Maximising the Accuracy of Hydraulic Models

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Maximising the Accuracy of Hydraulic Models
Today's Webinar

Background a benchmark model used to demonstrate topics

Discuss and demonstrate topics that affect hydraulic model accuracy

- Input data
- Different ways of solving the fluid flow equations
- Parameters such as Manning's n and bend loss values
- Discretisation – how you break up the real world into discrete cells or elements

Importance of testing software example

Recommendations

Hydraulic Models
Maximising their Accuracy

To use a model with confidence
is all about maximising its accuracy

or, minimising the uncertainty

Hydraulic Models
Uncertainties Everywhere

Input Data

- Terrain and bathymetric elevations
- Land-use (surface material)

Parameters

- Manning's n; Energy losses; Infiltration

Boundaries

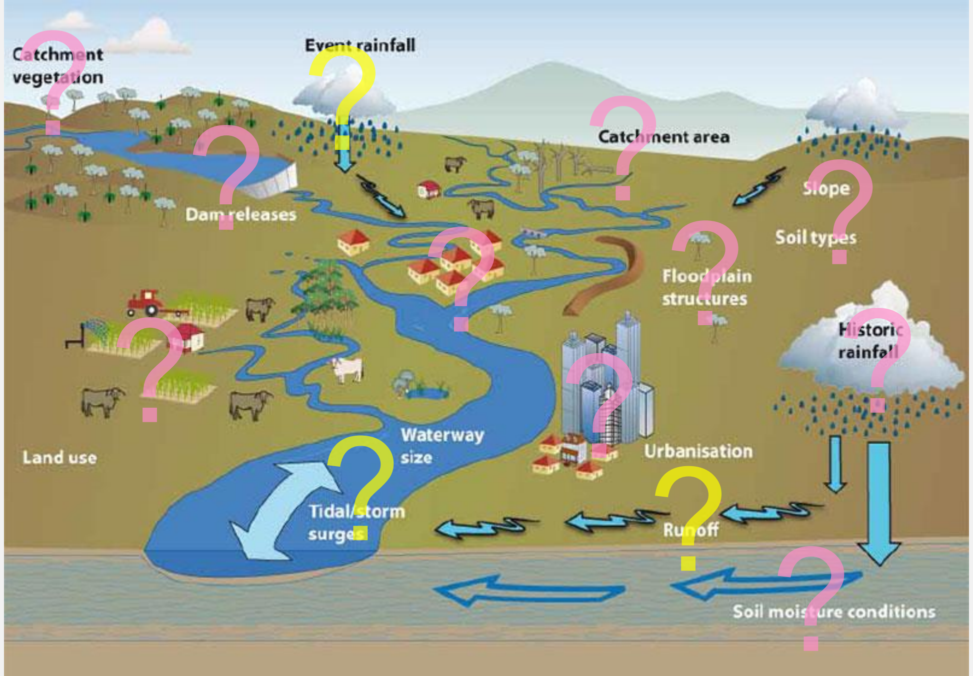
- Flows; Rainfall; Water Levels

Model Design / Discretisation

- Cell size; Structures; Boundary locations

Numerical Computations

- Never 100% correct; Not all the same



https://www.chiefscientist.qld.gov.au/publications/understanding-floods

Maximising the Accuracy of Hydraulic Models
The TUFLOW Journey

TUFLOW HPC 2020 Release

- Flumes to urbanised catchments to major rivers
- Use industry guideline Manning's n values for all scales
- Same turbulence model parameters for all scales
- Excellent cell size results convergence, especially with Sub-Grid Sampling (SGS)
- Changing timestepping gives consistent results
- Advanced (2nd order) numerical solver
  - Not affected by error accumulation (numerical diffusion)
  - Can use industry guideline Manning's n values from backwaters to high velocity flowpaths

Can now achieve a highly confident result without calibration

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Maximising the Accuracy of Hydraulic Models

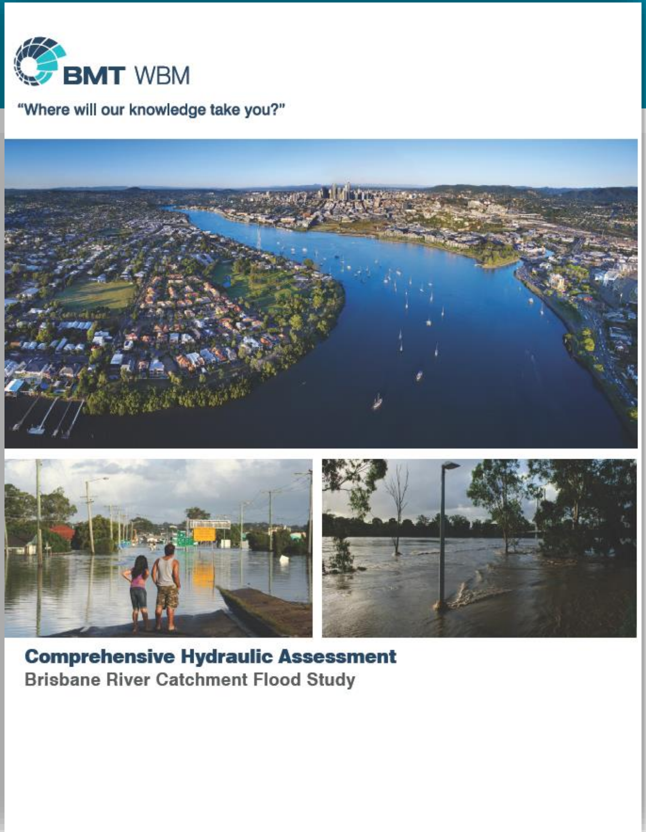
Benchmark Model

Benchmark Model Demonstrate Accuracy

Need a real-world hydraulic model that exhibits

- Strong calibration to range of flow magnitudes
- High confidence in accuracy (low uncertainty)
- Preferably quick to run
- Challenging hydraulics to model

Brisbane River Comprehensive Flood Study Hydraulic Assessment (2016)



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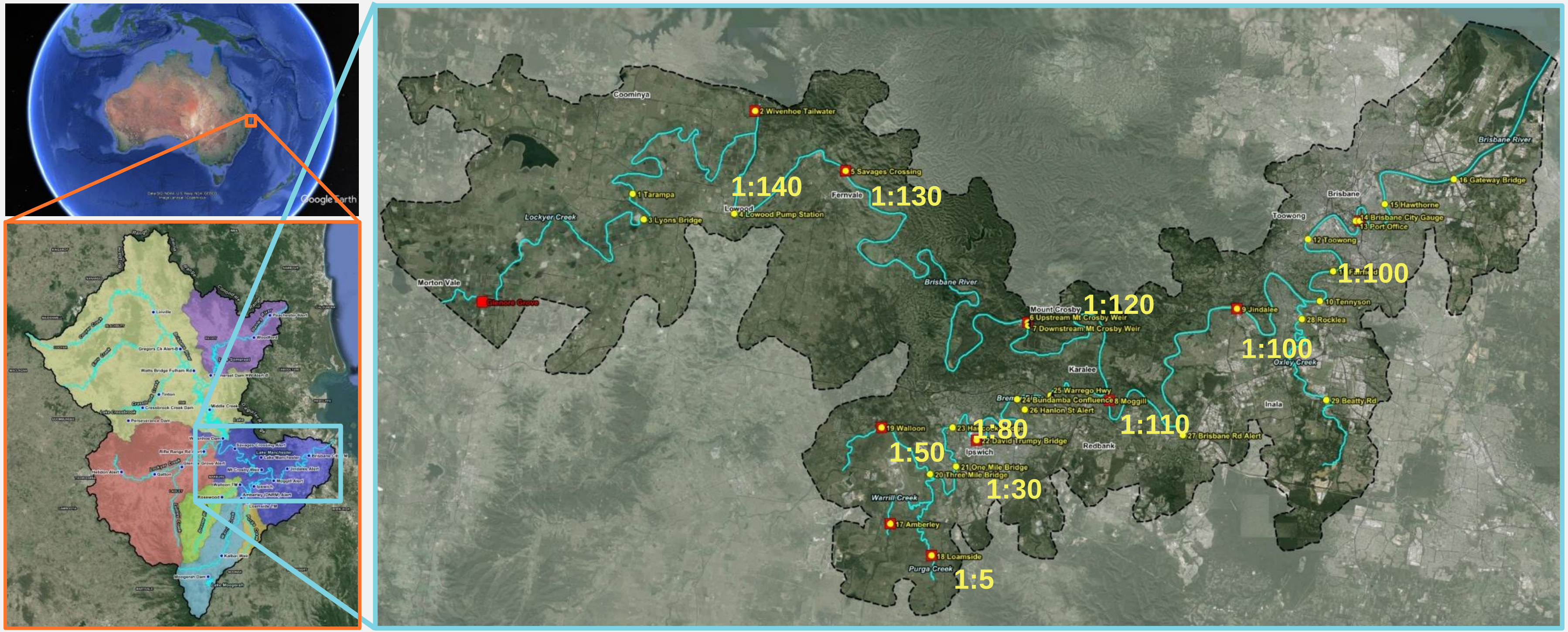
Brisbane River Hydraulic Model
Estimated Severity (AEP) of the 2011 Flood



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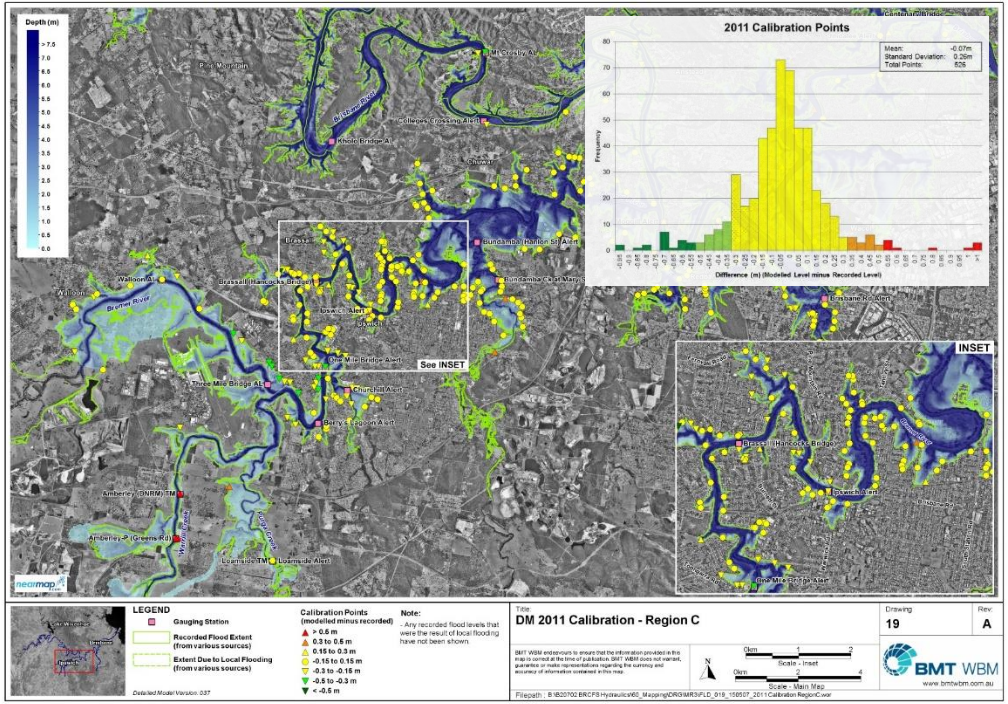
Brisbane River Hydraulic Model Exhaustive Calibration

- Thousands of flood marks
- ~30 gauges within hydraulic model area
- Calibrated to:
  - tide only
  - 3 minor floods (1 in 10 to 1 in 20 AEP)
  - 2 major floods (~1 in 100 AEP) (including ADCP flow measurements)

