Recent Advancements in 2D Hydraulic Modelling

Water NZ Modelling Symposium

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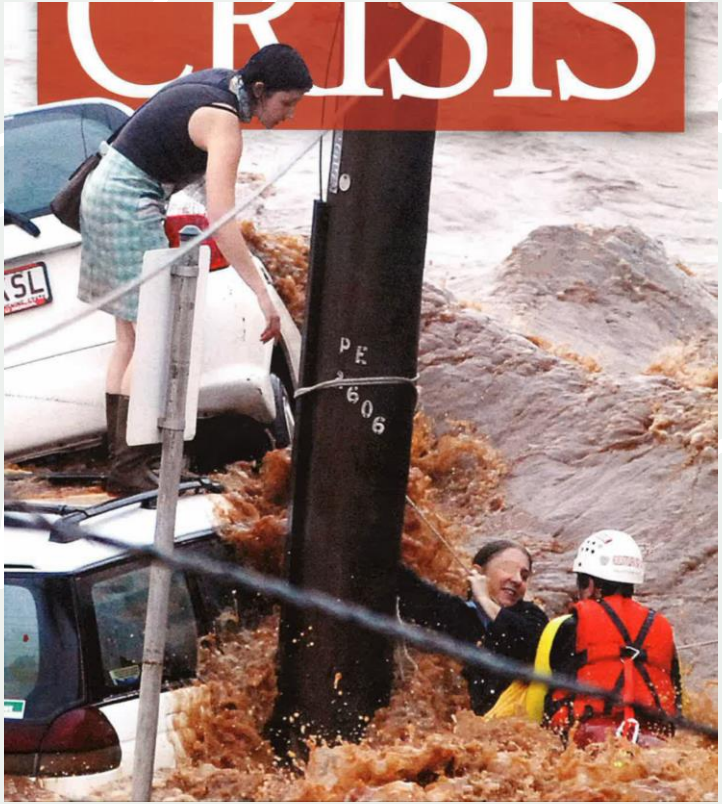


The Toowoomba Chronicle

Overview
A Step-Change in 2D Flood Modelling

Cell Size Independent Turbulence Model

- Model at any scale at any resolution

Sub-Grid Sampling (SGS)

- Rotate regular grid in any direction
- Excellent mesh or cell size convergence

Quadtree Mesh

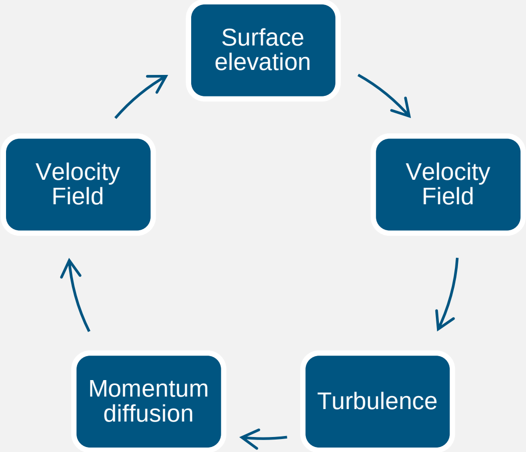
- Very easily vary mesh resolution

Above Combination a Game-Changer!

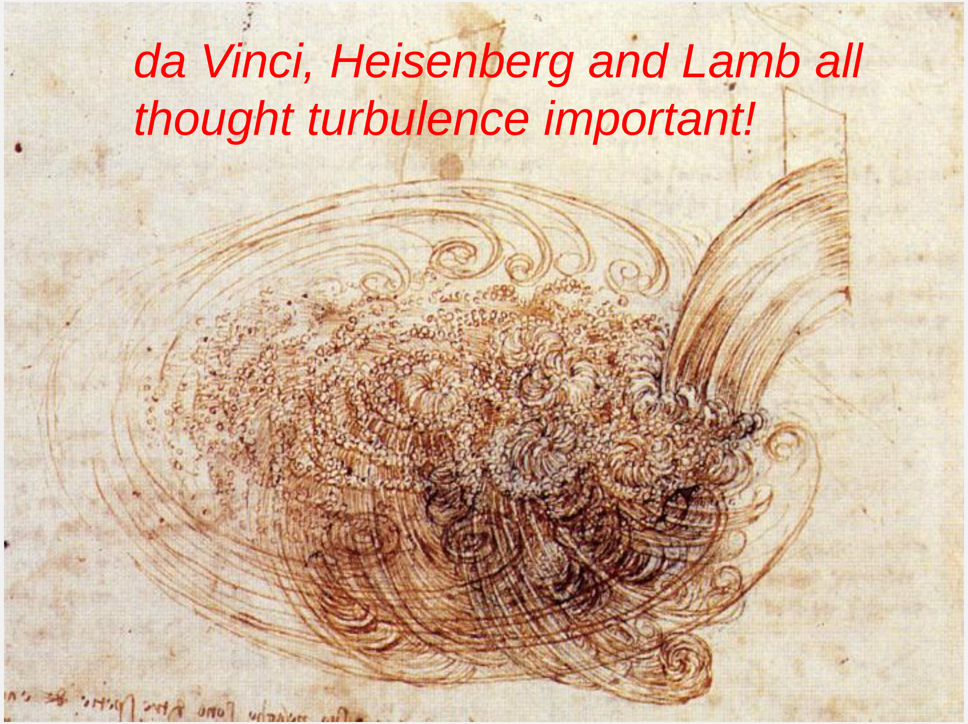
Why Turbulence?

Turbulence causes

- almost infinite flow detail
- momentum diffusivity



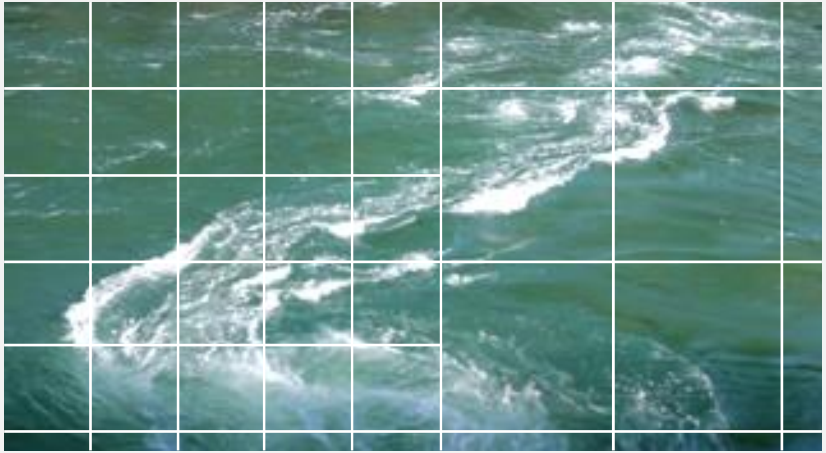
da Vinci, Heisenberg and Lamb all thought turbulence important!



Sub-Grid Turbulence
What is “Eddy Viscosity”?

Turbulence in 2D Schemes

- Energy loss due to turbulence within 2D cell
- Traditionally Large Eddy Simulation (LES) approach
  - e.g. Smagorinsky Formulation
  - Good for large cells (relative to the depth)
  - Not designed for when cell size << depth



2D Cells

- Becoming smaller and smaller (cell size << depth)
- Irregular and Quadtree meshes vary cell size (which ideally use same turbulence parameters)

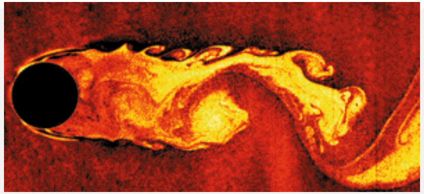
Need a 2D cell size independent turbulence model

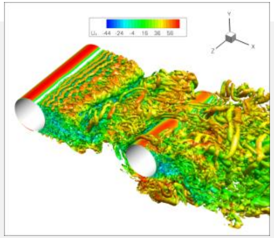
Turbulence in Shallow Fluid Flows

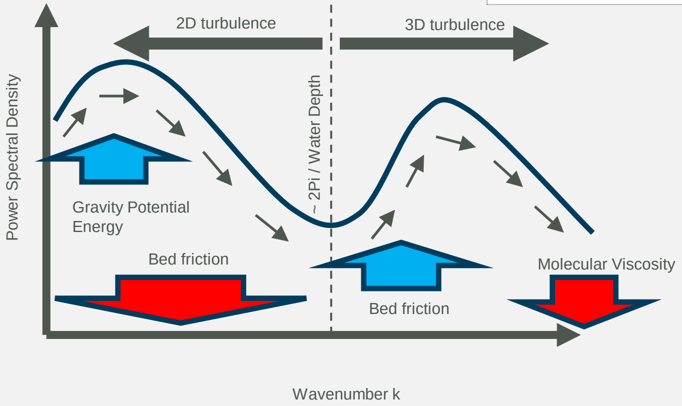
In shallow fluid flows we have both 2D and 3D flow behaviour

Bed friction converts larger scale 2D turbulence into smaller scale 3D turbulence

Need to represent and transition from 2D turbulence (LES) to 3D turbulence







Nadaoka, K., and Yagi, H. (1998). Shallow Water Turbulence Modelling and Horizontal Large Eddy Computation of River Flow. *J. Hydraulic Engineering*, pages 493–500.

Cell Size Independent Sub-Grid Turbulence Approach

Testing of a range of turbulence models

- Constant, Smagorinsky, Wu, Prandtl, k-omega, k-epsilon

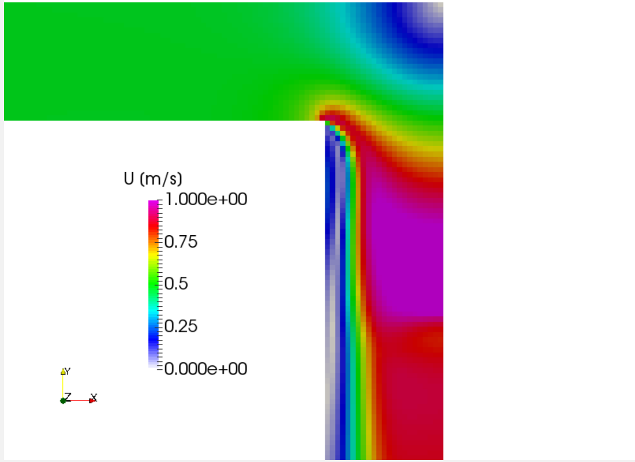
Benchmark to a range of physical scales and range of cell sizes

- Flume Tests
- Real-World: Low data and boundary uncertainties and high quality calibration data
- Determine optimum turbulence model parameters for each scenario

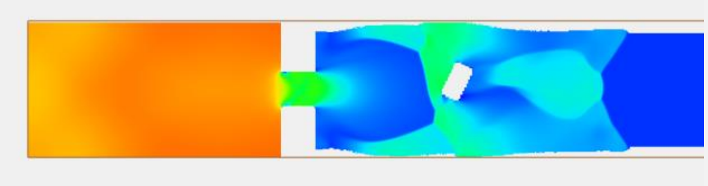
Objective

- A ‘one size fits all’ turbulence model?

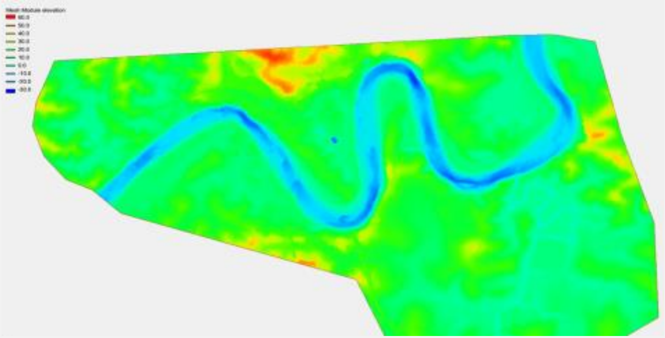
Sub-Grid Turbulence Modelling
Benchmark Cases



