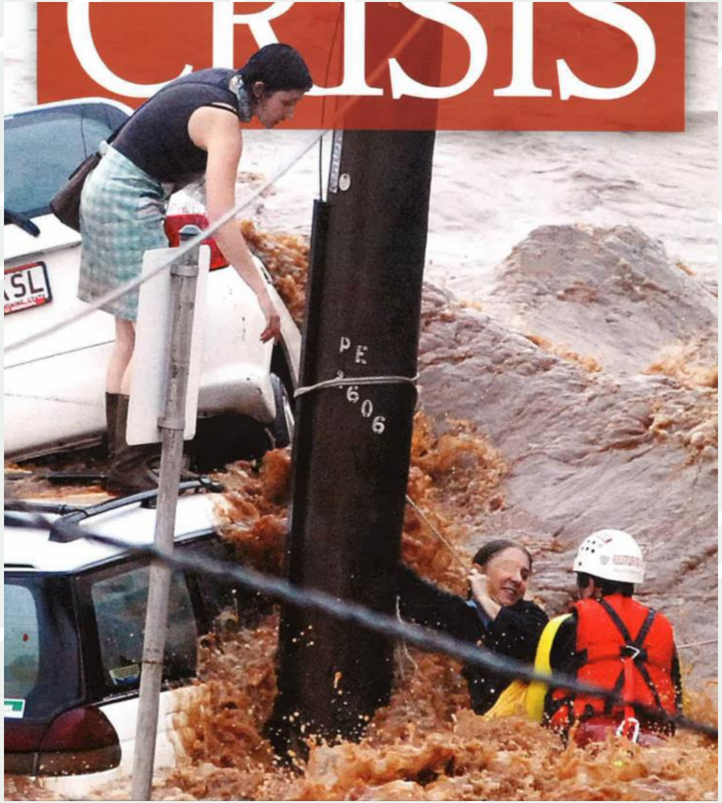
High Resolution 1D/2D Stormwater Drainage Assessments using GPU Acceleration

Bill Syme
Senior Principal, BMT



The Toowoomba Chronicle

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Presentation Overview

1. Challenges and Complexities of Modelling Urban Areas
2. Necessity to Benchmark Models/Solutions
3. Game Changers – GPU Acceleration and 2D Solution Enhancements

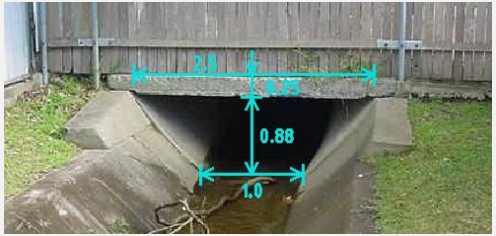
Challenges of Modelling Urban Areas
Man-made Topography

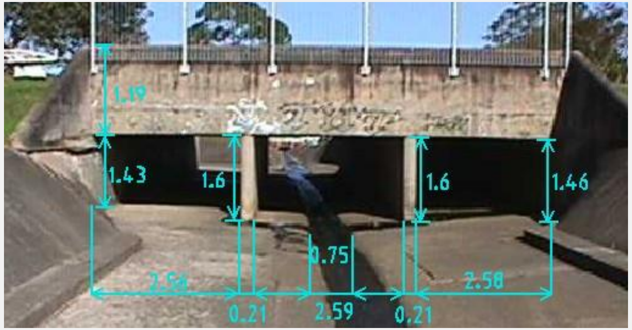
Unnatural Flowpaths

- Non-meandering formations
- Engineered cross-sections
- Smooth (concrete) surfaces
- Steep longitudinal slopes

Solid Obstructions

- Buildings
- Fences
- Vehicles!






