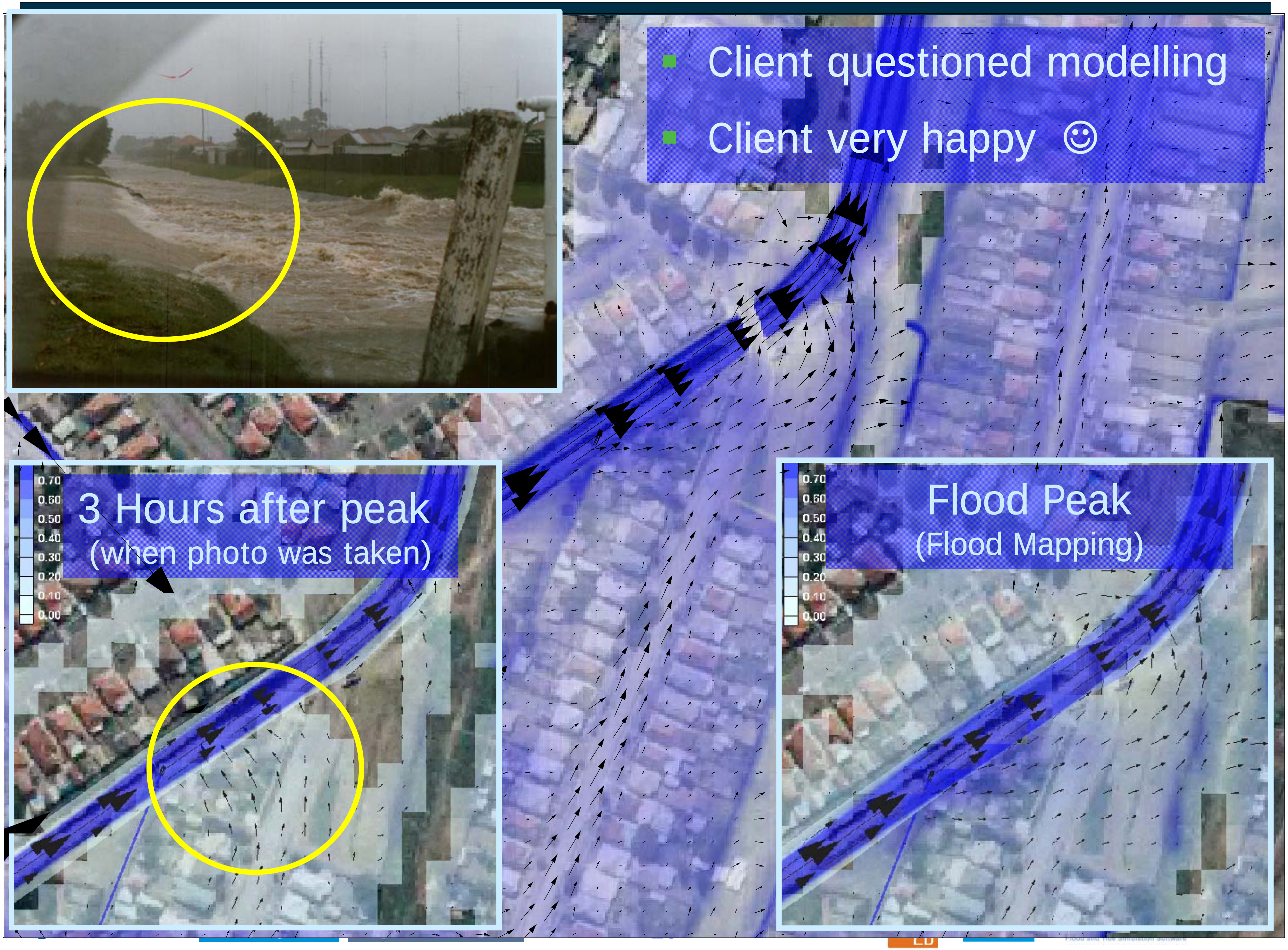
1D/2D Model Results




12.89
-0.08
13.60
0.05
10.72
0.28
1.19
1.43
1.6
1.6
1.46
0.75
2.58
2.58
0.21
2.59
0.21
12.06
0.06
13.86
-0.17
12.97
-0.18
12.62
-0.02
12.47
0.14
13.83
-0.15
12.68
0.12
12.69
-0.04
13.15
-0.12
12.70
0.18


TUFLOW Feb 1990 Calibration Profile - Throsby Main Branch
Elevation (m AHD)
25
20
15
10
5
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
Distance from Source (m)
(Refer to Map Drawings for Location)
Bed Channel/Culvert (1D)
Top of Bank or Culvert Soffit (1D)
TUFLOW Predicted Flood Level
Recorded Flood Marks within 100m
Water levels near channel up to one metre different
Need 2D away from channel to reproduce recorded marks

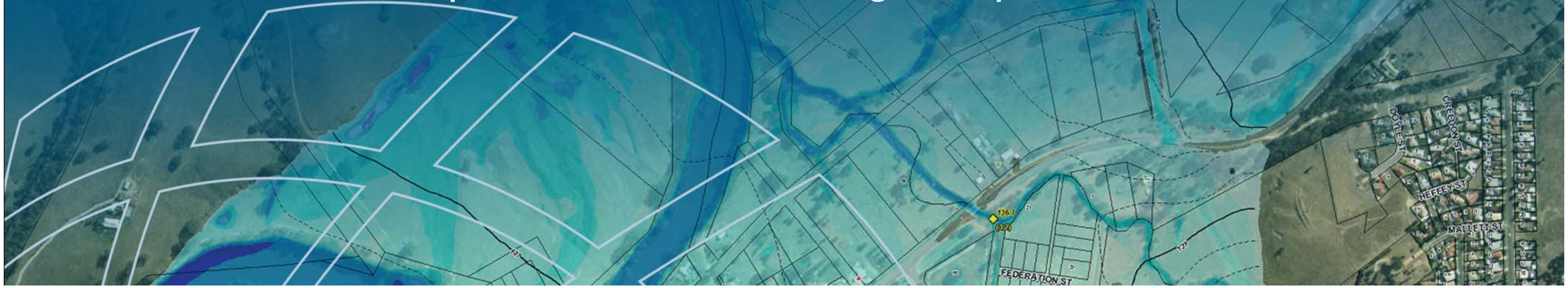




Client questioned modelling
Client very happy ☺
3 Hours after peak
(when photo was taken)
Flood Peak
(Flood Mapping)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00

June 2007

- ~100 year flood
  (1 week after submitting 100 year flood maps!)
- $700 million in damages
- 5,000 cars written off
- Thousands of homes inundated
- >1,200 flood marks to verify model!
- Field observations indicate an excellent comparison with modelling except…



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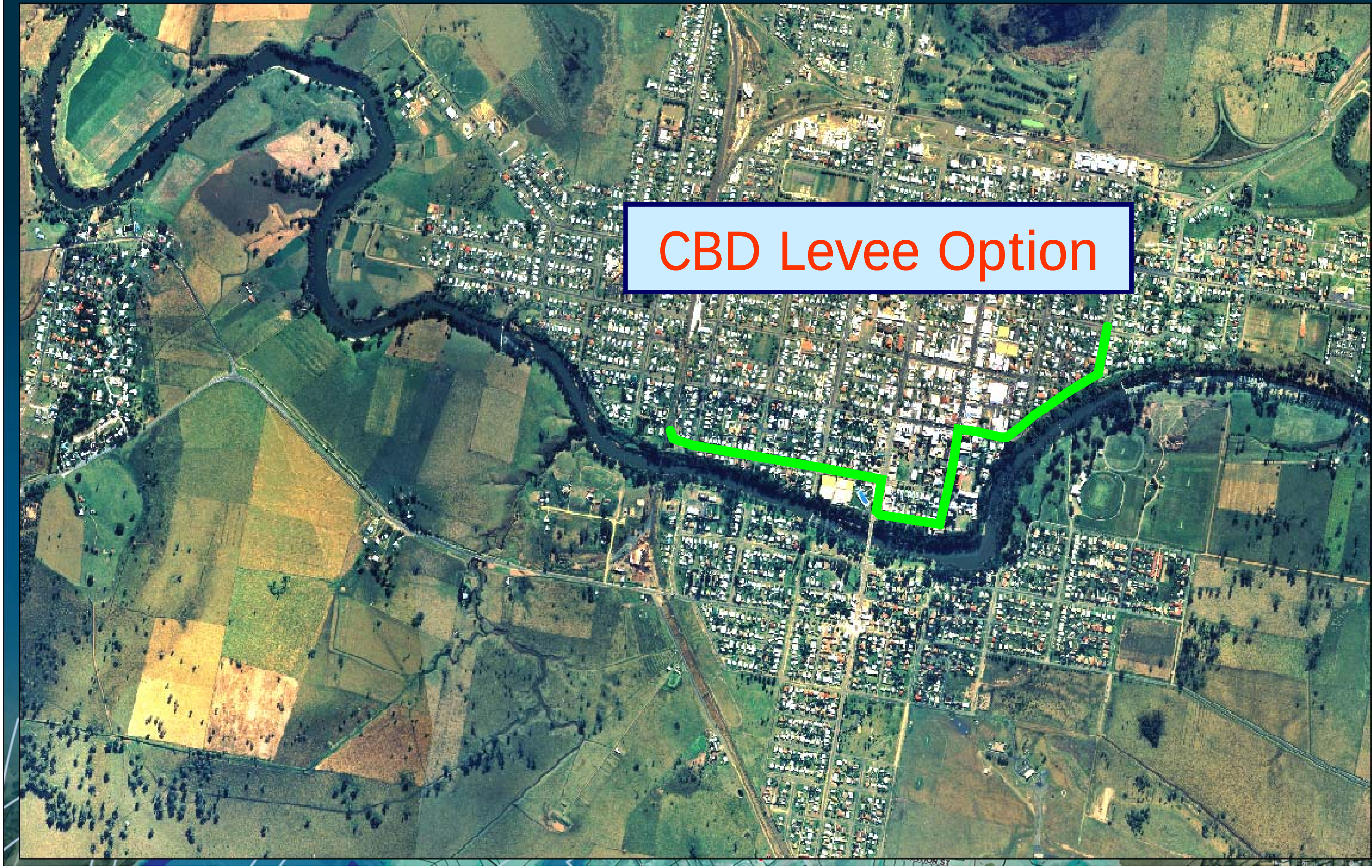
June 2007 Throsby Creek Flood