Right angled flume bend, Scale 0.15 m width

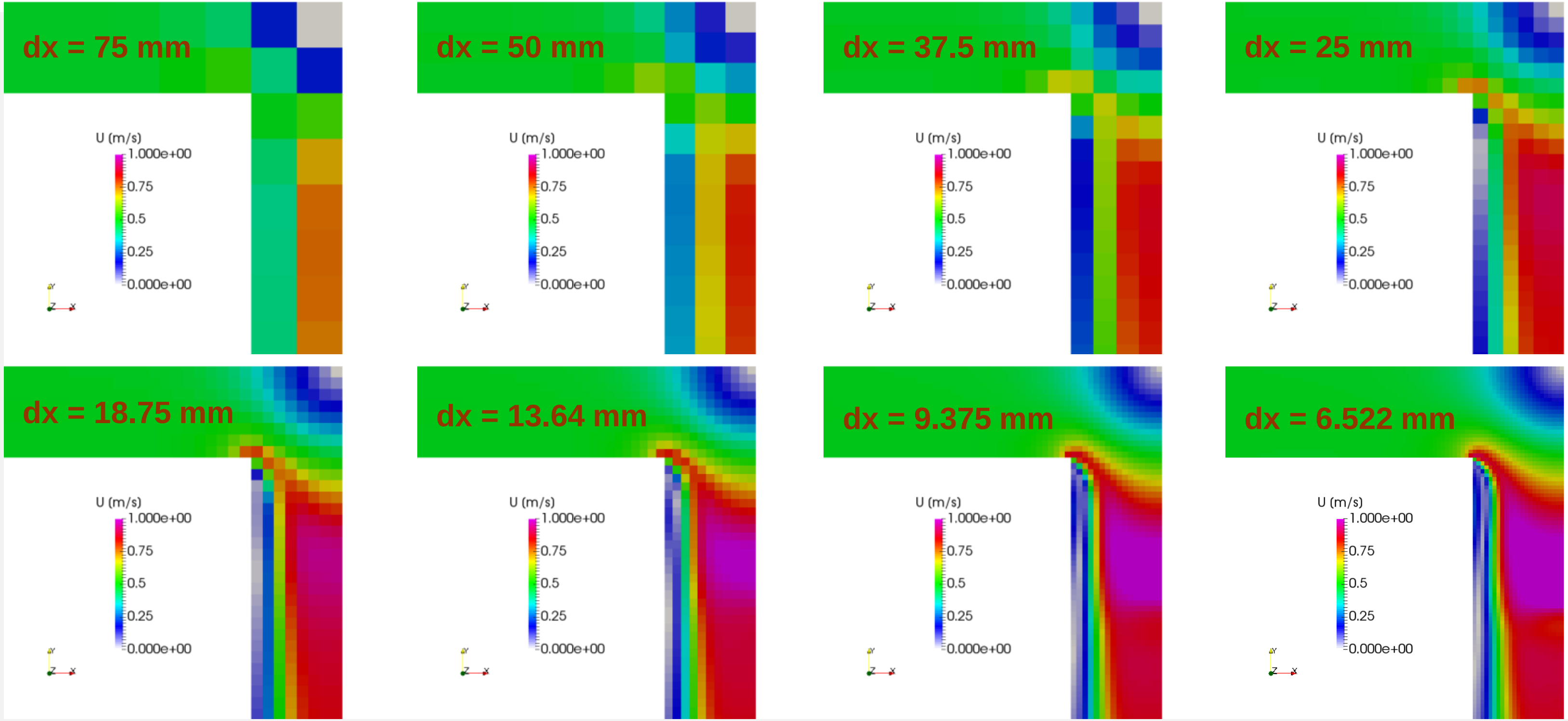


UK EA T06, Scale 3 m width

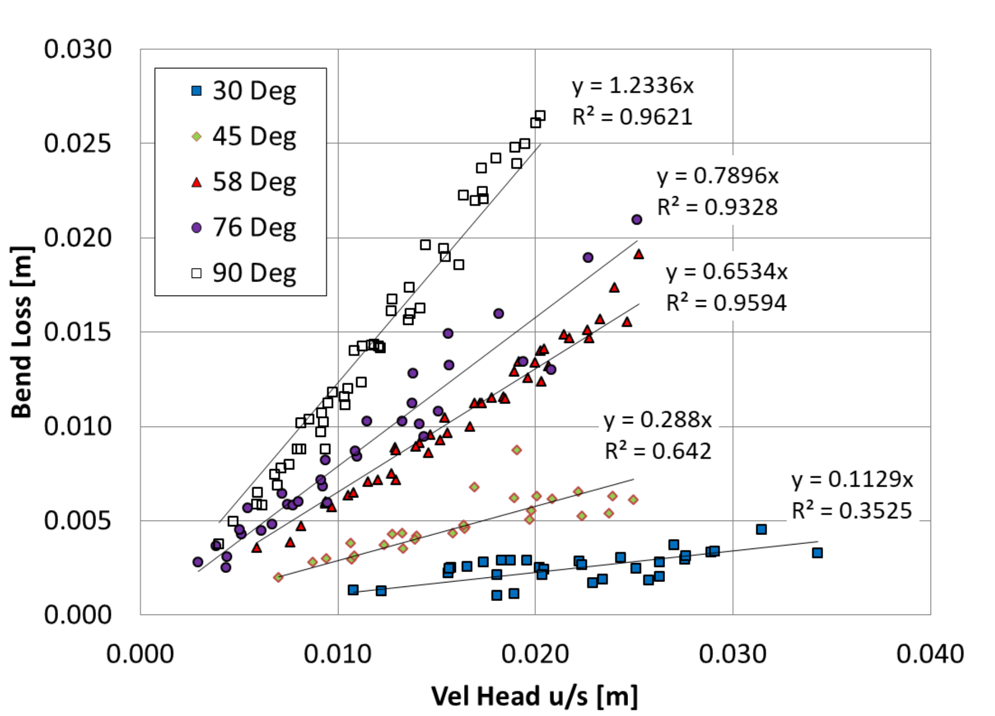


Brisbane River 2011 flood event, Scale 200 m

Sub-Grid Turbulence Modelling
Kansas Uni Right Angled Flume Test



Sub-Grid Turbulence Modelling
Kansas Uni flume test bend results



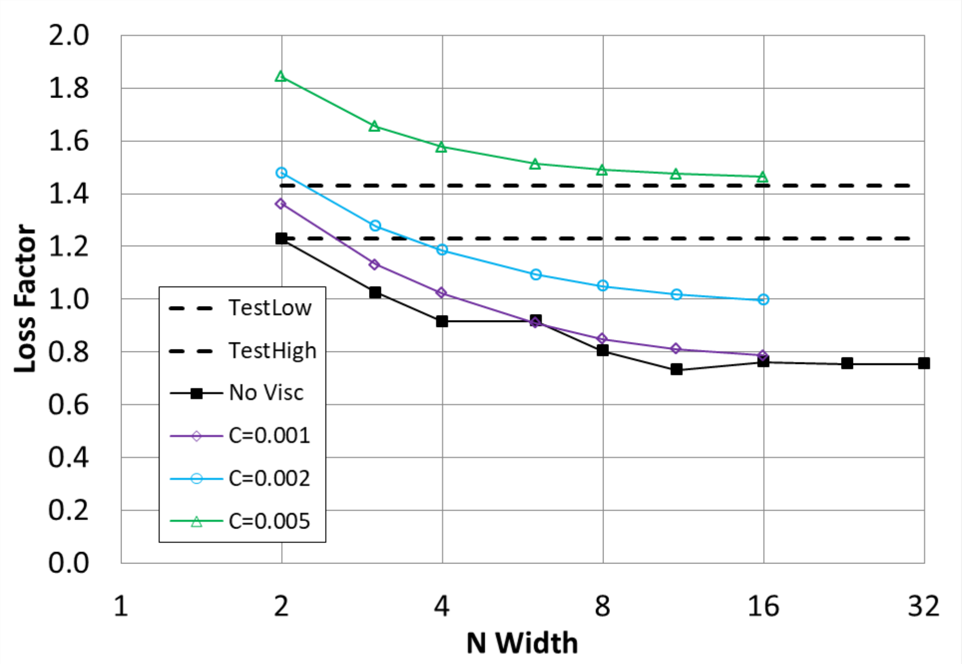
- Malone, T, Parr, D. (2008). Bend Losses in Rectangular Culverts, Kansas Department of Transport (http://ntl.bts.gov/lib/30000/30900/30935/KU-05-5_Final_Report.pdf)
- Excellent correlation between head loss and upstream velocity head
- 90° bend loss factor of 1.22 to 1.42

Sub-Grid Turbulence Modelling
90° Bend – Head Loss vs Cell Size

Cell size convergence test

Optimum constant viscosity

- C = 0.004 to 0.005 m^2/s



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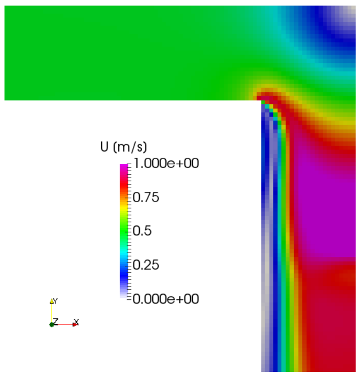
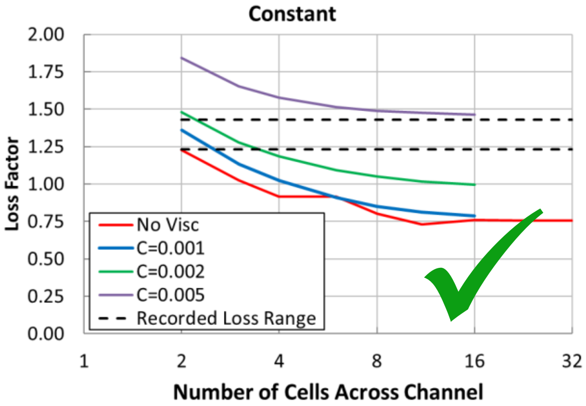
Sub-Grid Turbulence Modelling
Sesame Street Game

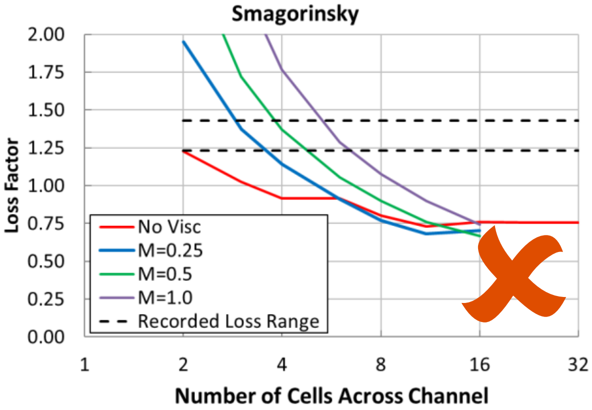


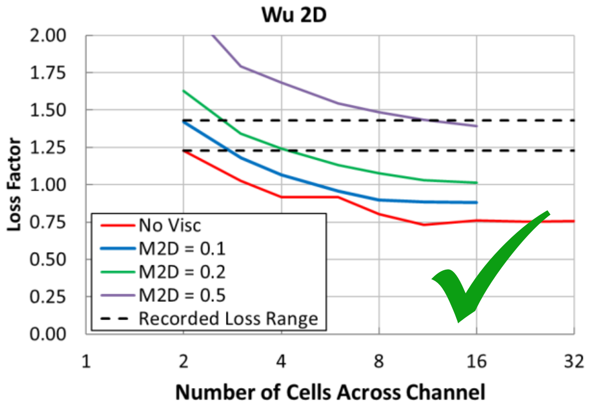


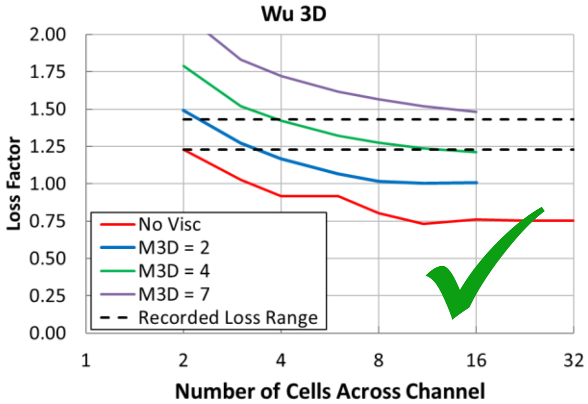

Sub-Grid Turbulence Modelling
90° Bend – Head Loss vs Cell Size

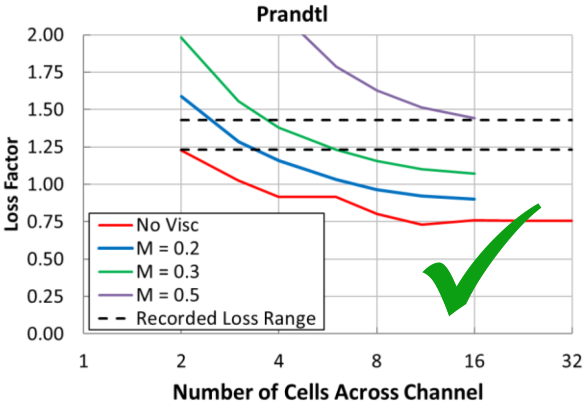




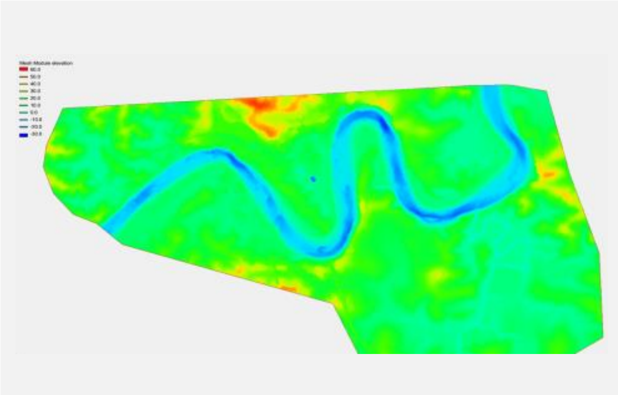


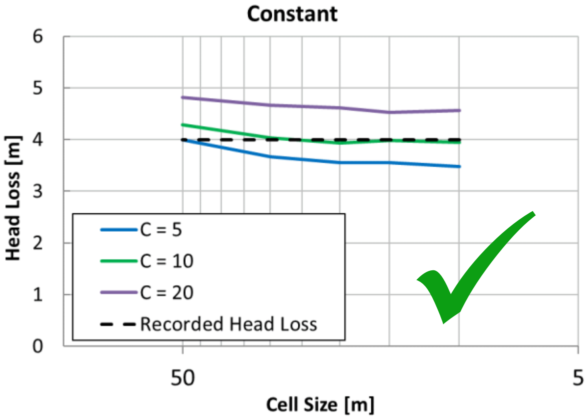


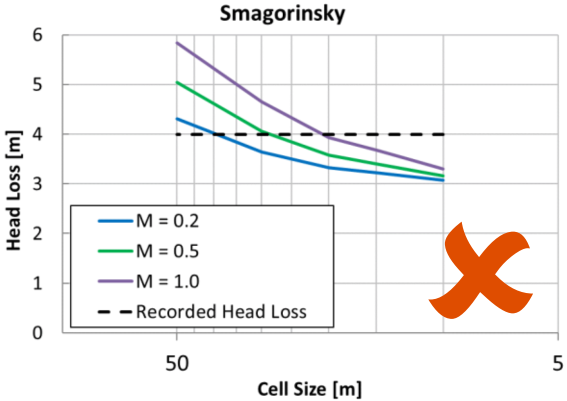


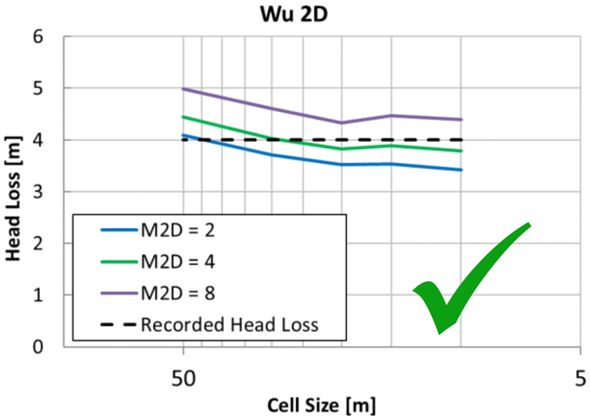


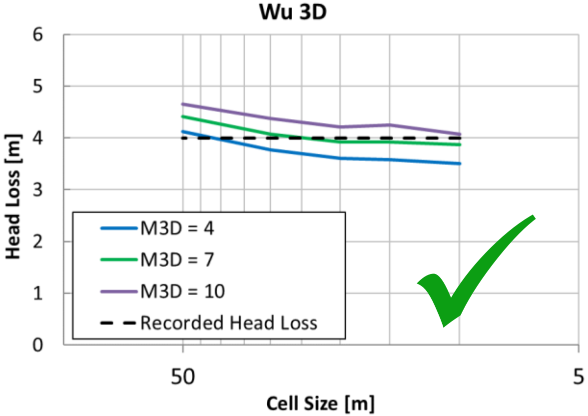
Sub-Grid Turbulence Modelling
Brisbane River – Head Loss vs Cell Size

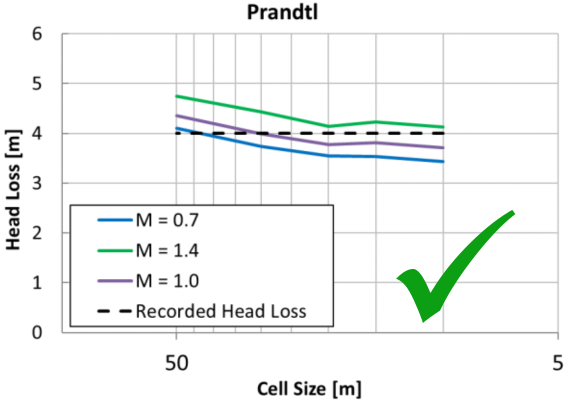












Sub-Grid Turbulence Modelling
Optimum Parameters Comparison

Case	Smagorinsky	Constant	Wu 2D	Wu 3D	Prandtl
90 Deg Bend (0.15 m)	No optimum	0.004	0.5	6	0.4
Dambreak Flume (3 m)	No optimum	0.01	0.5	3	0.5
Brisbane River (200 m)	No optimum	10	4	7	1.0

Not an option

Impractical
(Very strongly cell size dependent)

OK
(Some cell size dependency)

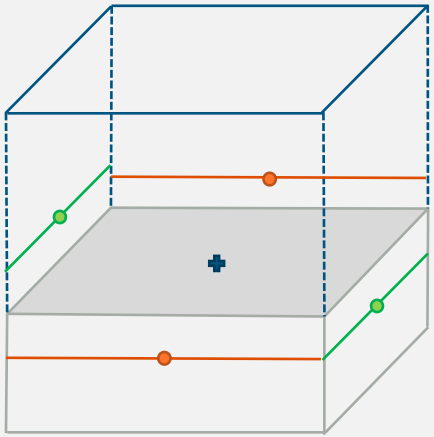
Excellent outcome

Good
(computationally and memory intensive)

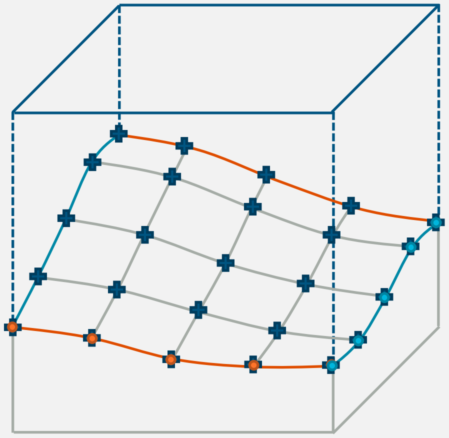
Sub-Grid Sampling (SGS)
Why?