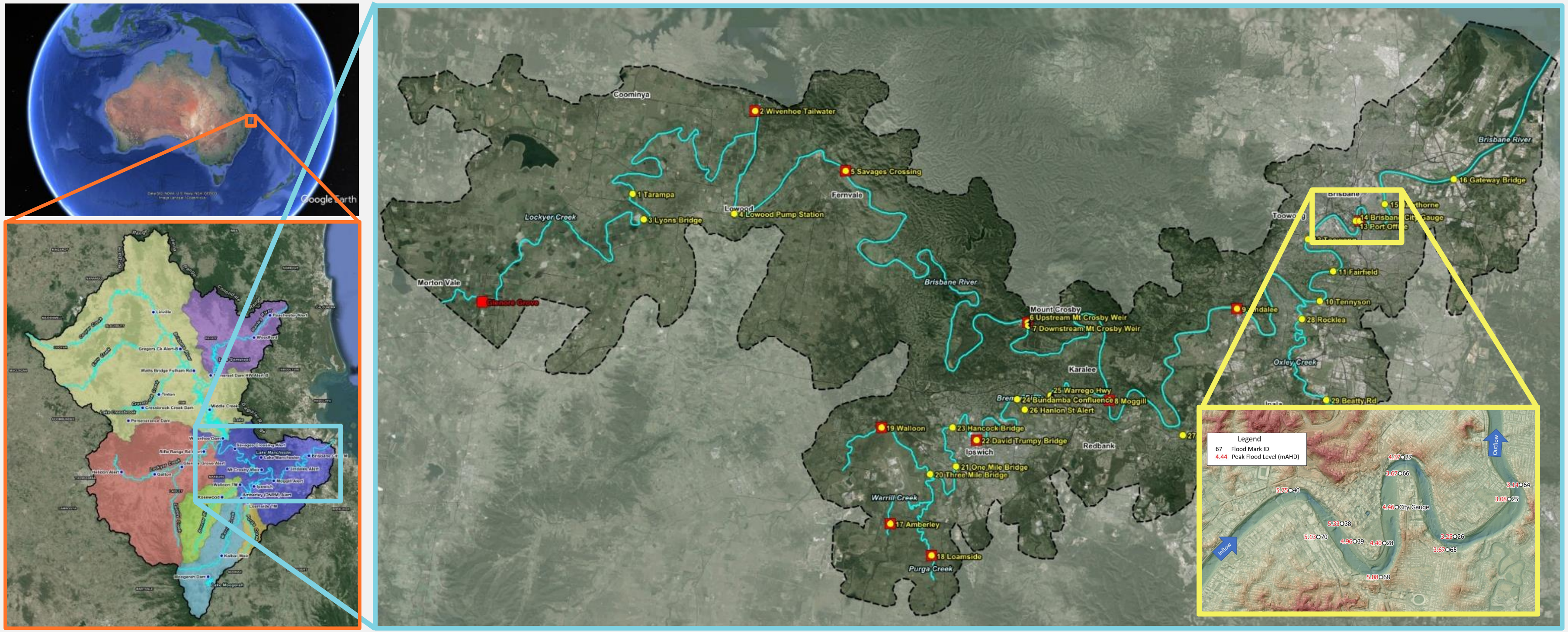
Same parameters for ALL events

- No event specific parameters

About as good as it gets



Brisbane River Hydraulic Model
Cut-down Benchmark Model



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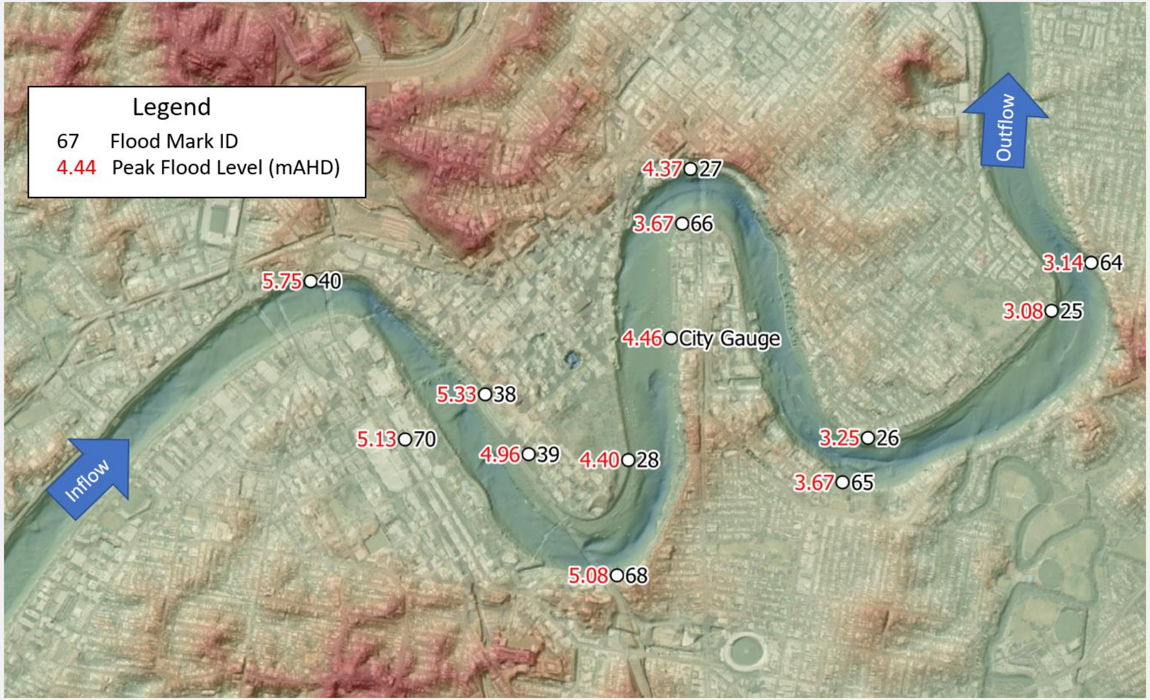
Brisbane River Cut-Down Benchmark Model 2011 Flood

Cut-Down Model

- 11 km stretch
  (6 reaches and 5 bends)
- Eight bridges
  (pier losses – all clear spanning)
- 13 flood marks of good to reasonable accuracy
- 1 gauge (City Gauge)
- Superelevation evident at bends
- 30 m fixed grid
  (same as flood study)
- Boundaries extracted from flood study model



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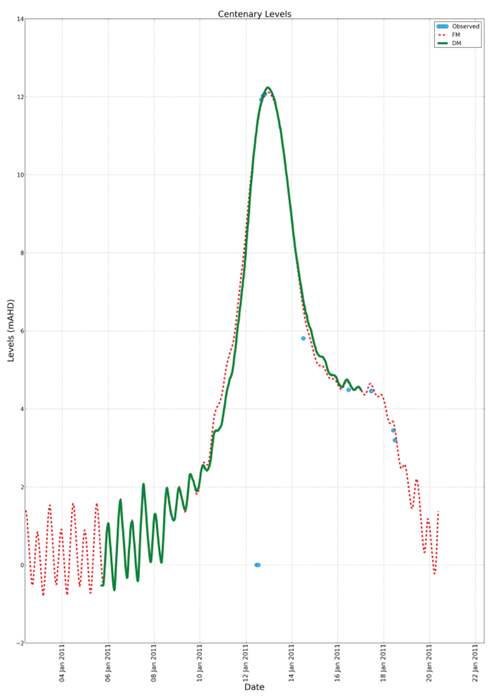
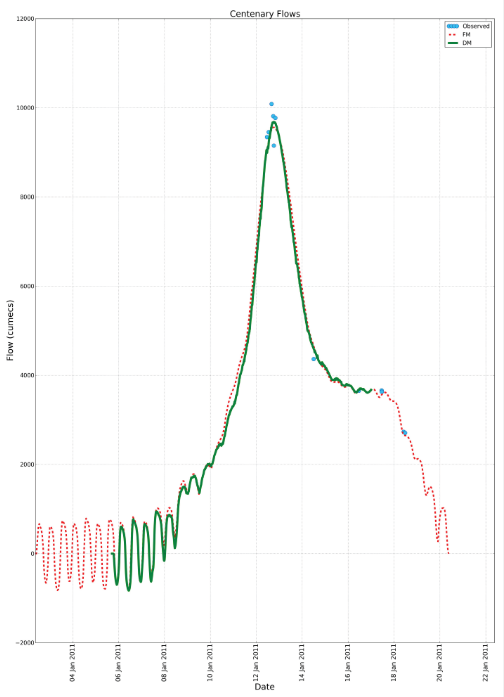
Brisbane River Cutdown Benchmark Model
2011 Flood Calibration

Very low uncertainty

- Excellent high resolution and accurate terrain and bathymetry
- Little uncertainty over flood flows
  - Several ADCP recordings around peak (~1:100 AEP) at bridge 22 km upstream
- Good land-use data





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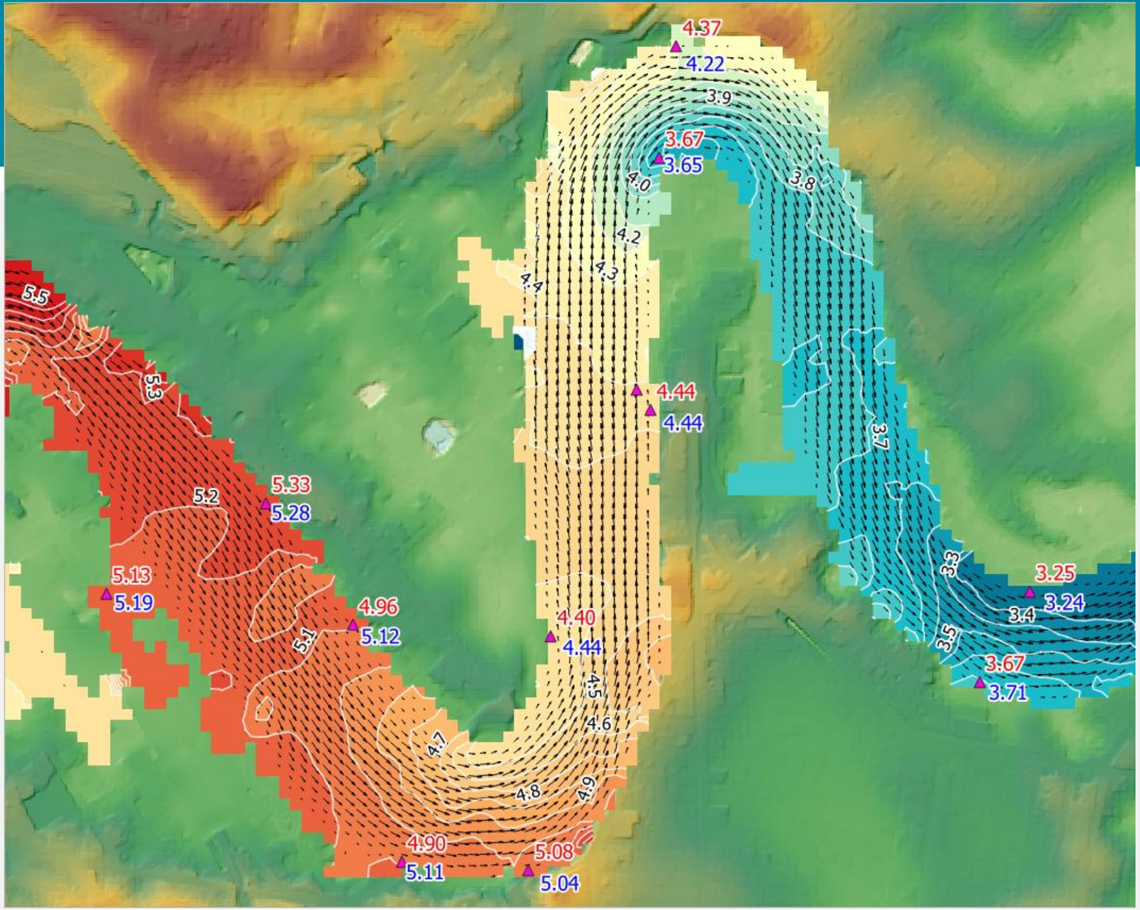
Benchmark Model 2011 Check