(After) 2007 Flood, Newcastle

Challenges of Modelling Urban Areas
Wide Range of Hydraulic Phenomena

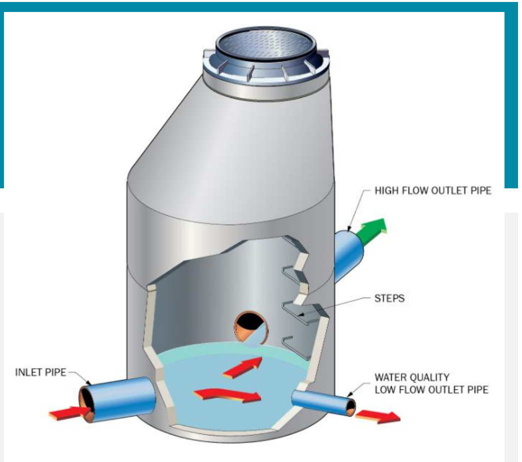
Subcritical to supercritical flow

Still water to hydraulic jumps

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

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

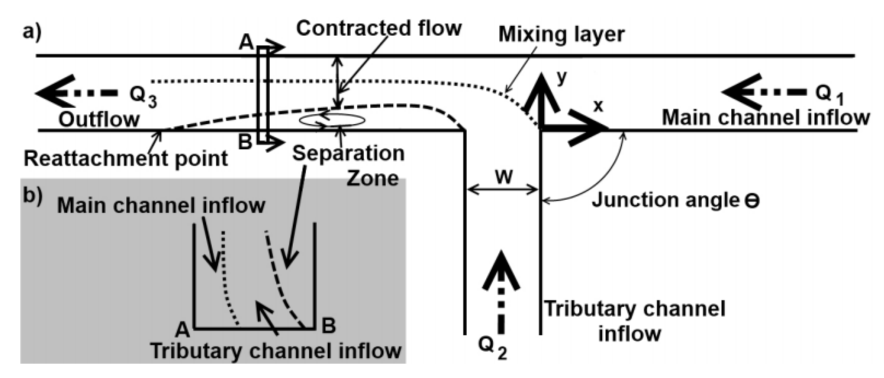
Challenges of Modelling Urban Areas
Energy Losses Everywhere



https://www.conteches.com

High velocities therefore high energy losses
(Complex 3D flows)

- Manholes
- Junctions and bends



Creëlle, et al, Ghent University, Ghent, Belgium

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

Challenges of Modelling Urban Areas
Pit Flow Capture

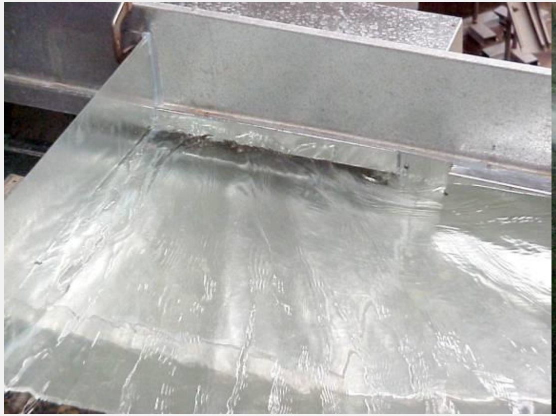
Sag pits

- Depth / Discharge curves

On-grade pits

- Approach flow / Discharge curves
- Varies with grade

Accurate 2D reproduction of depth or approach flow essential to model pit capture

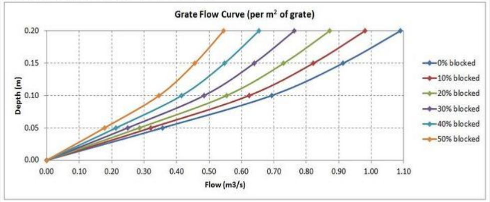


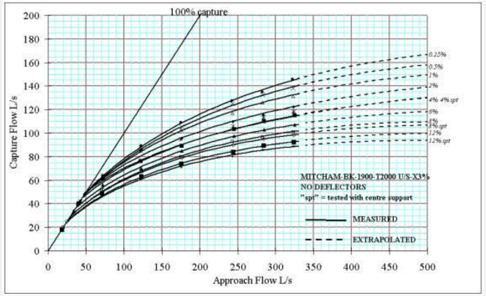
http://www.unisa.edu.au/IT-Engineering-and-the-Environment/Natural-and-Built-Environments/