To make better use of terrain information within a 2D cell

Without SGS
(Conventional Approach)

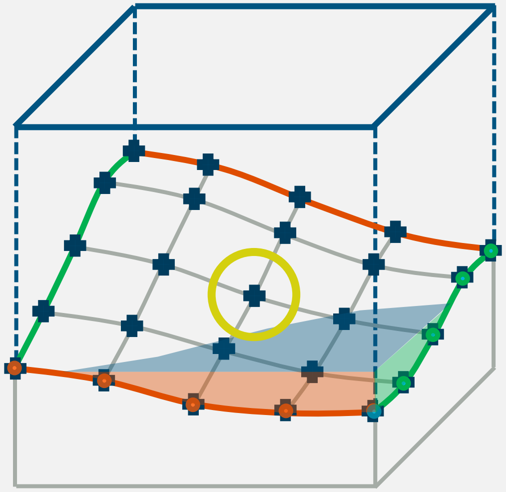


With SGS

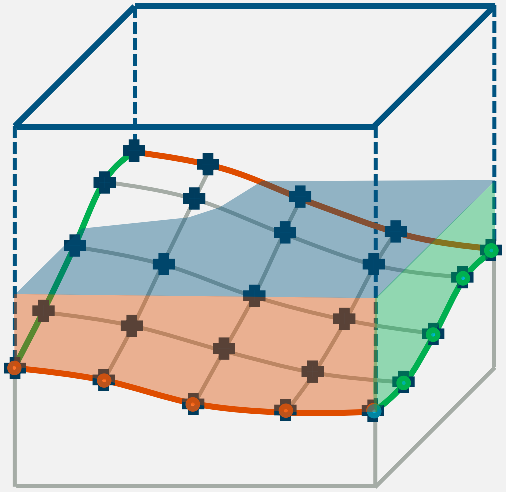


Sub-Grid Sampling (SGS)
Improved Conveyance and Storage

Without SGS cell would be dry at this water level
as cell center is above water level



With SGS cell 25% partially wet.
Two cell faces flowing.

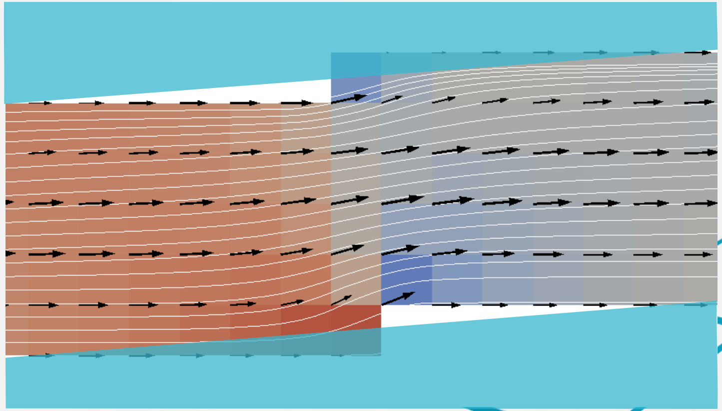


Cell 85% partially wet.
Four cell faces flowing.

SGS Benchmarking
Deep Sided Channels Unaligned to Grid

Mesh not aligned with deep banks (e.g. concrete drains)

- Distorts streamlines
- Artificial energy losses; steepens gradient



Traditional Solutions

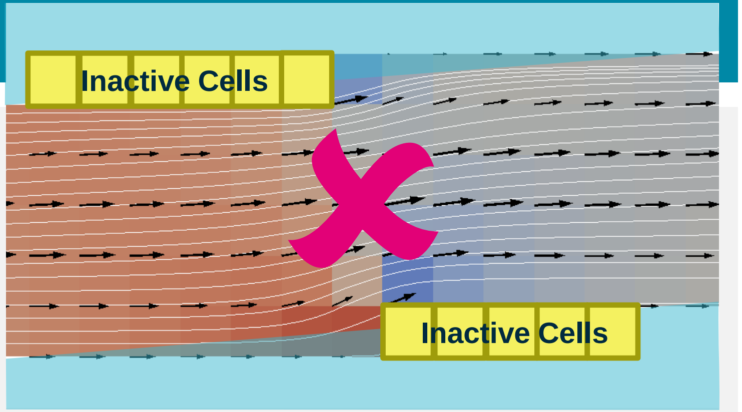
- 1D channel with cross-section (time-consuming; full 2D solution compromised)
- Irregular mesh (quadrilaterals aligned with banks)
- Much finer regular mesh (much longer run times)

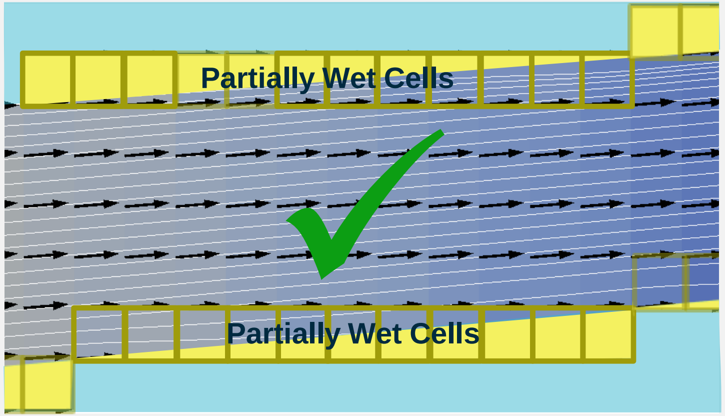
SGS Benchmarking

Deep Sided Channels Unaligned to Grid

Let's try SGS…

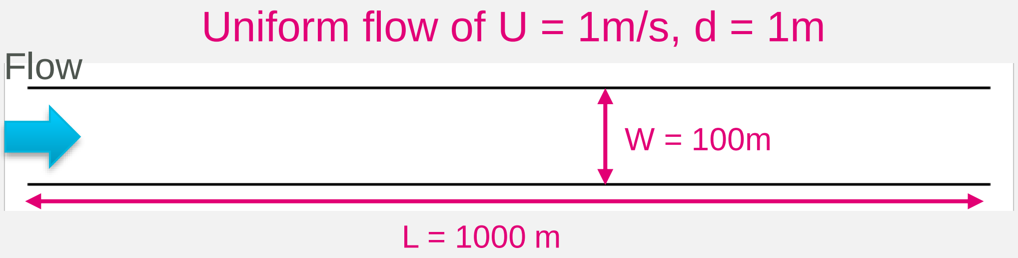
- Cells and cell faces along edge partially wet
- Streamlines parallel with banks ☺
- No apparent artificial energy losses ☺

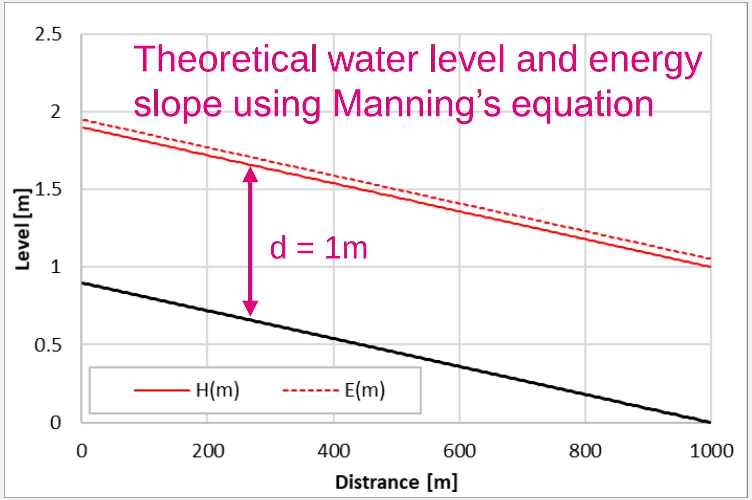




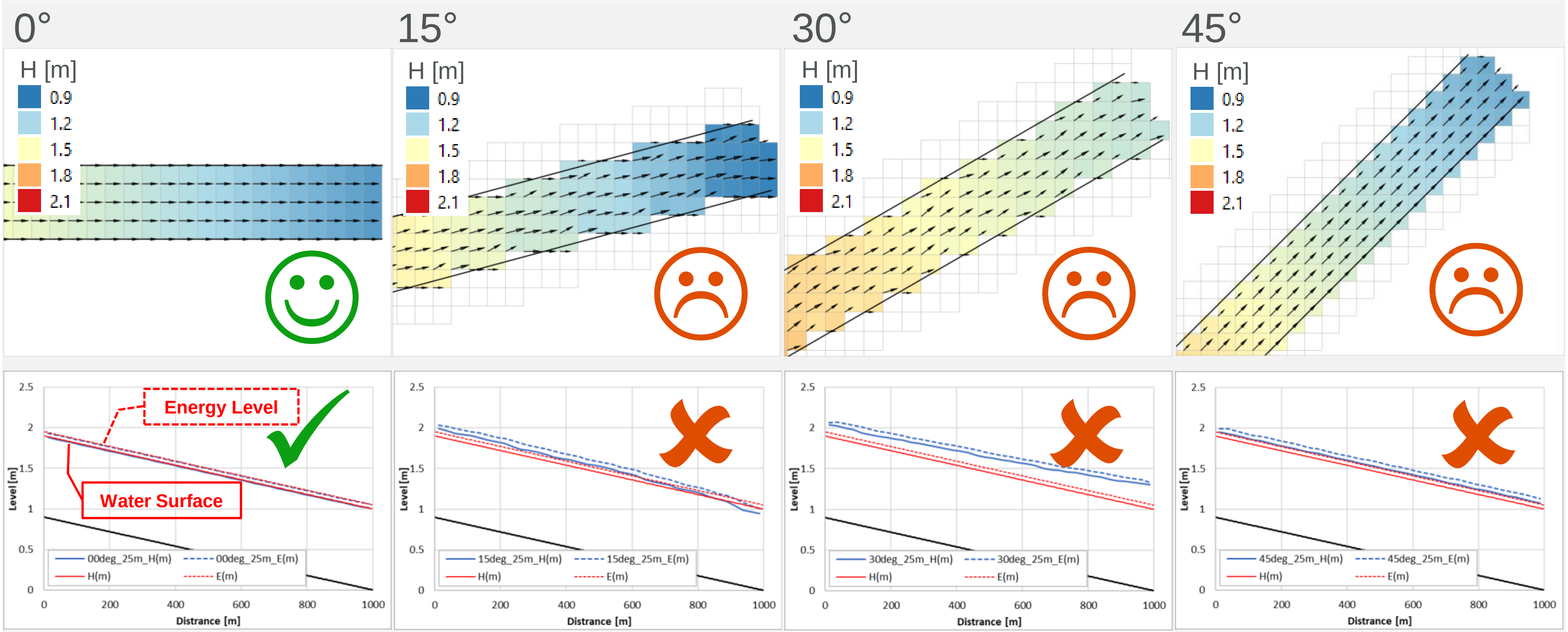
SGS Benchmarking – Manning's Equation
Rectangular Channel Test

- Rectangular channel with length of 1000m and width of 100m
- Flow rate = 100 m^3/s
- Depth = 1 m
- Slope = 0.0009
- Manning's n = 0.03