Original Flood Study Model

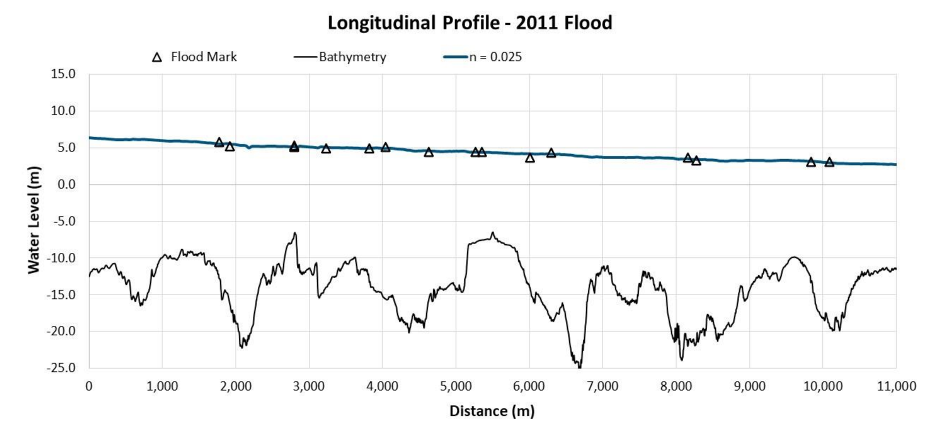
- TUFLOW Classic 2016
  - Implicit (matrix) solver
  - Smagorinsky + Constant turbulence model
  - n = 0.022

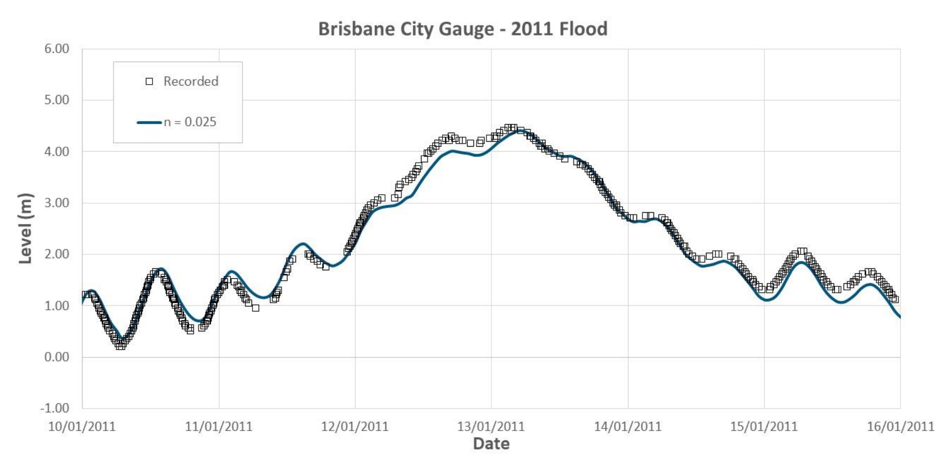
Benchmark Model

- TUFLOW HPC 2020
  - Explicit solver
  - Wu turbulence model
  - Sub-Grid Sampling (SGS)
  - n = 0.025



Benchmark Model
2011 Calibration Check





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Benchmark Model
2011 Calibration Check

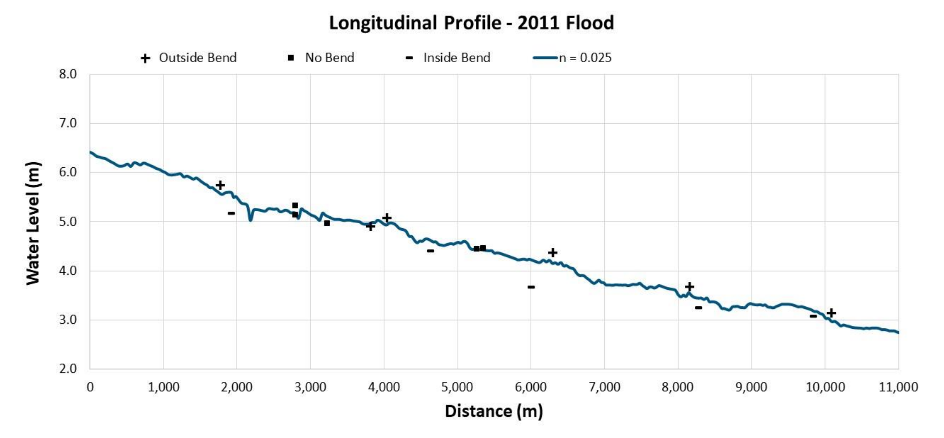
2011 Calibration Check

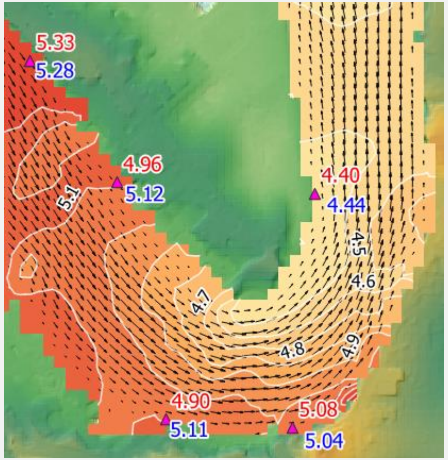
- All good

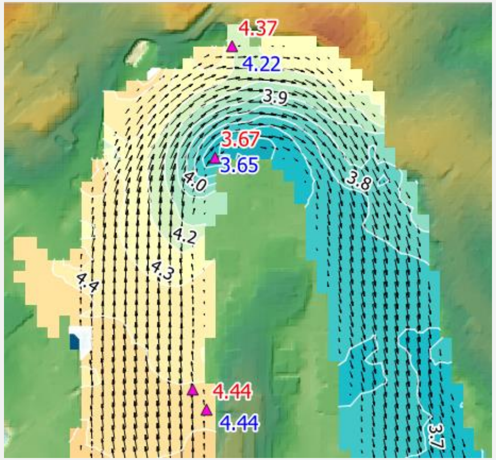
Model reproduces reality

- with a high level of accuracy, and
- little uncertainty

Using parameters within industry guidelines







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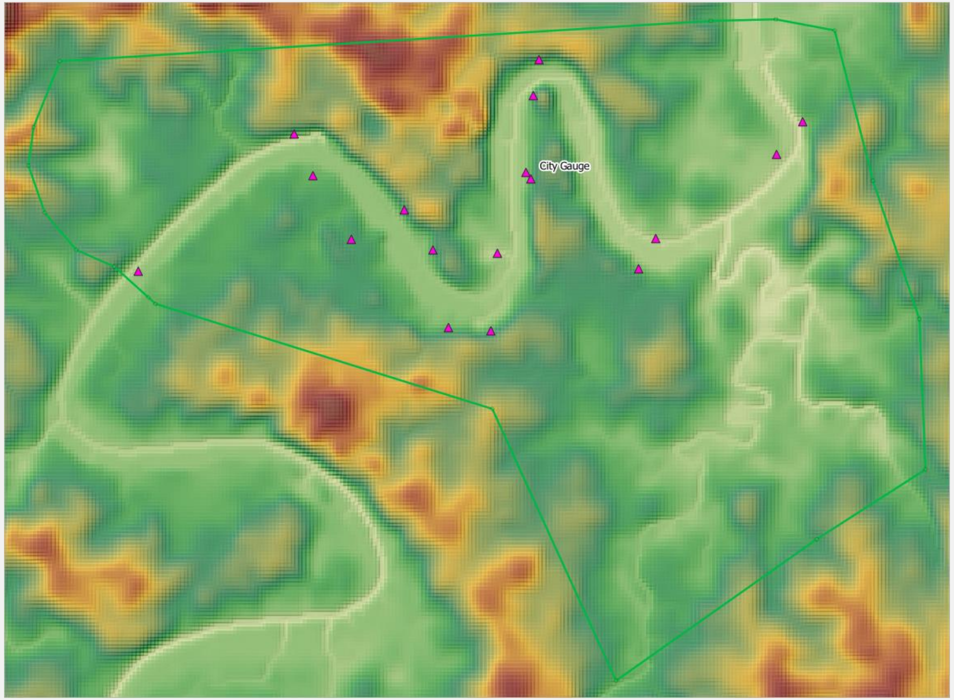
Maximising the Accuracy of Hydraulic Models

Input Data

Maximising the Accuracy Input Data

What if

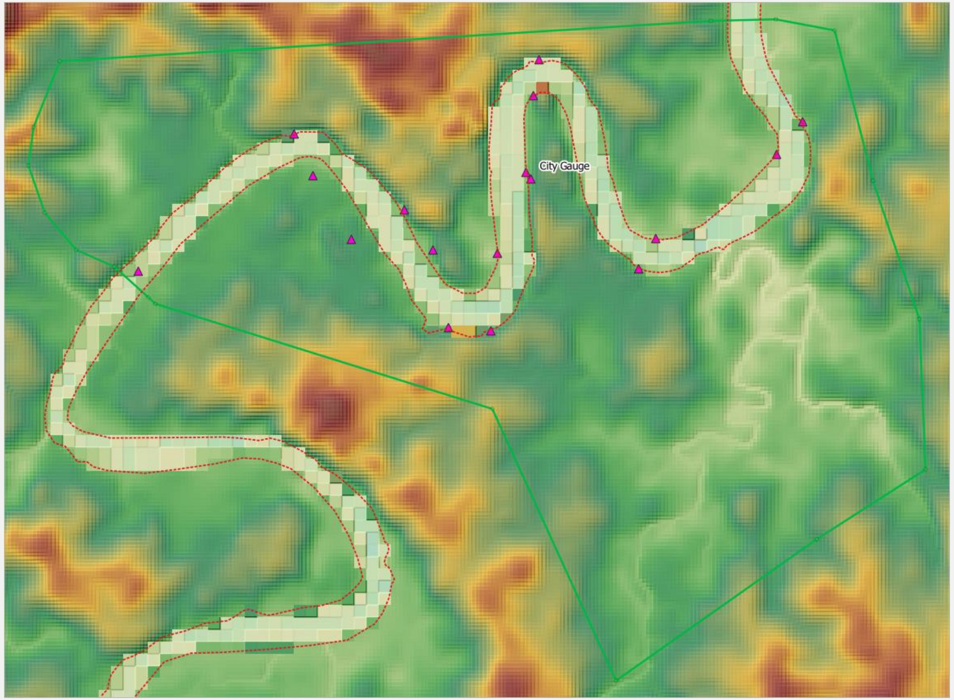
- Not supplied with terrain/bathymetric data
- No budget to carry out these surveys
- But, instead let's download the data
  - https://elevation.fsdf.org.au/
  - for free!
- And the terrain data seems to look OK
  - Awesome



Maximising the Accuracy
Input Data

- Also found some bathymetric data
  - Looks a bit rough
- But it's better than nothing for the river

