Flood Modelling 101

Bill Syme
Pavlina Monhartova

February 2023

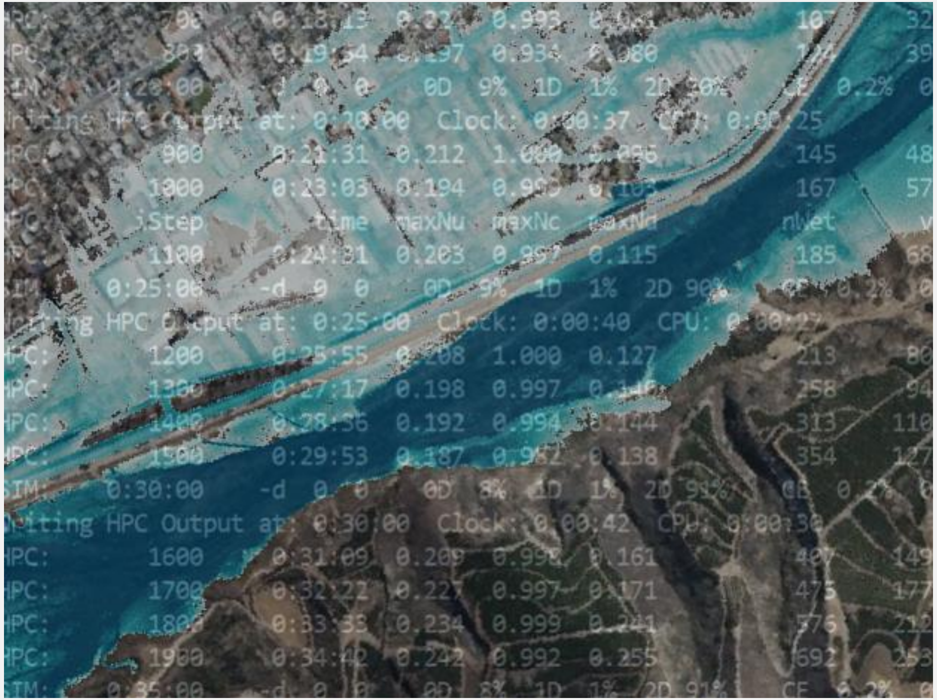
Flood Modelling 101
Today's Webinar

Fundamentals of flood modelling – Bill Syme

- Why?
- Brief history
- Solving the physics
- How Do You Know It's Right?
- Quality assurance
- Community consultation

Flood modelling check examples – Pavlina Monhartova

- Model resolution
- External boundaries
- Material spatial resolution
- Topography breaklines for hydraulic controls
- Timestep results check
- Culvert 1D/2D links

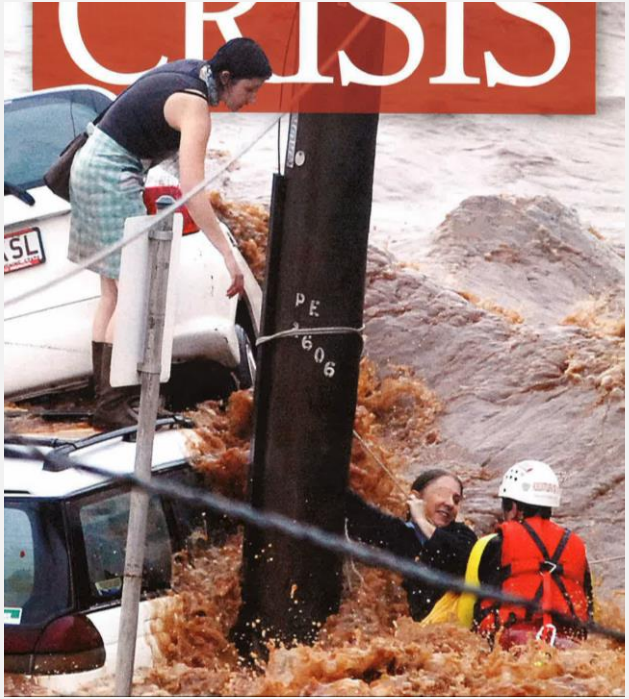


Flood Modelling
Why?

Inform Decision Makers
(Government, Authorities, Emergency Managers)

- Guidance on where and how to build
- Provide metrics
  - on the flood risk to people, infrastructure, the economy
  - to evaluate measures that reduce existing flood risks
- Predict the flood impacts due to
  - development
  - changes to land-use, climate
- Predict the flood risks during an event
- Advise on flood evacuation options for an event

Our flood modelling accuracy directly impacts the quality of the decision making

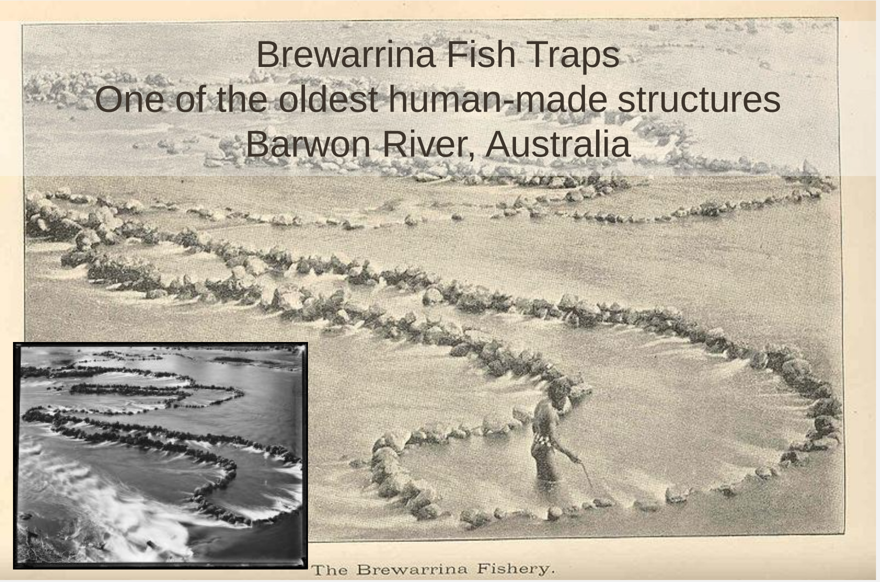


The Toowoomba Chronicle

Brief History

Flood Modelling 101

Brief History of Hydraulic Modelling
Before Computers



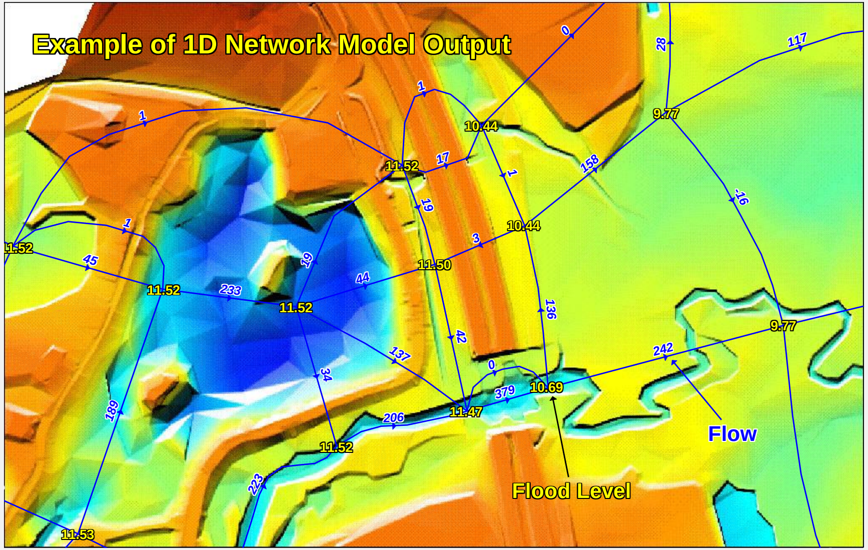
www.mpra.com.au/brewarrina-fish-traps
www.theguardian.com/australia-news/2015/jul/10/fish-traps-brewarrina-extraordinary-ancient-structures-protection

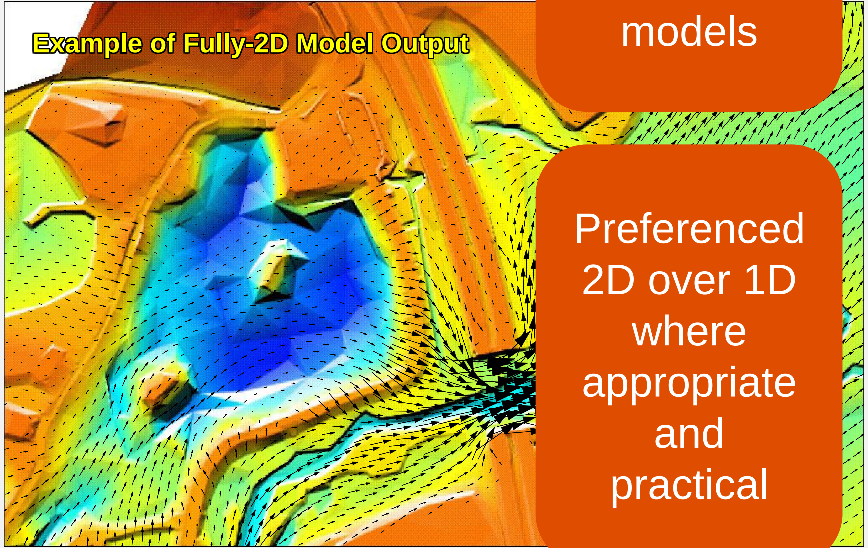
Brief History of Hydraulic Modelling 1970s to 1990s – 1D Rules!

Networked 1D models ruled flood modelling

Brief History of Hydraulic Modelling
Late 1990s – 2D or Not 2D?

2D models started to rule flood modelling from the early-2000s
(varies from country to country)





2D models proved to be more accurate than 1D models

Preferenced 2D over 1D where appropriate and practical

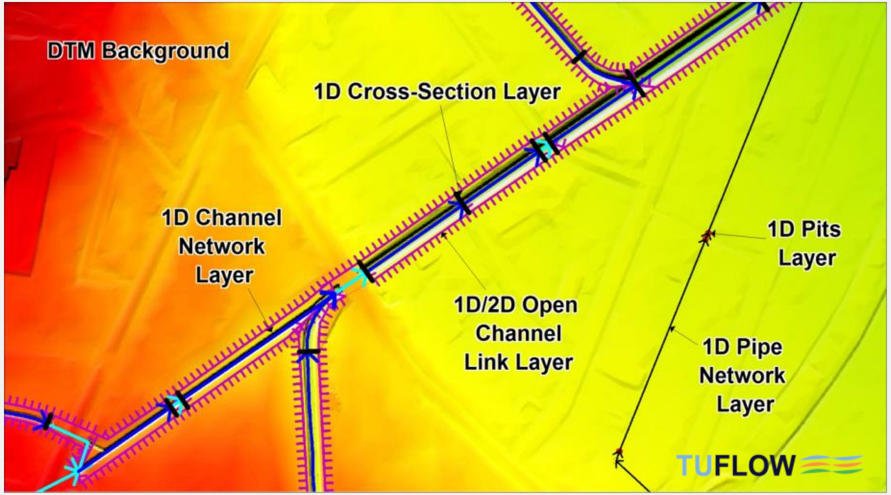
Brief History of Hydraulic Modelling
2000s – 1D/2D Linking a Game Changer

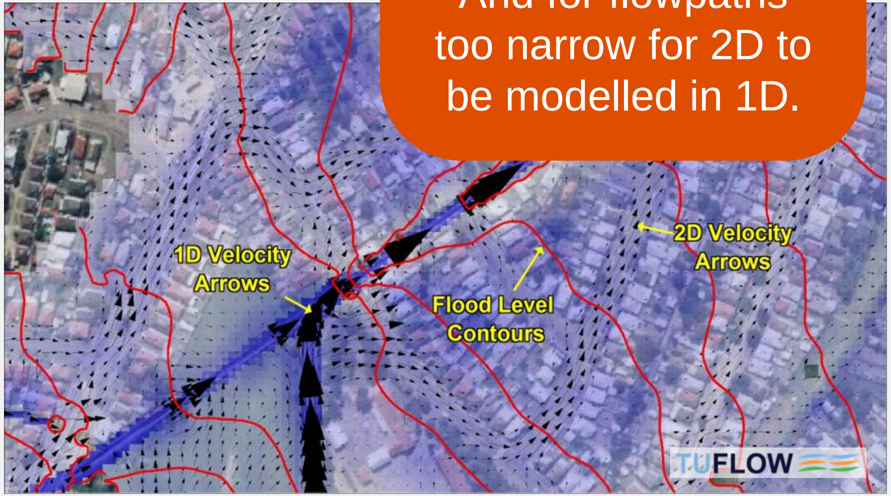
1D/2D linking allowed 2D models to be embedded inside broad-scale 1D models.

And for flowpaths too narrow for 2D to be modelled in 1D.

In 2000s computers were slow, 2D models small and coarse

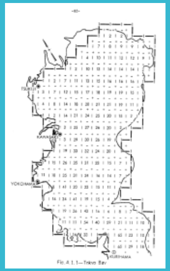
1D/2D linking was a game changer for flood modelling





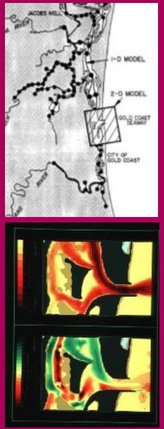
Brief History
Evolution of 2D (Flood) Hydraulic Modelling

1967
100 cells

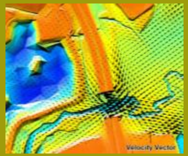


1984
1,000

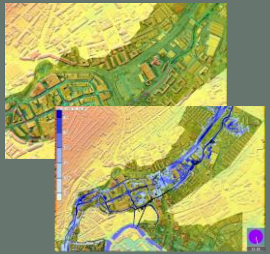
1990
10,000



1998
50,000



2003
100,000



2013
10,000,000 (GPU)

2020s
>1,000,000,000

Catchments

Pipes (1D) / Surfacewater (1D and 2D)

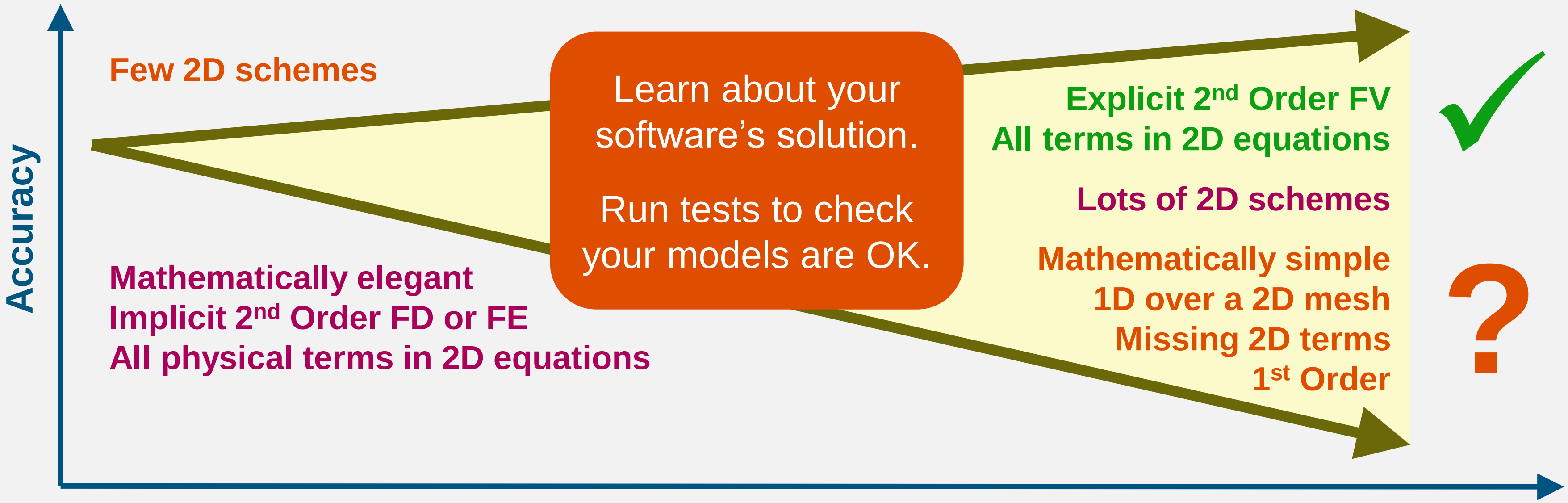
Rivers (Flooding)

Coastal Waters and Estuaries (Linked 1D/2D)