SGS Benchmarking – Manning's Equation
Rotated Channel Test – Without SGS



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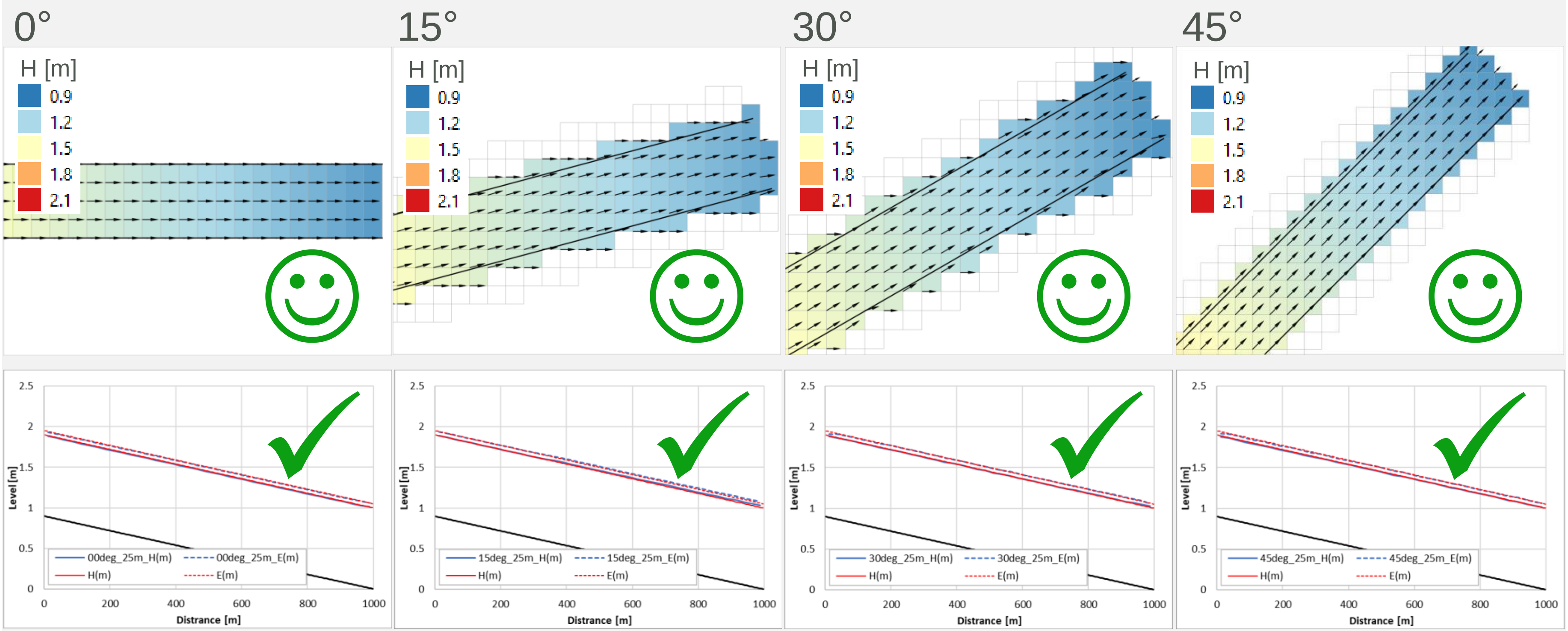
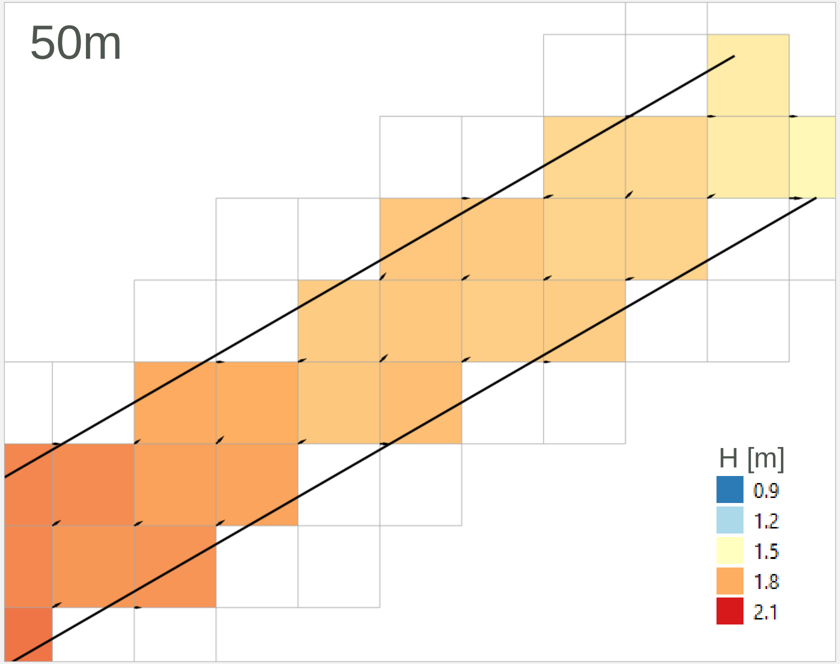
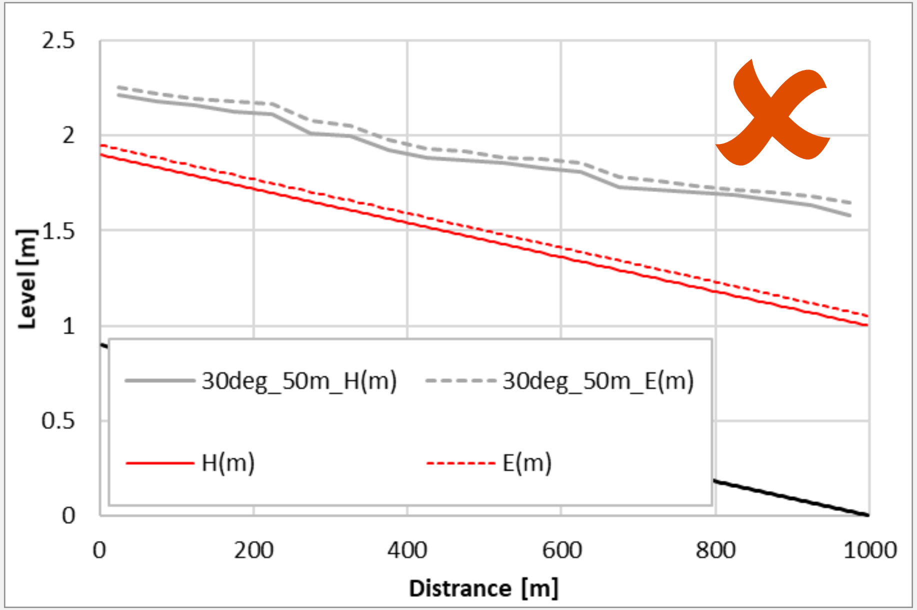
Rotated Channel Test – With SGS



SGS Benchmarking – Manning's Equation
Cell Size Sensitivity – Without SGS

TUFLOW HPC – Without SGS





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SGS Benchmarking – Manning's Equation
Cell Size Sensitivity – Without SGS

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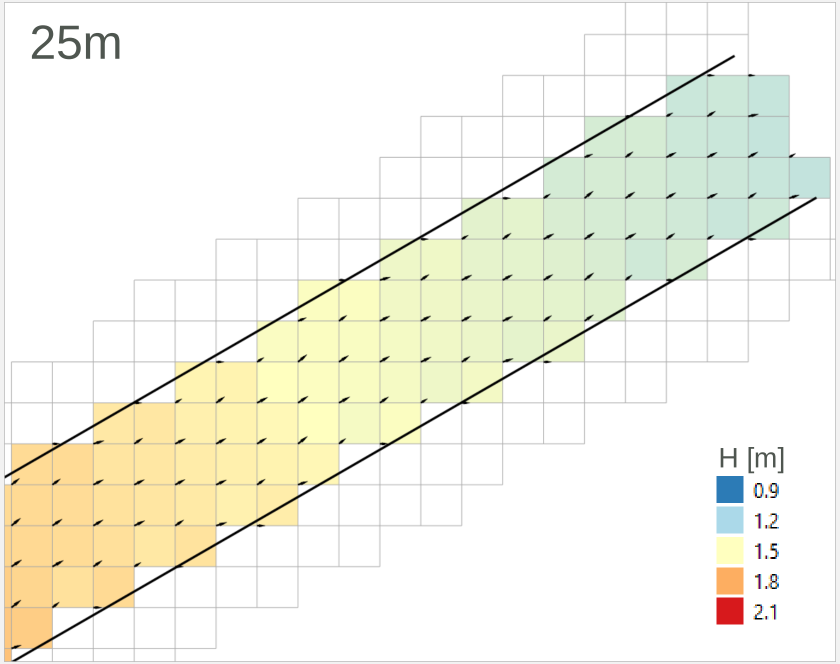

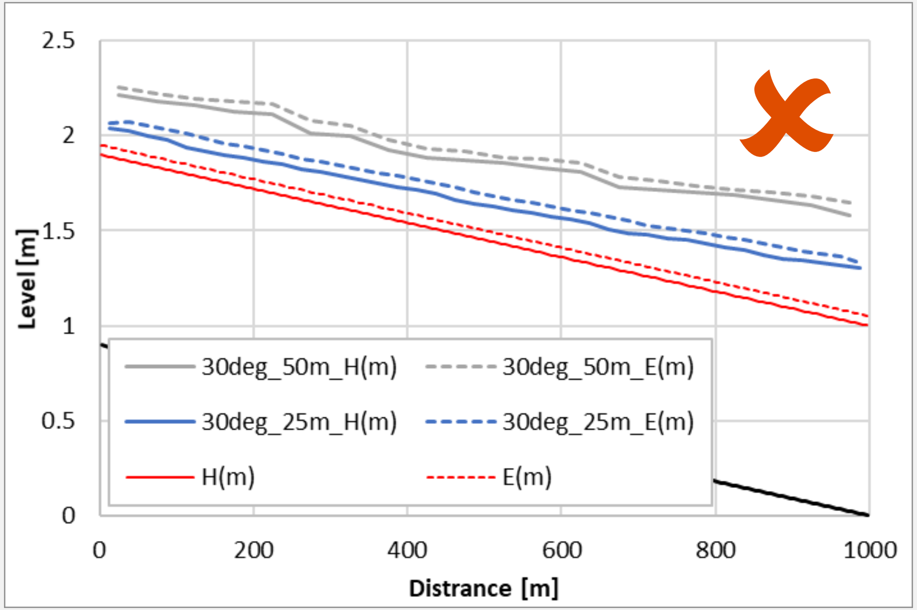

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Cell Size Sensitivity – Without SGS

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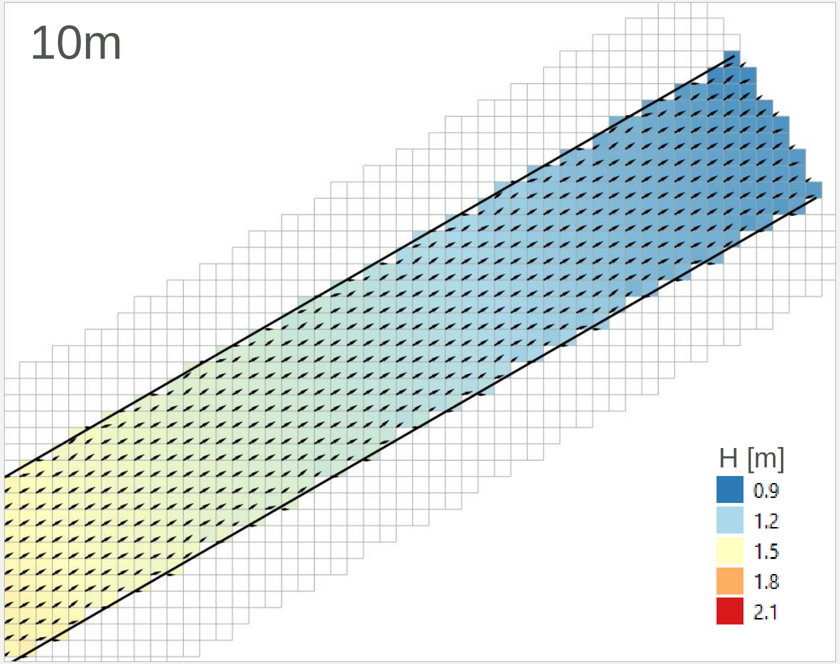

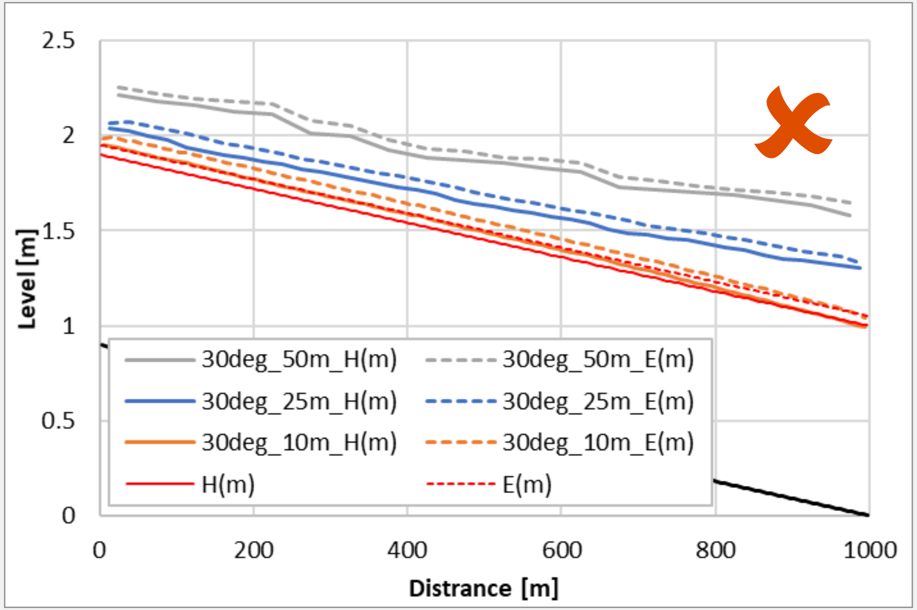

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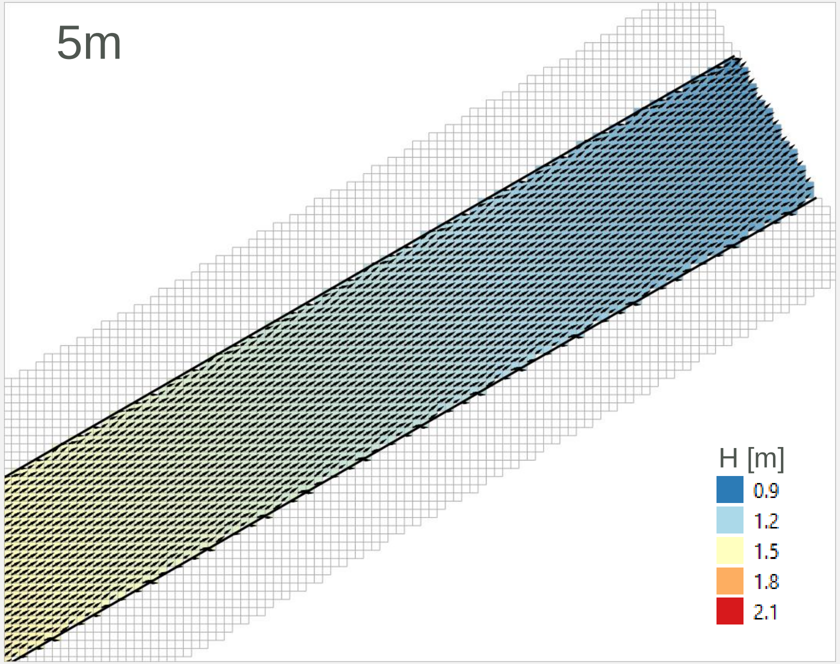
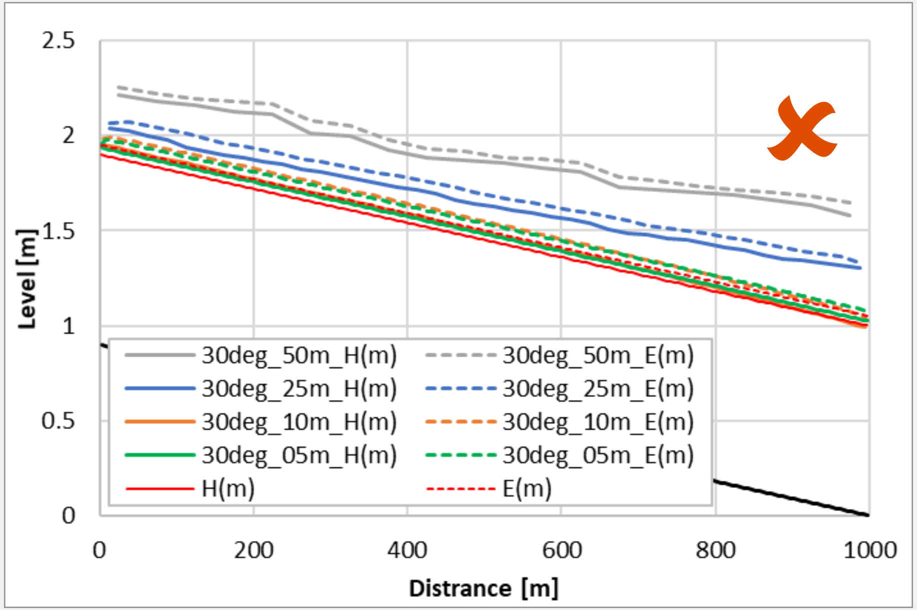
Cell Size Sensitivity – Without SGS