Grate Flow Curve

Water Depth (m)	Discharge (m^3/s) per m^2 of grate area					
	0% blocked	10% blocked	20% blocked	30% blocked	40% blocked	50% blocked
0.00	0.000	0.000	0.000	0.000	0.000	0.000
0.05	0.357	0.321	0.285	0.250	0.214	0.178
0.10	0.693	0.624	0.554	0.485	0.416	0.347
0.15	0.913	0.822	0.730	0.639	0.548	0.456
0.20	1.089	0.980	0.871	0.763	0.654	0.545

NOTE: Multiply table value by grate area to calculate site specific value





Challenges of Modelling Urban Areas

Low Impact Developments & Sustainable Drainage Systems

Water retention and infiltration

- 2D resolution usually too coarse
- Need soil infiltration (Green-Ampt, Horton, IL/CL)
- Represent surface imperviousness (e.g. bitumen over soil)

https://ww...rdenvisit.com/blog/suds-lid-wsud-urban-drainage-systems-and-landscape-architecture/

Challenges of Modelling Urban Areas
Modelling Fences!

Should we or should we not?

If yes need to be able to

- Raise cell faces as a thin barrier
- Cell faces wet and dry
- Layered parameters
  (vary blockage and losses with height)
- Switch between u/s and d/s controlled weir flow

Collapsible fences?

(After) 2007 Flood, Newcastle

(After) 2007 Flood, Newcastle

(After) 2007 Flood, Newcastle

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Challenges of Modelling Urban Areas

Blockages!

Increasingly the effect of blockages being sought

Very challenging to model as unpredictable!

(After) 2007 Flood, Newcastle

Toowoomba, 2011 (news.com.au)

(After) 2007 Flood, Newcastle

(After) 2007 Flood, Newcastle

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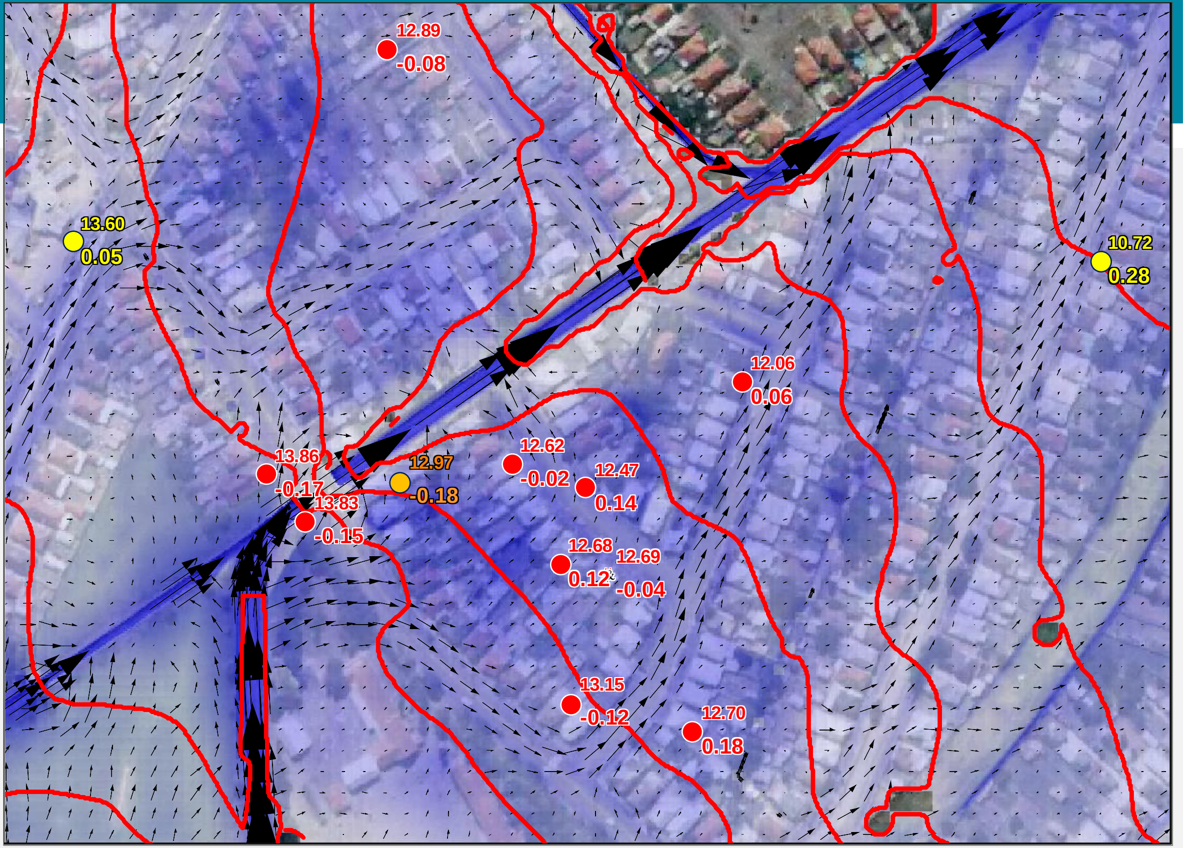
Benchmarking
Model Calibration