Coastal Bays

Brief History
Accuracy of 2D Hydraulic Modelling

1967	1984	1990	1998	2003	2013	2020s
100 cells	1,000	10,000	50,000	100,000	10,000,000 (GPU)	>1,000,000,000



Solving the Physics

Flood Modelling 101

Solving the Physics
The (Important) Physics Varies According to the Flow

Low velocity flows

- Slow moving water; backwaters
- Sub-critical flow (downstream controlled)
- Inertia and turbulence not important
- ➔ **Storage dominated flow**
- ➔ **Mass balance equation rules**

High velocity flows

- Fast moving water
- Complex flow patterns, hydraulic jumps
- Super or sub-critical flow
- ➔ **Conveyance dominated flow**
- ➔ **Momentum equation rules**

1990 Flood Newcastle. Courtesy David Gibbins, Newcastle City Council.

1990 Flood Newcastle. Courtesy David Gibbins, Newcastle City Council.

Solving the Physics
Many Different Approaches

Learn to appreciate what physical terms are important

How Velocity changes over time | Inertia Term | Gravity | Bed Resistance | Turbulence (Eddy Viscosity) | Other Forces

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

1990 Flood Newcastle. Courtesy David Gibbins, Newcastle City Council.

How Velocity changes over time | Inertia Term | Gravity | Bed Resistance | Turbulence (Eddy Viscosity) | Other Forces

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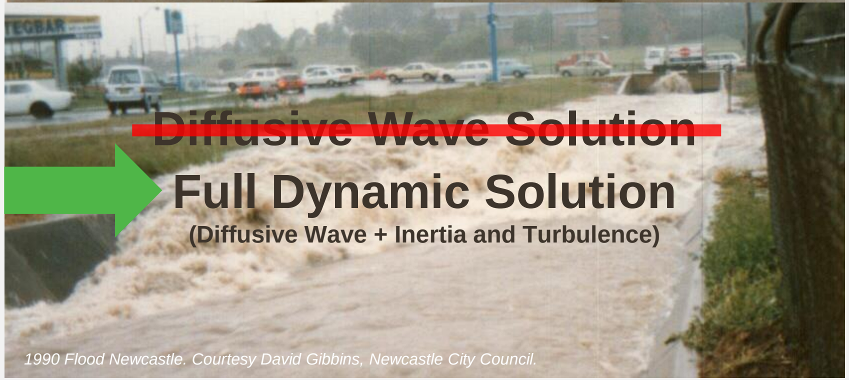


1990 Flood Newcastle. Courtesy David Gibbins, Newcastle City Council.

Solving the Physics
Learn to Appreciate the Energy of Water

Total Energy = h + $V^2/2g$

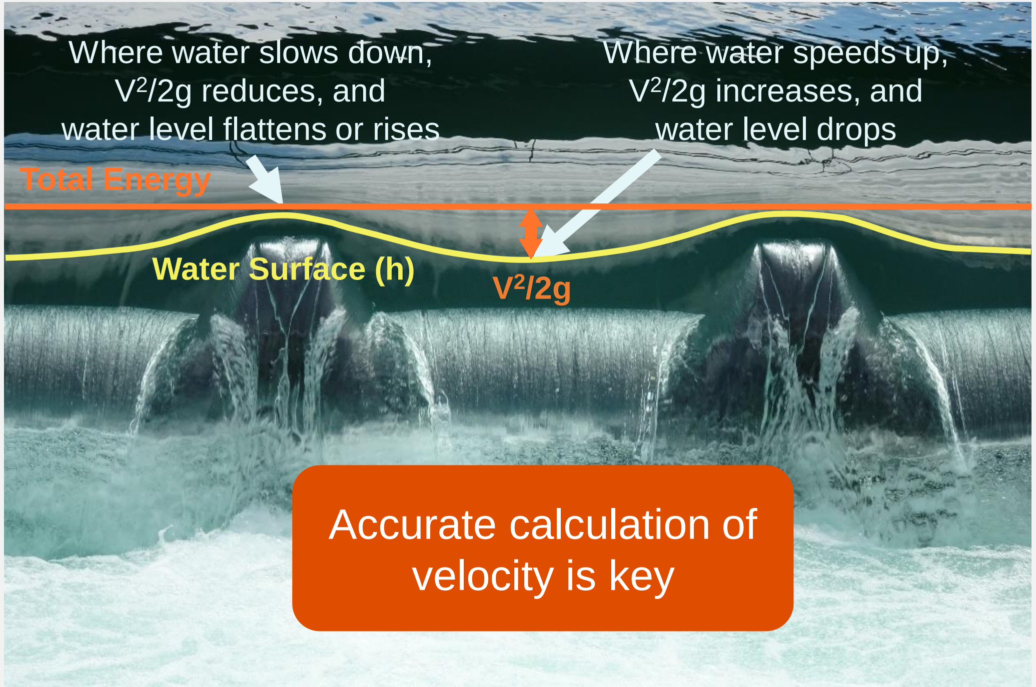
= water level + kinetic energy

Energy dissipation

- Bed resistance (e.g. Manning's formula)
- Turbulence (e.g. eddies)

Energy dissipation is all about V^2

- V = 1 m/s; kinetic energy = 0.05 m
- V = 4 m/s; kinetic energy = 0.82 m



Solving the Physics
Energy Dissipation

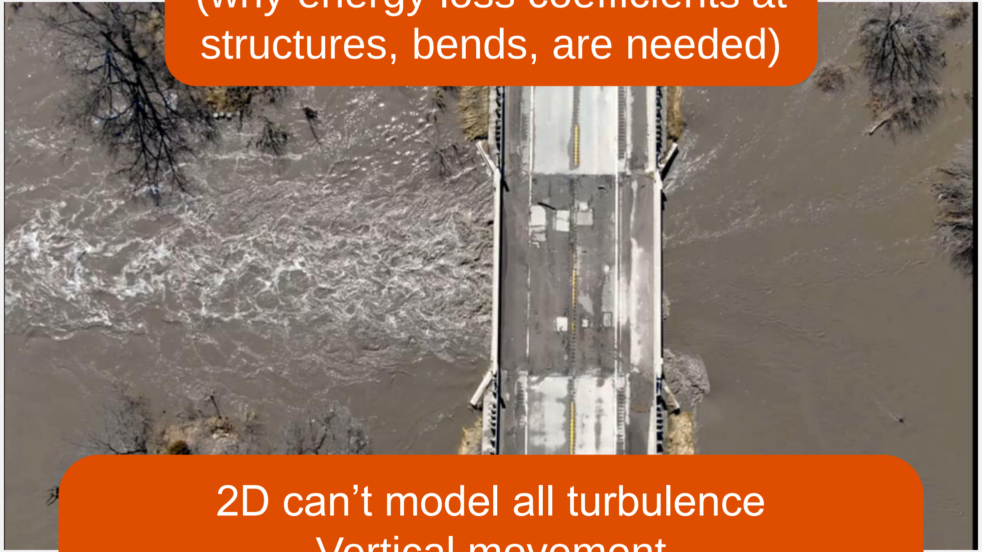
Flowing water dissipates its energy as heat

Bed friction (e.g. Manning's equation)

Turbulence

- Bends, rock ledges
- Constrictions
  (e.g. cross-drainage structures)
- 1D can't model turbulence
  (why energy loss coefficients at structures are needed)
- 2D can't model all turbulence, eg.
  - In the vertical
    (eg. may need additional energy losses at sharp bends)
  - Sub-grid obstructions
    (eg. energy losses for piers)
  - Sub-grid turbulence
    (need to include the 2D turbulence term in equations)

1D can't model turbulence
(why energy loss coefficients at structures, bends, are needed)



2D can't model all turbulence
Vertical movement
Energy losses from sub-grid obstructions
Sub-grid turbulence

How Do You Know It’s Right?

Flood Modelling 101

Flood Modelling
How Do You Know It's Right?

Young Me:
I've got my program running. Check out these (cool) results.

My Supervisor:
Well done, etc, etc. But how do you know it's right?

Young Me:
Ummm, errrr, not sure

How Do You Know It's Right?
Robert Manning, 1889

On the Flow of Water in Open Channels and Pipes.
By Robert Manning, M. Inst. C.E.; Past President,

Of those proposed by Mr. Manning, No. V. ($V = C\,S^{\frac{1}{2}}\,R^{\frac{2}{3}}$) is of simple form, and, judging by the tables given in the paper, gives as good results as those obtained by Bazin and Kutter.

of value. If the author's formula proves more exact in its results than those which have preceded it, and less laborious in calculation than that of Ganguillet and Kutter, then it will form a very valuable aid to the hydraulic engineer. Its accordance, however, in its results with the results of actual observation, is of far greater importance than the method by which it has been arrived at. Its being based on correct principles, and in conformity with ascertained data, may lead to accuracy in results; but, in the absence of any exact theory, its concordance with experiments over a wide range is the only real standard of its value.

Mr. L.F.Vernon-Harcourt's feedback on Robert Manning's work in 1889

Manning's formula

- A very simple representation of a very complex process
  - Bed resistance (force) that slows water down
- The words ***"its concordance with experiments over a wide range is the only real standard of its value"*** ***are no less true today***

https://www.enviroengineer.scot/home/engineer/robert-manning/

There is no exact solution to our equations

No model precisely reproduces reality

So benchmarking to known data is paramount

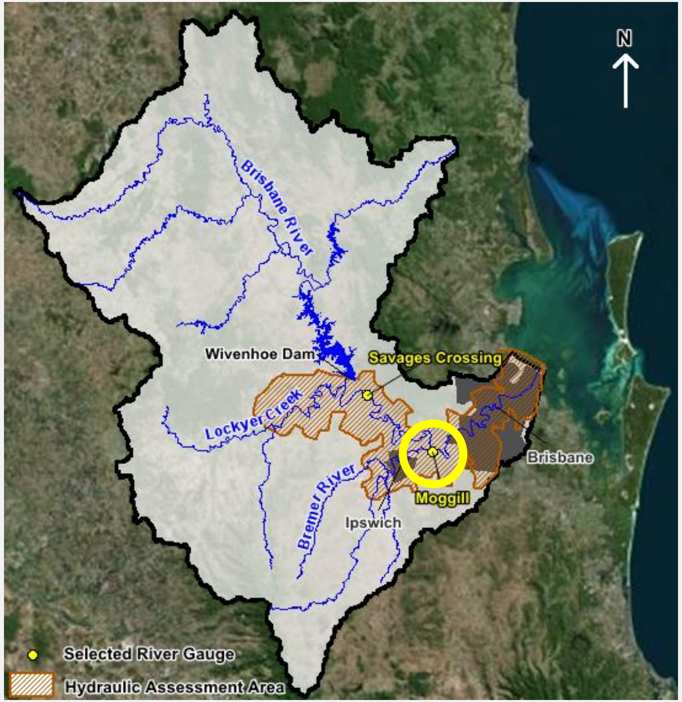
How Do You Know It's Right?
Calibration Example – Brisbane River

Brisbane River Data Set

- Excellent and comprehensive – quality data set
- Wide range of floods
- **River flows measured (unusual)**
  - **i.e. accurate inflows**

Moggill Gauge

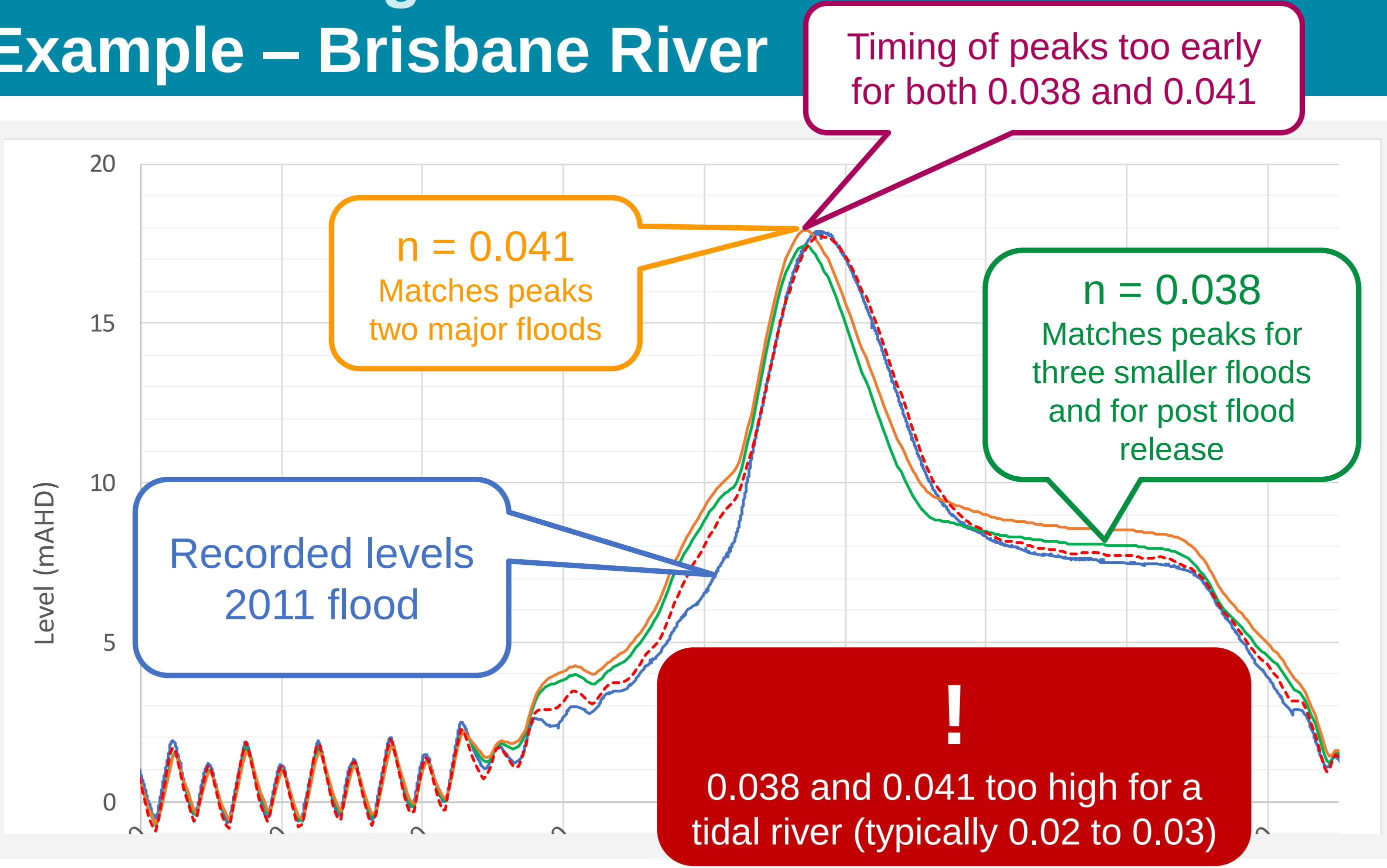
- 75 km up river from ocean
- Tidal
- 2011 flood (~1 in 100 event)
  - Peak 18 m above mean tide



How Do You Know It's Right?
Calibration Example – Brisbane River

Moggill Gauge

- River Manning's n of **0.038** matches peaks for three **minor** floods and steady-state post flood dam releases
- n = **0.041** matches peak for **major** floods
- Both show poor timing of flood peak



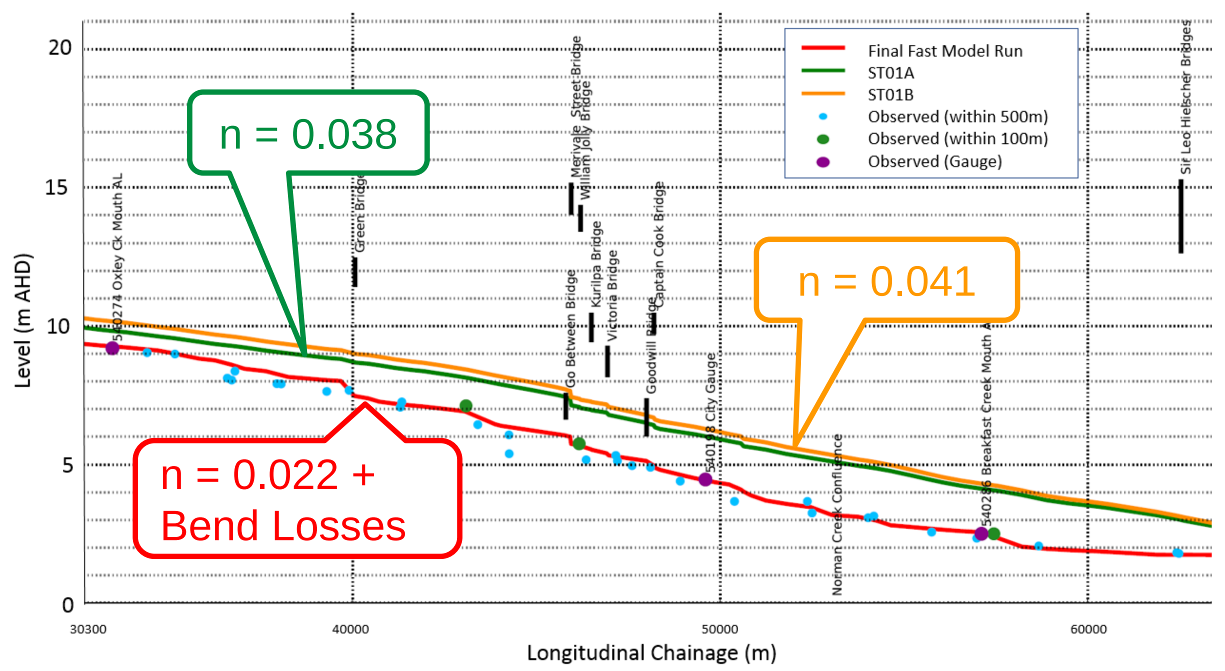
How Do You Know It's Right?
Calibration Example – Brisbane River

If you stuck with 0.038 or 0.041 you would be terribly wrong!