Let's run the model…



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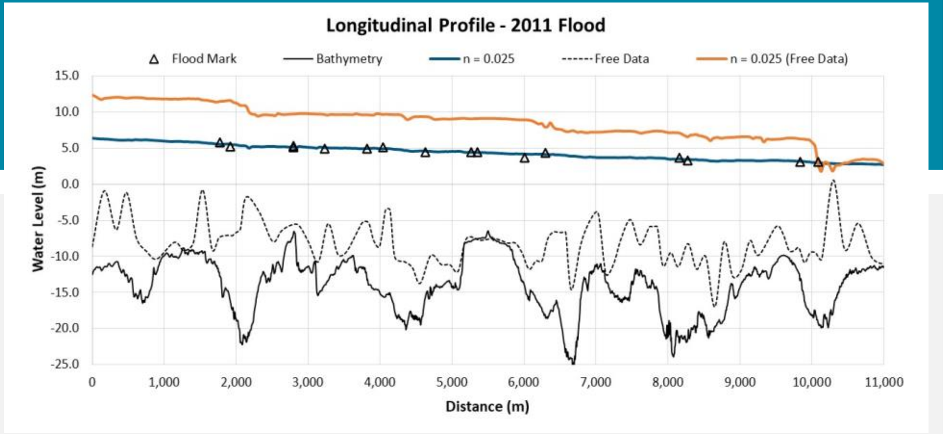
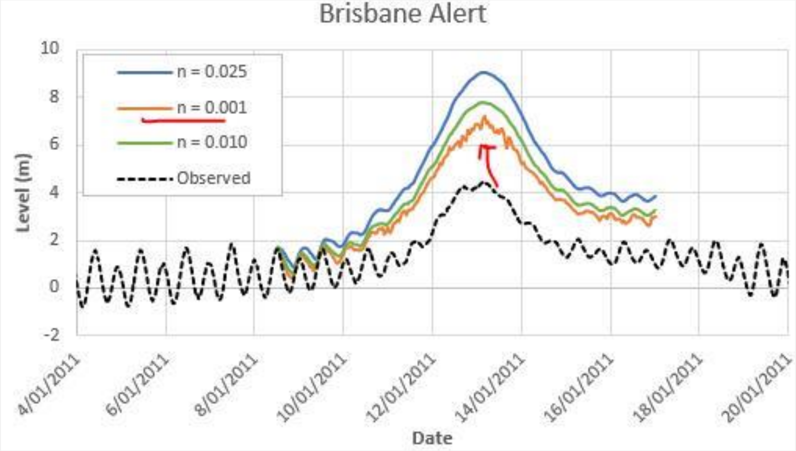
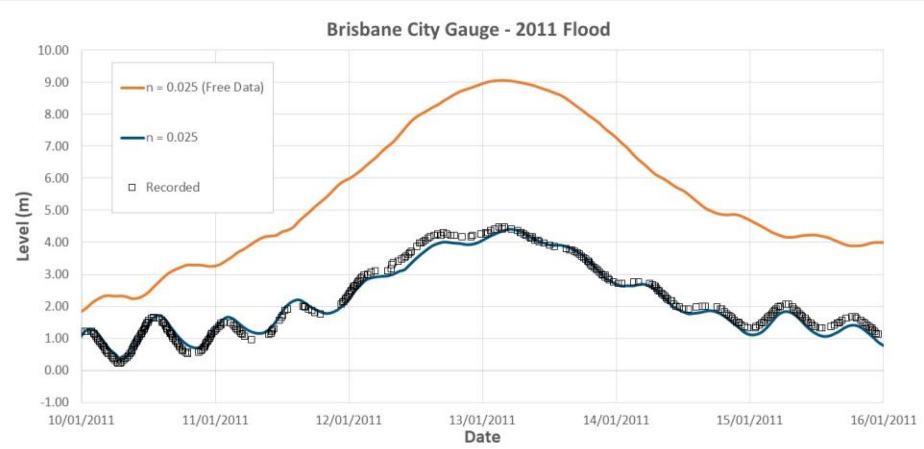
Maximising the Accuracy Input Data



Model runs fine

But it is horribly wrong





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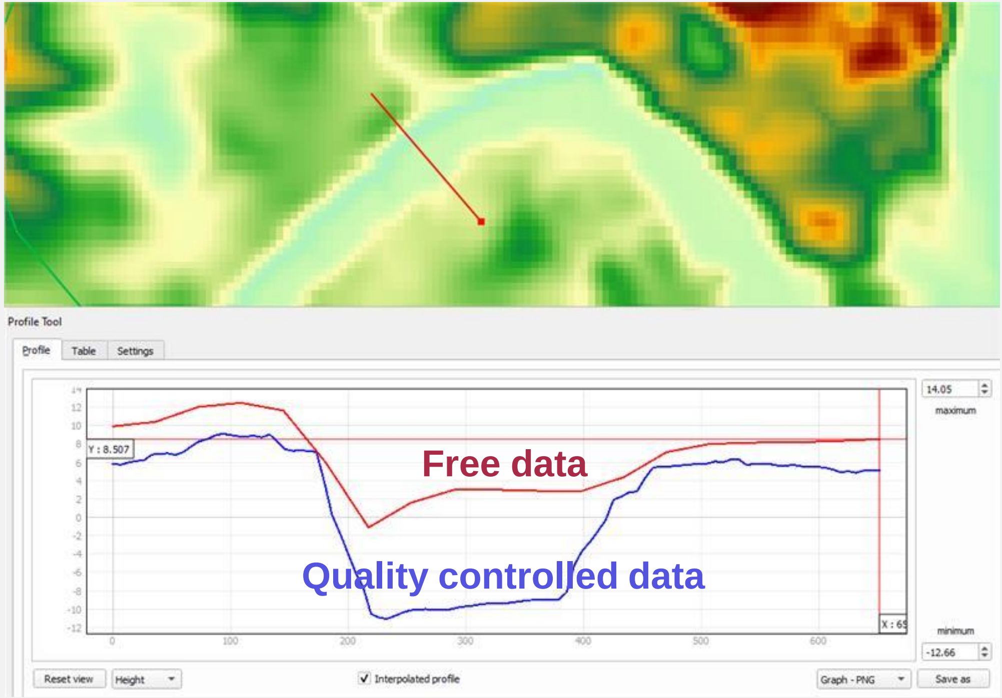
Maximising the Accuracy Input Data

Why so wrong?

- Simply because the data is inaccurate
  - Has a high error or uncertainty
- **So your modelling will be inaccurate**

GIGO – Garbage In, Garbage Out

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



Maximising the Accuracy of Hydraulic Models

Solving the Fluid Flow Equations

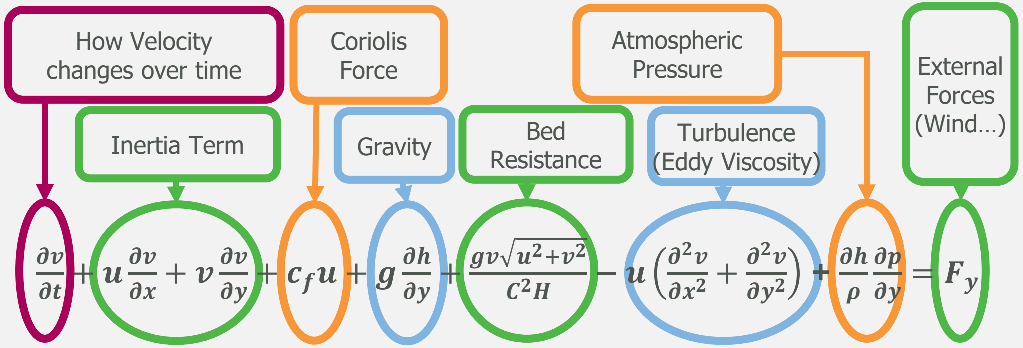
Fluid Flow Equations
Different Forms

Spatial Dimension

- 1D
- 2D
- 3D (Layered or CFD)

Common Forms

- Kinematic wave (bed resistance, e.g. Manning's)
- Diffusive wave (+ gravity)
- Dynamic wave without turbulence (+ inertia) – Slow moving hydraulics
- Dynamic wave (+ turbulence) – Flood hydraulics
- Complete (+ pressure + Coriolis) – Coastal hydraulics



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

Numerical Solution Approaches

- Simple
- Advanced

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Fluid Flow Equations
Solution Approaches

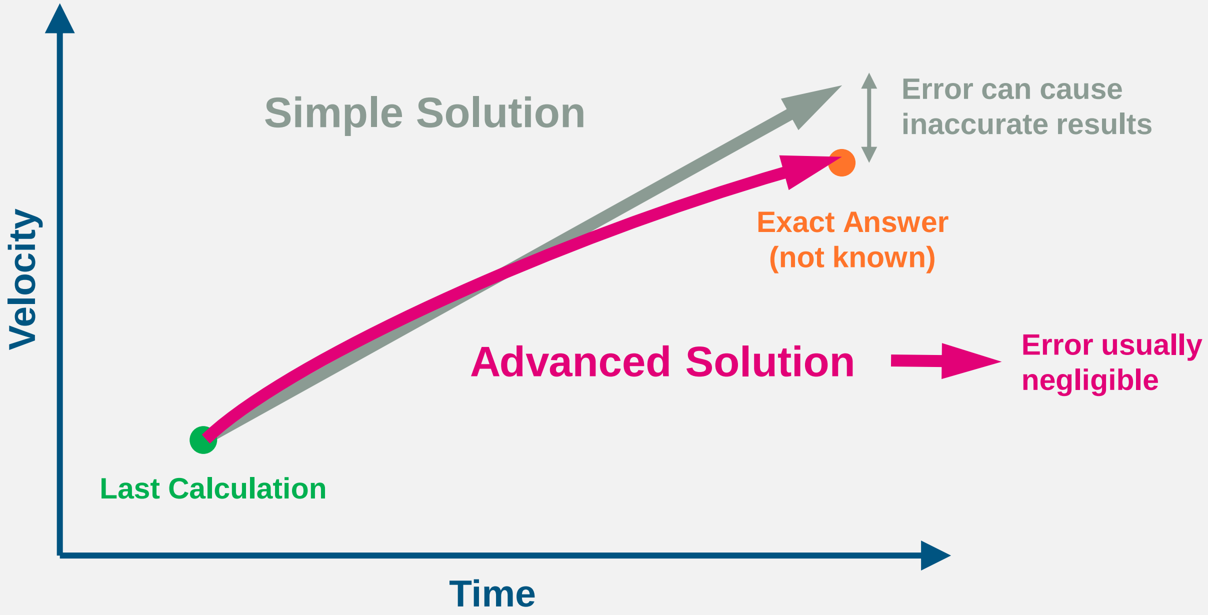
Many ways to solve

- No two solutions will give identical results for real-world flows
- There is no exact answer
  - Need to approximate and extrapolate

Fluid Flow Equations
Solution Approaches

Two common approaches for Dynamic Wave solvers

- Simple (1st Order)
- Advanced (2nd Order)