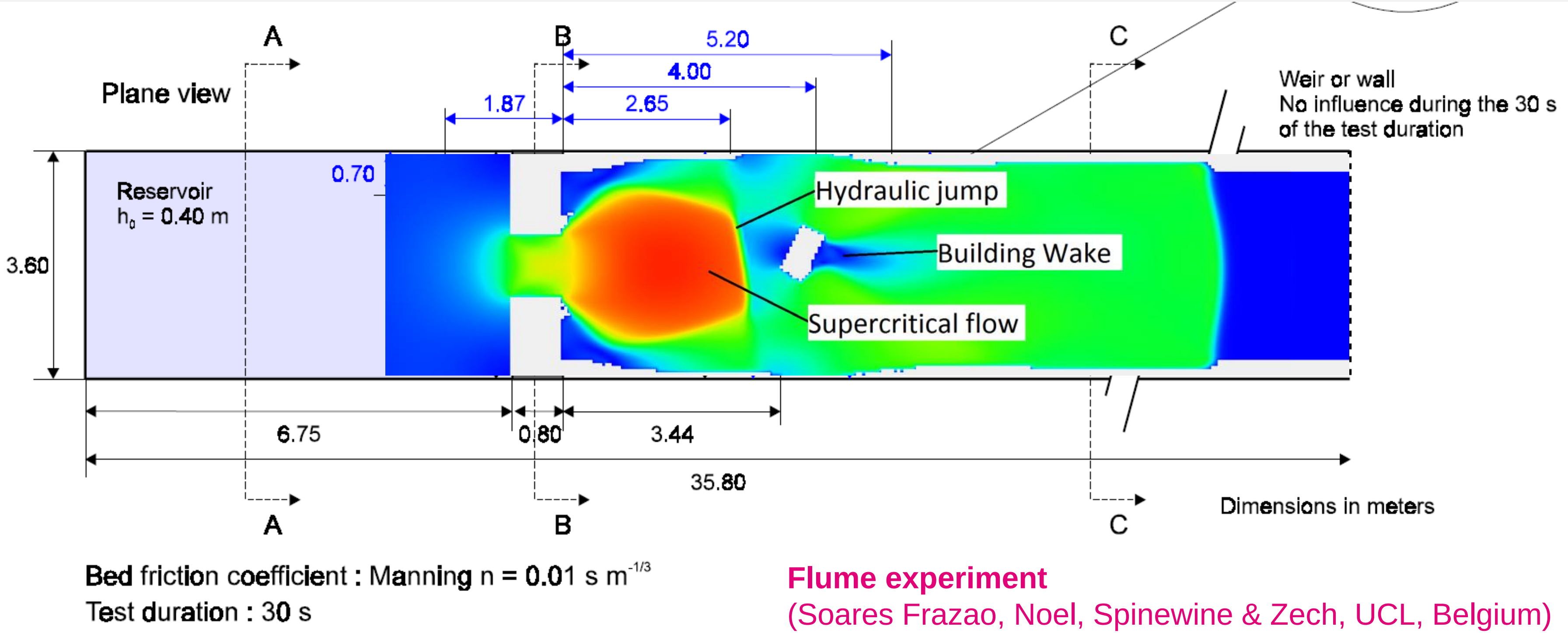
Calibrate, calibrate, calibrate!