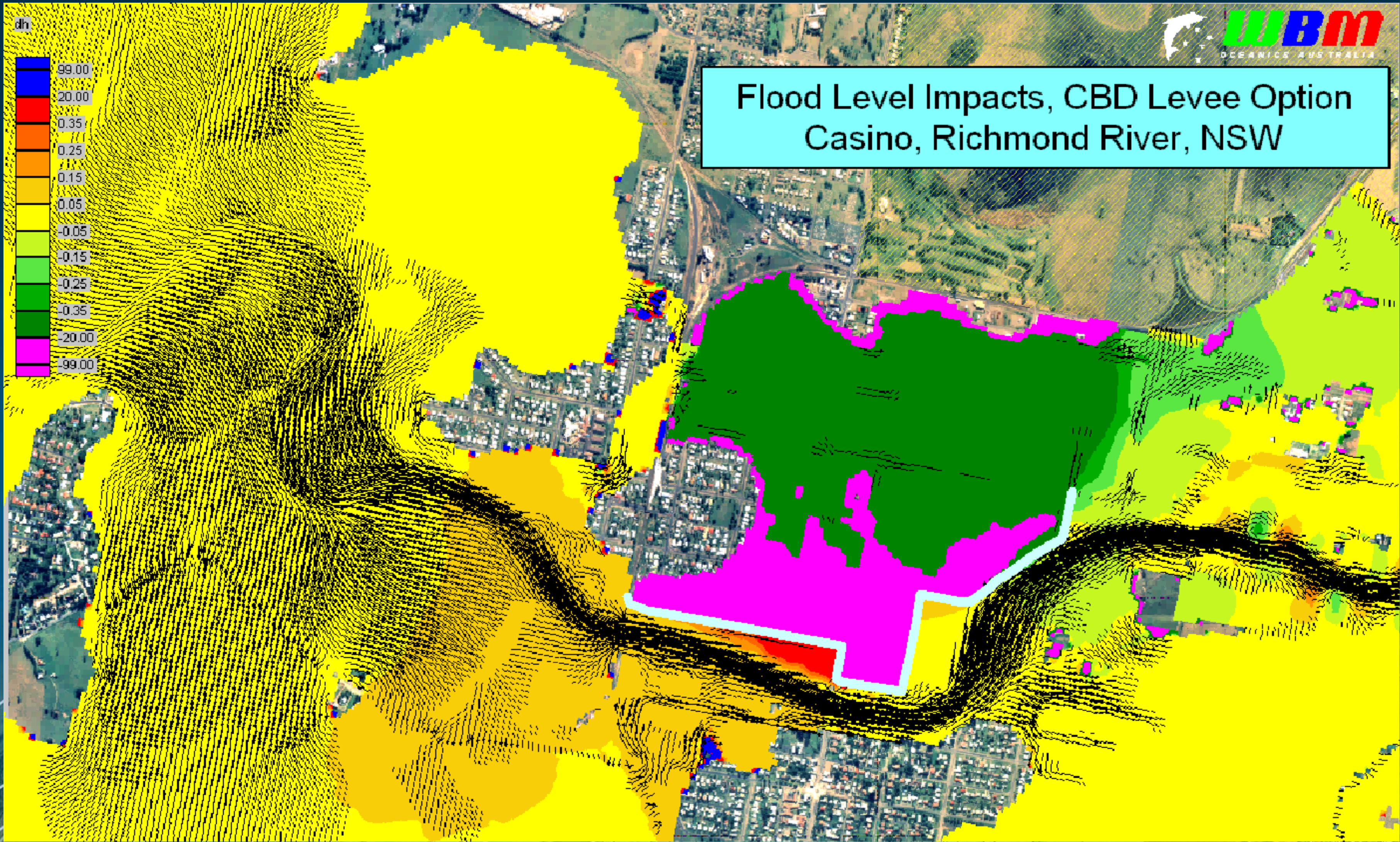
- Newcastle CBD
  - 1m deep – should be dry!
  - Outlet to harbour blocked by shipping container
- New housing estate flooded
  - Should be dry
  - Two cars blocked main drain d/s
- When blockages modelled, excellent comparisons resulted