Why?

- More data downstream
- **Modelled peak levels wrong by up to 2 metres**

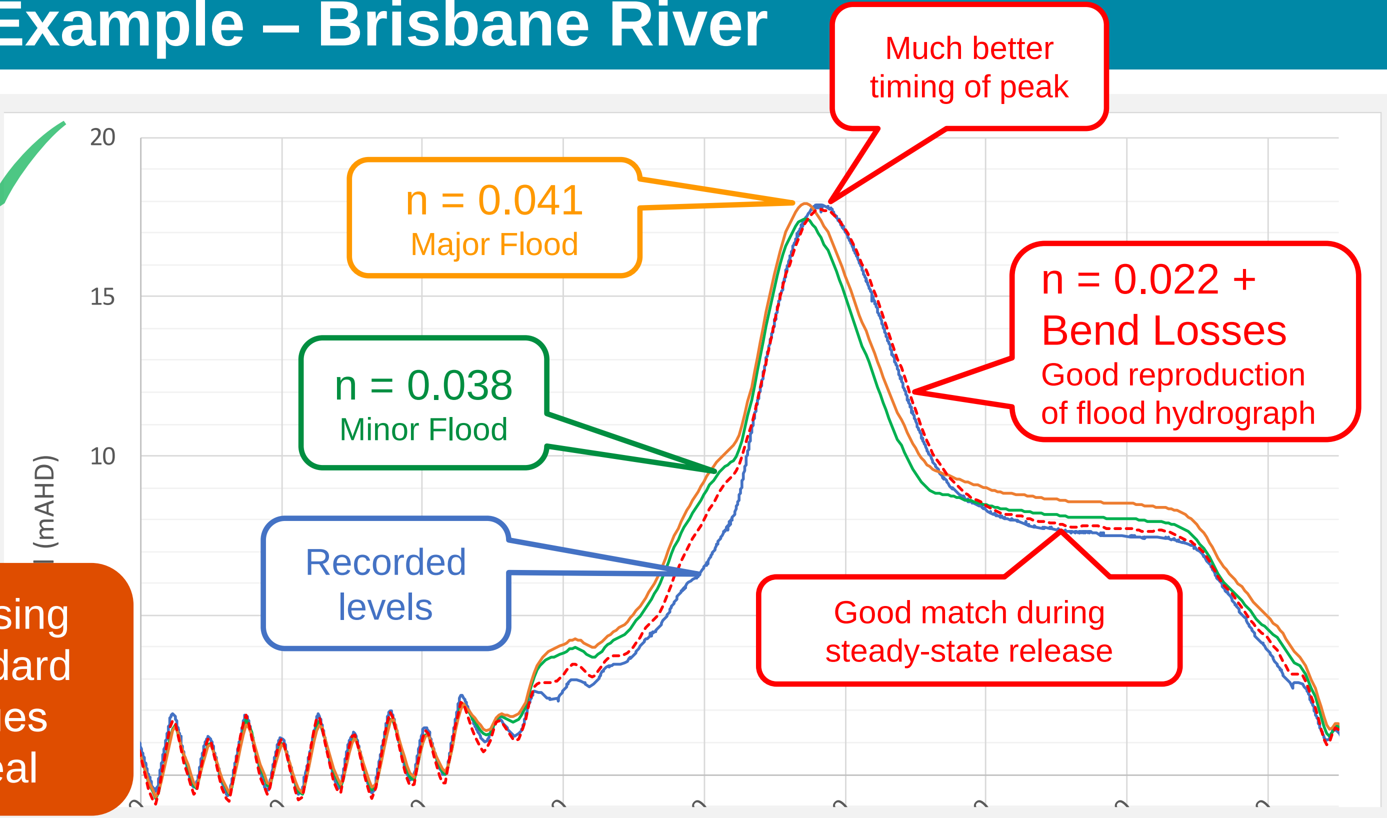
Switched to using industry standard Manning's n (0.022) with energy losses at bends



How Do You Know It's Right?
Calibration Example – Brisbane River

n = 0.022 + bend losses

- Good calibration for
  - tide
  - three minor floods
  - two major floods
  - post-dam releases
  - **using one set of parameters**



Be very wary of using non-industry standard Manning's n values – they are not real

How Do You Know It's Right?
Calibration Example

Previous slides from a 1D Only Model

What about 2D?

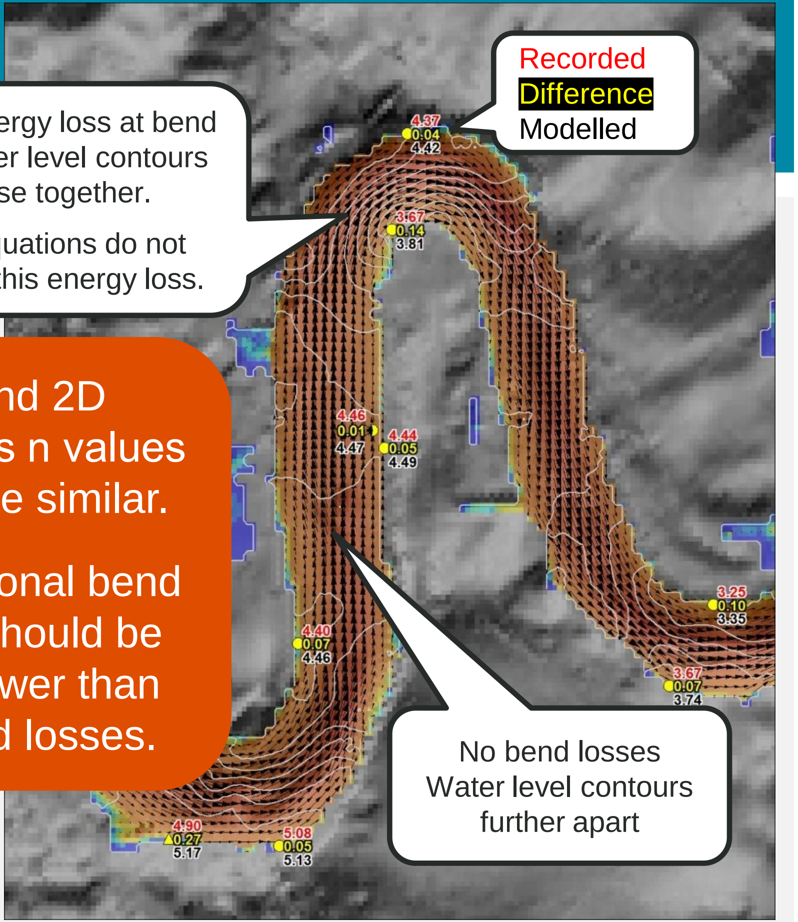
- Terrible calibration using n = 0.038 or 0.041
- **Good 2D calibration for all events using same n = 0.022 and ~20% of 1D bend losses**
- Typical calibrated bend loss ($V^2/2g$) values:
  - **180** degree bend: **1D = 1.5** **2D = 0.3**
  - **90** degree bend: **1D = 0.75** **2D = 0.15**
- Why are (additional) bend losses needed for 2D?
  - Because 2D equations simulate majority of bend losses
  - But not the losses due to vertical (3D) water circulations

High energy loss at bend
2D water level contours close together.

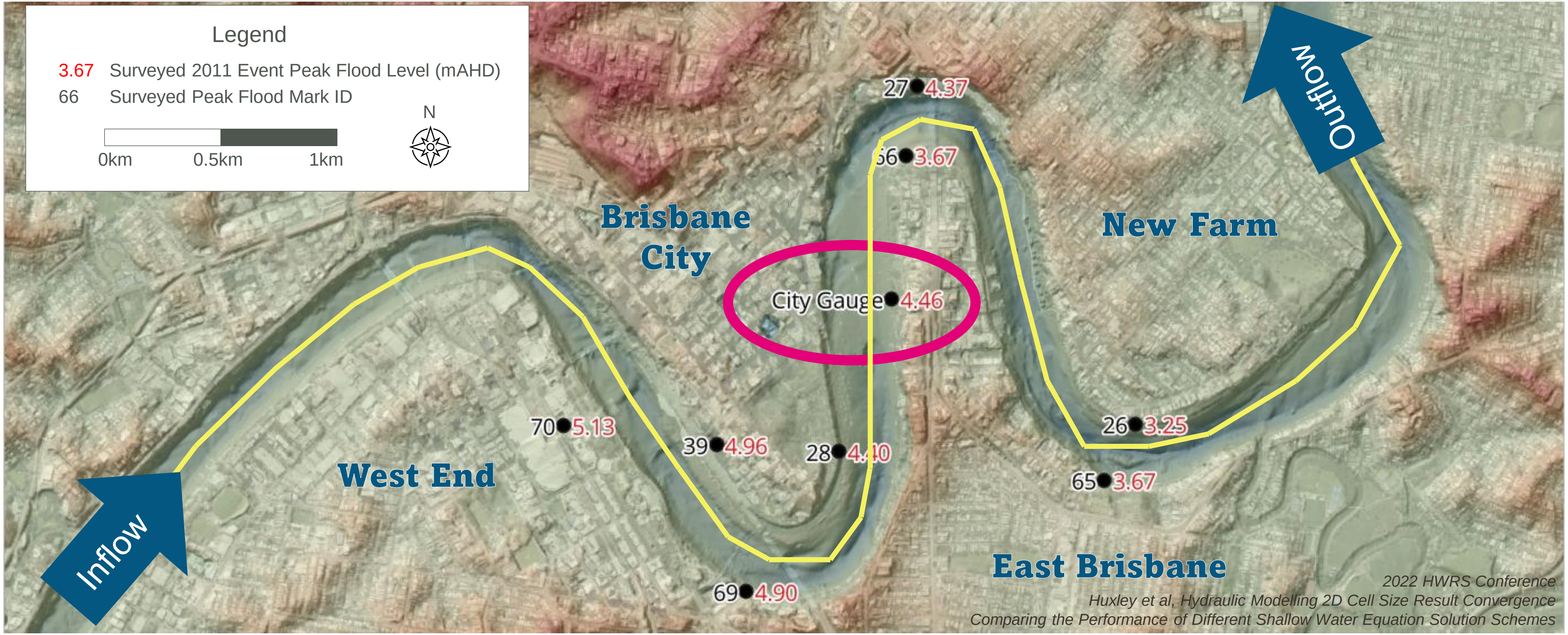
1D equations do not model this energy loss.

1D and 2D Manning's n values should be similar.

2D additional bend losses should be much lower than 1D bend losses.



How Do You Know It's Right?
Brisbane River Benchmark Model



2022 HWRS Conference
Huxley et al, Hydraulic Modelling 2D Cell Size Result Convergence
Comparing the Performance of Different Shallow Water Equation Solution Schemes

How Do You Know It's Right?
Solution Accuracy

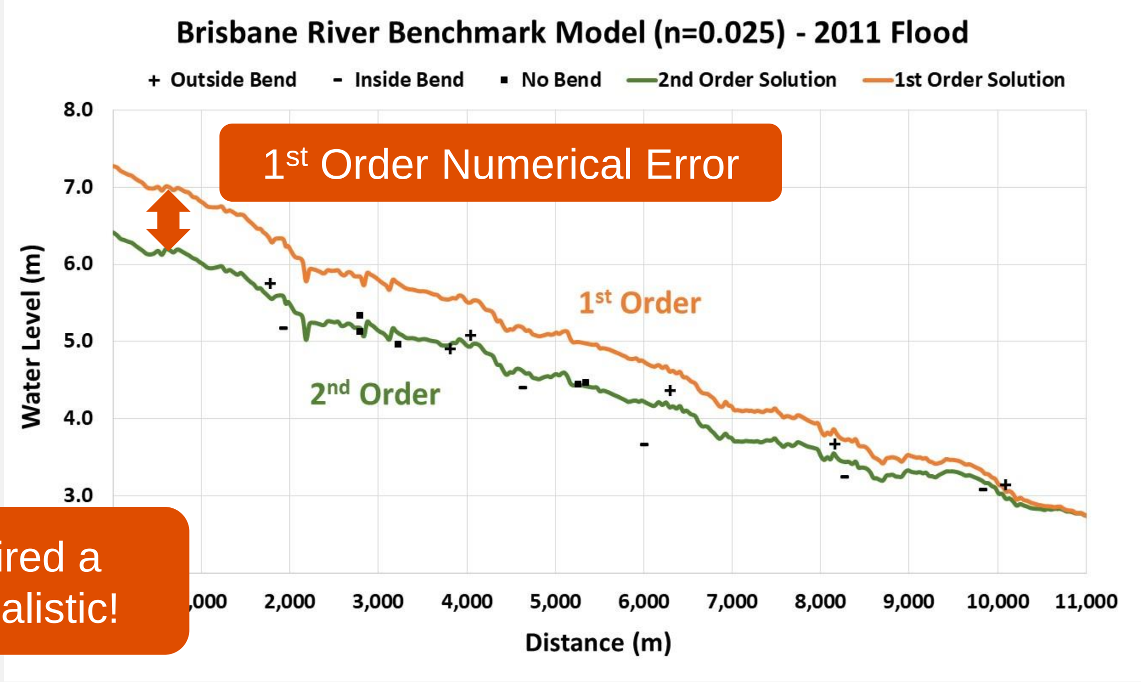
No two solutions are the same

- Wide choice now available

Which one? Is it appropriate?

➔ Benchmarking is needed

- Theory
- Flume measurements
- Calibration data
- Comparison of solvers

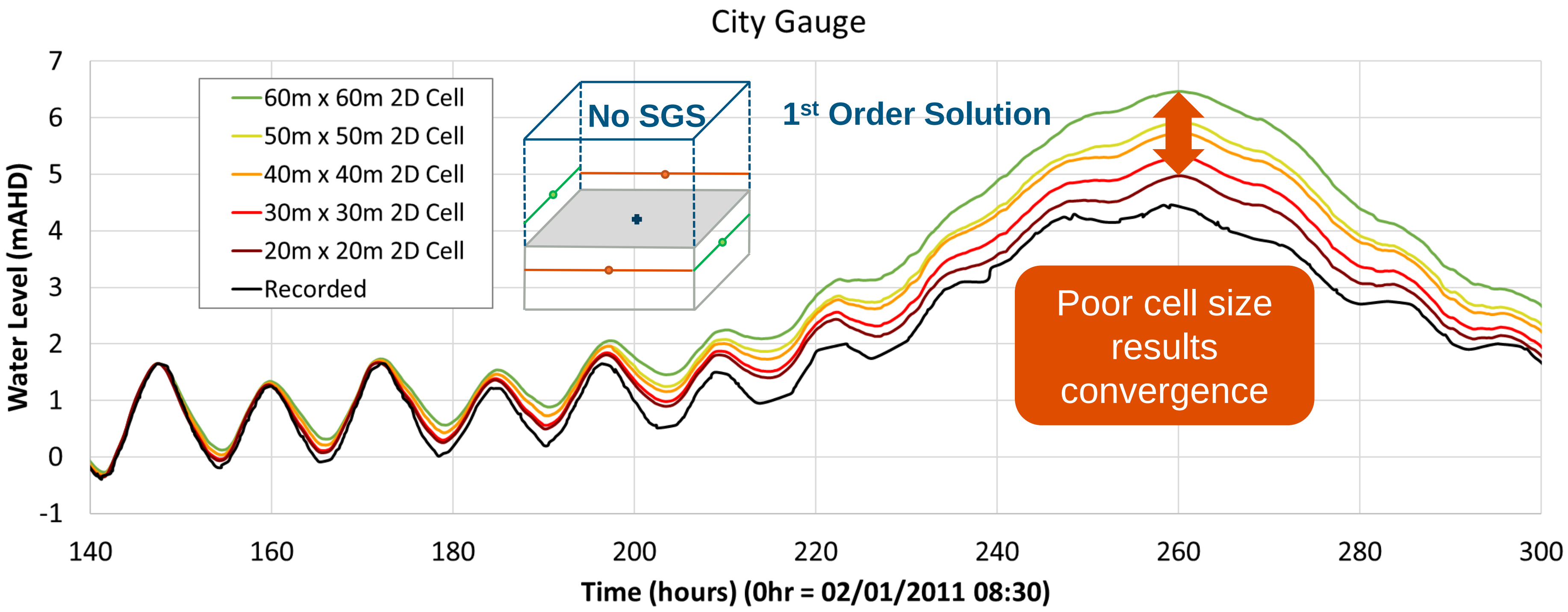


To calibrate 1st Order required a Manning's n = 0.018 – unrealistic!