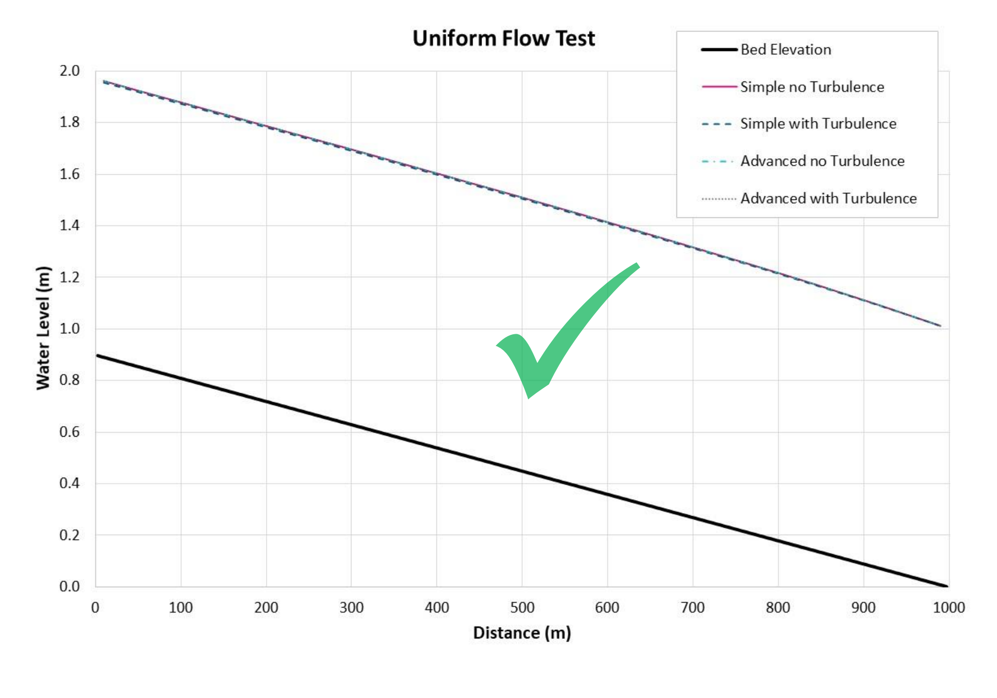


Fluid Flow Equations
Uncomplex Hydraulics

Steady-state uniform flow

- Inertia = zero
- Turbulence = zero
- Just gravity and friction (Manning's equation)
- Easy to solve – has an exact solution

All solvers should give identical answers



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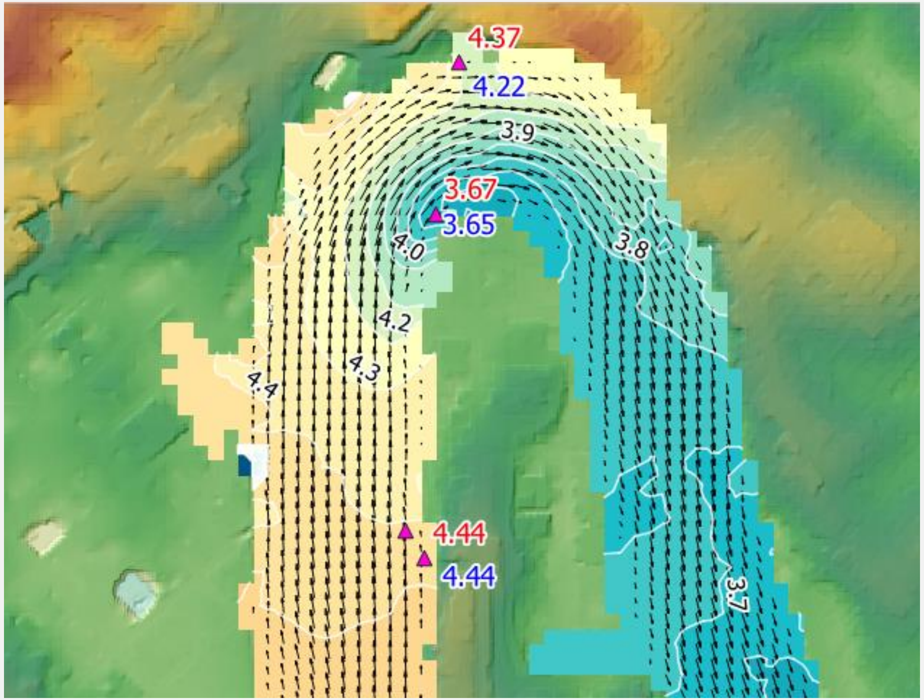
Fluid Flow Equations
Complex Hydraulics

Brisbane River

- High velocities – high resistance » V^2
- Changing bathymetry – inertia; turbulence
- Sharp bends – strong inertia; turbulence



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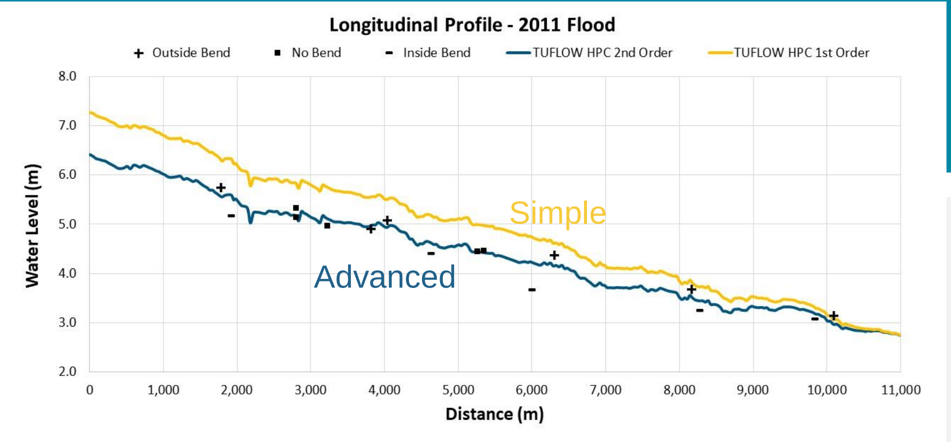
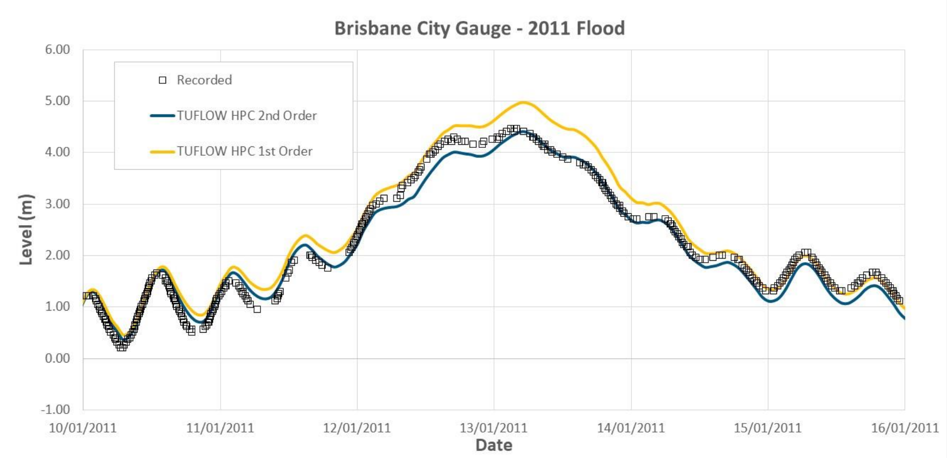
Fluid Flow Equations
Complex Hydraulics

Simple solution overpredicts

- Error accumulation during simulation
  - Referred to as numerical diffusion

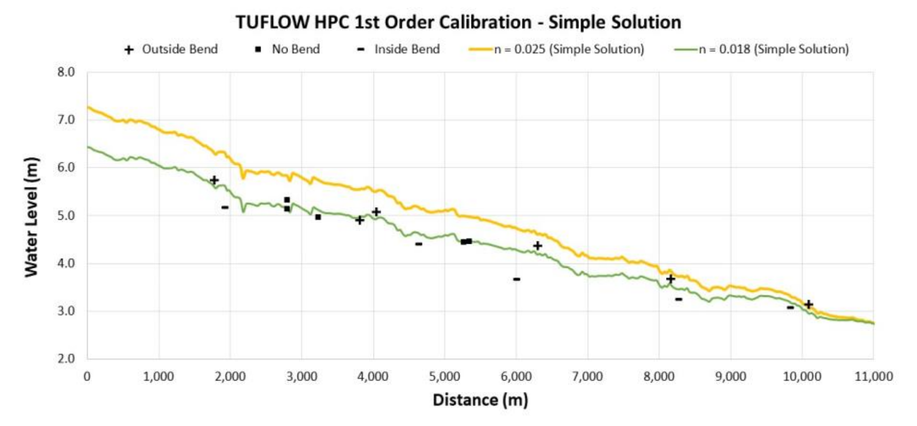




Maximising the Accuracy of Hydraulic Models

Manning’s n

Manning's n
Simple Solution



Let's calibrate Simple Solution

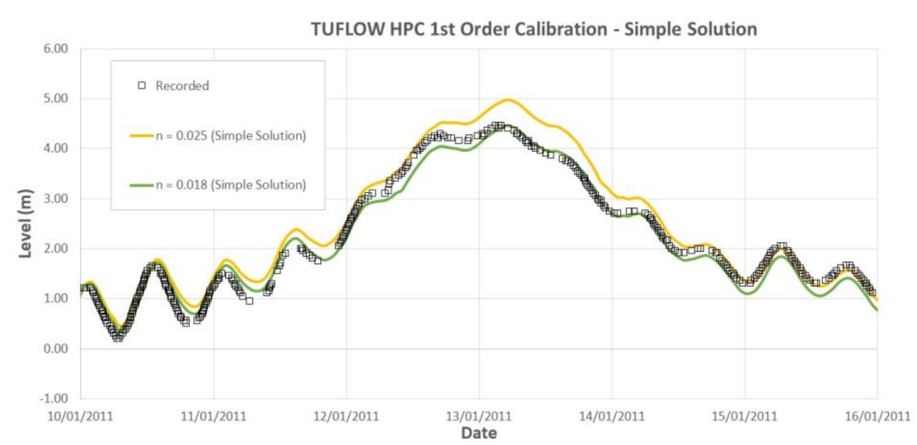
- Requires lower n of 0.018
  (compared with 0.025 for Advanced Solution)
- 0.018 not within industry guidelines

Simple Solution

- Unable to accurately resolve inertia and turbulence
- Not suited to complex hydraulics

If n values outside industry norms

- Something is wrong! – BEWARE



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Manning's n Recommendations

- MUST be within industry standard ranges
- 1D and 2D n values should be very similar
  - Except where 1D n values are increased to approximate 2D and 3D energy losses (eg. bends, structures, flow expansions, rock ledges, etc)

Outside industry guidelines means something is wrong

- Inaccurate data
- Poor numerics (Simple solution)

Example Ranges

- Tidal waterways 0.020 to 0.025
- Roads ~0.020
- Concrete 0.011 to 0.015
- Perennial waterways 0.03 to 0.05
- Vegetated waterways 0.04 to 0.08
- Grassland ~0.03
- Open vegetation 0.03 to 0.08
- Dense vegetation 0.08 to 0.20

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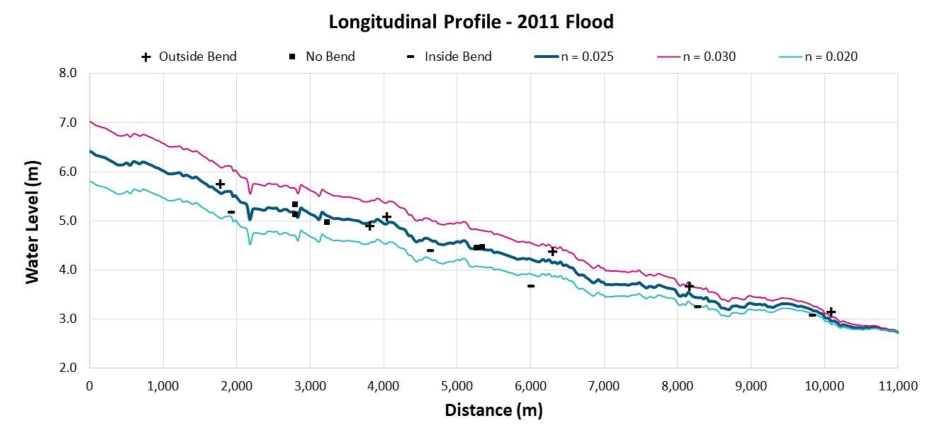
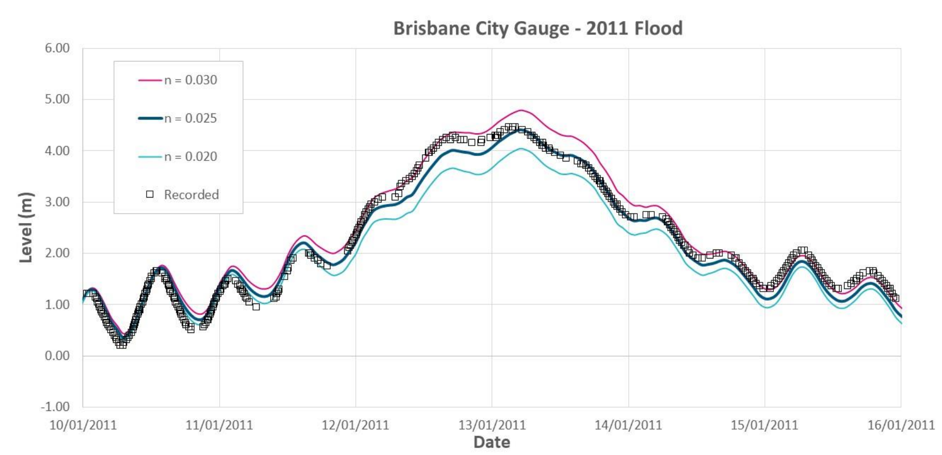
Manning's n Sensitivity Recommendations

Sensitivity Test

- +/- 10 or 20% – good test to ascertain uncertainty bounds
- n values along the primary flowpaths will have the biggest sensitivity
- n values in backwater/storage areas much less important





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Manning's n – Different for 1D and 2D?
What do the Equations and the Physics Signify?