Casino Floodplain Management Study, NSW, 1999 – 2001



Casino Floodplain Management Study, NSW, 1999 – 2001

Switching to 2D no longer made the community skeptical about modelling



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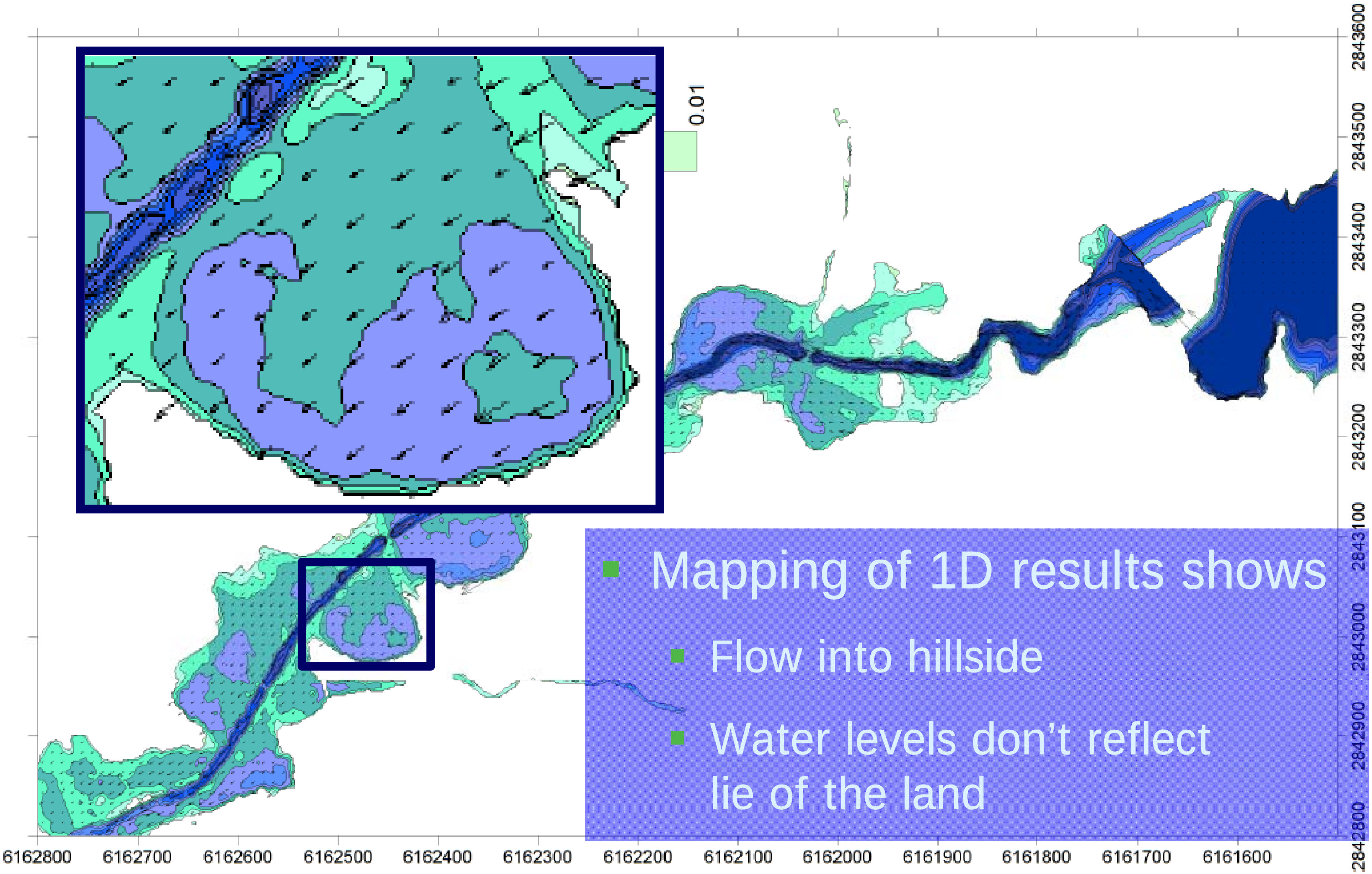
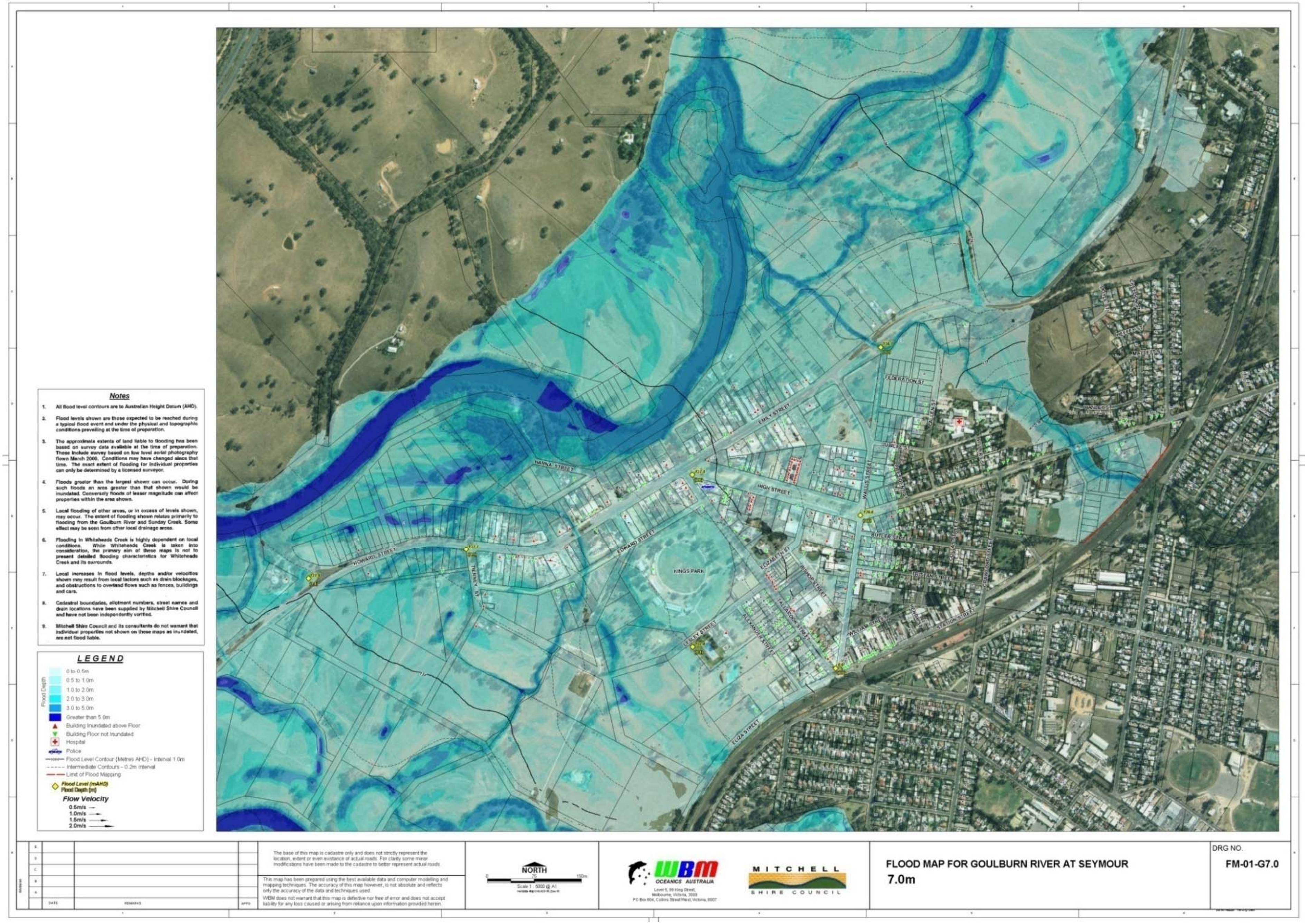
Mapping 1D Results

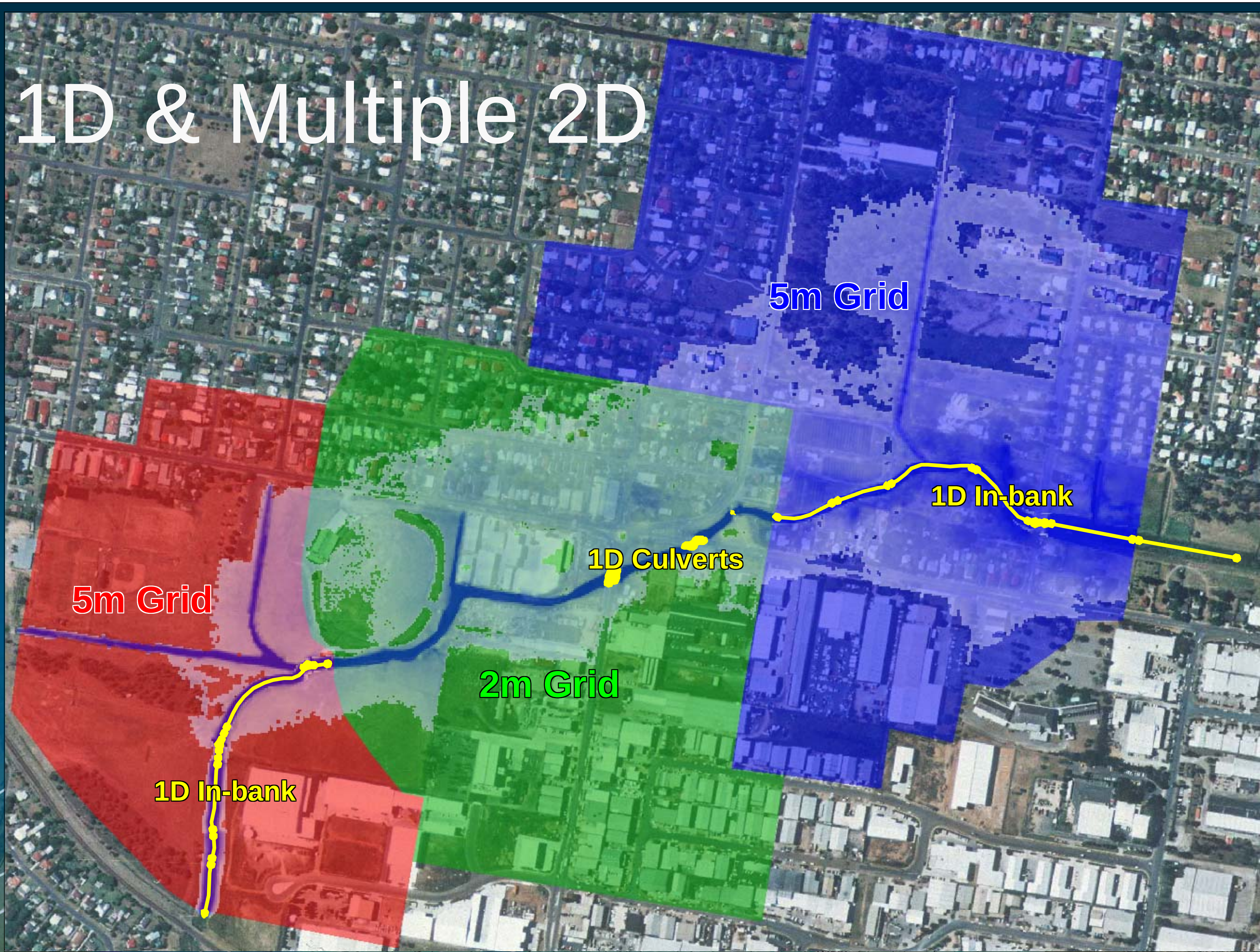


- Mapping of 1D results shows
  - Flow into hillside
  - Water levels don't reflect lie of the land