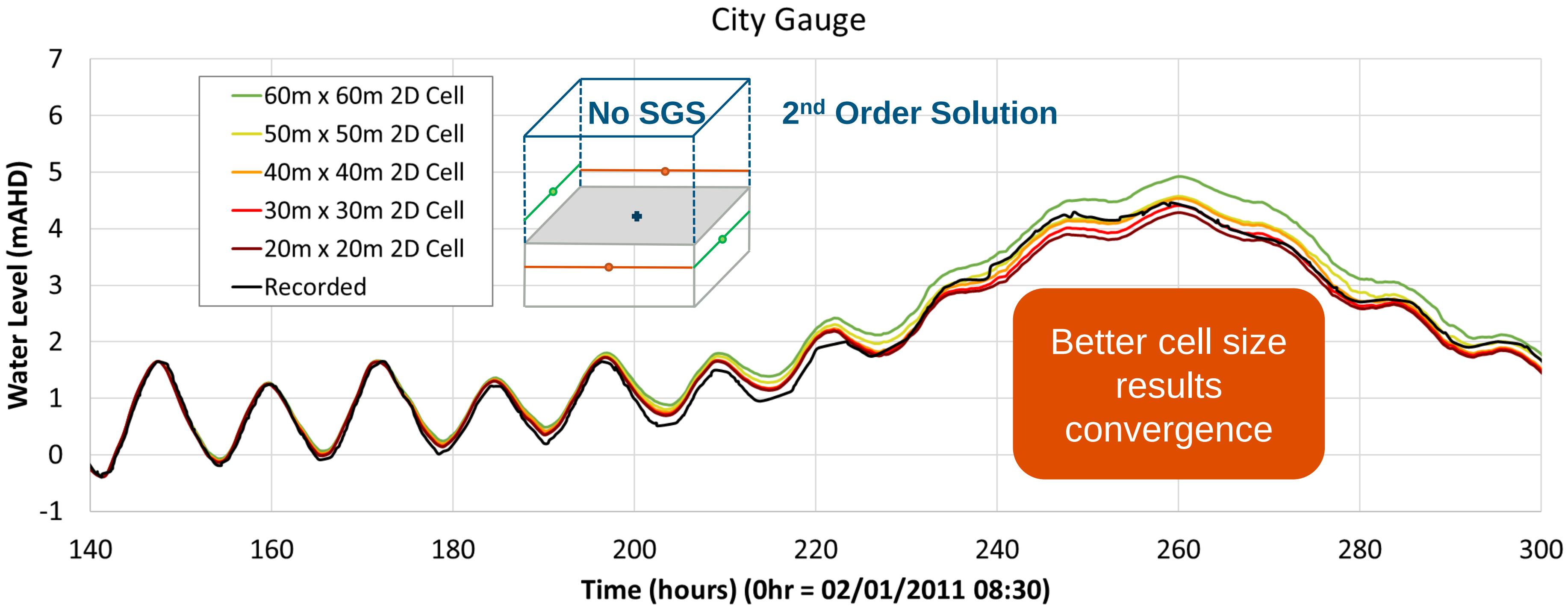
TUFLOW

aws Australian Water School

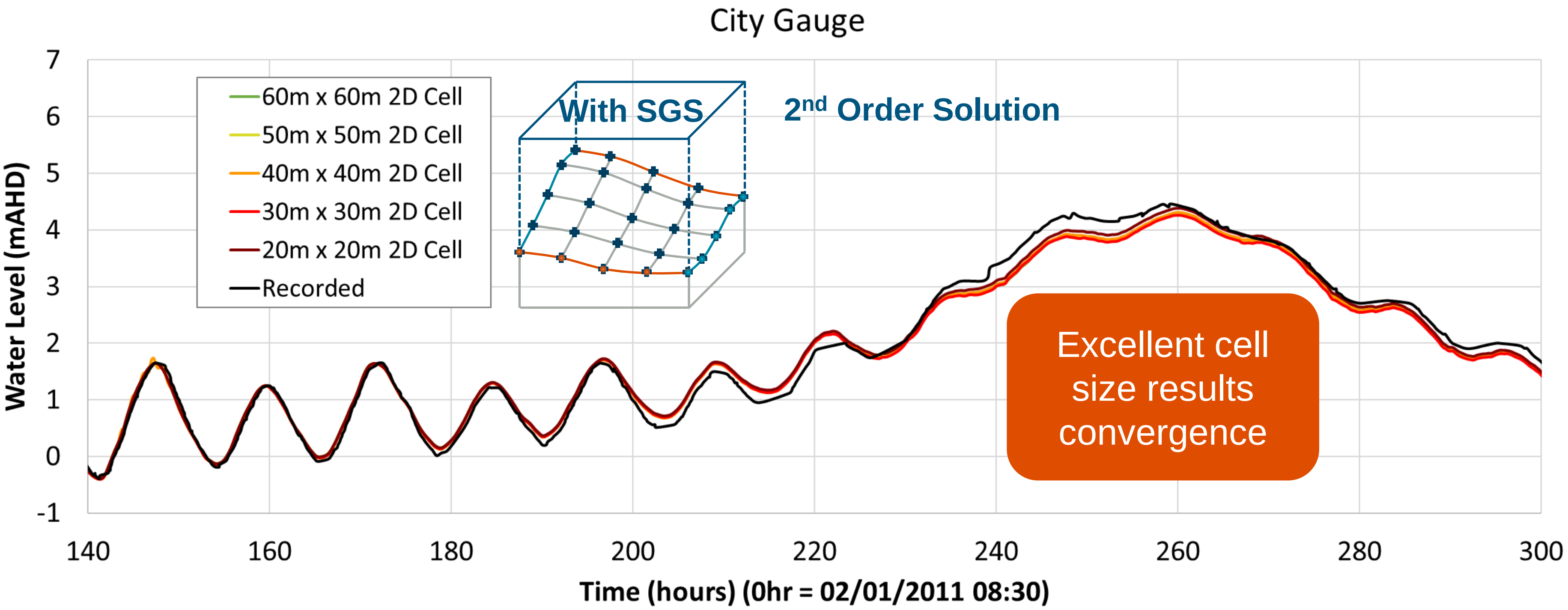
How Do You Know It's Right?
1st Order Solution – Cell Size Results Convergence



How Do You Know It's Right?
2nd Order Solution – Cell Size Results Convergence



How Do You Know It's Right?
2nd Order Solution with SGS – Cell Size Convergence



Quality Assurance

Flood Modelling 101

Quality Assurance
Garbage In, Garbage Out

GIGO!

Accuracy of your model is directly dependent on

- Accuracy of your input data
- Good model setup (schemetisation)

I can't EMPHASISE this enough!!!

https://marketbusinessnews.com/financial-glossary/gigo-garbage-in-garbage-out/

Quality Assurance
Types of Garbage

Topographic Data (Ground Levels / Bathymetry)

- #1 – topographic accuracy MUST reflect the modelling objectives
- Hydraulic controls (eg. road embankments) must be enforced

Unrealistic Bed Resistance Values (Manning's n)

- Non-industry standard Manning's n values are a red flag (calibrated or not calibrated)
- For uncalibrated models use industry standard values

Unrealistic Energy (Form) Losses

- Must reflect fundamental physics – think $V^2/2g$
- Relevant at, for example, pronounced bends, submerged rock ledges, structures
- Challenging as sometimes minimal guidance
- 2D may need additional energy losses but 2D values much less than 1D values

Boundaries

- Inaccurate inflows – often the greatest source of uncertainty!
- Stage-discharge (hQ) boundaries close to area of interest – must be well downstream
- Poor boundary configuration – must reflect the boundary assumptions
  - Most boundaries assume there is a horizontal water or energy level, so digitise the boundary ~perpendicular to flow

Structures – another whole webinar (or two)!

- See these AWS webinars
  - tuflow.com/library/webinars/#structures
  - tuflow.com/library/webinars/#nov2022_hydraulic_modelling_bridge
  - tuflow.com/library/webinars/#urban_pipes

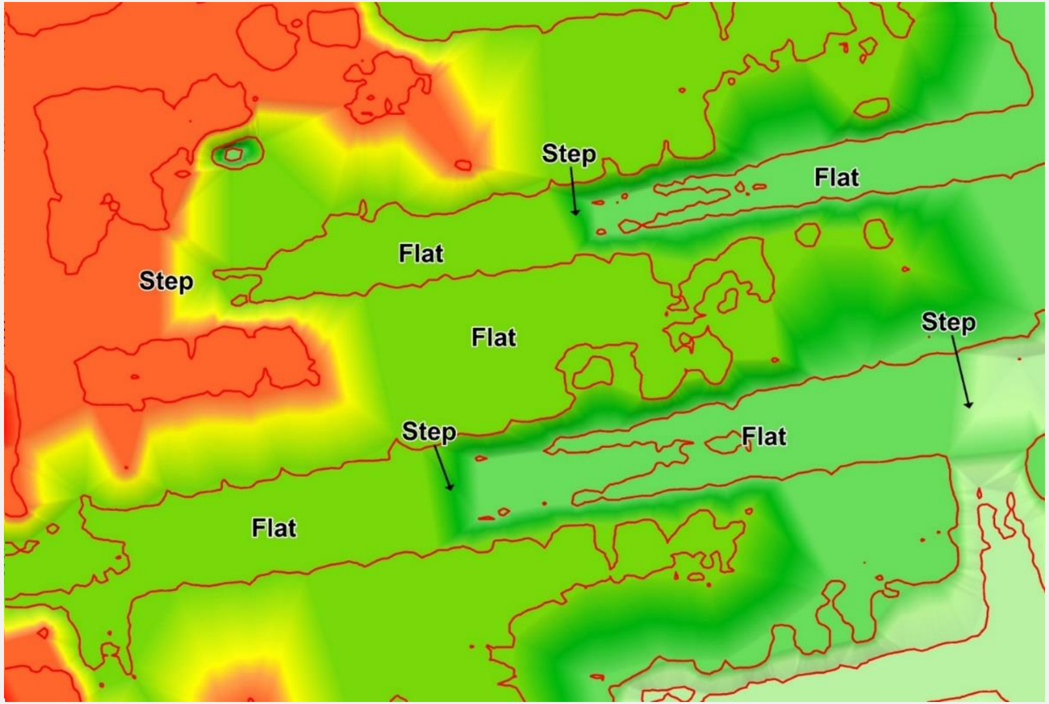
Quality Assurance
Look at the Results, Please

Please spend time

- Panning around looking at how the water is moving
- Display
  - Velocity arrows
  - Water level contours as lines
  - Depth shading

Any time spent onsite invaluable

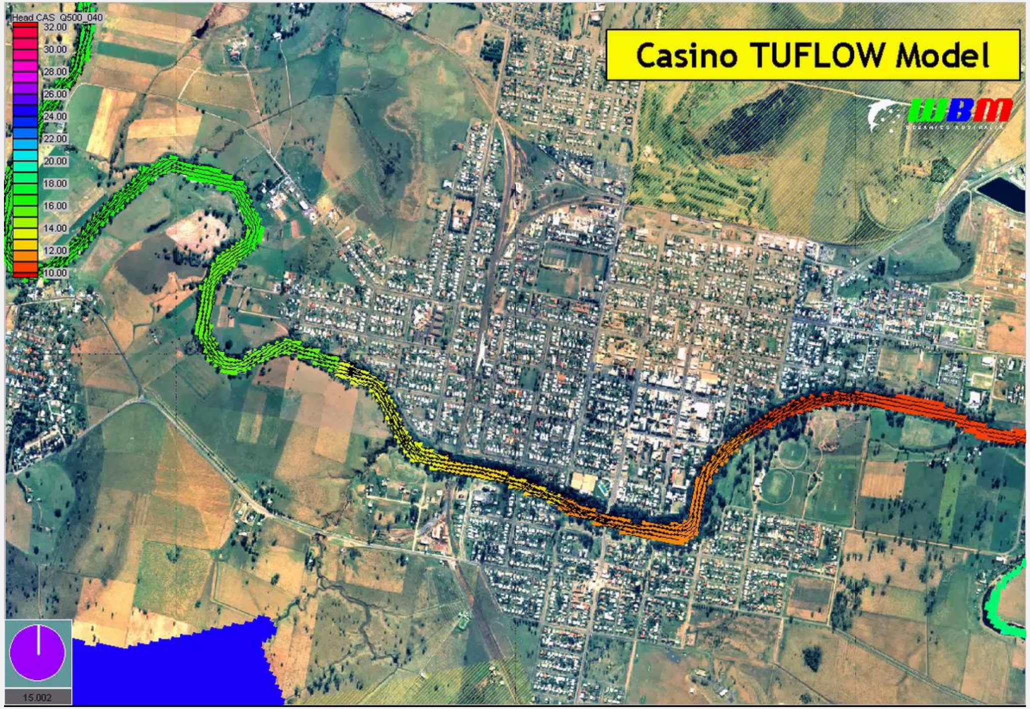
- Talk with locals – they know
- Appreciate the scale



Community Consultation

Flood Modelling 101

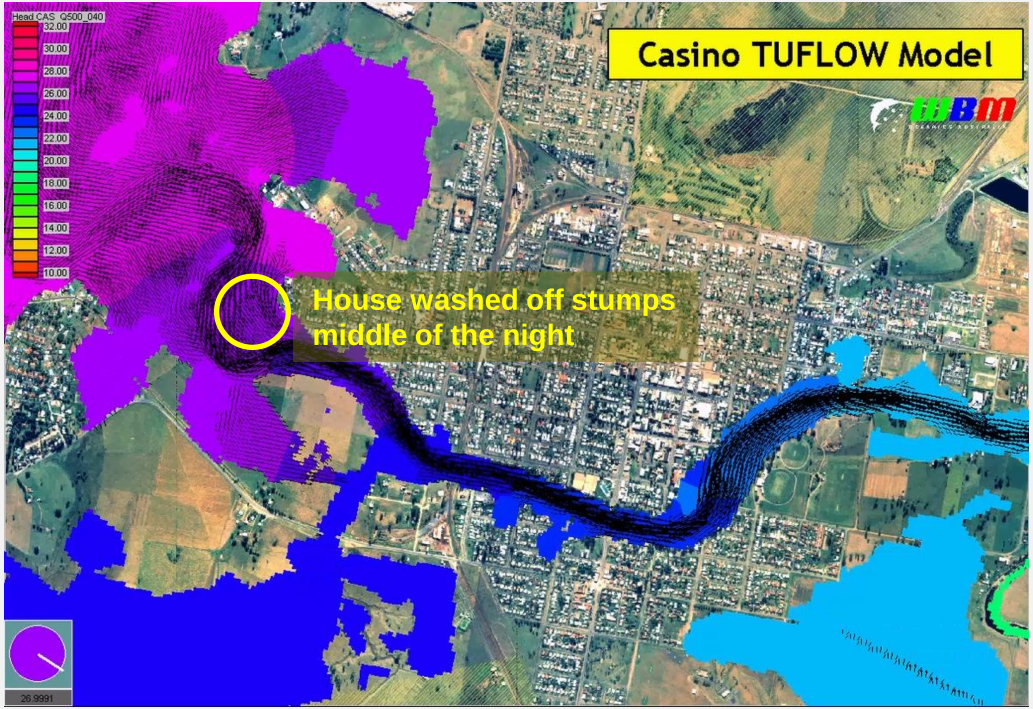
Community Consultation
Don't Exclude Stakeholders – They Know!



Community Consultation in 1999
Casino, NSW, Richmond River

Whilst showing the (sceptical) audience this animation, one of the attendees came up on stage and pointed to the screen.

Community Consultation
Don't Exclude Stakeholders – They Know!