…but rare in urban areas



1990 Flood Newcastle - TUFLOW Model Calibration.

Benchmarking
Flume Tests – Flow Against a Building



Flume experiment
(Soares Frazao, Noel, Spinewine & Zech, UCL, Belgium)

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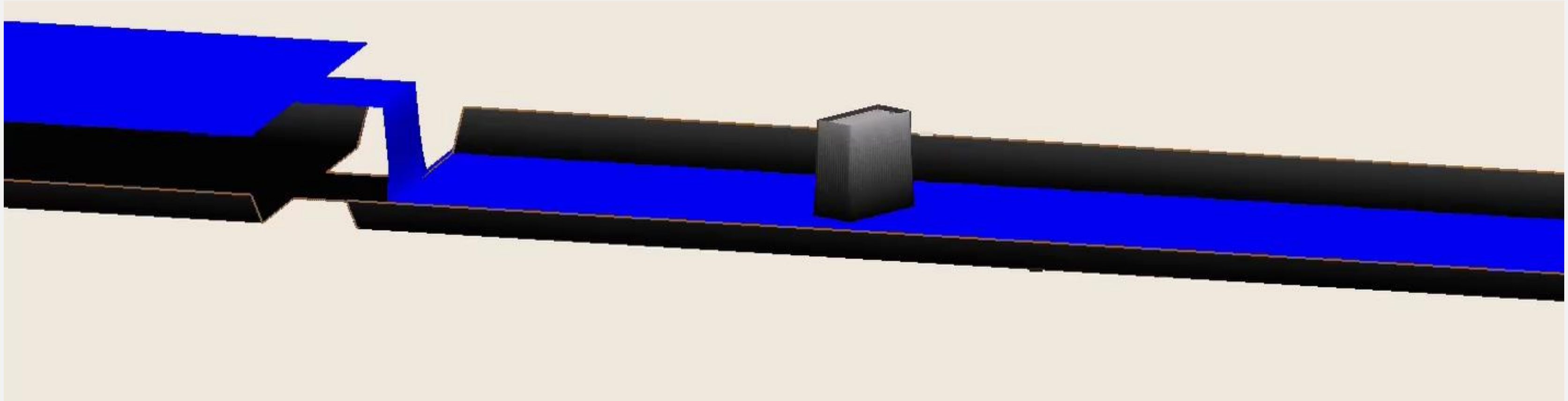
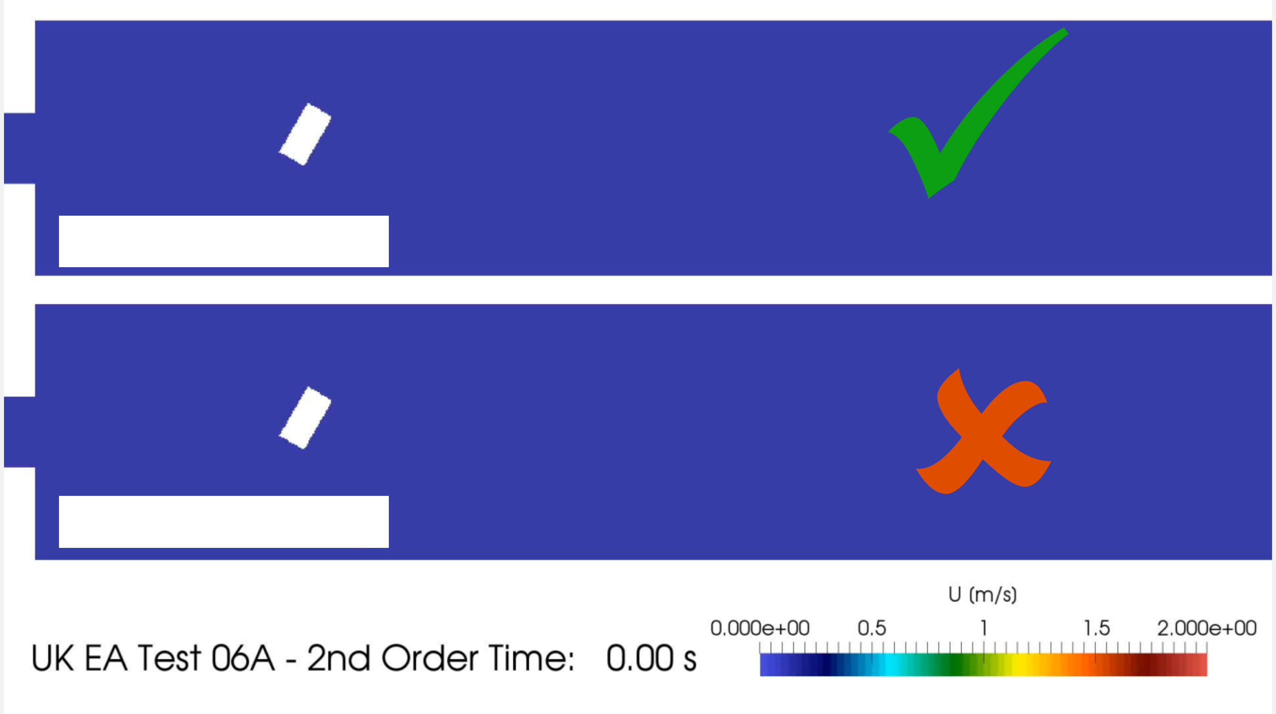
Benchmarking
Flow Against a Building Flume Model