2002 – High Quality Flood Maps based on 2D Modelling



1D & Multiple 2D



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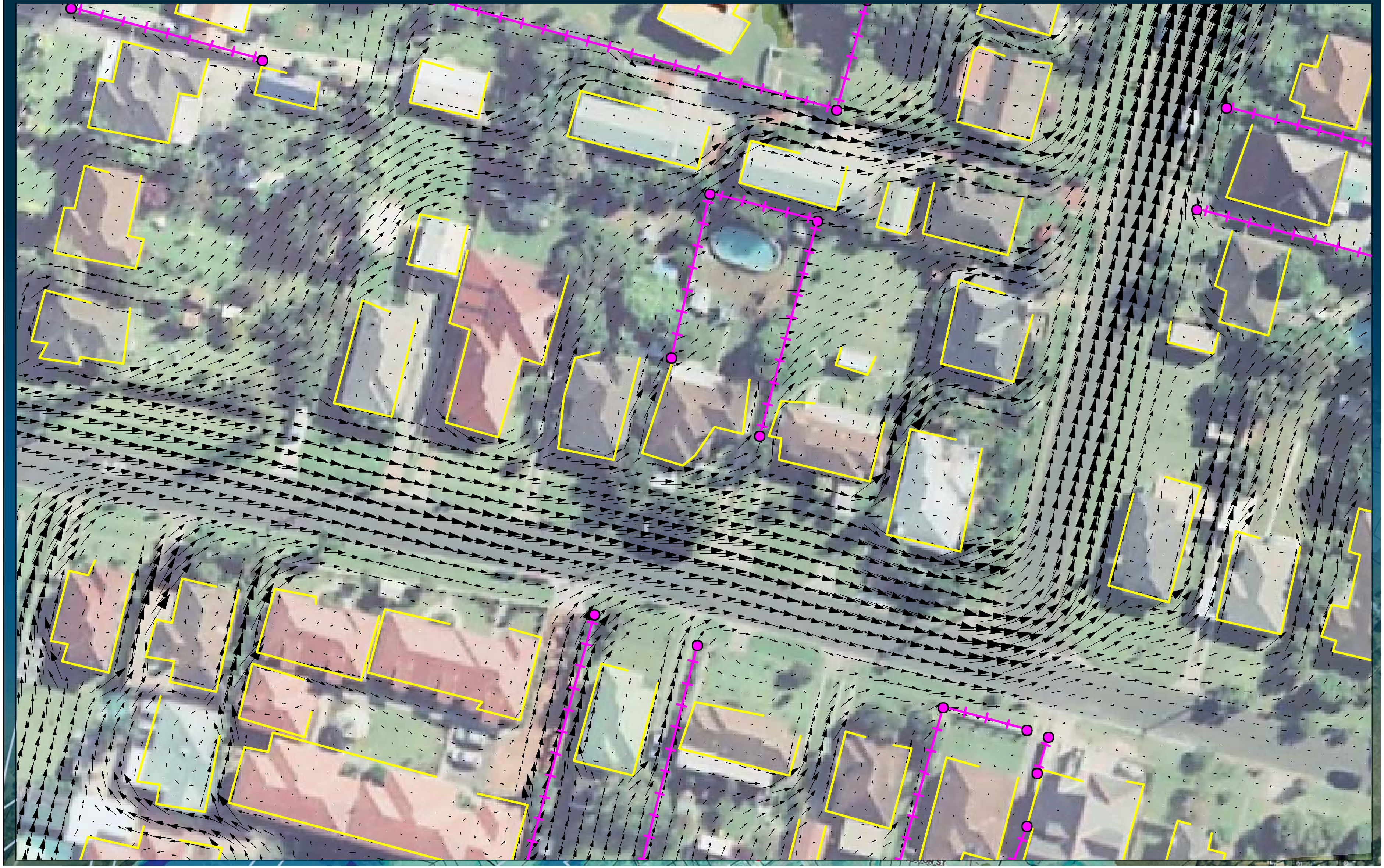
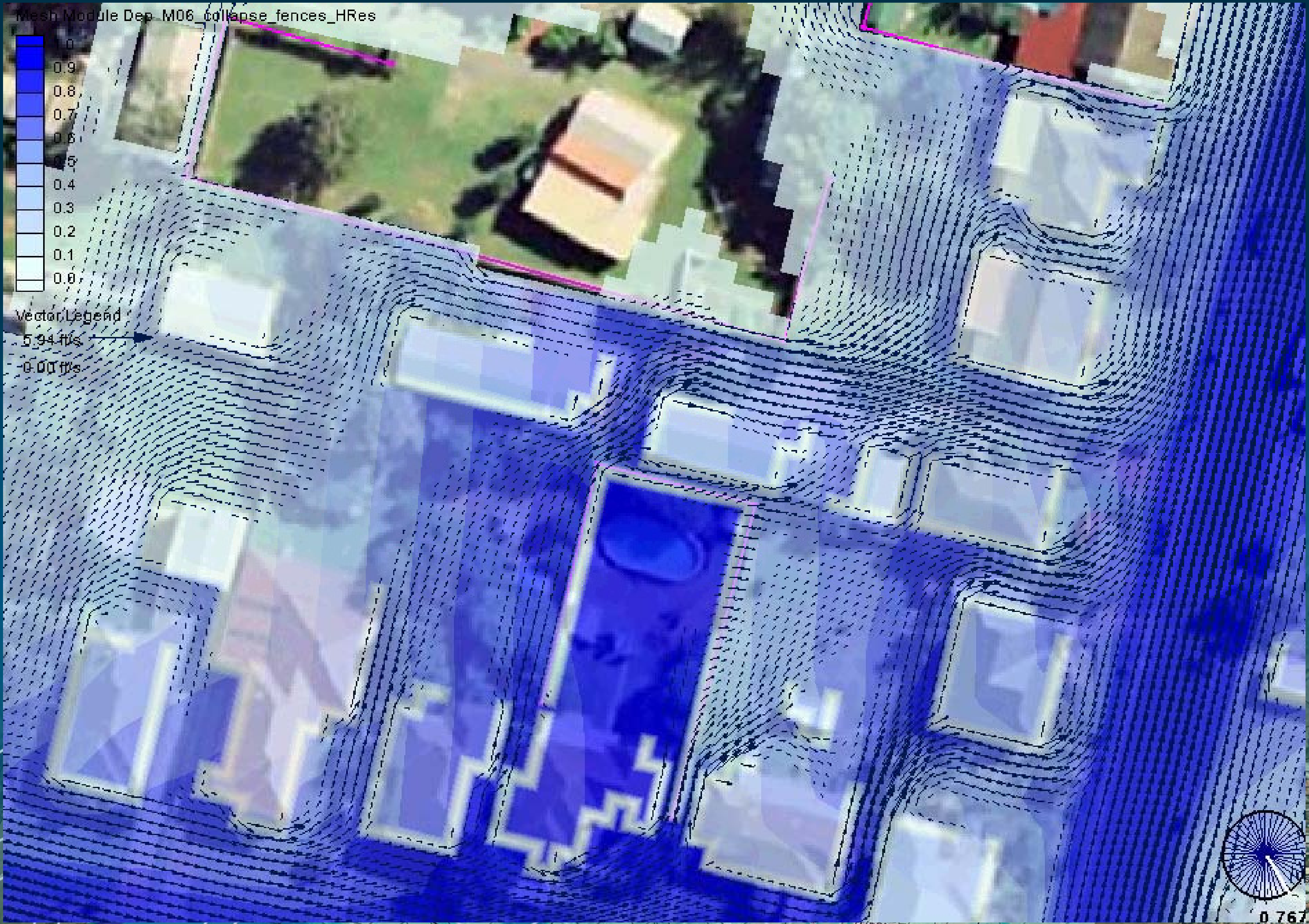
Urban Areas – Buildings and Fences



Modelling Fences!

- Able to raise element sides
- Element sides wet and dry
- Layered parameters
  - eg. vary blockage and losses with height
- Collapse element sides
- Switch between u/s and d/s controlled weir flow