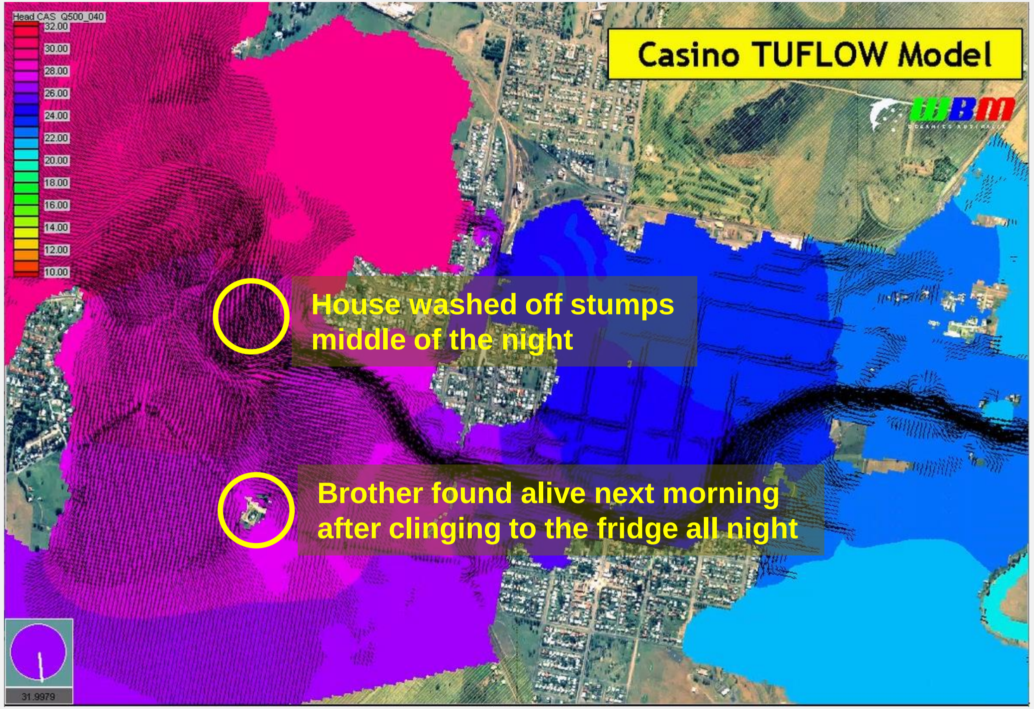


Community Consultation in 1999
Casino, NSW, Richmond River

He said *"This is where my family home washed away during the 1954 flood."*

This was where the 2D model showed high velocities as the flood shortcut a meander.

Community Consultation
Don't Exclude Stakeholders – They Know!



Community Consultation in 1999
Casino, NSW, Richmond River

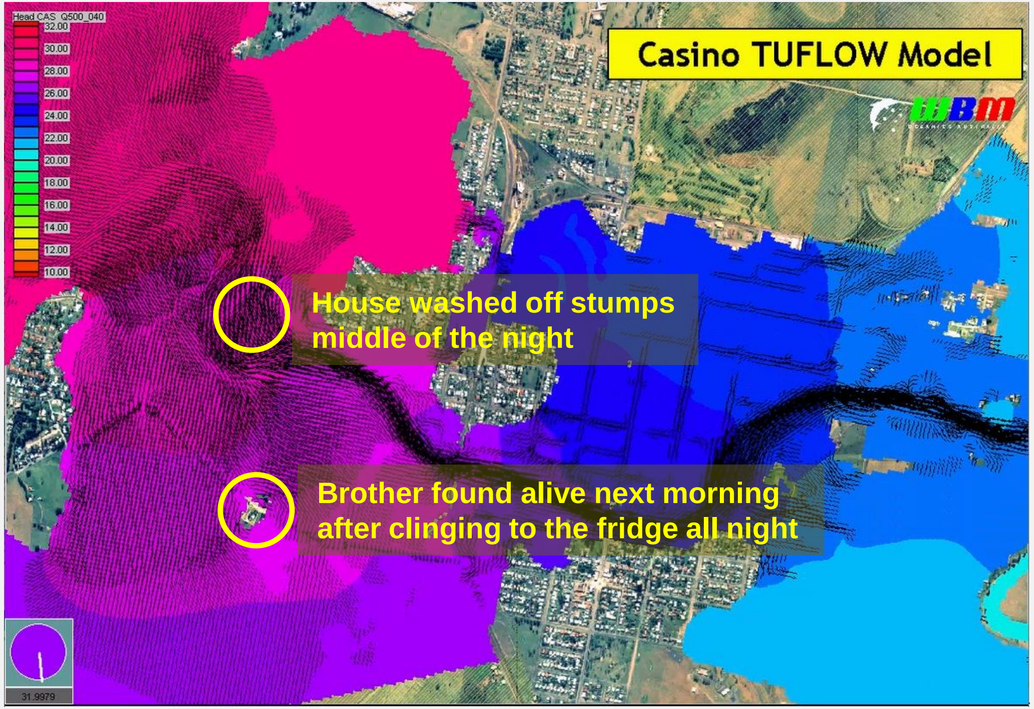
He then followed the animation's flow velocities southwards as the flood continued to rise to what became an island.

He said *"that's where my brother was found (alive) the next morning after spending the night clinging to the fridge"*.

He turned around to the audience and emphatically said ***"this model is right"*** and sat back down.

From then on the community were no longer sceptical.

Community Consultation
Don’t Exclude Stakeholders – They Know!



Community Consultation in 1999
Casino, NSW, Richmond River

In the following days, he posted me this photo taken of the family home after the 1954 flood.

Model Check Examples

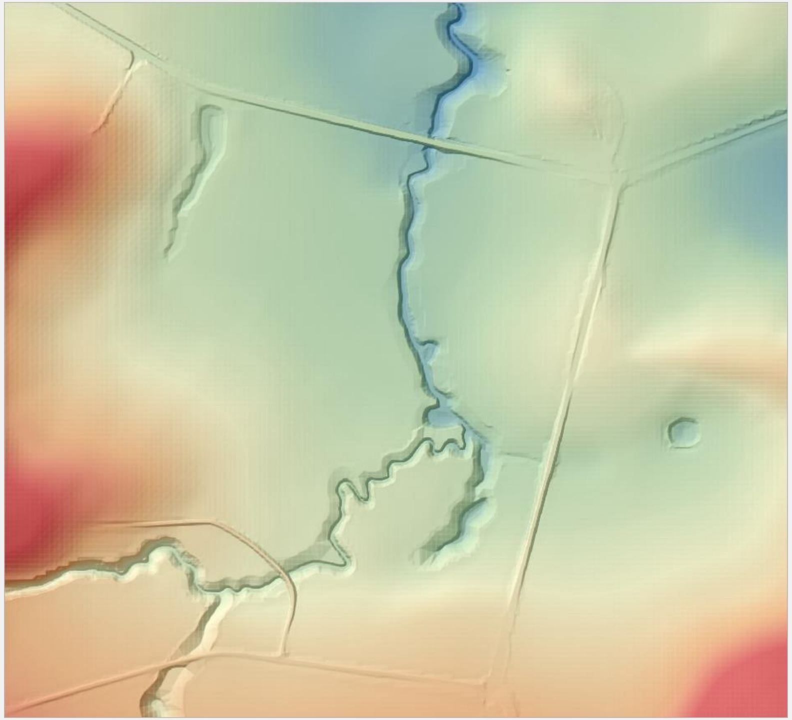
Flood Modelling 101

Tips and Tricks

Overview

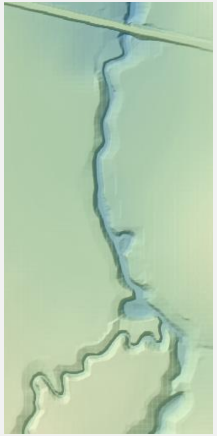
- Model resolution
- External boundaries
- Material spatial resolution
- Breaklines
- Culvert quality assurance

https://wiki.tuflow.com/index.php?title=Tutorial_Introduction



Model Resolution
Assumptions

- Hydraulically at least 4-5 cells across the channel, less cells with SGS and fine DEM
- Review results resolution is appropriate to the modelling task
- Check runtime (use Quadtree)
- Conduct cell size convergence (use SGS)



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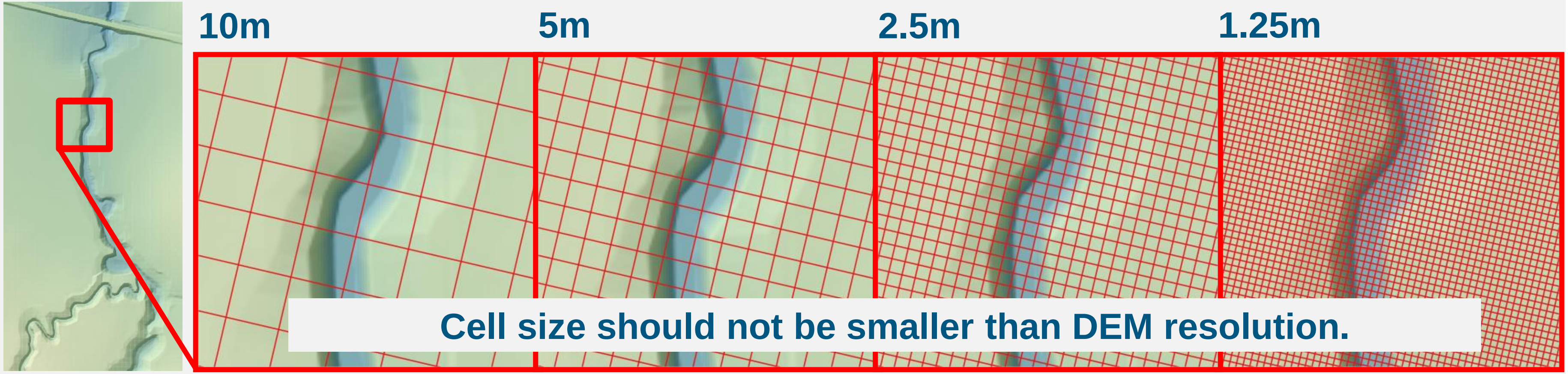

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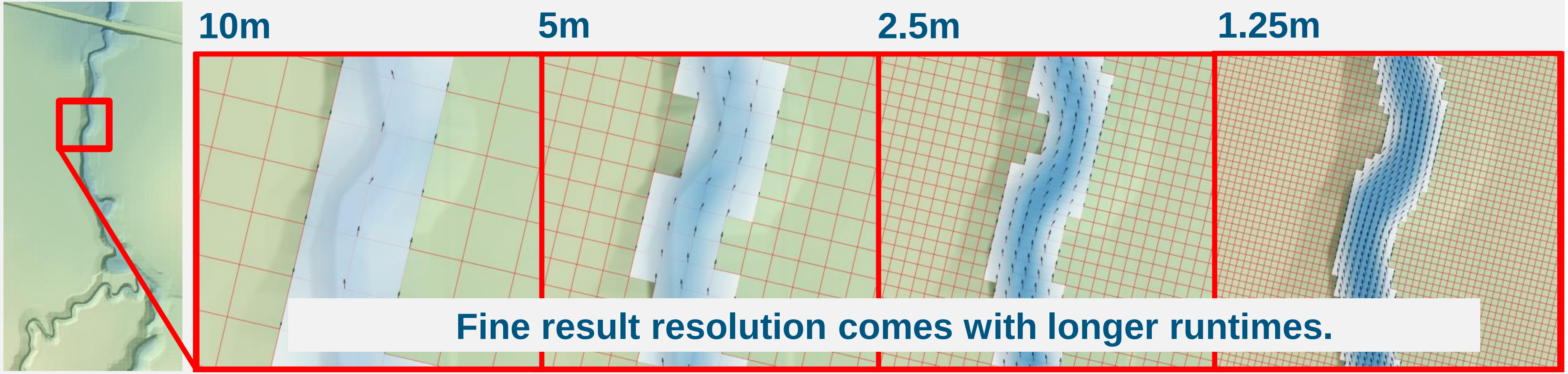

Fine result resolution comes with longer runtimes.

Model Resolution
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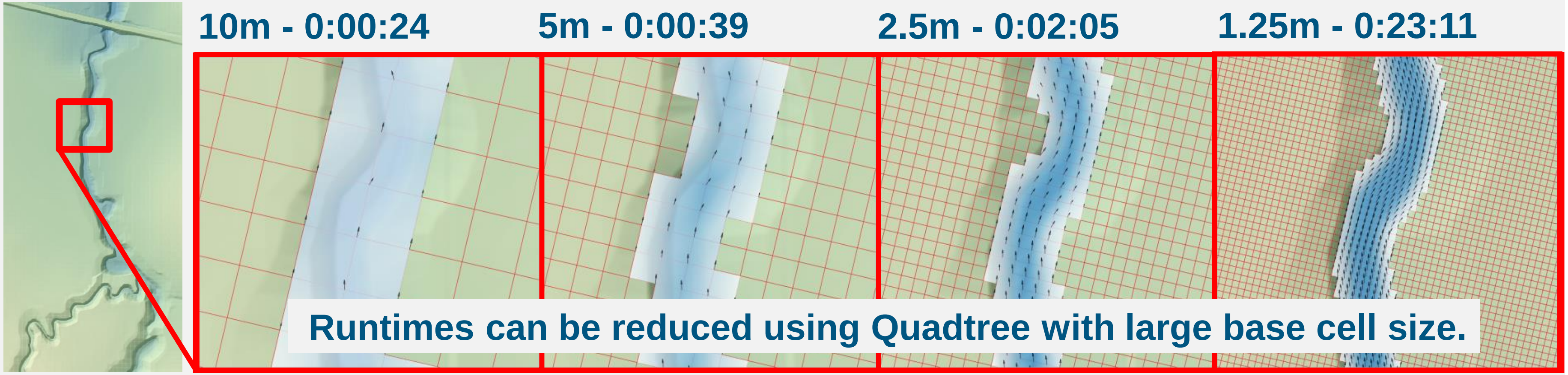

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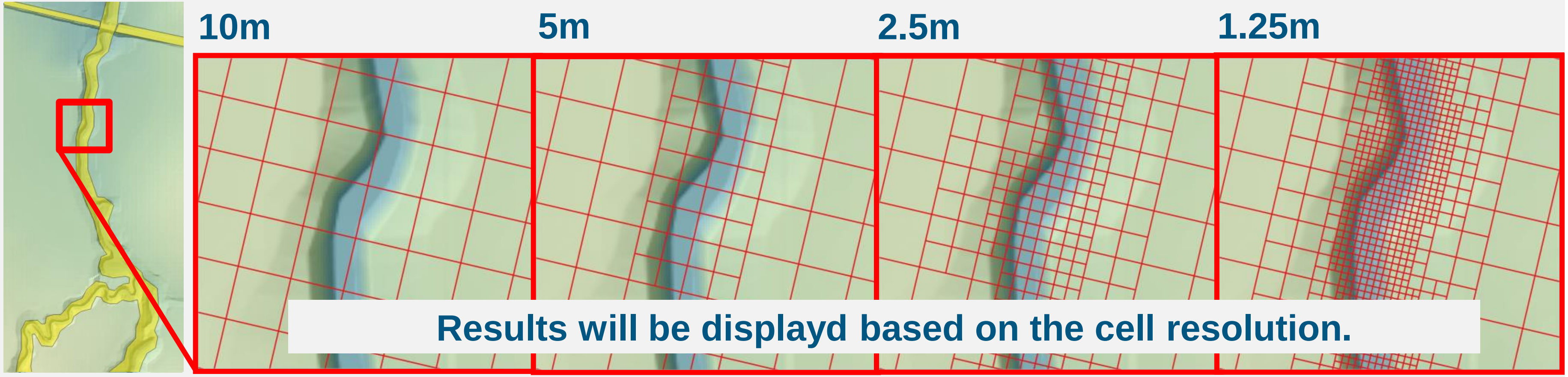