- Hydraulic jump forms in front of building
- Eddy shedding downstream of building
- Jump propagates upstream as flow eases



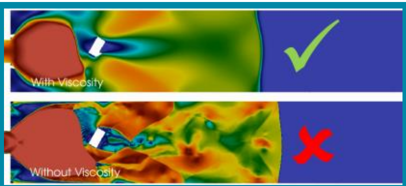
Benchmarking
Flow Against a Building Flume Model

Which result is least wrong?



Benchmarking

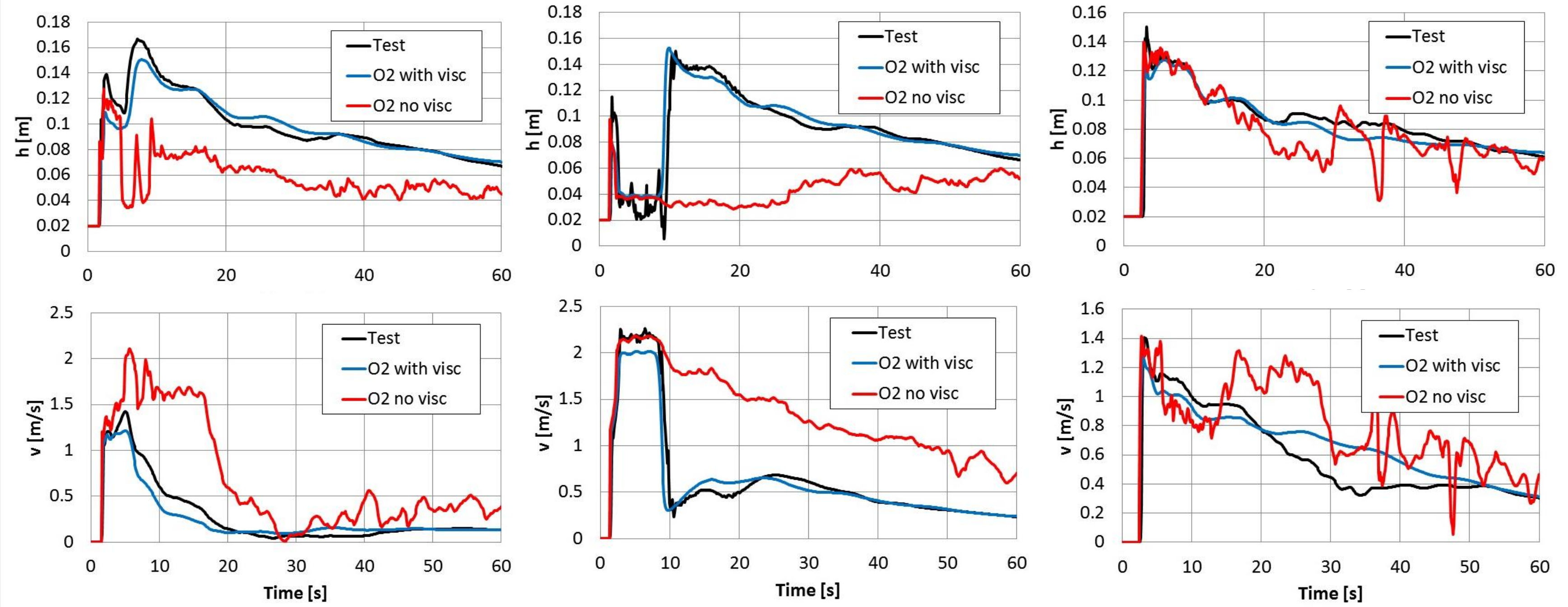
Flow Against a Building



With turbulence (eddy viscosity)

Without turbulence (eddy viscosity)