Collapsible Fences Animation



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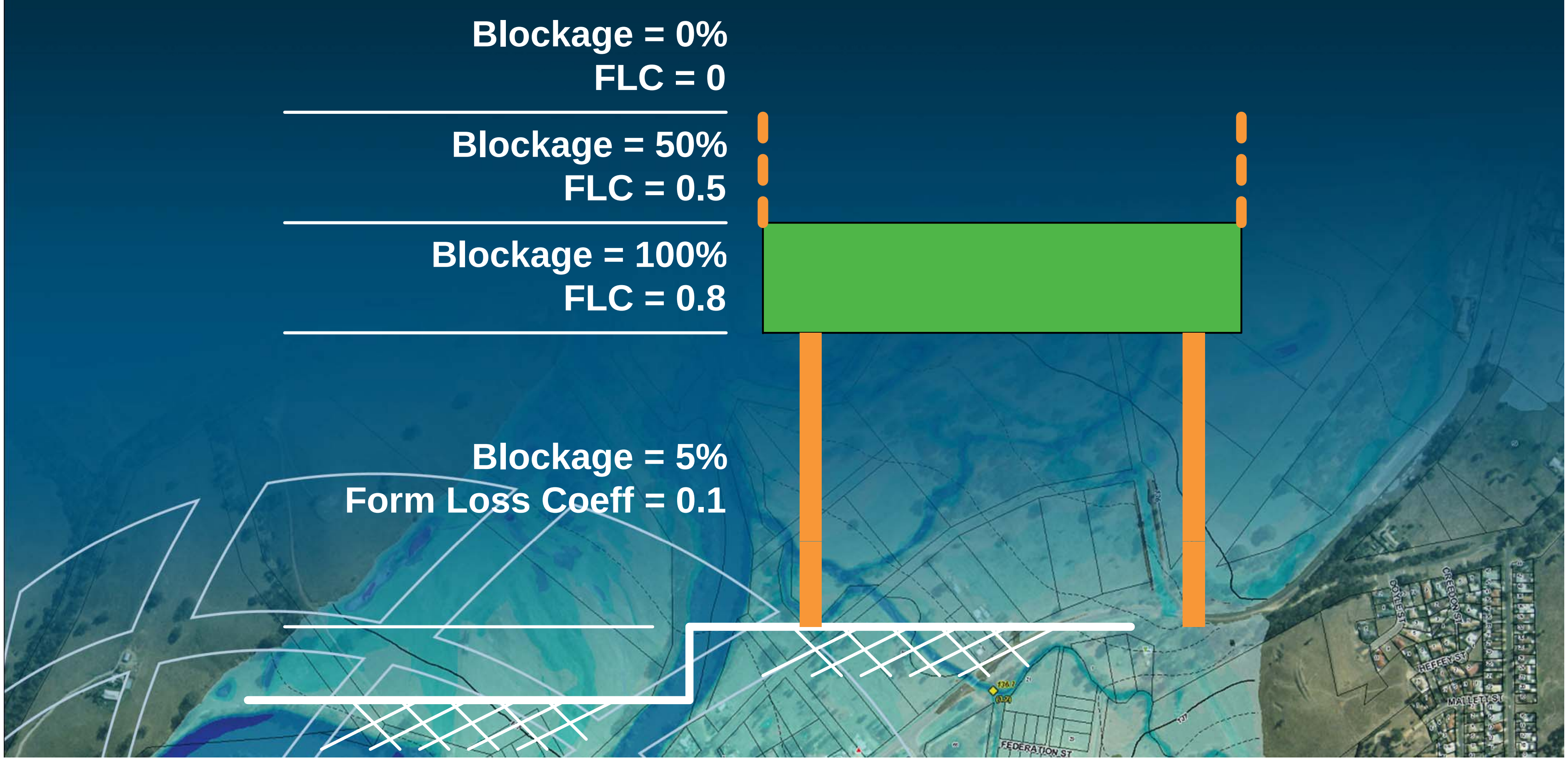
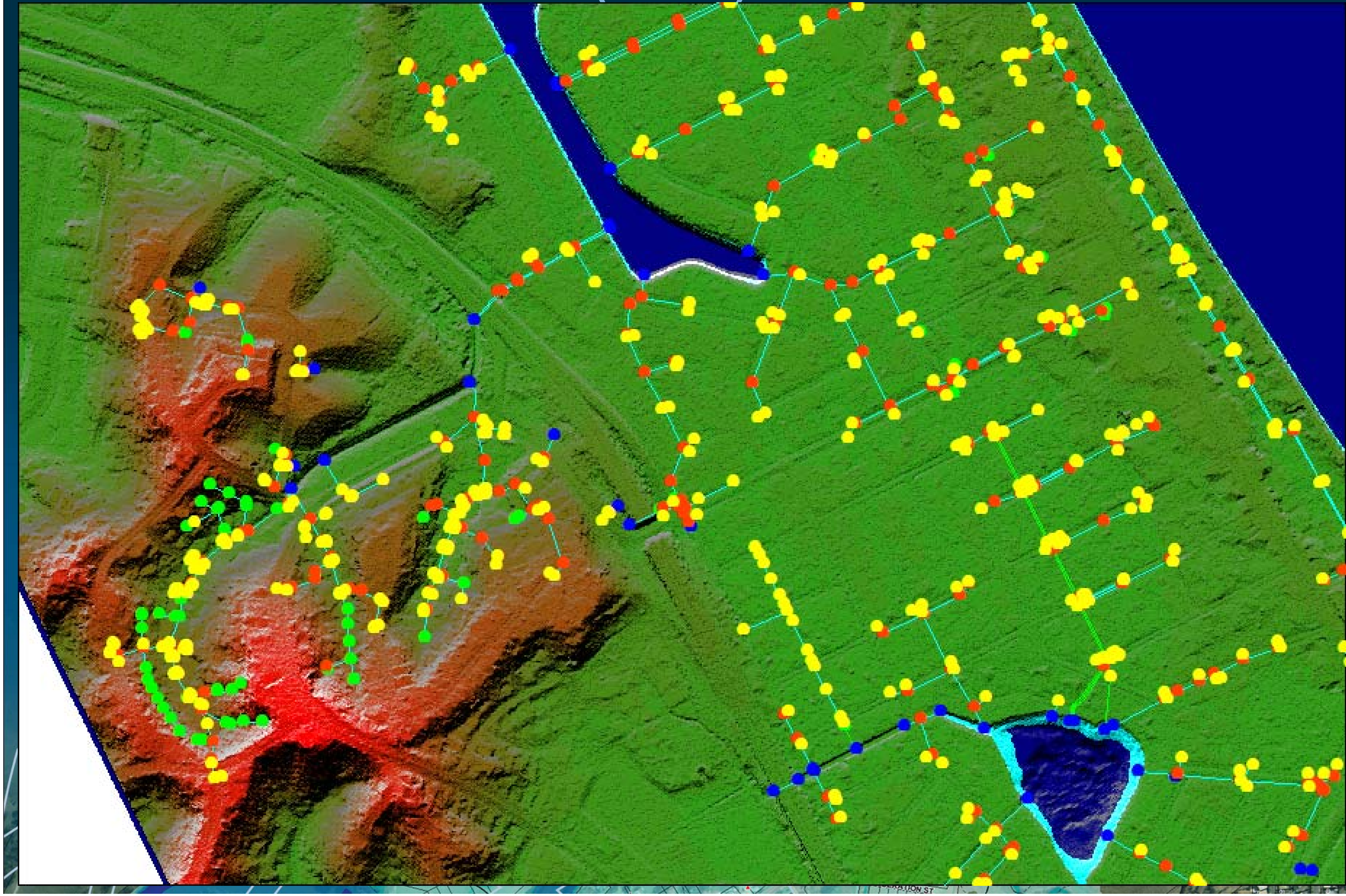
Modelling Blockages!?

(These rails are recommended because they don't collect debris…)

2D Layered Adjustments



Detailed Urban Models (2008)