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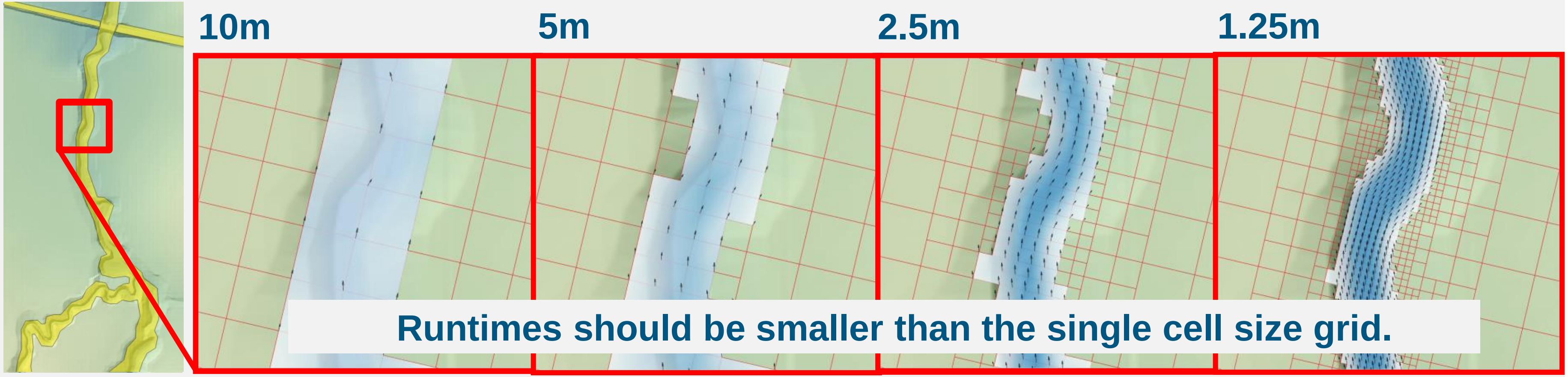
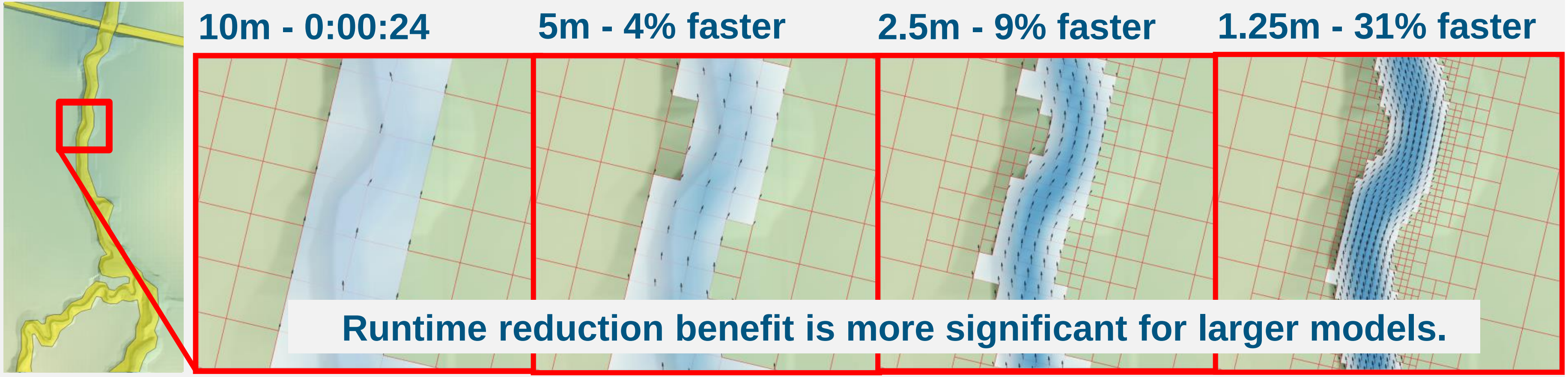
- **Check runtime (use Quadtree)**
- Conduct cell size convergence (use SGS)



Runtimes should be smaller than the single cell size grid.

Model Resolution
Assumptions

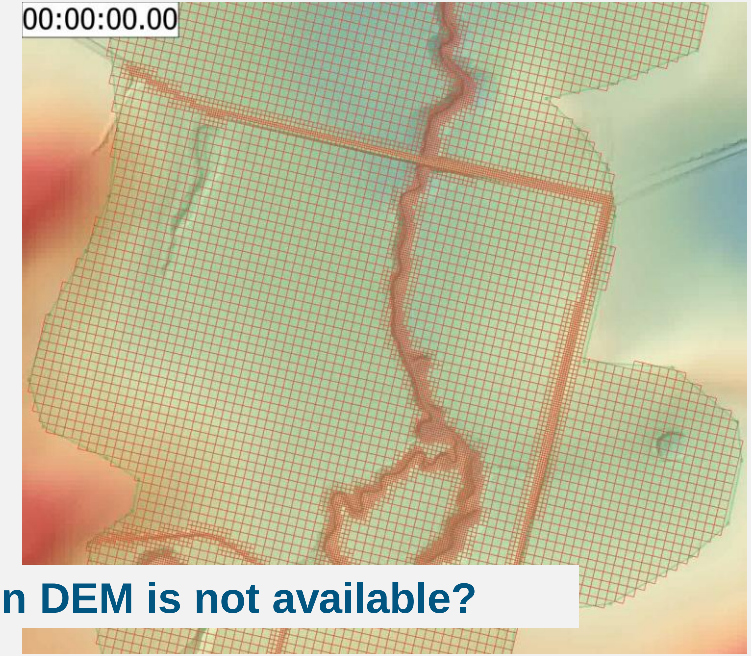
- Hydraulically at least 4-5 cells across the channel, less cells with SGS and fine DEM
- Review results resolution is appropriate to the modelling task
- **Check runtime (use Quadtree)**
- Conduct cell size convergence (use SGS)



Model Resolution
Uniform Grid and Quadtree Grid

Uniform grid 10m

Quadtree grid 10m/5m/2.5m

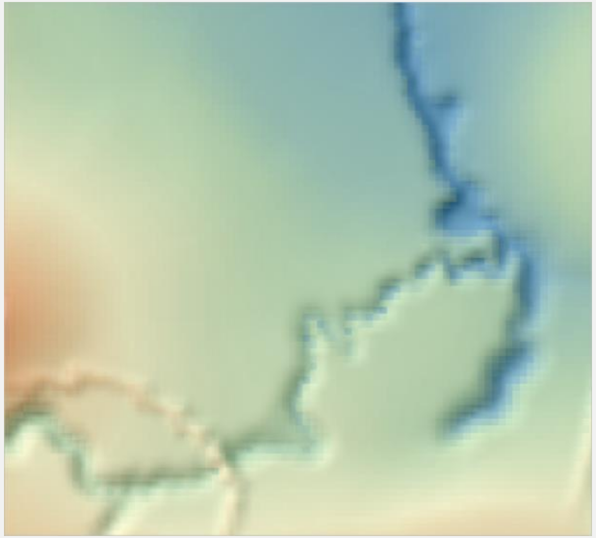


What if fine resolution DEM is not available?

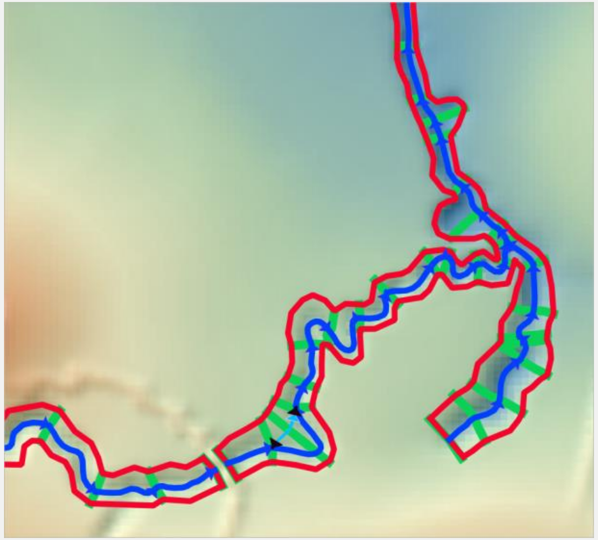
Model Resolution
Quadtree Grid vs 1D Channel

Poor bathymetry data / coarse DEM - What are the options?

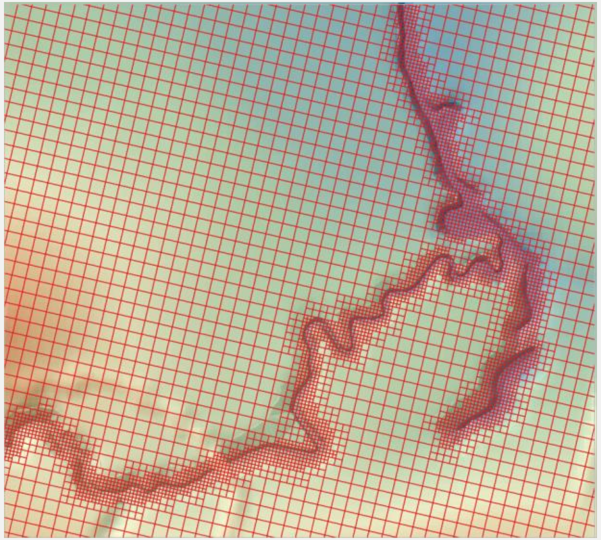
Coarse DEM



1D open channel

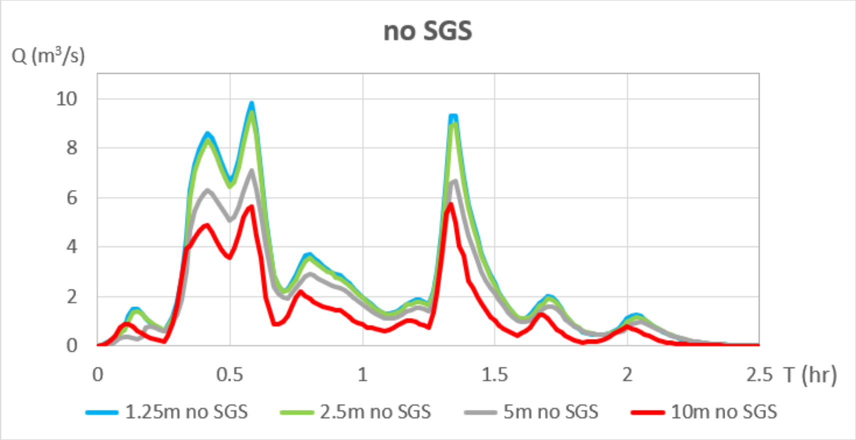


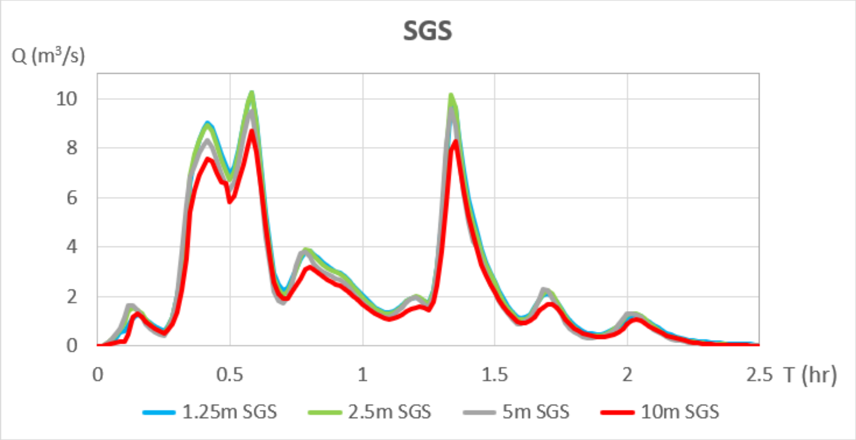
High res bathymetry survey



Model Resolution Assumptions

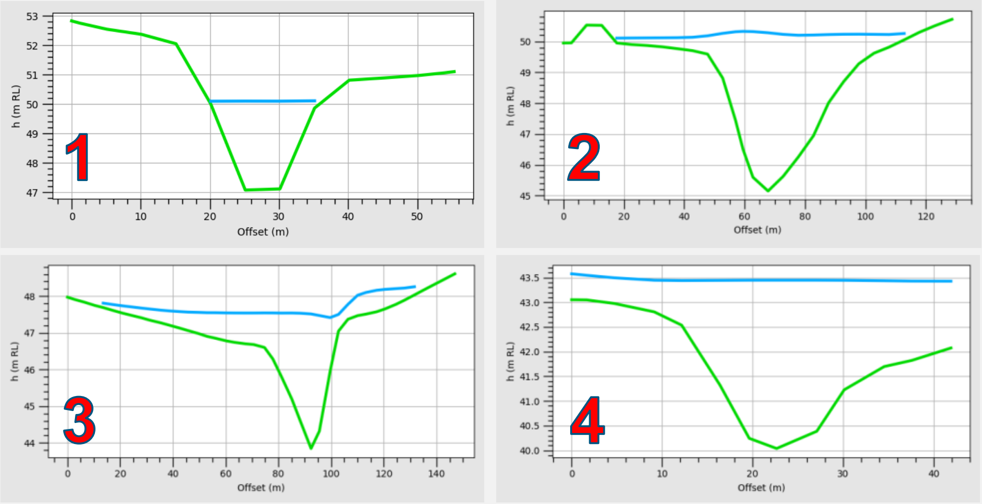
- Hydraulically at least 4-5 cells across the channel, less cells with SGS and fine DEM
- Review results resolution is appropriate to the modelling task
- Check runtime (use Quadtree)
- **Conduct cell size convergence (use SGS)**

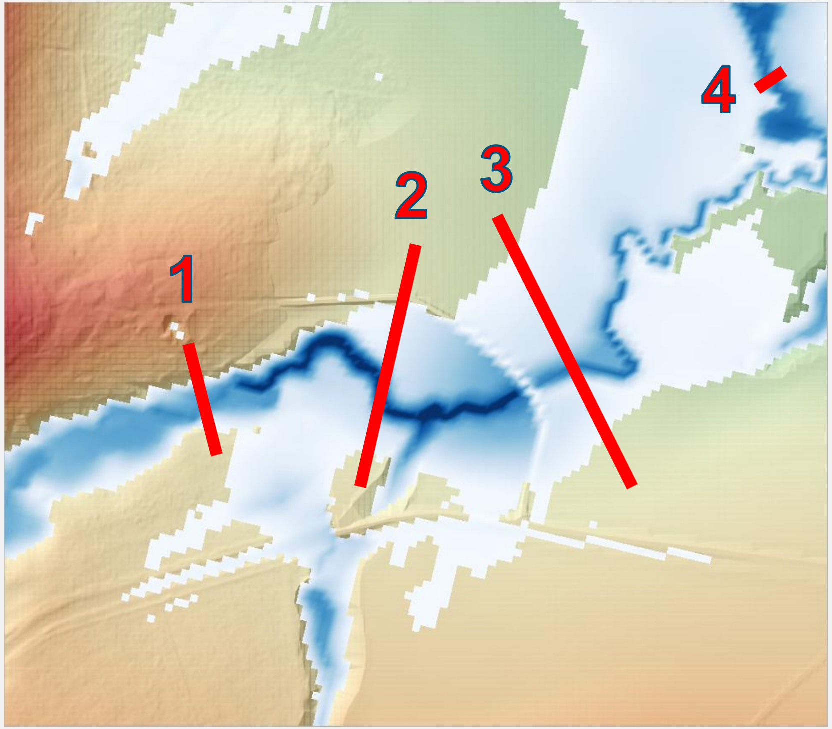




External Boundaries
Assumptions

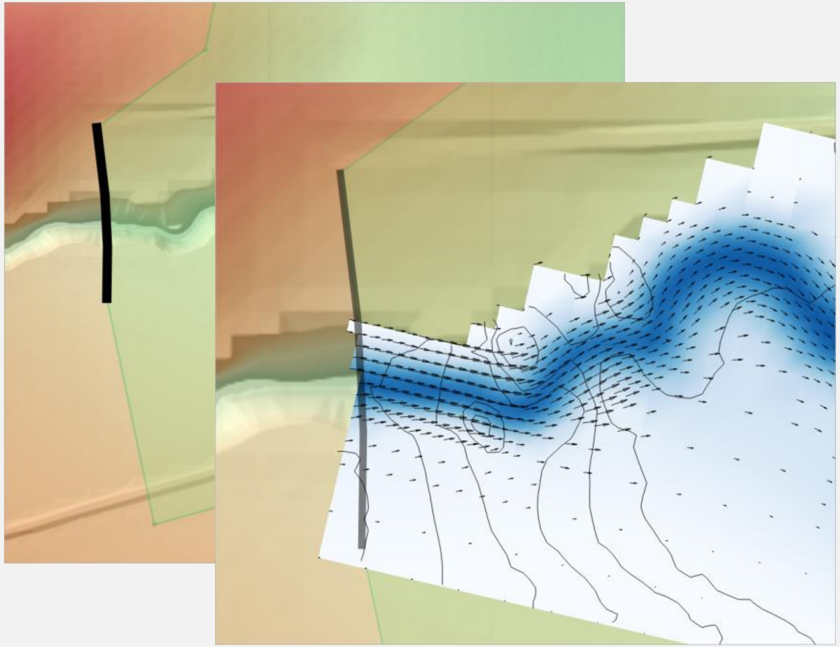
- **Water level is horizontal**
- **Boundary in confined space**
- **From high ground to high ground**