Location 1 | Location 2 | Location 3



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Benchmarking
Flow Against a Building Flume Model

Turbulence term needed

Beware the cool animation!

Game Changers
GPU Acceleration

TUFLOW Classic (Implicit Solver)

Central Processing Unit (CPU)

VS

TUFLOW HPC (Explicit Solver)

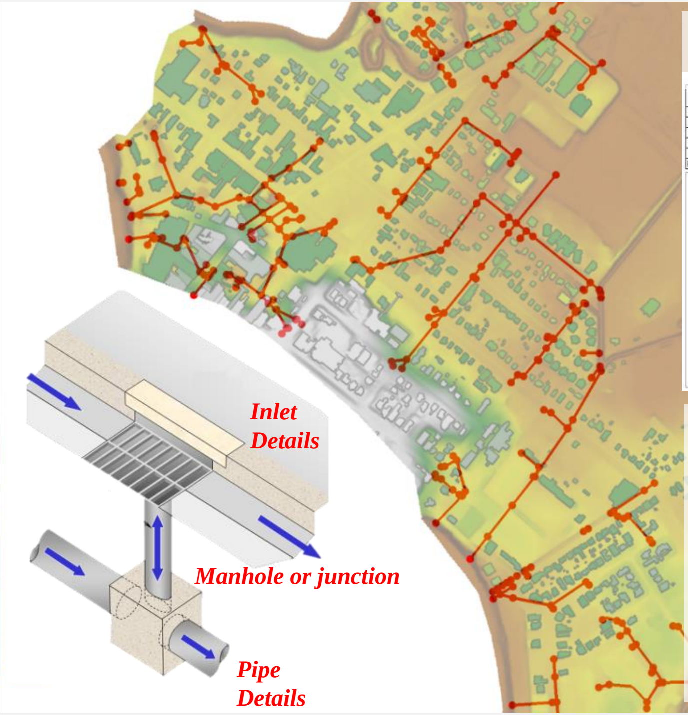
Graphic Processing Unit (GPU)