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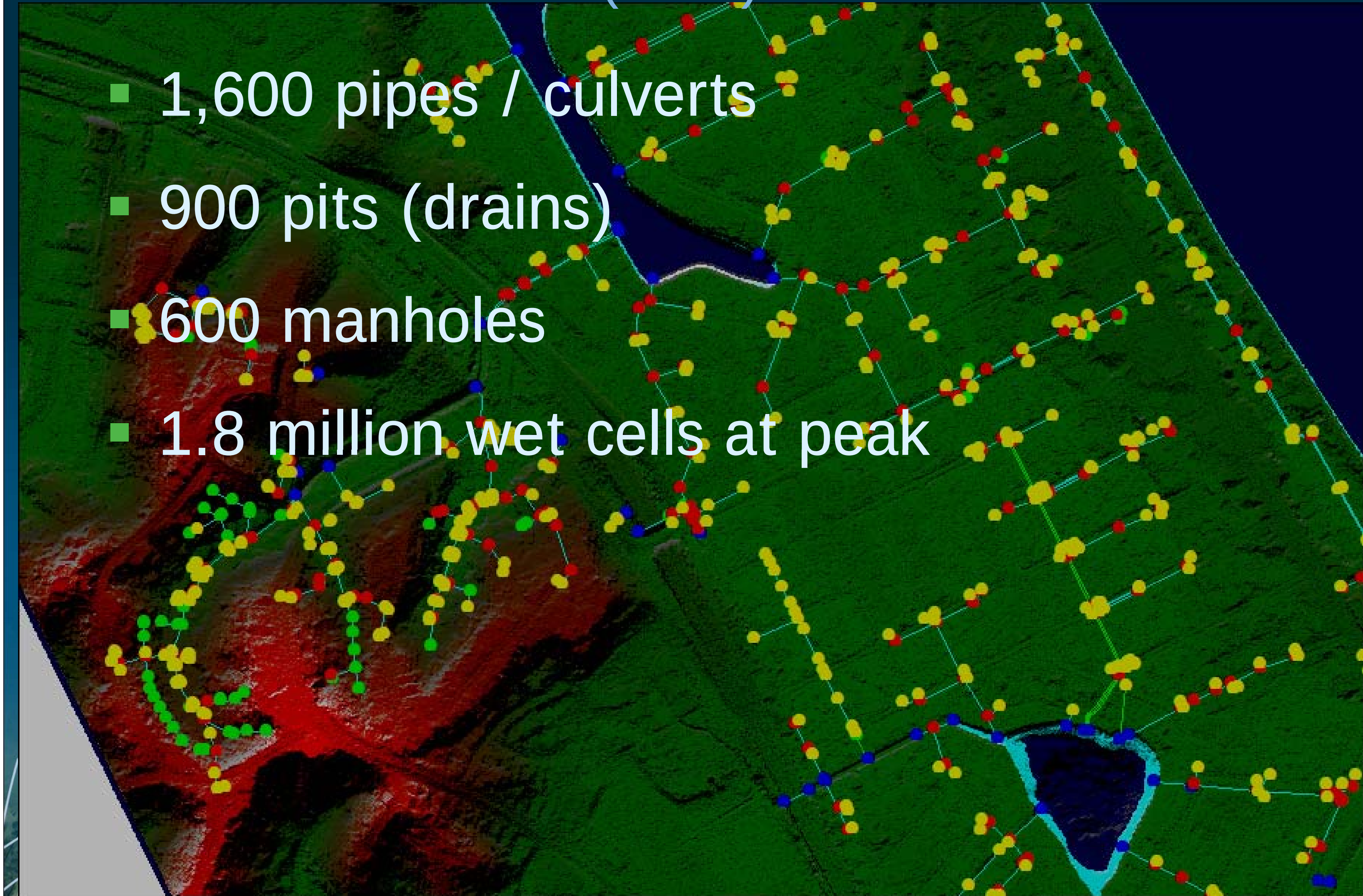
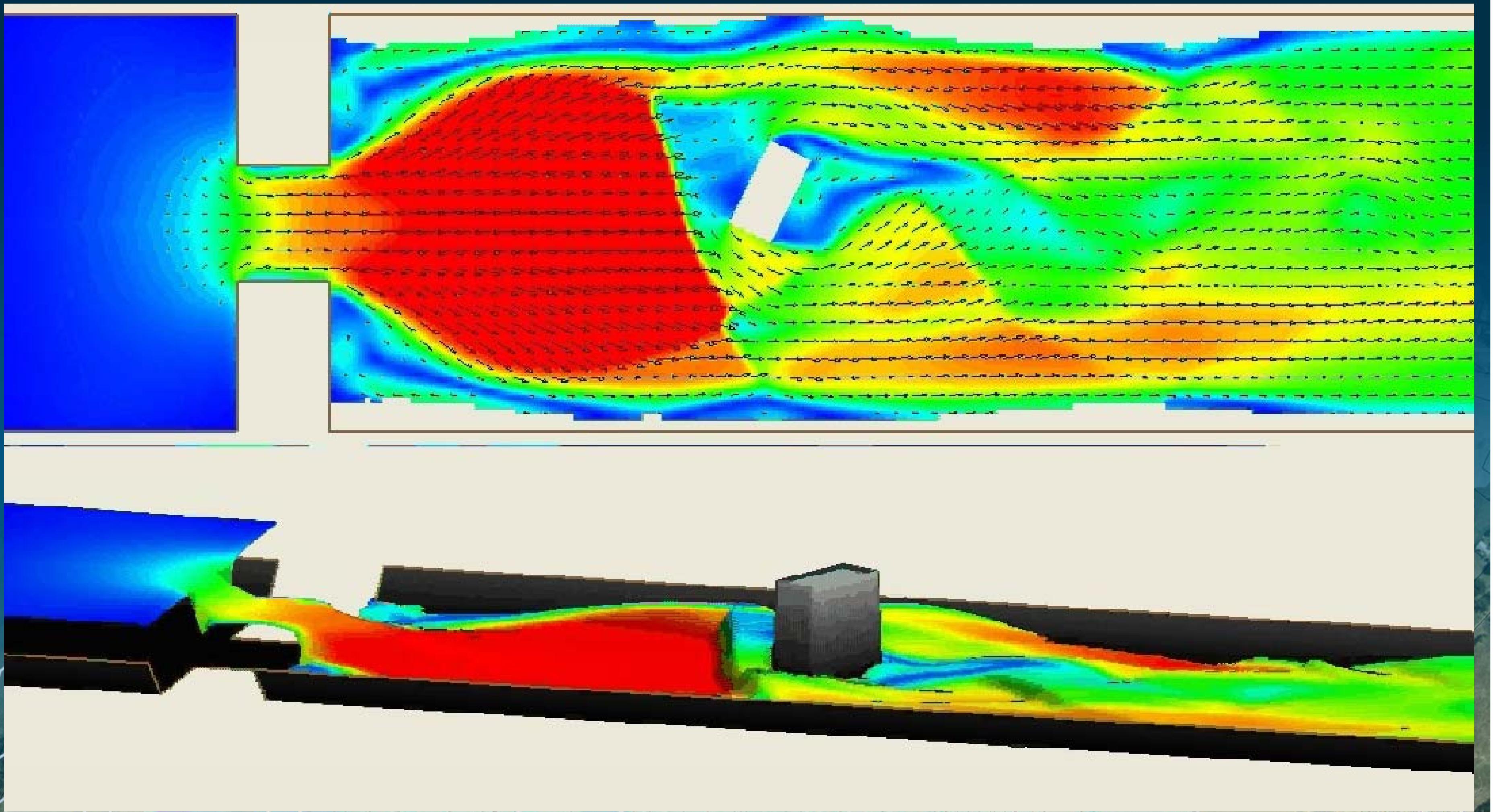
Detailed Urban Models (2008)



- 1,600 pipes / culverts
- 900 pits (drains)
- 600 manholes
- 1.8 million wet cells at peak

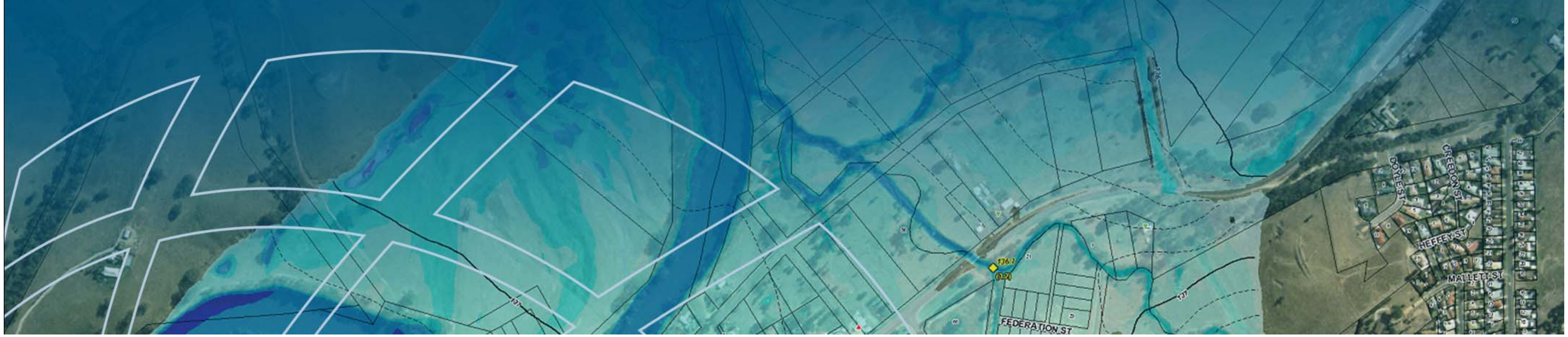
Fine-Scale Modelling
(TUFLOW FV Flexible Mesh Engine)