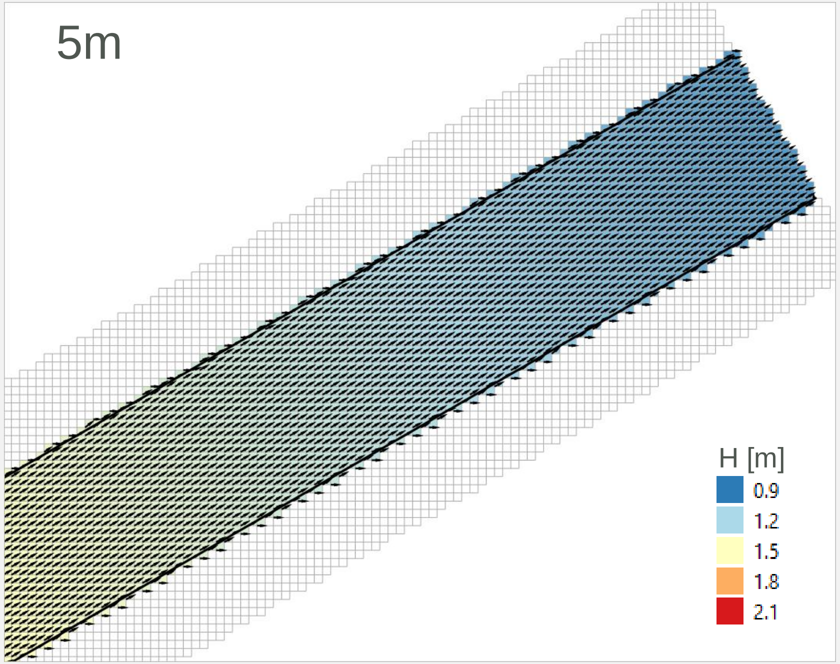
TUFLOW HPC – Without SGS

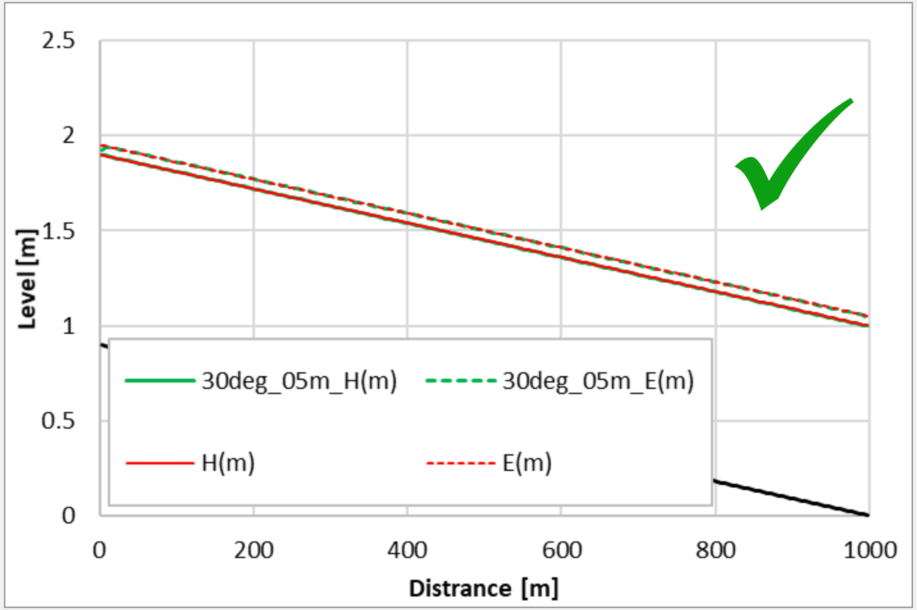




SGS Benchmarking – Manning's Equation
Cell Size Sensitivity – With SGS

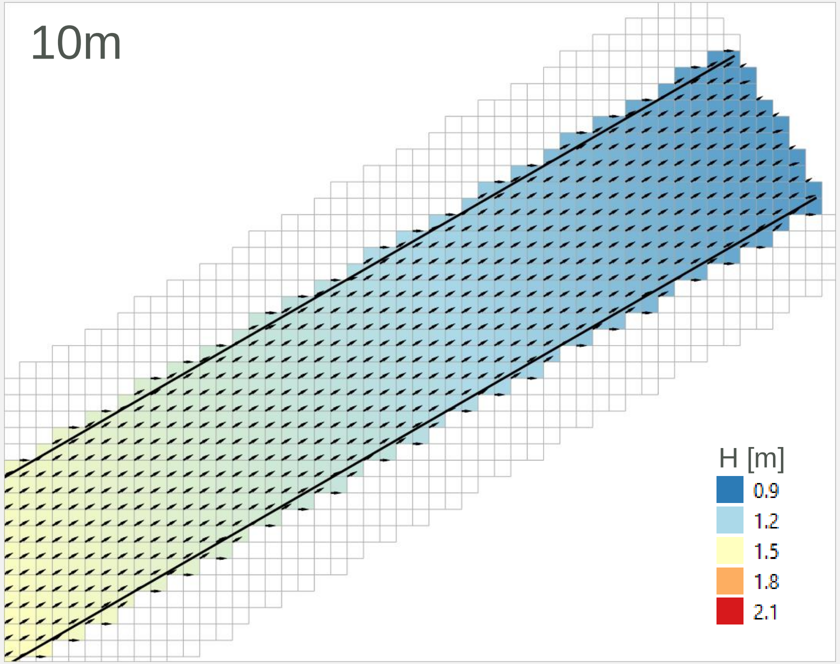
TUFLOW HPC – With SGS

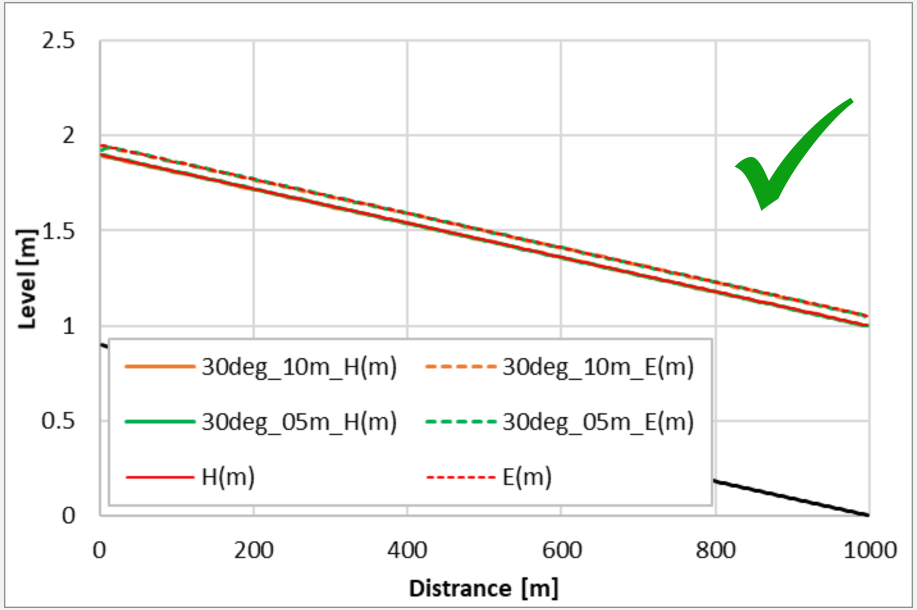




SGS Benchmarking – Manning’s Equation
Cell Size Sensitivity – With SGS

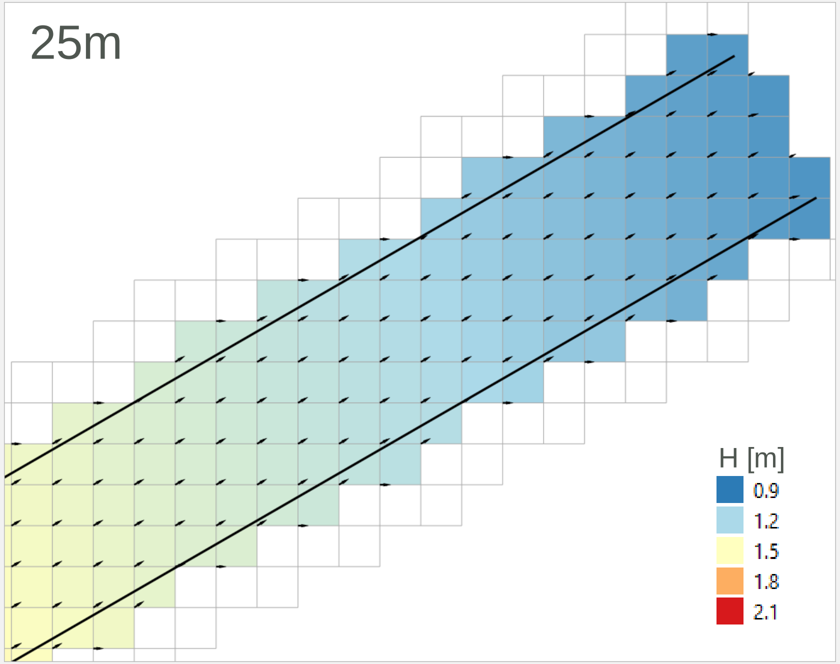
TUFLOW HPC – With SGS

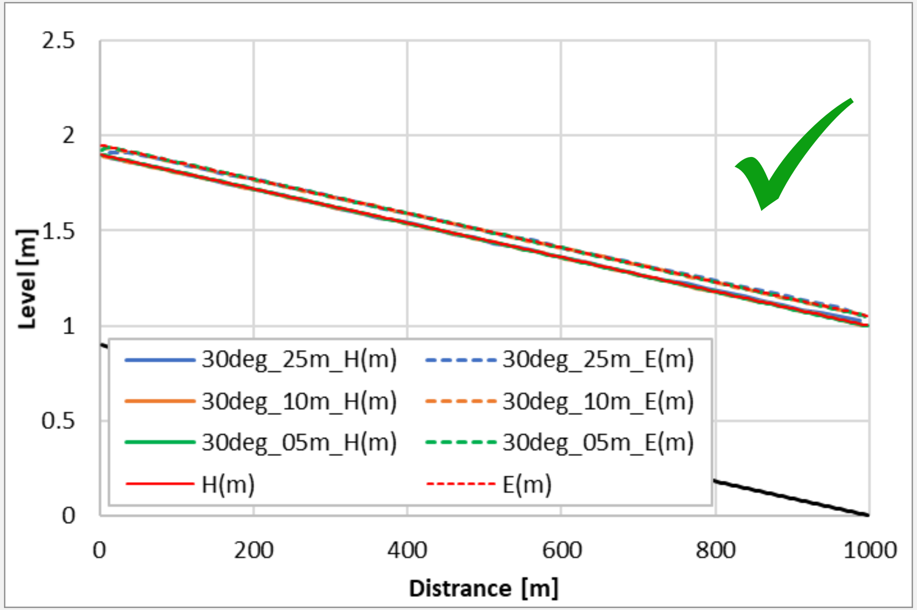




SGS Benchmarking – Manning's Equation
Cell Size Sensitivity – With SGS

TUFLOW HPC – With SGS





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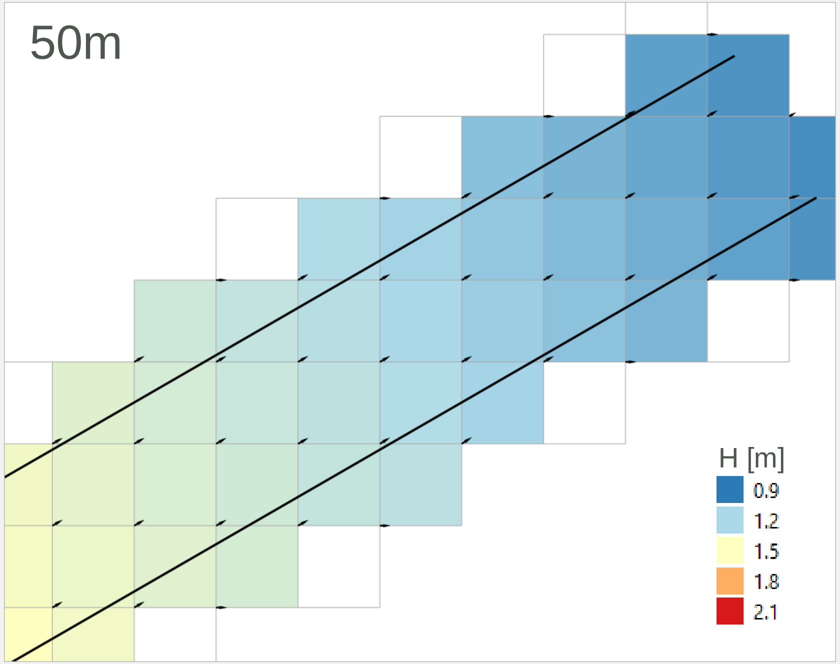
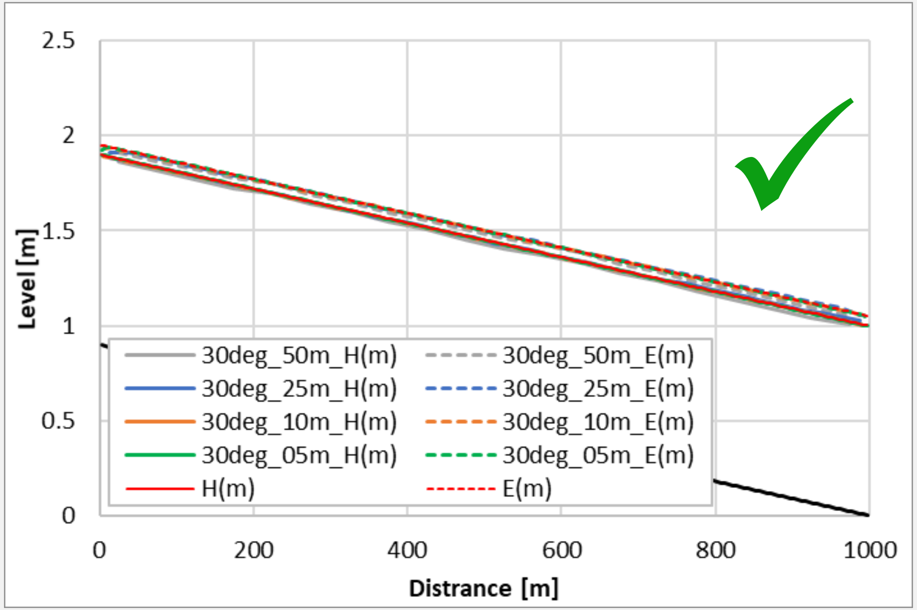
SGS Benchmarking – Manning's Equation
Cell Size Sensitivity – With SGS