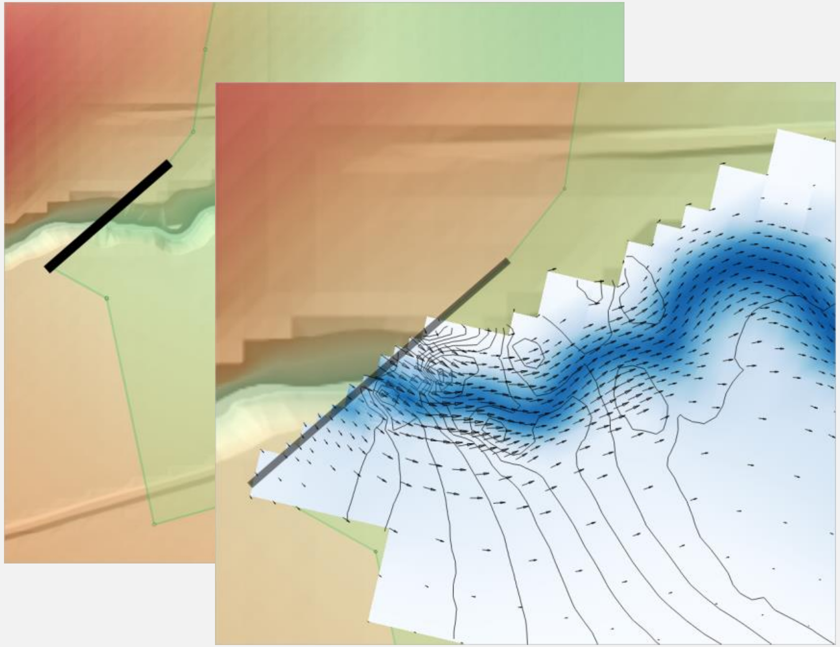




External Boundaries
Upstream Boundary

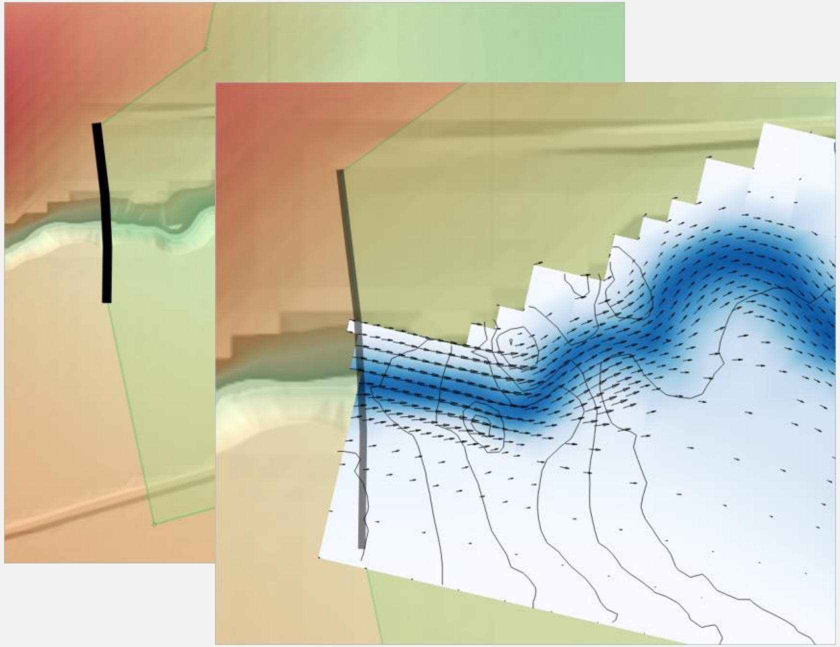
Recommendation - boundary perpendicular to the flow

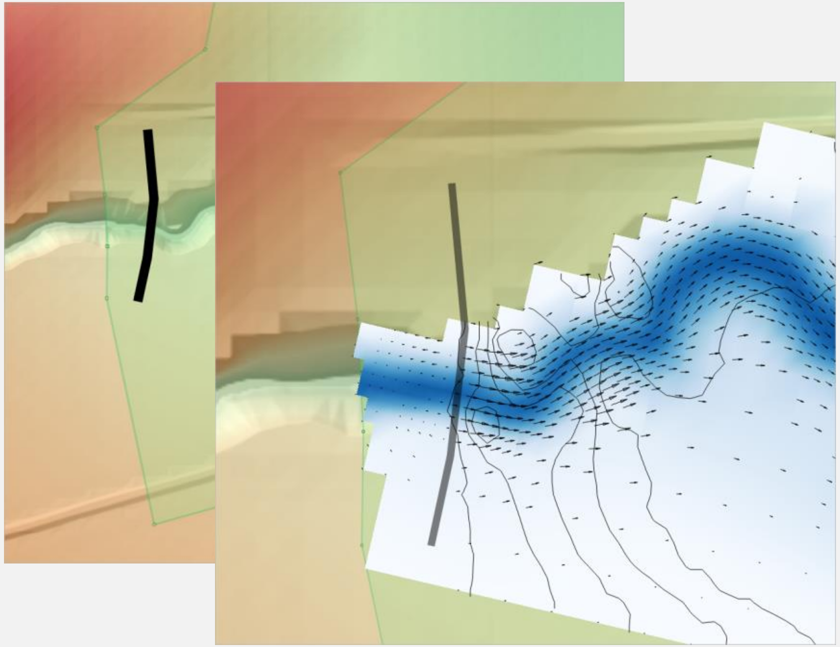




External Boundaries
Upstream Boundary

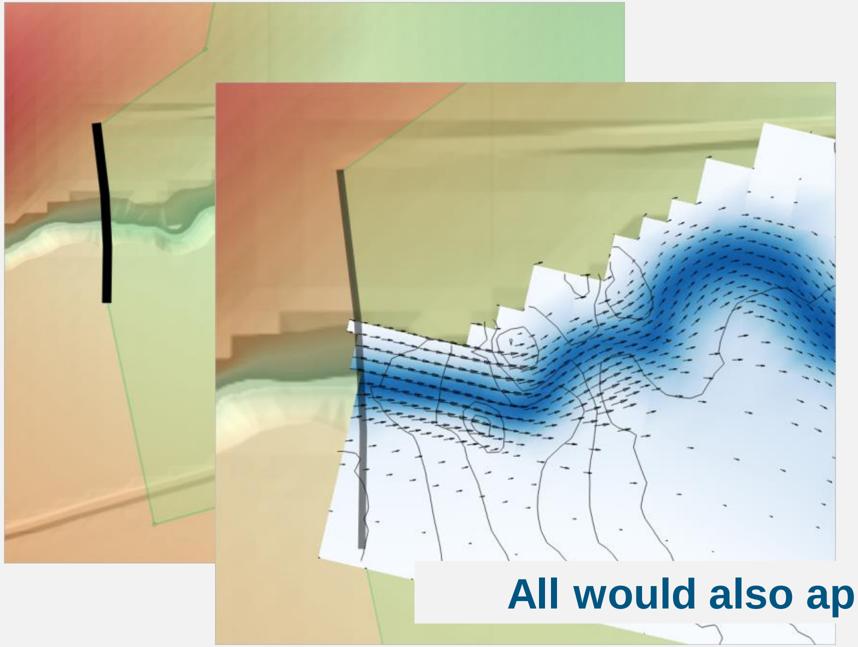
Recommendation - boundary snapped to the model area

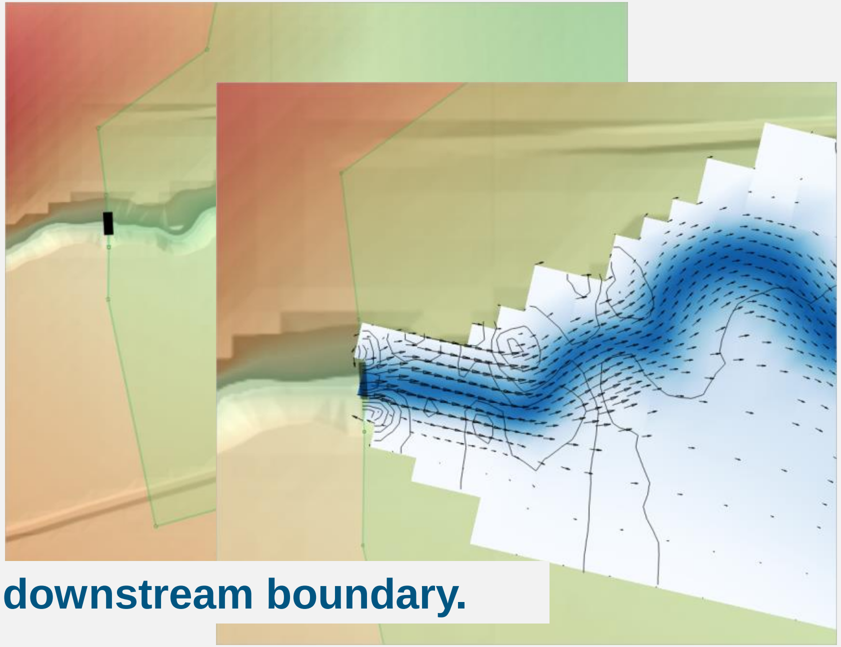




External Boundaries
Upstream Boundary

Recommendation - boundary wide enough





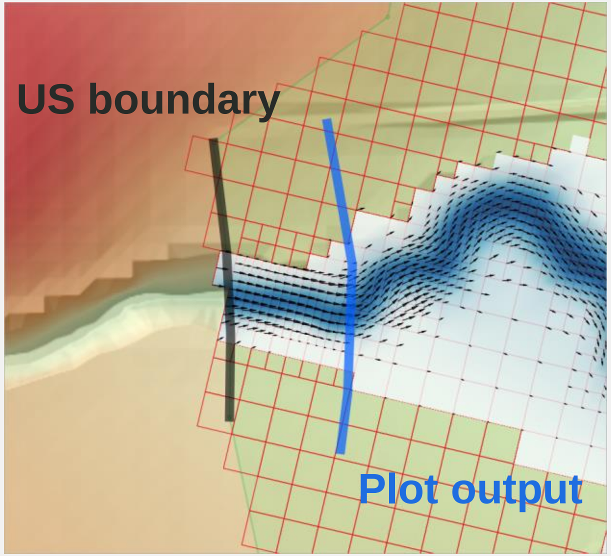
All would also apply to downstream boundary.

External Boundaries
Upstream Boundary

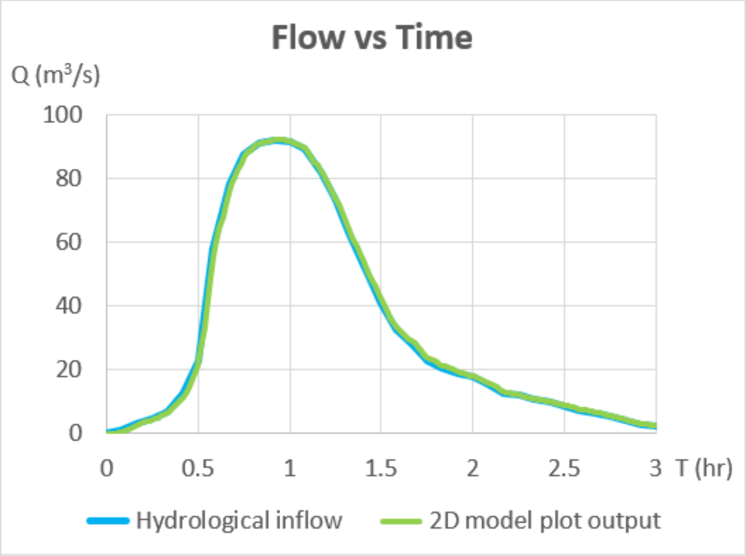
Recommendation - check inflow is as expected

time	inflow
0	0
0.08	0.84
0.17	3.31
0.25	4.6
0.33	7.03
0.42	12.39
0.5	22.63
0.58	58.02
0.67	78.22
0.75	87.68
0.83	91.13
0.92	92.24
1	91.78
1.08	89.3
1.17	81.91

Hydrological inflow



Inflow in 2D model



Inflow comparison

TUFLOW

aws Australian Water School

External Boundaries
Upstream Boundary

Recommendation - check inflow is as expected

time	inflow
0	0
0.08	0.84
0.17	3.31
0.25	4.6
0.33	7.03
0.42	12.39
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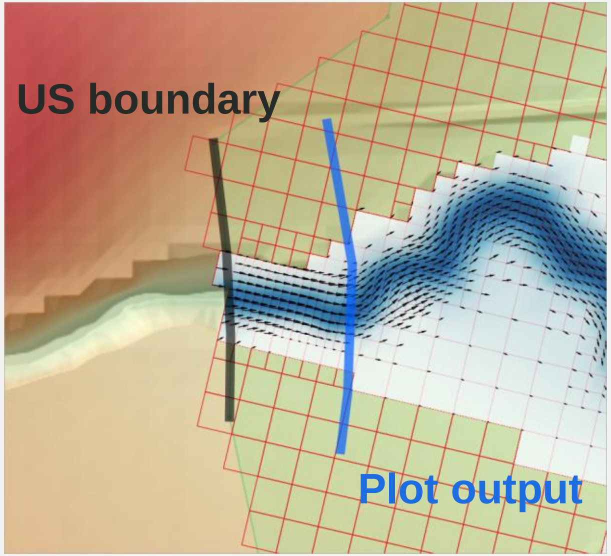
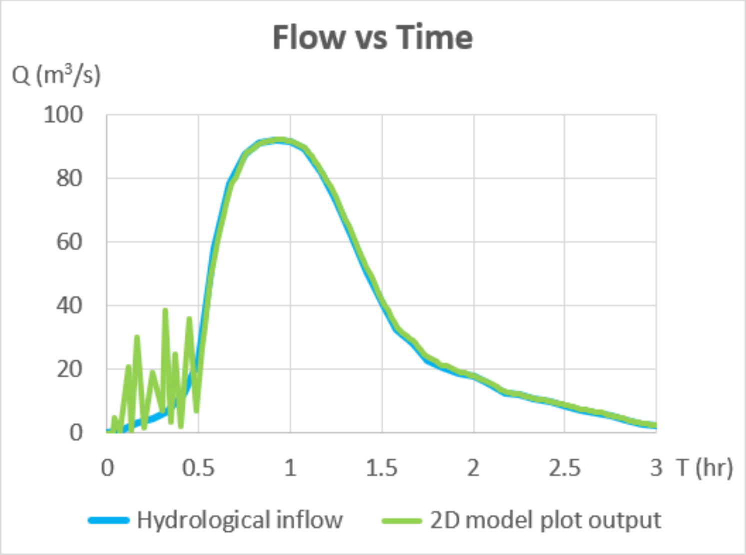
Hydrological inflow