Influence of Cell Size

- 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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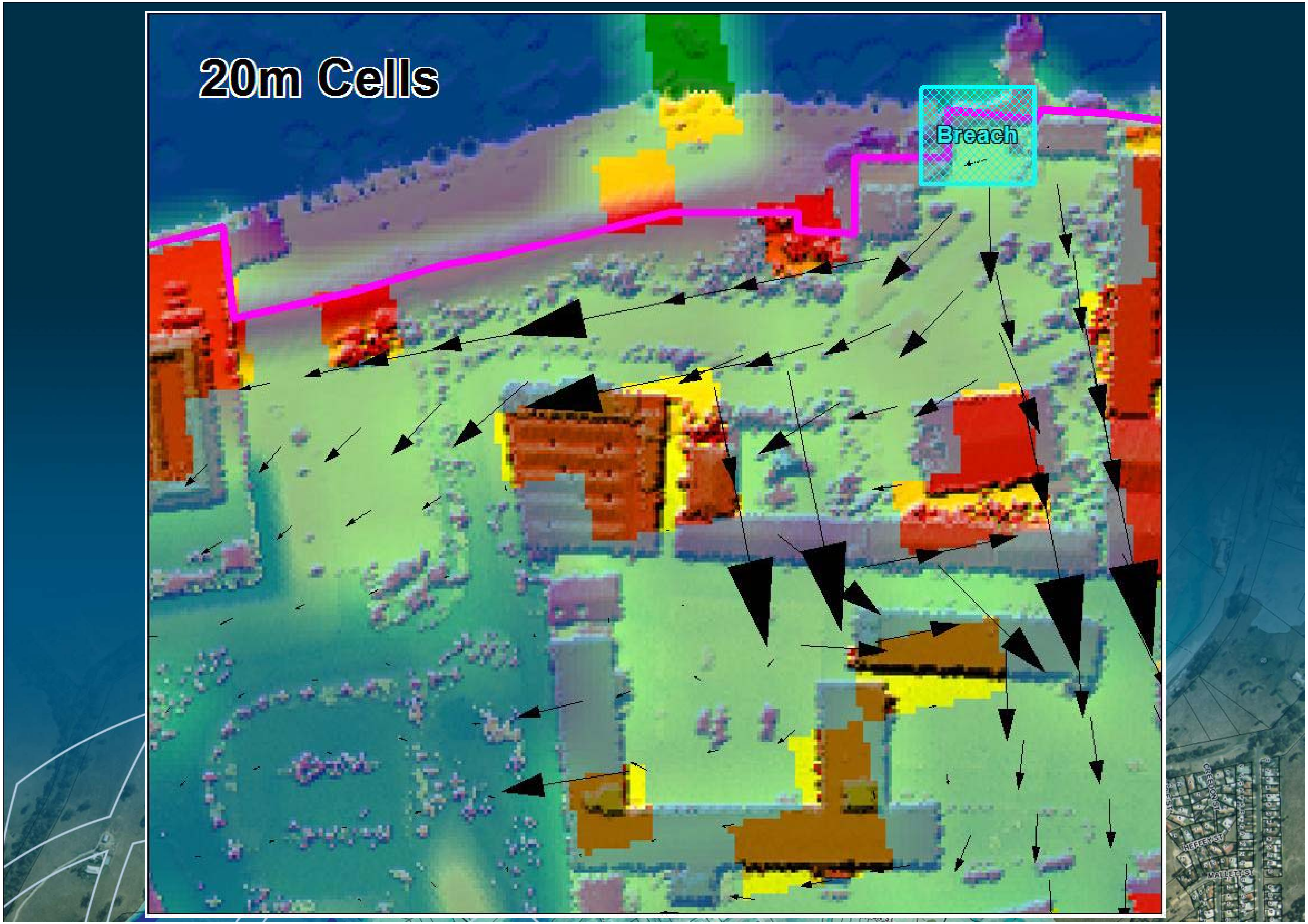
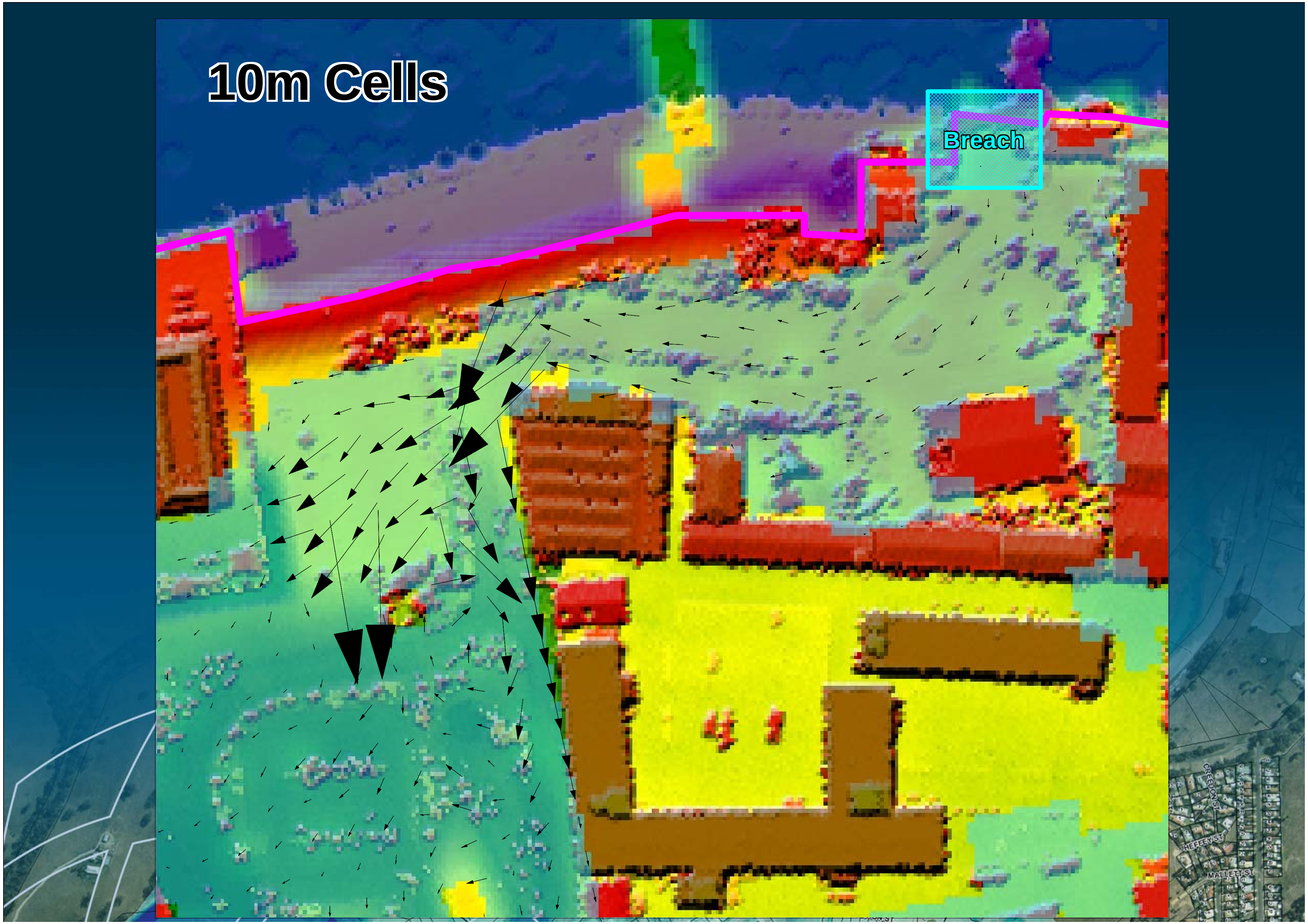
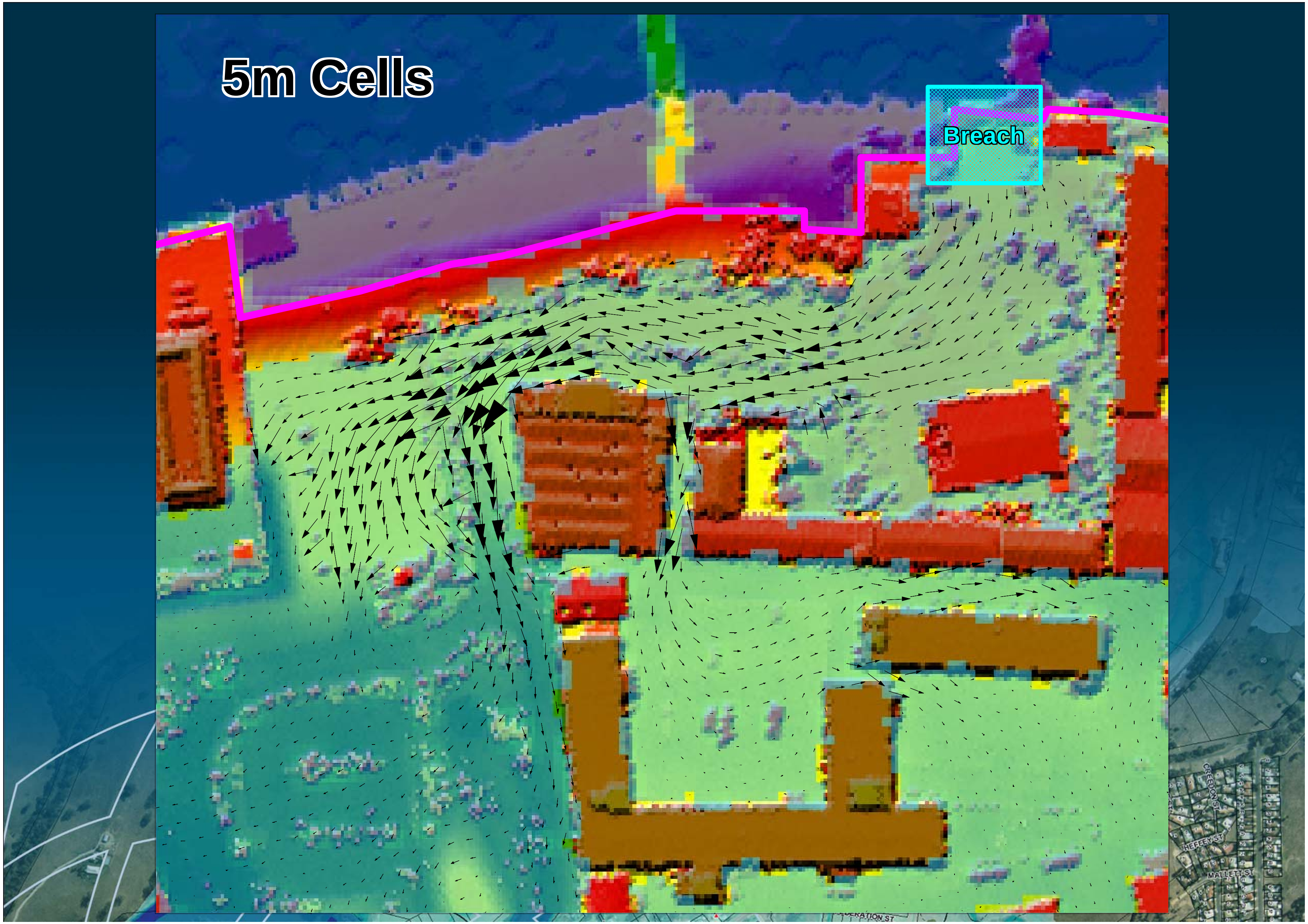
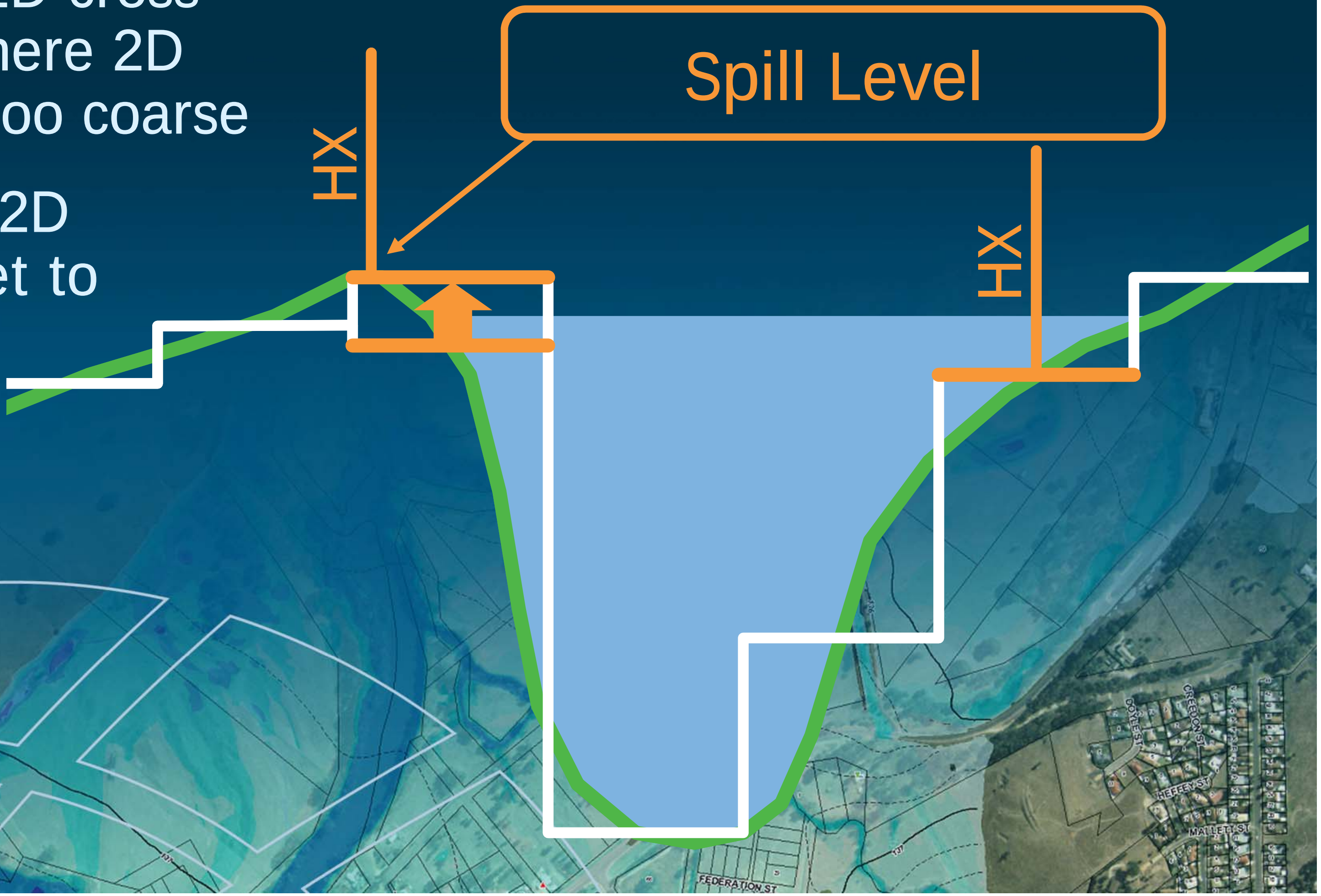