TUFLOW HPC – With SGS





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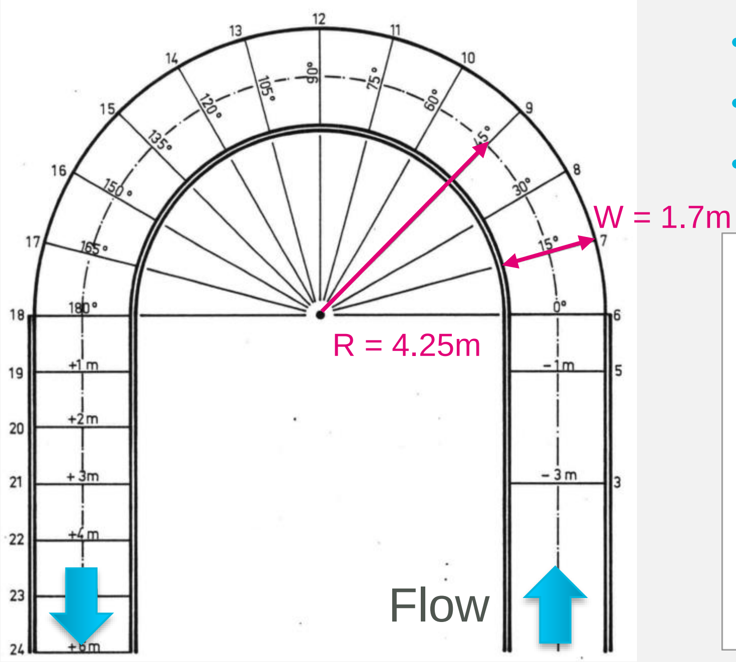
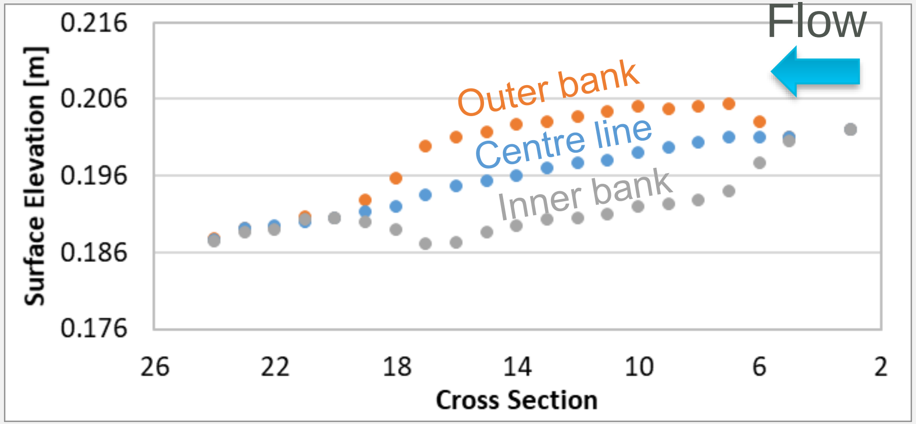
SGS Benchmarking
U-Bend Flume Test – Experiment Set-up

- Flume experiment conducted by De Vriend (1978)

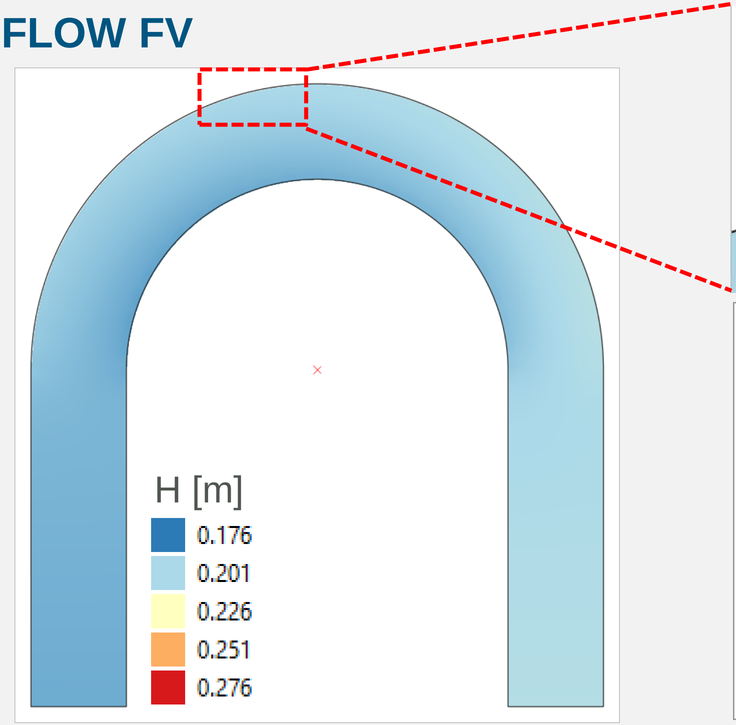


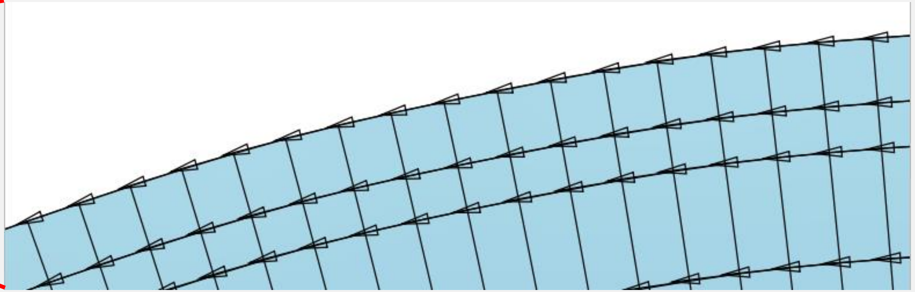
- Flow rate = 0.189 m³/s
- Downstream H = 0.18 m
- Manning's n estimated to be 0.0115 ~ 0.0125

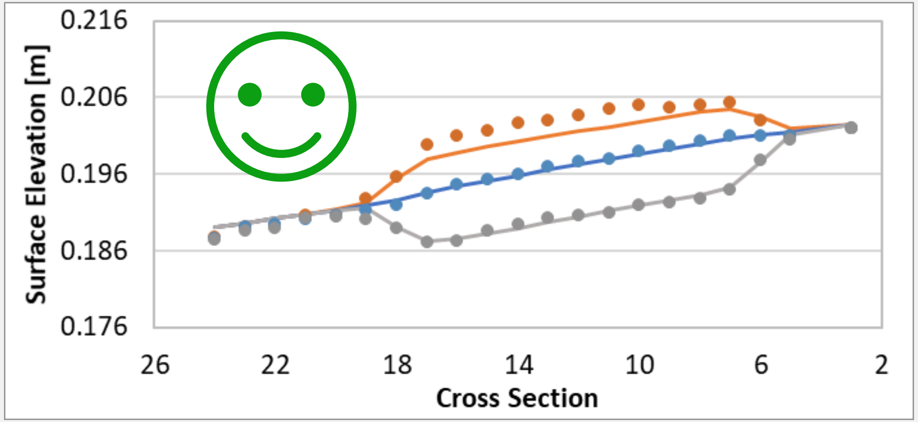


SGS Benchmarking
U-Bend Flume Test – Irregular Mesh

TUFLOW FV

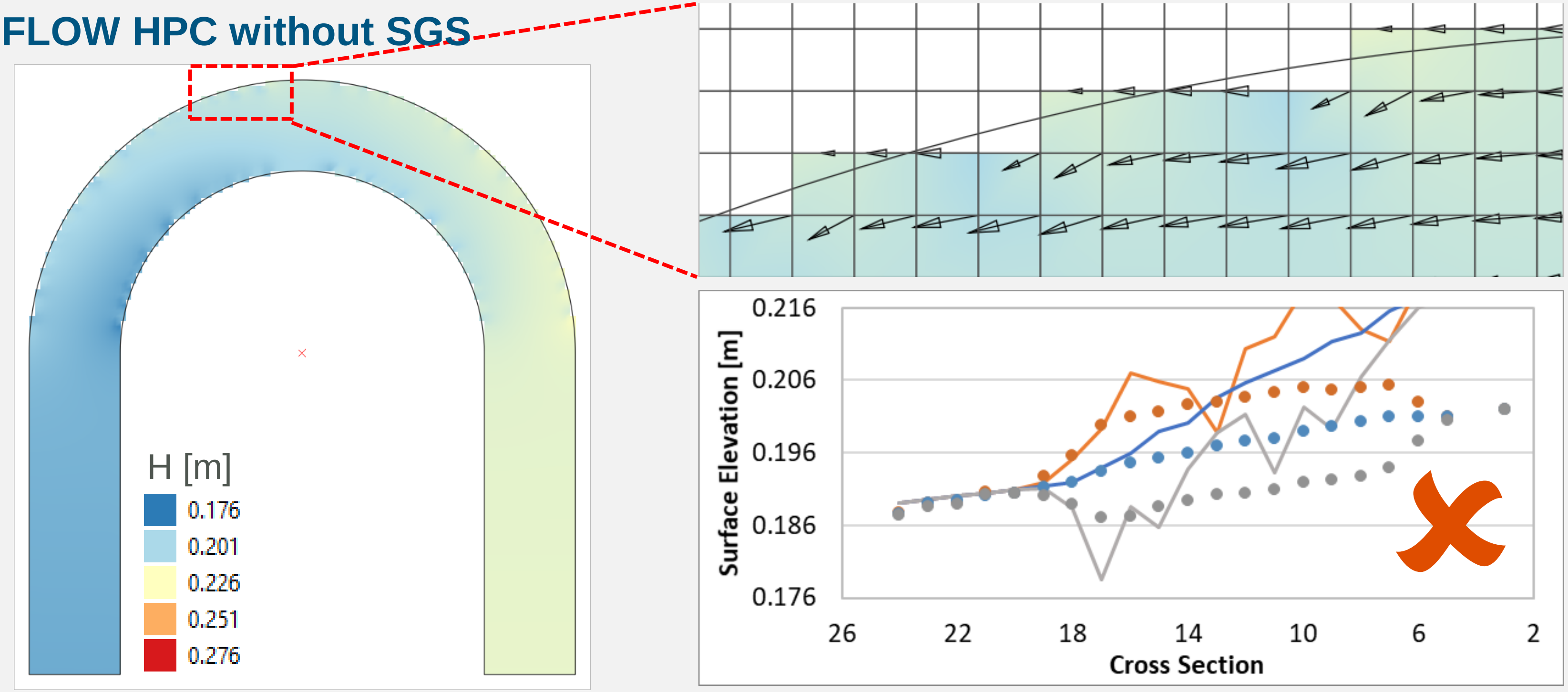






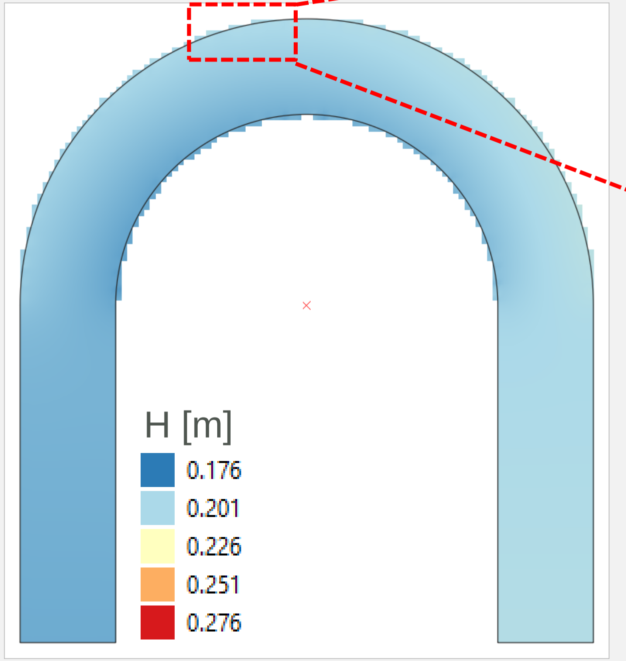
SGS Benchmarking
U-Bend Flume Test – Regular Mesh Without SGS

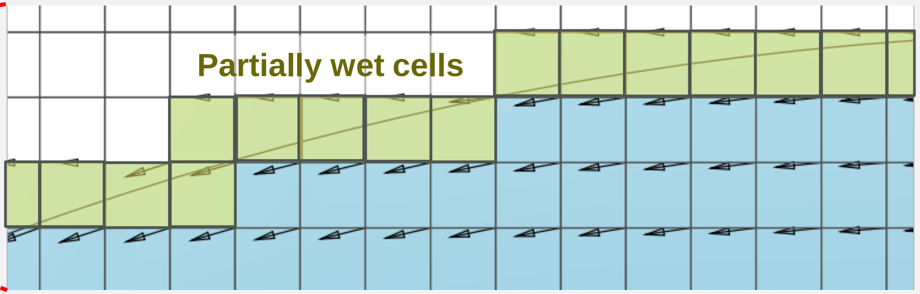
TUFLOW HPC without SGS

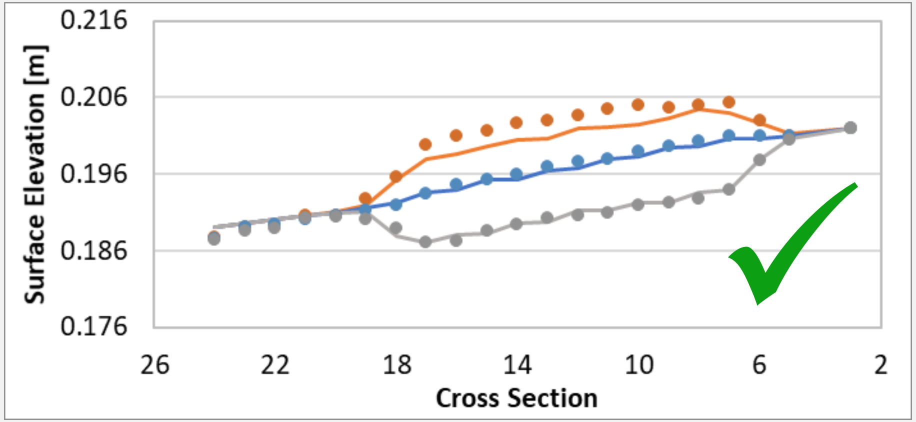


SGS Benchmarking
U-Bend Flume Test – Regular Mesh With SGS

TUFLOW HPC with SGS

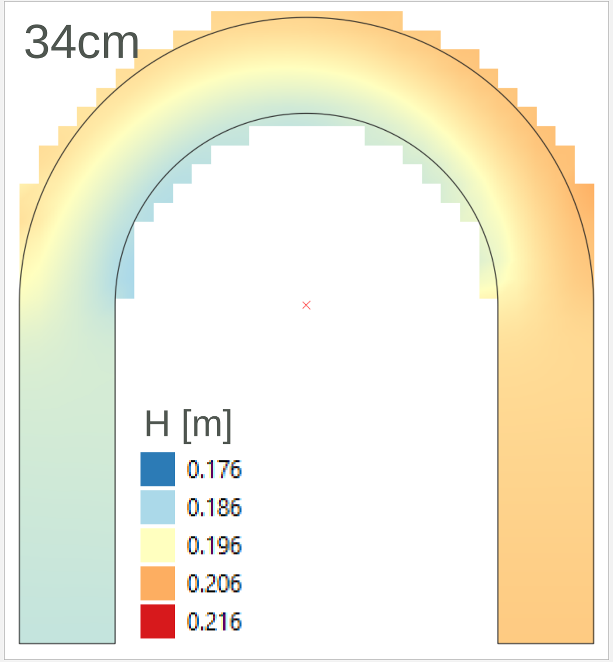




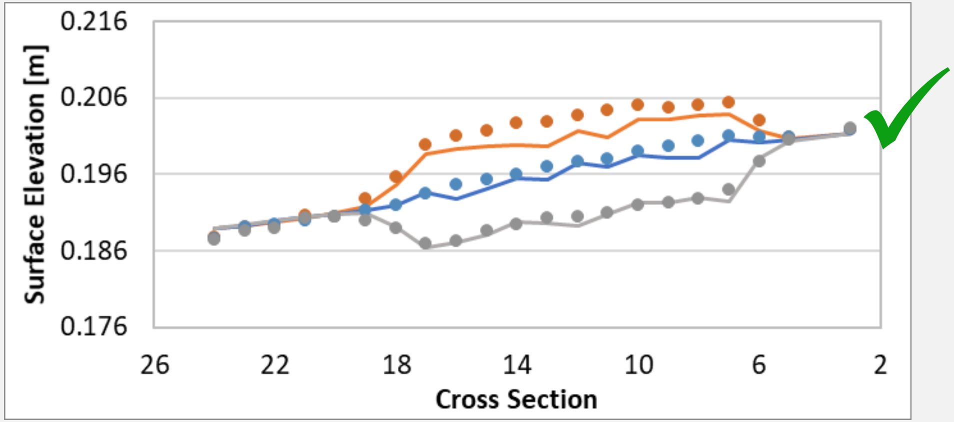


SGS Benchmarking – Cell Size Sensitivity
U-Bend Flume Test – Regular Mesh With SGS