Inflow in 2D model



Inflow comparison

External Boundaries
Downstream Stage Discharge Boundary

Recommendation - boundary well away from area of interest

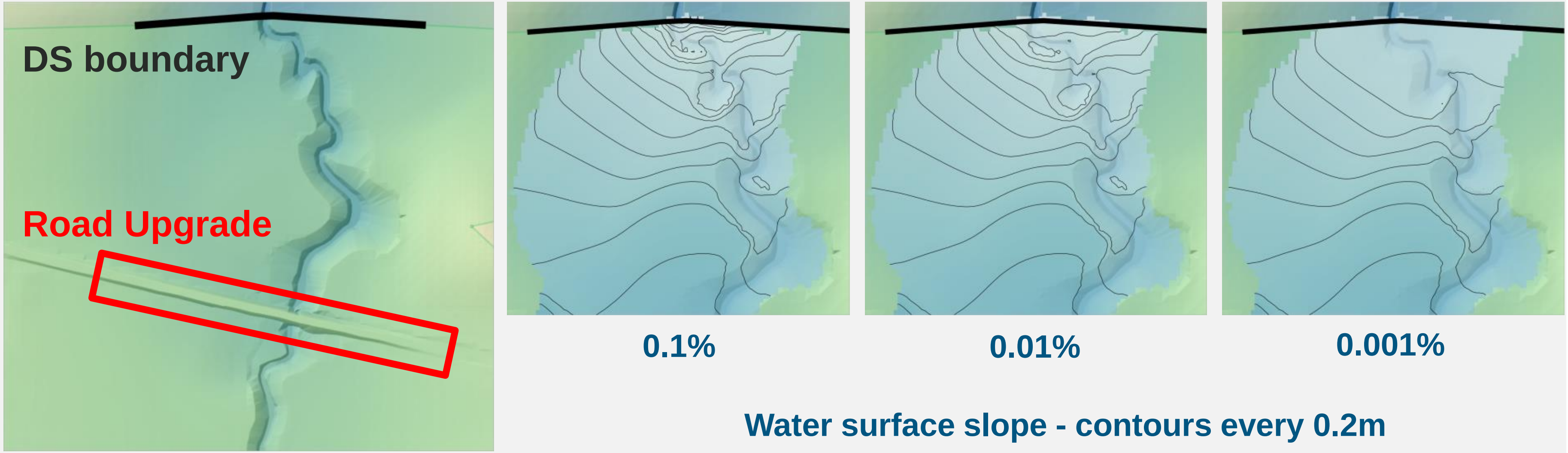
0.1% minus 0.01%

0.001% minus 0.01%

Water level difference based on water surface slope

External Boundaries
Downstream Stage Discharge Boundary

Recommendation - boundary well away from area of interest

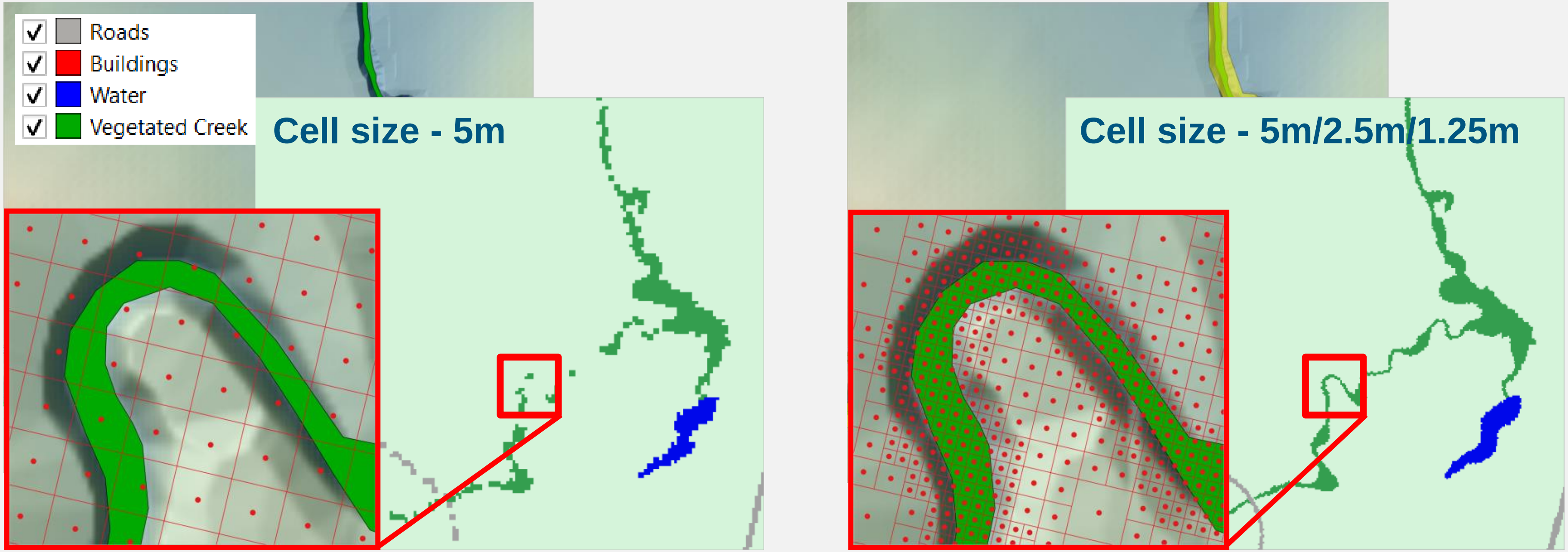


Water surface slope - contours every 0.2m

Materials

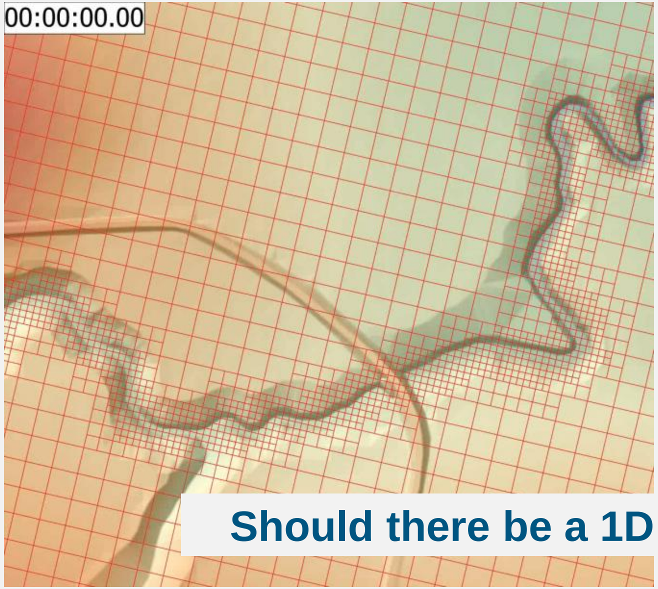
Material Spatial Resolution

Recommendation - review material spatial resolution

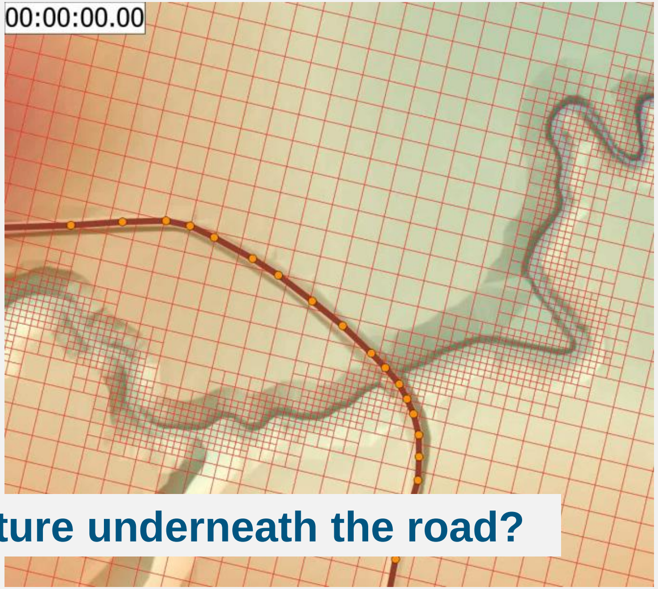


Breaklines
Roads, Levees, Embankments

Recommendation - insert breaklines where required



Without breaklines

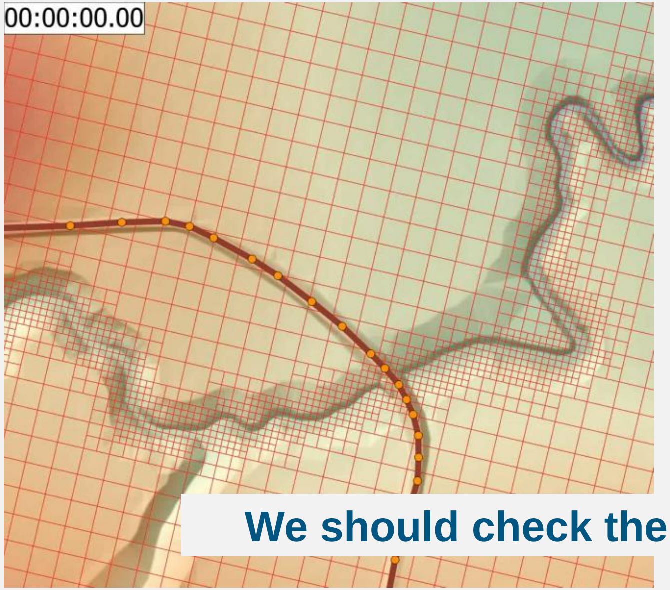


With breaklines

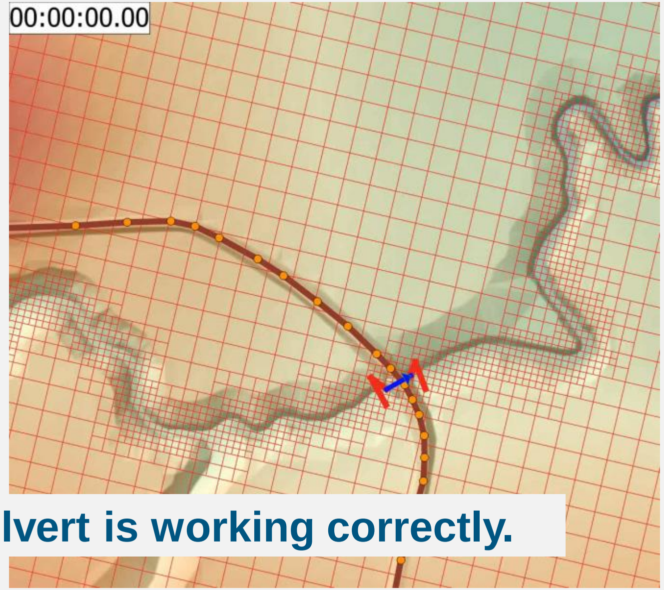
Should there be a 1D feature underneath the road?

Breaklines
Road with Culvert

Recommendation - check if overtopping embankment should have a culvert



With breaklines no culvert

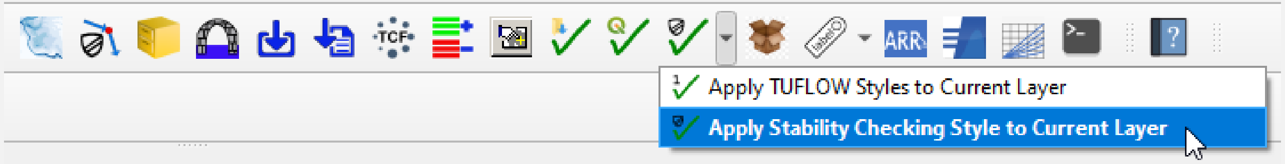


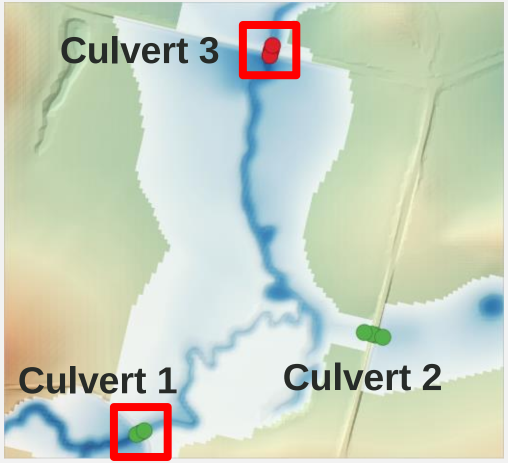
With breaklines with culvert

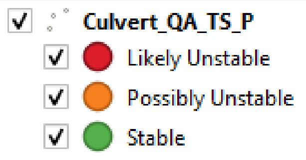
We should check the culvert is working correctly.

Culvert Quality Assurance
QGIS Tool

TUFLOW Plugin - Apply Stability Checking Style to Current Layer tool







Culvert Quality Assurance
1D Timestep

High timestep

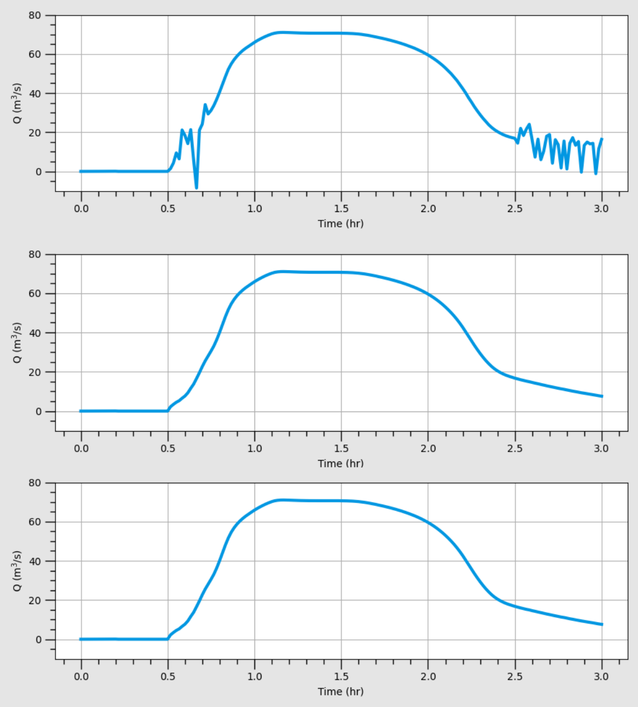
(1 second)

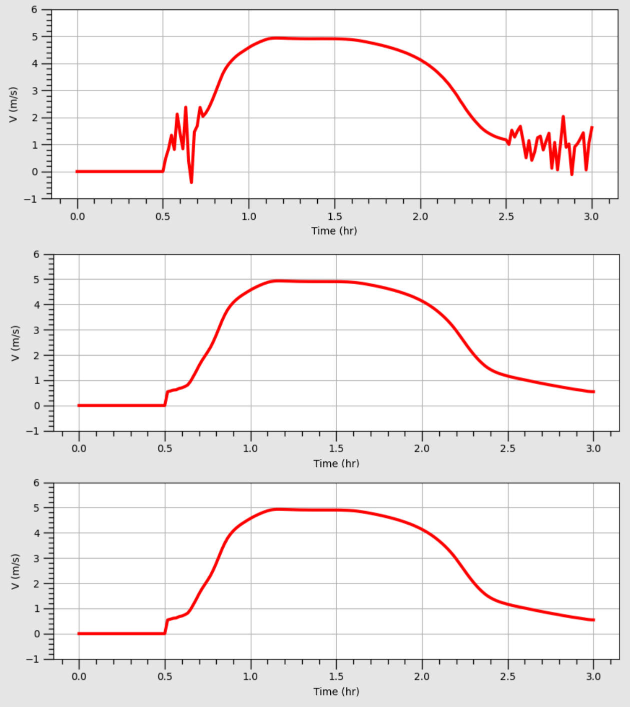
Mid range timestep

(0.5 second)

Small timestep

(0.1 second)





Summary
Key Learnings

Why flood model?

- To inform decision makers
- Accuracy of that information directly impacts their decisions

Solving the Physics

- Large choice of solvers/software that vary in accuracy
- Benchmarking / calibration
  increases the accuracy, decreases the uncertainty
- Check you have cell size results convergence – demonstrates
  - solution is converging; and
  - cell sizes not too large
- Test for timestep results convergence and check stability
- In most cases, do not use the diffusive wave solution
- 2nd order solvers with inertia and sub-grid turbulence
  needed for higher velocity (>1 m/s) flows

Garbage In, Garbage Out

- Appropriately accurate ground elevation and bathymetric data
- Boundaries
  - Inflows notoriously inaccurate – understand the uncertainty
  - Locate stage-discharge boundaries well downstream
- Structures
  - Another whole webinar (or two)! See these AWS webinars:
    - tuflow.com/library/webinars/#structures
    - tuflow.com/library/webinars/#nov2022_hydraulic_modelling_bridge
- Parameter values (e.g. Manning's n, Bend Losses)
  - Never use values outside industry norms (unless justified)

Look at Your Results!

Listen to the Community – the old-timers know!

Summary
Useful AWS TUFLOW Webinars for Flood Modelling

How Wrong is Your Flood Model?

www.tuflow.com/library/webinars/#jul2019_how_wrong

2D Cell Size Selection for Accurate Hydraulic Modelling

www.tuflow.com/library/webinars/#nov2020_2d_cell_size

Modelling Energy Losses at Structures

www.tuflow.com/library/webinars/#structures

1D, 2D, 3D Hydraulic Modelling of Bridges

www.tuflow.com/library/webinars/#nov2022_hydraulic_modelling_bridge

Maximising Hydraulic Model Accuracy

www.tuflow.com/library/webinars/#maximise_accuracy

Hydraulic Model Calibration to Historic Events

www.tuflow.com/library/webinars/#202104_cal

Operational Structure Modelling

www.tuflow.com/library/webinars/#202204_operation_control

The Future of 2D Modelling

www.tuflow.com/library/webinars/#sep2020_future

Is Direct Rainfall (Rain-on-Grid) Accurate?

www.tuflow.com/library/webinars/#feb2021_direct_rainfall

Urban Pipe Network Modelling

www.tuflow.com/library/webinars/#urban_pipes

Next Generation 2D Hydraulic Modelling

www.tuflow.com/library/webinars/#quadtree

Flood Risk Management

www.tuflow.com/library/webinars/#june2022_flood_rm

Hardware Selection and Trends in Hydraulic Modelling

www.tuflow.com/library/webinars/#oct2020_hardware