For flow along a straight channel (i.e. 1D flow)

- 2D should require slightly higher n values than 1D depending on radius formulation
- Most 1D solvers default to hydraulic radius (A/P)
- Most 2D solvers default to resistance radius (depth)
  - Resistance radius excludes wall friction therefore may need slightly higher n (~0 to 5%)

Manning's n – Different for 1D and 2D?
What do the Equations and the Physics Signify?

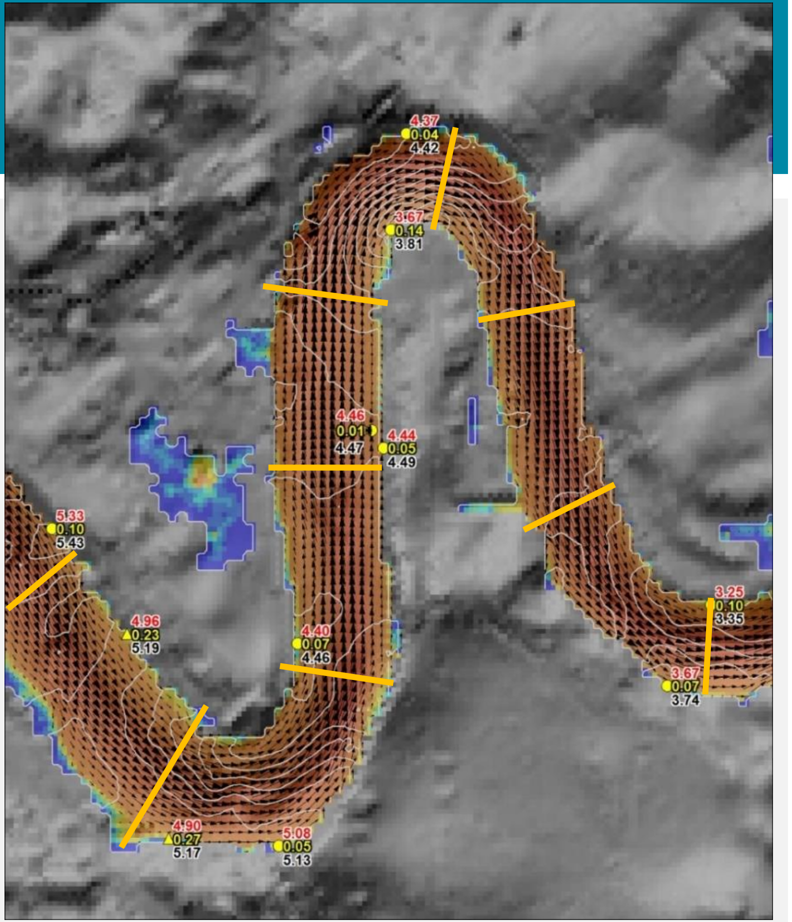
For flow that changes direction (i.e. 2D flow)

- 1D solutions
  (including 1D solutions over a 2D mesh/grid)
  - Not suited for this type of flow
  - Need form loss ($V^2/2g$) term or higher n values at bends/transitions, sometimes substantially higher than 2D
- 2D solutions
  - Kinematic or diffusive wave equations should never be used
  - With good turbulence model, simulate majority of energy losses but not losses in third (vertical) dimension
  - Need for any form loss (or higher n values) at bends/transitions should be much less than for 1D
  - Simple solutions (1st order) inaccurate for high velocities / complex hydraulics
    – typically overestimate gradient
    – need lower Manning's n – maybe outside industry guidelines

Maximising the Accuracy of Hydraulic Models

Bend Losses

Bend (Energy) Losses
Different for 1D and 2D? YES!



Average Vel 3-4 m/s, 20 m deep, 0.7m superelevation

1D Equations

- Don't simulate bend losses
- Need to apply additional losses
  (eg. higher n or energy loss)
- Superelevation not modelled

$$\Delta H = K\frac{V^2}{2g}$$

2D Equations

- Simulates bend losses and superelevation
- Don't simulate all losses such as those in the vertical
  (eg. helicoidal circulations)

3D Equations

- Layered 3D should be closer again, but there are assumptions
- CFD using the Navier-Stokes equations "should" be closest

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Bend Losses Recommendations

1D and 2D will differ

- 1D bend losses needed to represent 2D and 3D effects
- 2D bend losses needed to represent 3D effects (minor compared with 2D)

Gentle meandering bends through alluvial floodplains

- 1D may need slightly higher Manning's n or a form loss
- 2D not needed

Sharp bends controlled by rock

- 1D values: K = 0.25 (45°) to 0.75 (90°) to 1.5 (180°)
- 2D values: K = 0.05 (45°) to 0.15 (90°) to 0.3 (180°)

$$\Delta H = K\frac{V^2}{2g}$$

Submerged rock obstructions

- 1D values: K = 0.25 (minor) to 1.0 (major)
- 2D values: K = 0.05 (minor) to 0.2 (major)

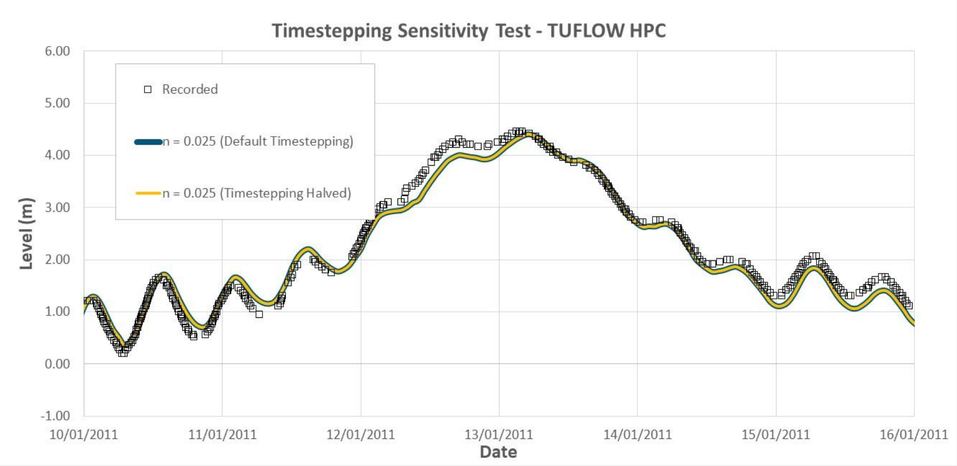
Maximising the Accuracy of Hydraulic Models

Discretisation

Temporal Discretisation (Timestepping)
Does different timestepping change the results?

Good (mandatory?) test

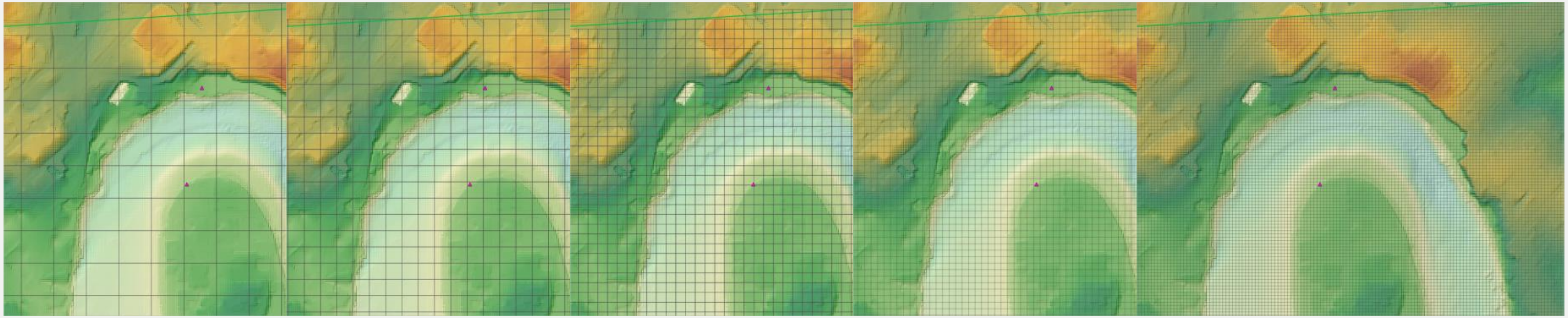
- Halve the timestepping and compare
  - Should give consistent results
- If smaller timestep needed for stability
  - Timestep is too large
    (typically occurs in a fixed timestep solution)
  - Bad data
  - Poor boundary configuration
- Some solutions may not give consistent results if timestepping changed
  - Not a good sign!
  - Investigate further or use another software



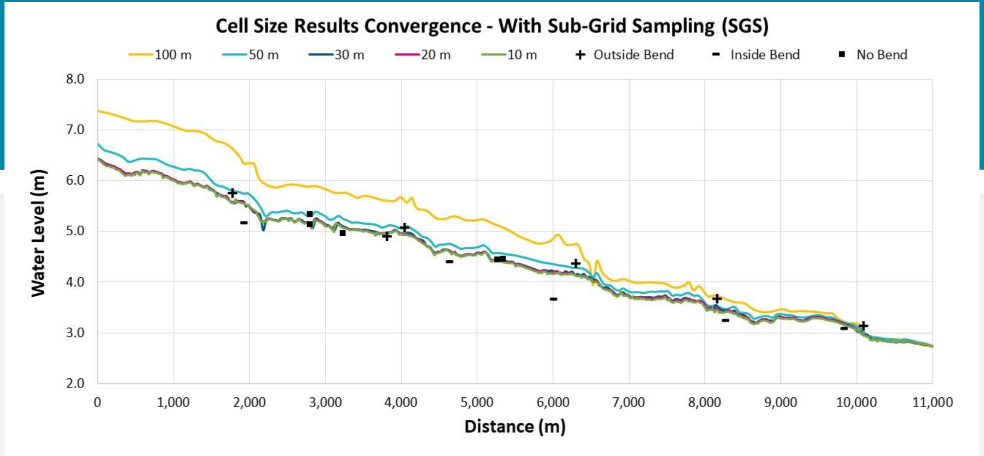
Spatial Discretisation – Cell/Element Size
Do different cell sizes change the results?