TUFLOW HPC with SGS



Good agreement with measured upstream water level across wide range of cell sizes ☺



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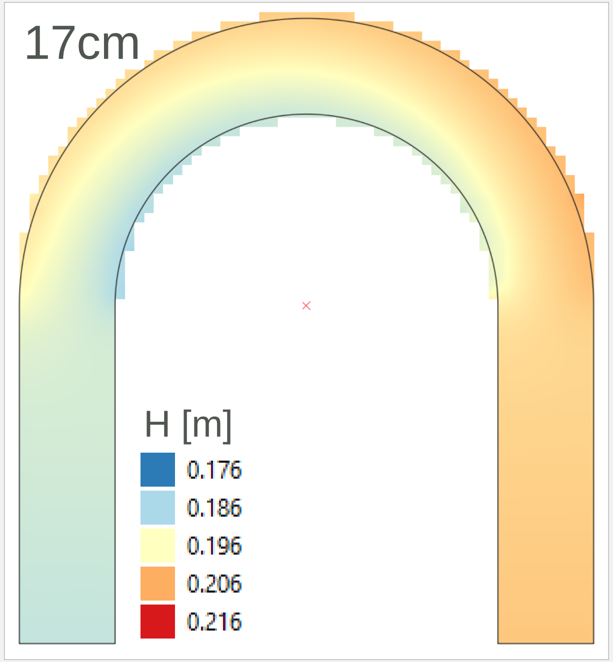

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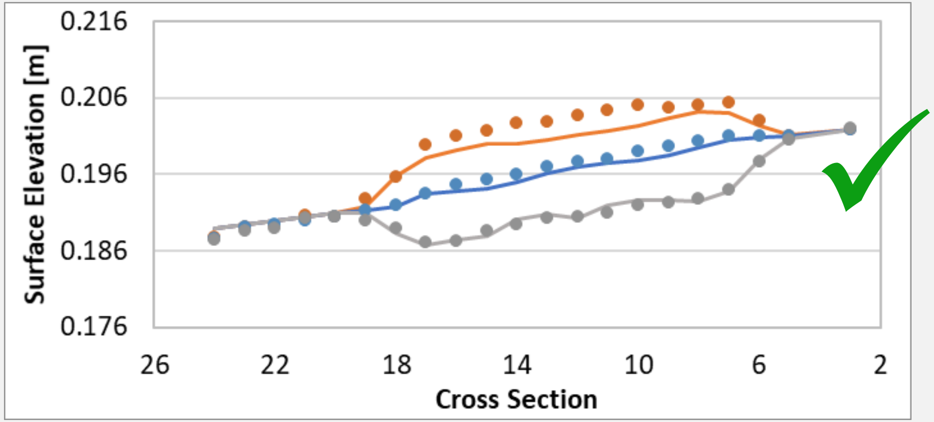

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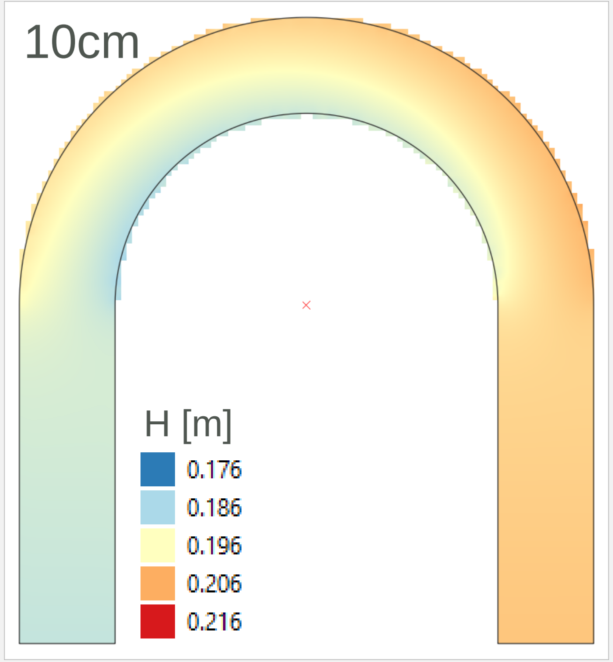

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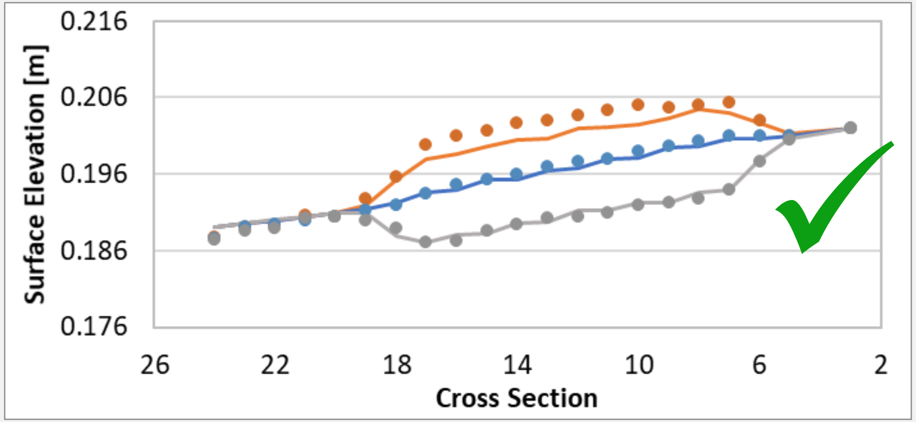
Finer resolutions as good as TUFLOW FV irregular mesh



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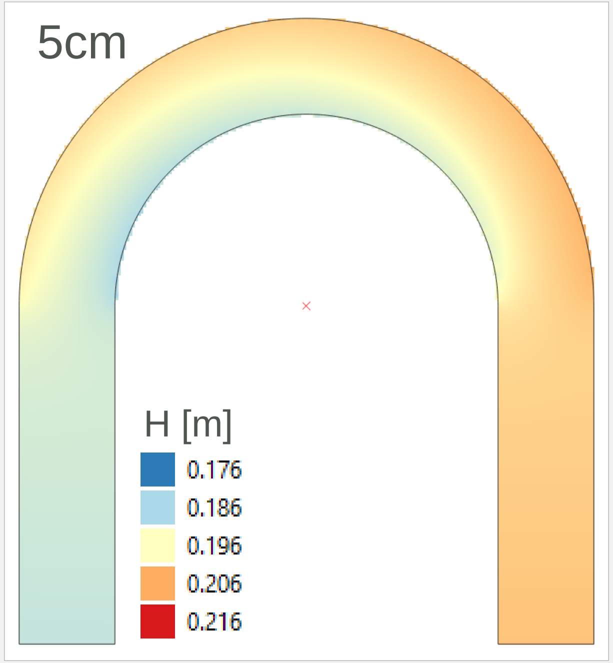
SGS Benchmarking – Cell Size Sensitivity
U-Bend Flume Test – Regular Mesh With SGS

TUFLOW HPC with SGS



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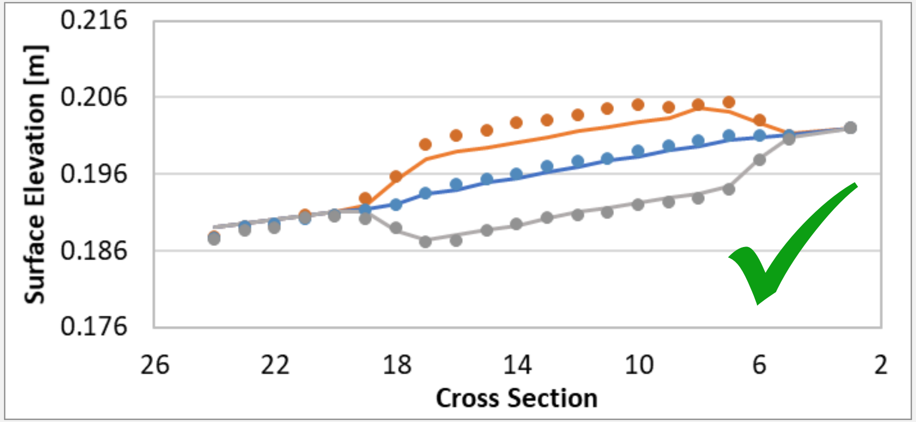
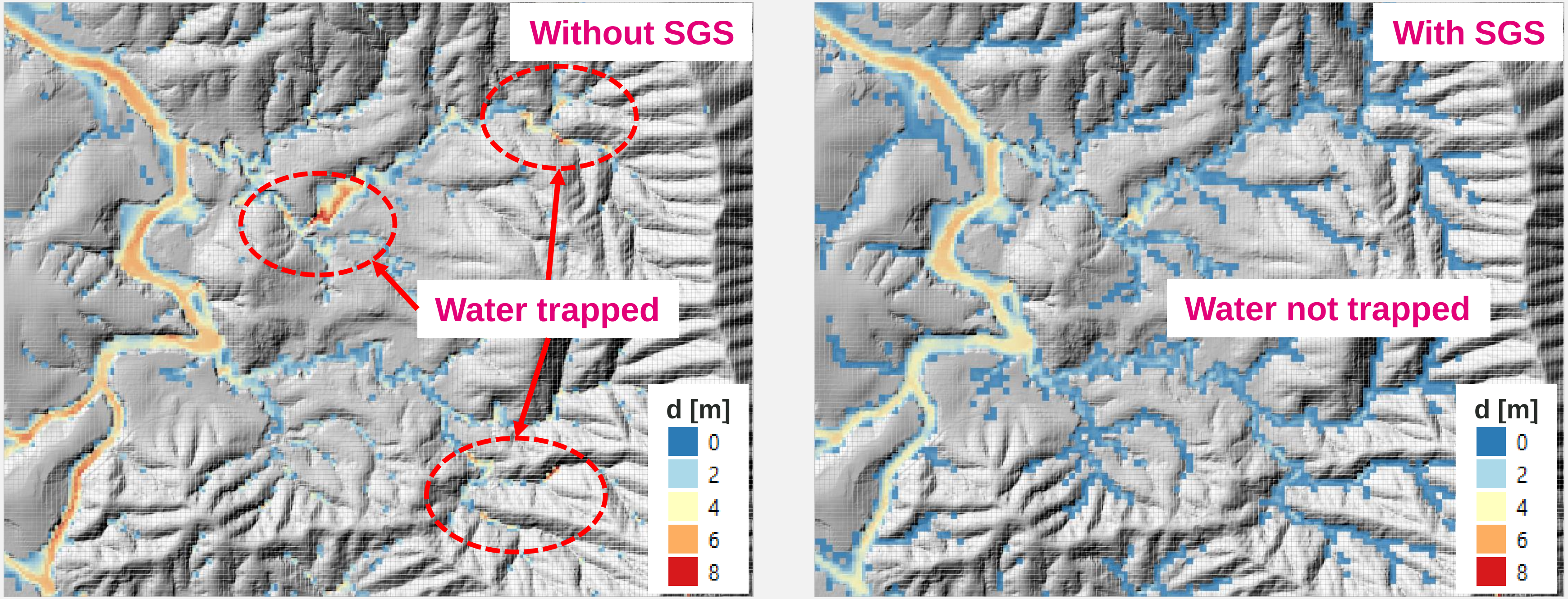


Direct Rainfall – Whole of Catchment
South Johnstone River Catchment

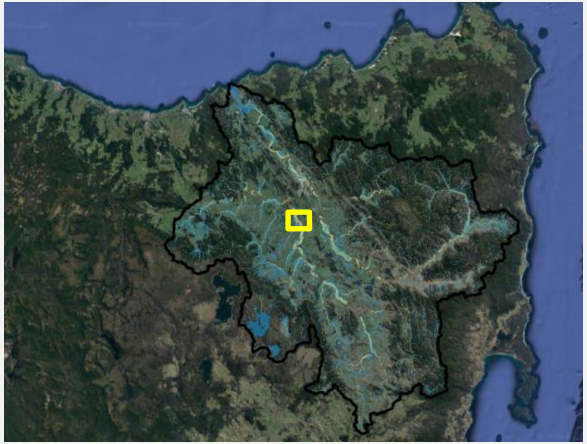
Effect of having coarse cell sizes

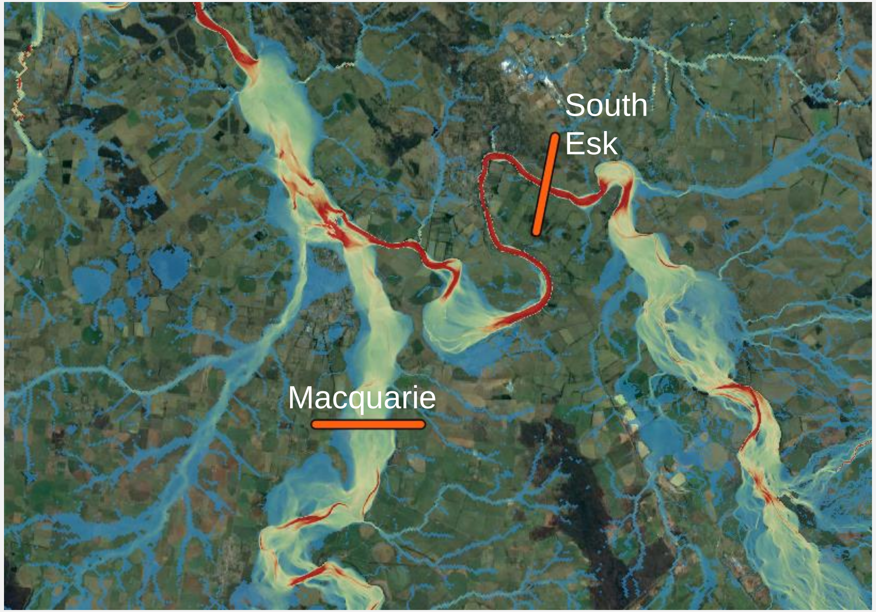


Cell Size Convergence Benchmarking
Tamar River Catchment Model

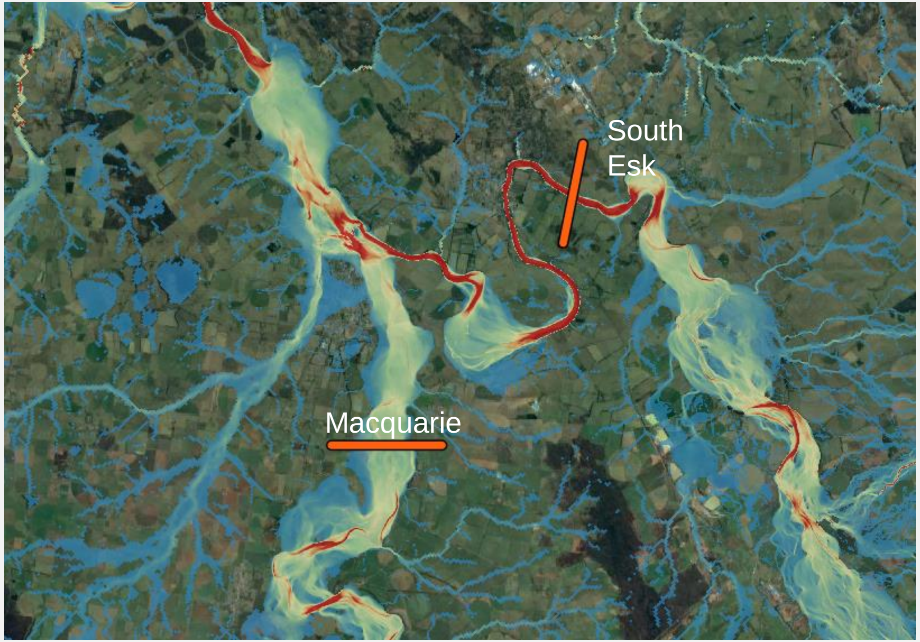
Cell Size Convergence Test

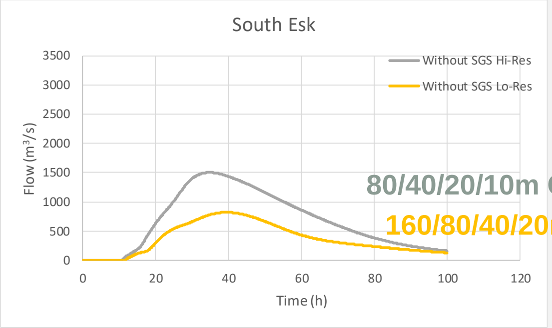
- Do your results (unacceptably) change if you reduce your cell/element sizes?
- A very good test!