20m Cells
Breach


10m Cells
Breach


5m Cells
Breach

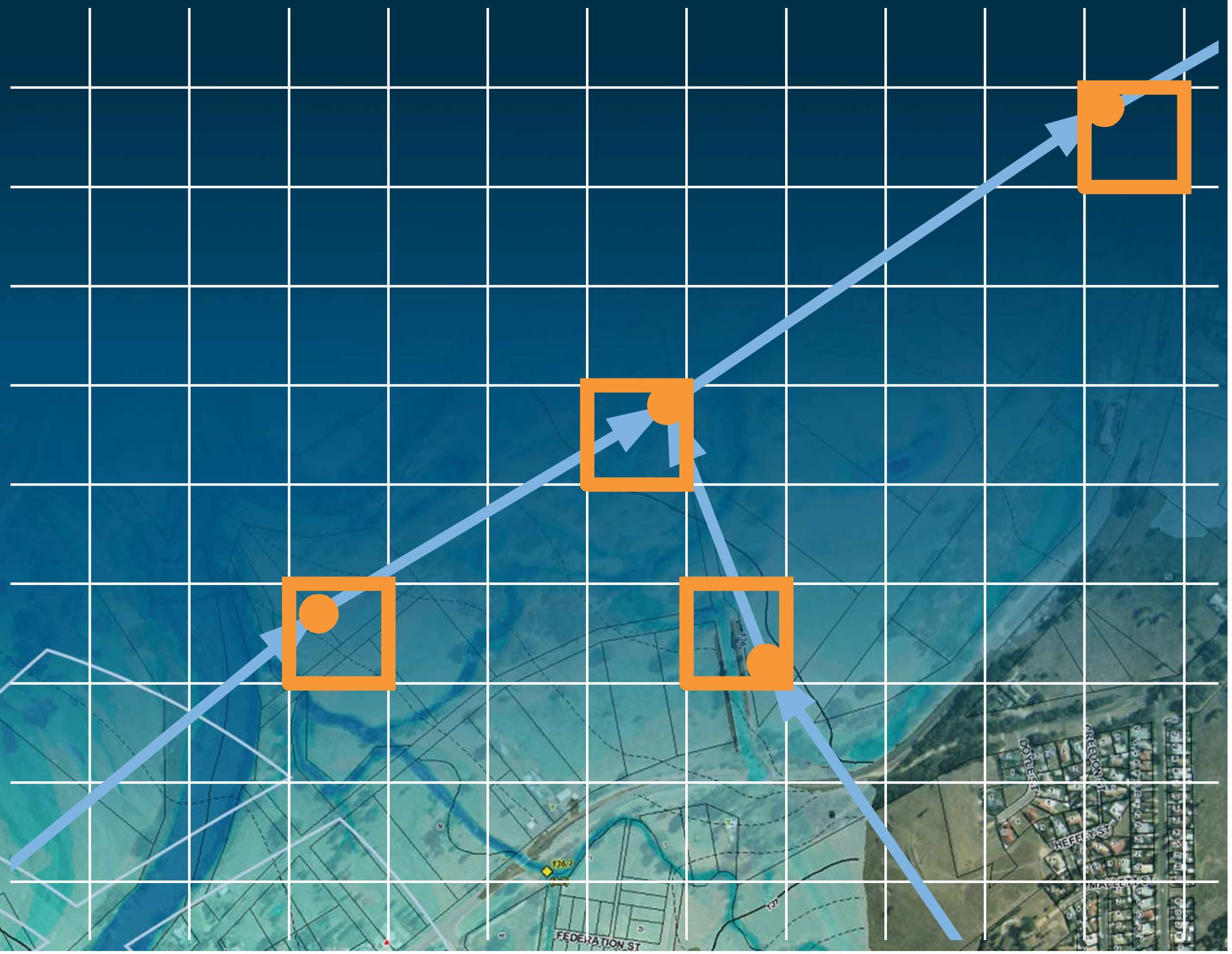
Use 1D Cross-Sections
Where 2D Resolution Too Coarse

- May need 1D cross-sections where 2D resolution too coarse
- Ensure 1D/2D interface set to levee crest



1D Underground Pipe Networks

- Use pits to connect pipe network with overland 2D
- 2D water level at cell drives 1D pipe hydraulics
  (unless pit is not full)
- Net pipe flow in/out of pit applied as sink/source to 2D cell



Conclusions

- 2D or 1D/2D models offer significant gains
  - in accuracy of flood modelling, risk and flood affect predictions
  - in stakeholder understanding and acceptance
- Need experience to operate/understand software
  - Make sure your 2D scheme solves key physical processes correctly
- Models still need to be
  - Calibrated where possible
  - Quality Controlled: Garbage In / Garbage Out


Eudlo Creek, 1952
Thank You