Cell size results convergence test (mandatory)

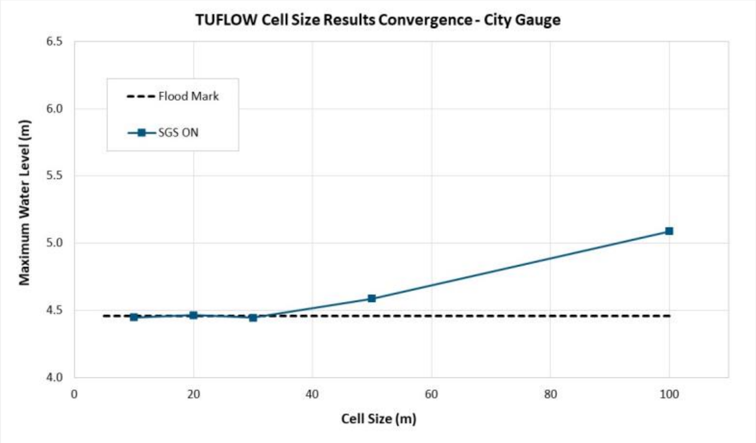
- Increase or decrease the cell sizes of the grid/mesh
- If results consistent, all good (can use coarser resolutions with confidence)
- If results inconsistent, keep reducing until consistent



Spatial Discretisation Results Convergence

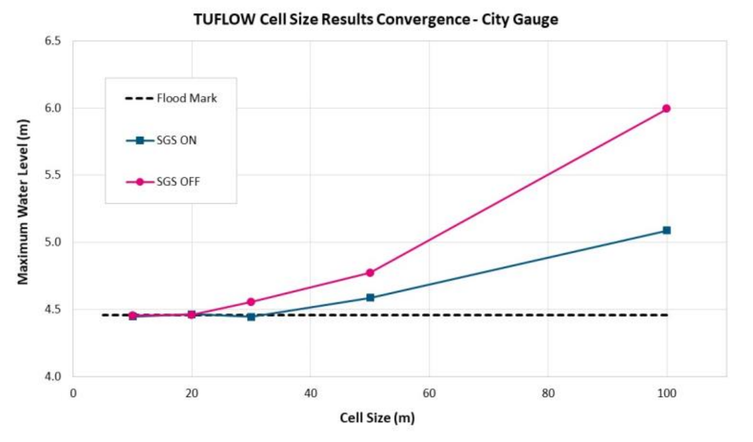


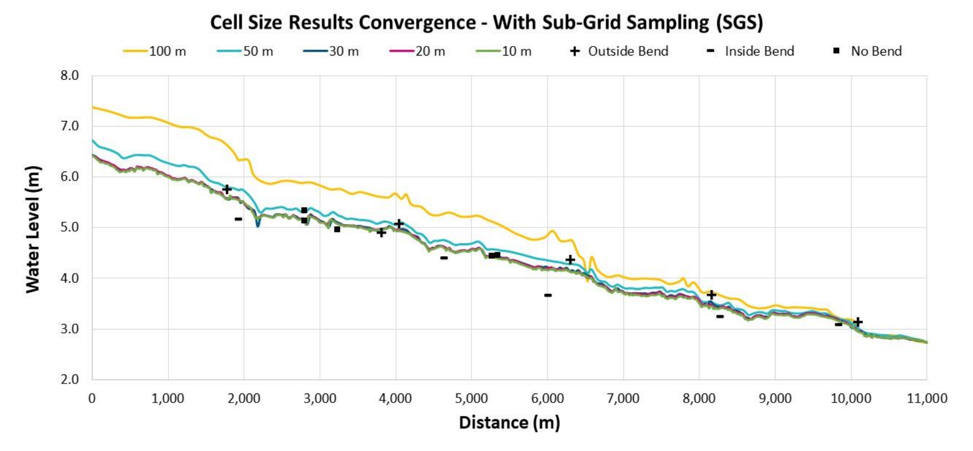
Looking for little change in results as cell size reduces

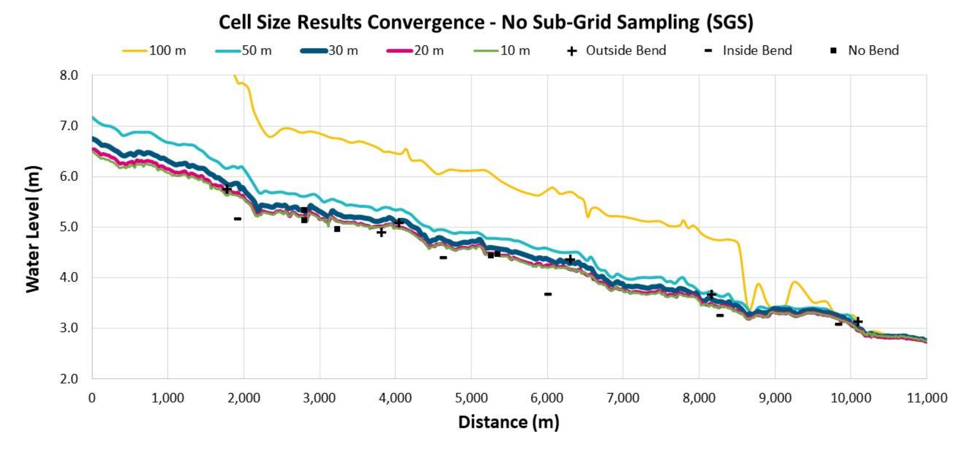


Spatial Discretisation Results Convergence

Sub-Grid Sampling (SGS) Affect



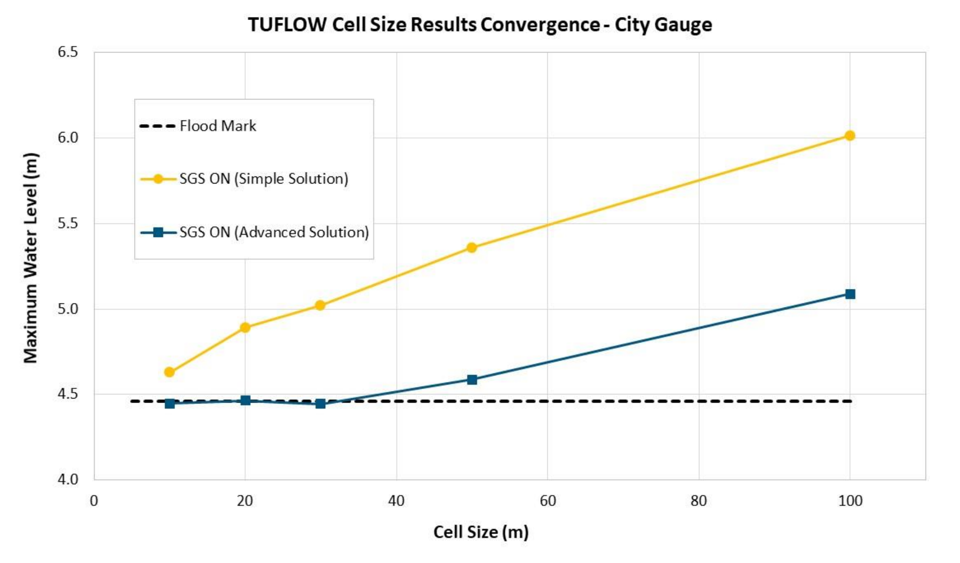




Spatial Discretisation
Results Convergence – Solution Approach

Numerical Solution Approach Affect

- Simple (1st order) solutions show poor convergence
  - Even if using Sub-Grid Sampling (SGS)



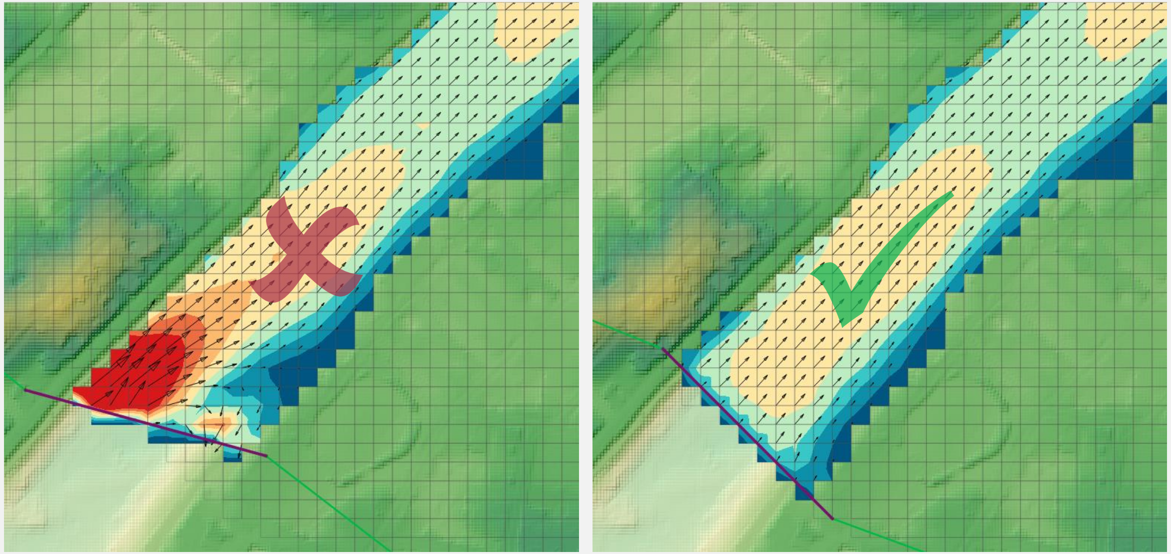
Boundaries
Discretisation and Uncertainties

Uncertainties in boundary values major source of inaccuracies

- Flow boundaries often highly uncertain – review/understand
- HQ boundaries often rough approximation – keep well away from area of interest
- Water level boundaries usually low uncertainty (Ocean, Lake)

Check performance

- Flow patterns are realistic
- No mass loss/gain



Maximising the Accuracy of Hydraulic Models Structures

Whole webinar planned for structures

- 20^{th} October, 2021

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Maximising the Accuracy of Hydraulic Models

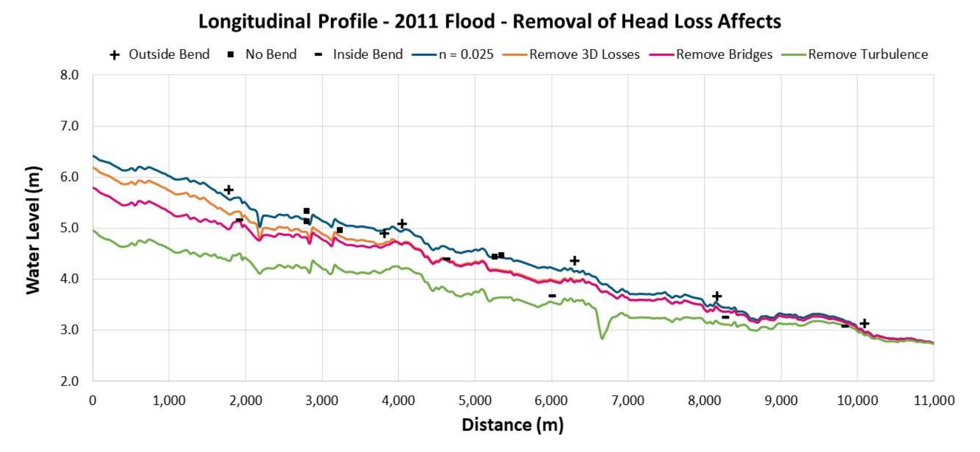
Test Your Software

Test Your Software Understand Limitations

Let's apply benchmark model to another commonly used hydraulic modelling software

In the interests of simplicity and like for like comparison of how 2D equations are solved

- Additional 3D bend losses removed
- Eight bridges removed
- Also removed turbulence (out of interest)



Head Loss Component	Head Loss (m)	% Contribution
n = 0.025 Calibrated Model	**3.69**	
Removal 3D Losses at Bends	0.23	6%
Removal 8 Bridges	0.43	12%
Removal Turbulence	0.81	22%
Manning's n	2.22	60%