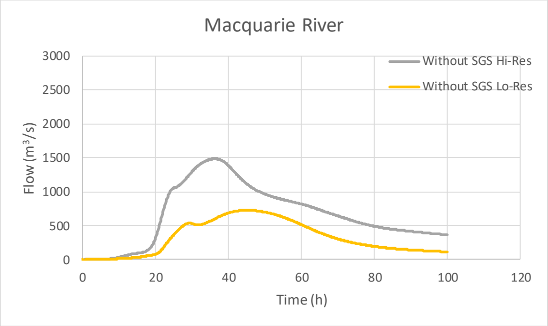
Cell Size Convergence Benchmarking
Tamar River Catchment Model – Without SGS



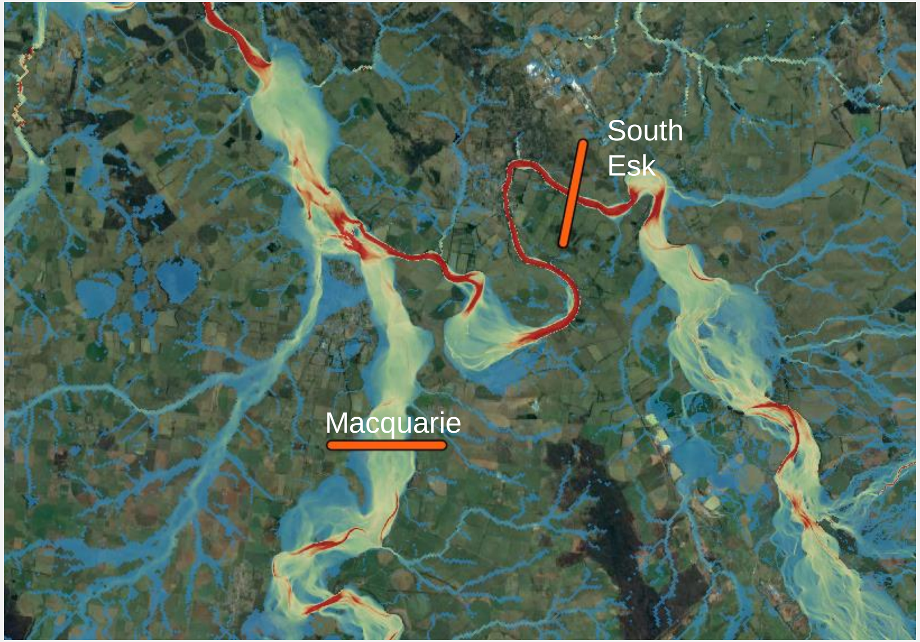


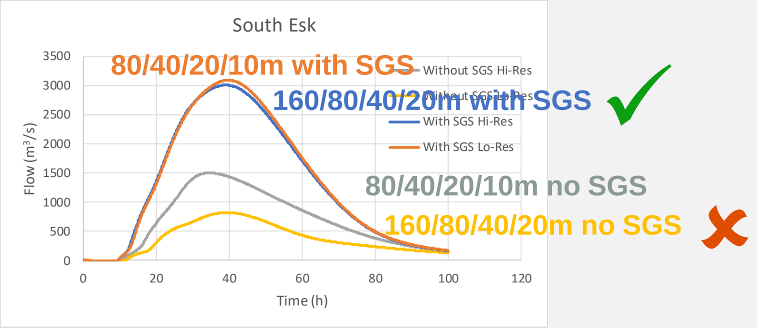
80/40/20/10m Cells

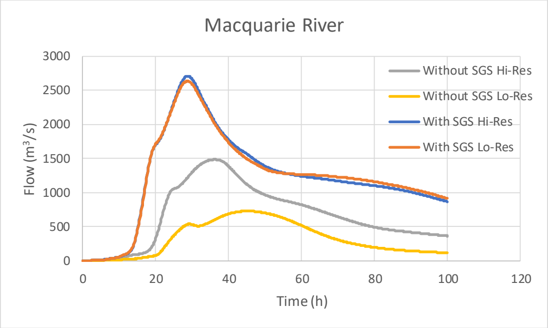
160/80/40/20m Cells ✗



Cell Size Convergence Benchmarking
Tamar River Catchment Model – With SGS







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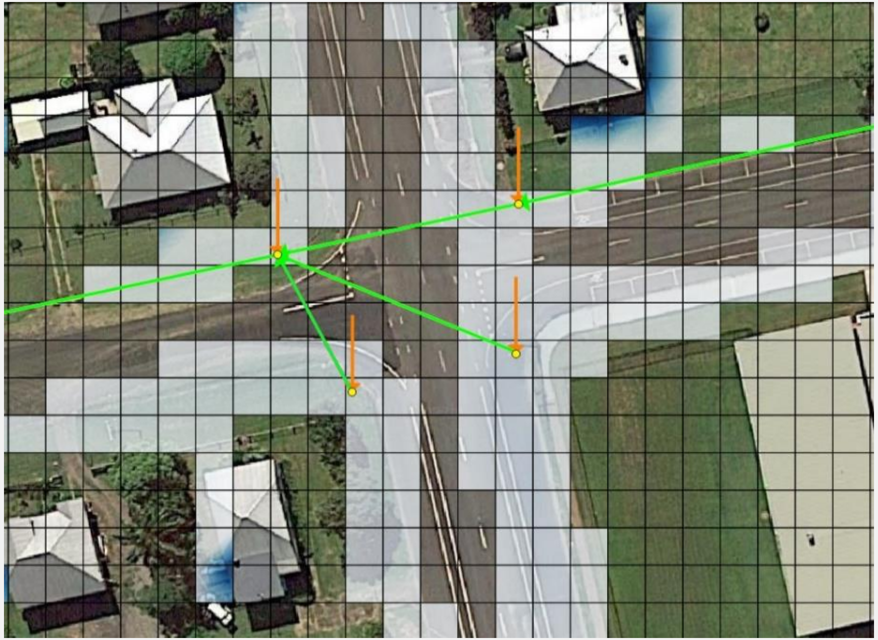
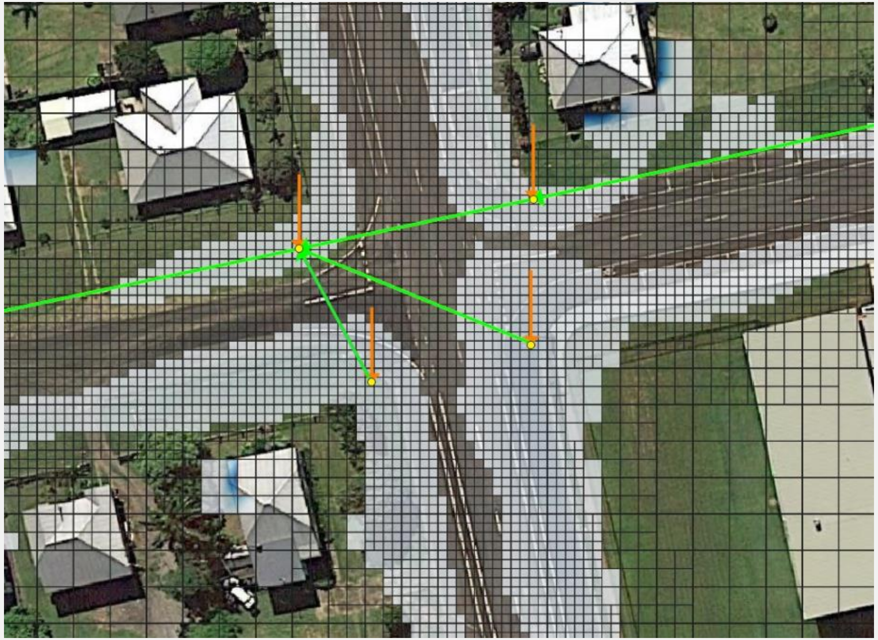
Urban Modelling
Quadtree/SGS Improving Catch-Pit Flow Capture

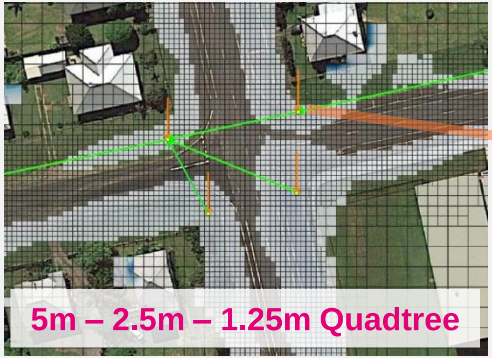
5 m Single Domain

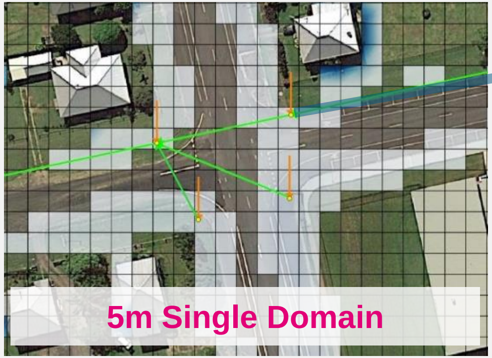


5m – 2.5m – 1.25m Quadtree Domain



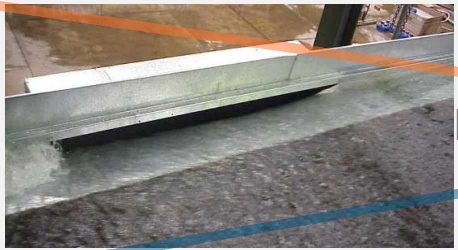
Urban Modelling
Quadtree/SGS Improving Catch-Pit Flow Capture

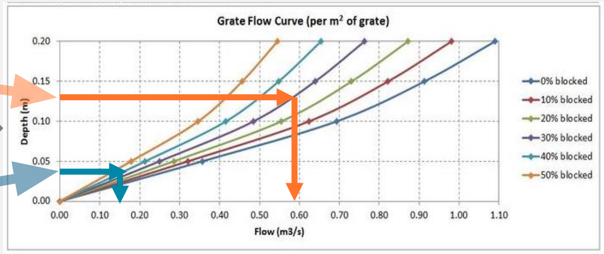


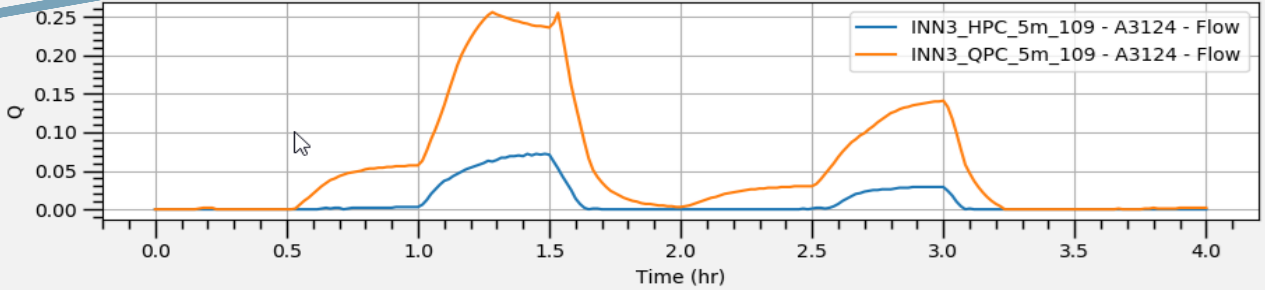


Improved pit inlet flow capture

- 2D depth at pit inlet more accurate







Conclusion

Three new major features that collectively will benefit all aspects of flood modelling

Cell Size Independent Turbulence Model

- Needed for models using small cells (cell size << depth)

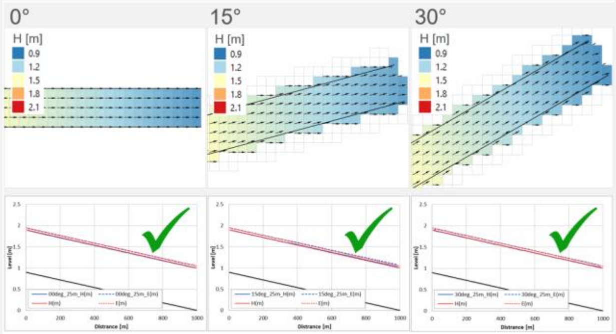
Sub-Grid Sampling

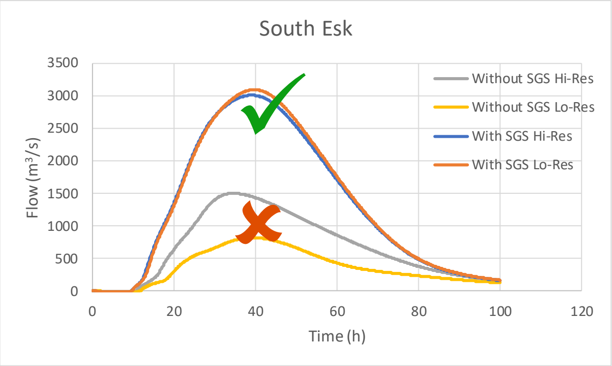
- Regular mesh can be rotated at any orientation
- Excellent cell size convergence
  (carry out preliminary runs at much coarser resolutions)

Quadtree

- Smarter model design
- Excellent mesh creation efficiency

Thank you





TUFLOW BMT