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Test Your Software
Other 2D Solver

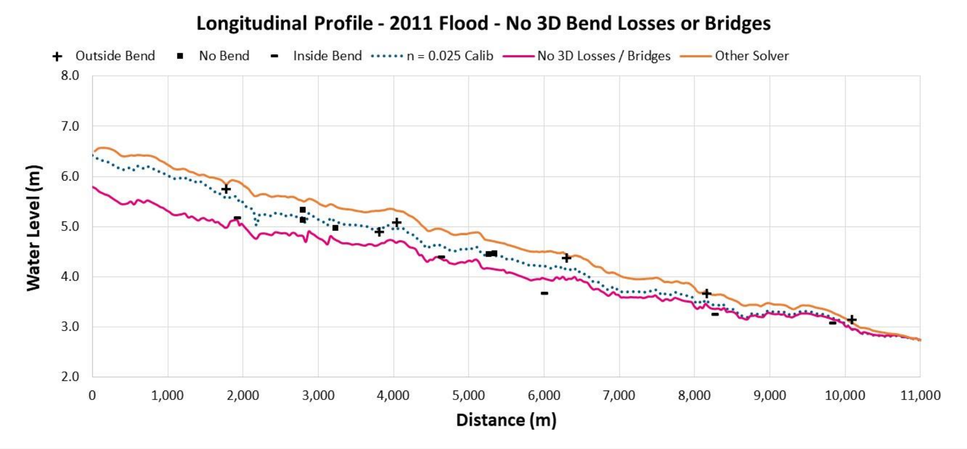
- Commonly used for flood modelling
- Dynamic fluid flow equation
- New explicit solver
- Sub-grid sampling
- Run dynamic solver with defaults

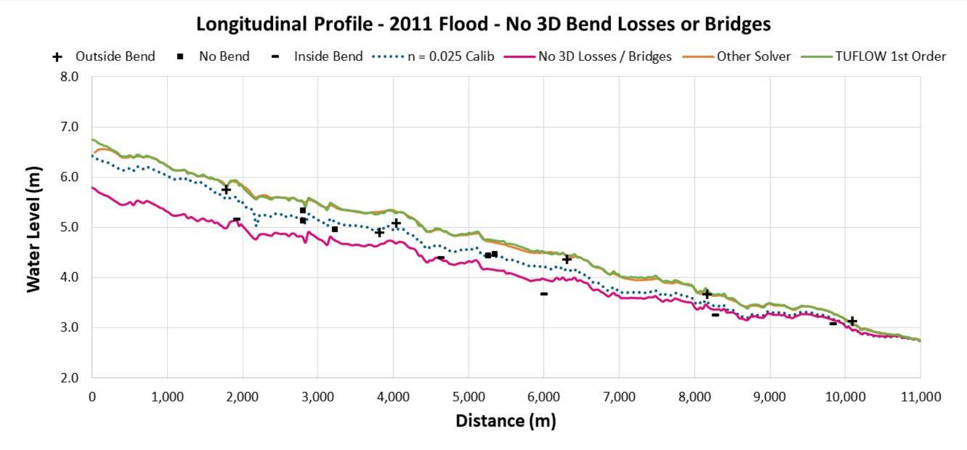
Ran with

- No bridges
- No 3D bend losses
- ~30 m average cell size

Significantly overpredicts head loss

- ~1 m (30%)





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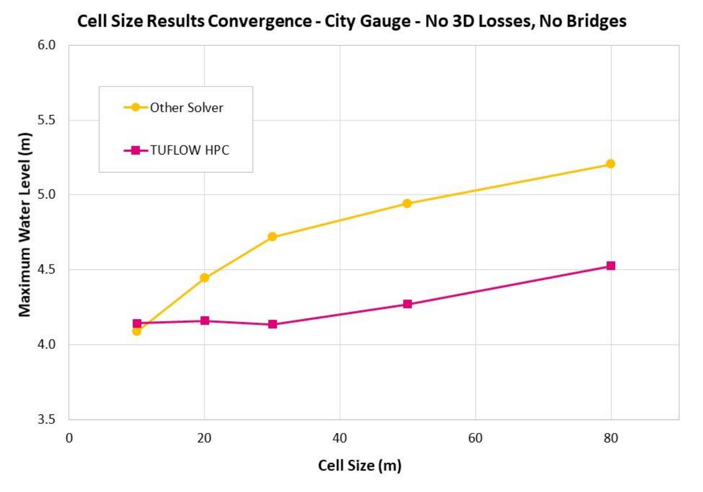
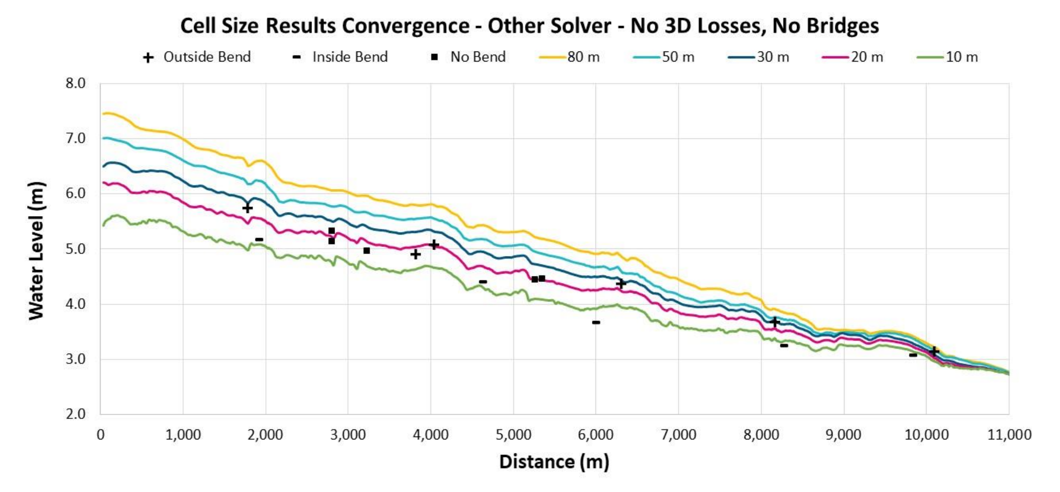
Test Your Software
Other 2D Solver – Cell Size Results Convergence

Doesn't demonstrate cell size results convergence – BEWARE!





Maximising the Accuracy of Hydraulic Models

Recommendations

Recommendations
Storage Dominated Areas

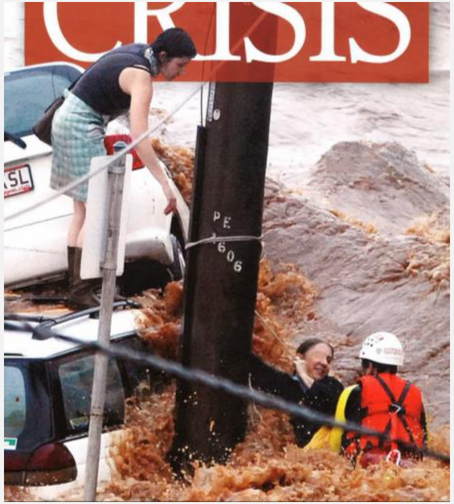
Where you have

- Large floodplains, lakes, tidal flats
- Flat gradients; slow flowing (low velocities)

Recommendations
Conveyance Dominated Areas

Where you have

- Primary flowpaths (rivers, creeks, estuaries)
- Contraction / expansion / change in direction of flow (structures, embankments, rock obstructions)



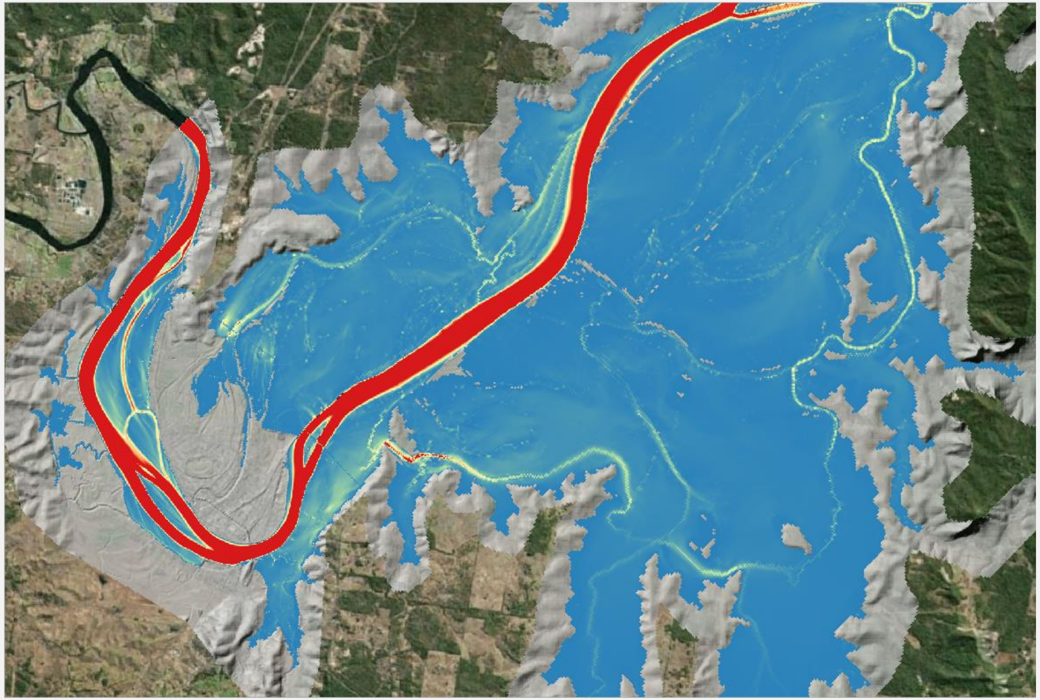
The Toowoomba Chronicle

TUFLOW

Recommendations
Unit Flow (DxV)

Use q (Unit Flow = DxV)

- High q
  - Primary flowpath
  - Conveyance dominated
- Low q
  - Backwater
  - Storage dominated



Recommendations
Storage Dominated Areas

Recommendations

- Accurate elevations above still water level
  (storage below lowest water level not critical)
- Reasonable representation of flowpaths
- Correct overtopping height of embankments (use breaklines!)
- Industry guidelines Manning's n values
- Simple solutions (1st order) may suffice
- Turbulence and inertia terms minor or no influence – not essential
- Larger cell sizes can be used – Sub-Grid Sampling (SGS) beneficial

Recommendations
Conveyance Dominated Areas

Recommendations

- Accurate terrain/bathymetric elevations and land-use coverage
- Industry guidelines Manning's n values
- 1D will need bend or form ($V^2/2g$) losses at sharp bends or submerged obstructions
  - 2D may need minor form losses if 3D circulations
- Good representation of structures, crests of embankments
- **Quality advanced solution (2nd order) solver with good turbulence model essential**
- Good reproduction of velocities essential – cell sizes need to be fine enough
- Sub-Grid Sampling beneficial
- Carry out cell size results convergence testing

Recommendations
Conclusion

Maximising accuracy is achieved by:

- Accurate terrain and bathymetric elevations – essential
- Sub-Grid Sampling (SGS) – especially where 2D cell size >> DEM cell size
- 3D breaklines along the crest of hydraulic controls (e.g. embankments)
- Industry guidelines Manning's n values – may not apply to Simple (1st order) solutions
- Form (energy) losses at rock controlled bends/transitions (2D values around 20% of 1D values)
- Good representation of hydraulic structures (Oct 2021 webinar)
- Advanced (2nd order) Dynamic Wave solution essential for conveyance dominated areas
- Cell size results convergence testing – mandatory

Thank you!