Case Study – Surfacewater Modelling Innisfail
1D Stormwater Network / 2D Surfacewater Flooding

Stormwater pipes

Inlet pits/drains
(Linked to 2D ground surface)

Manholes and junctions



Pit Inlet Depth vs Flow Curves

Grate Flow Curve

Water Depth (m)	Discharge (m^3/s) per m^2 of grate area					
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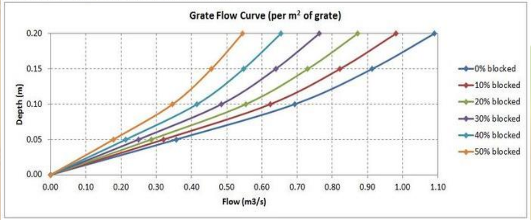


Manhole & Junction Losses

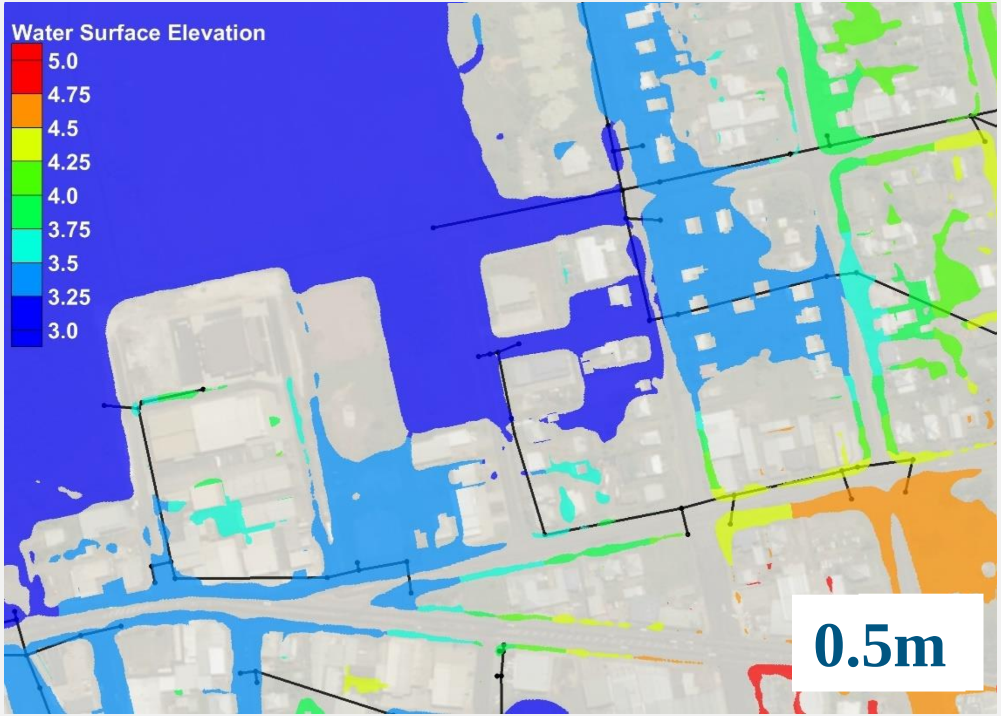
Fixed = QUDM compatible where required

Engelund method (elsewhere)

1) Expansion / contraction of flow
2) Changes in pipe size
3) Changes in angle at junctions
4) Change in elevation at junctions

Case Study – Surfacewater Modelling Innisfail
What 2D Cell Size Resolution?

Size	Cells
20 m	7,500
10 m	31,000
5 m	125,000
2 m	750,000
1 m	3,100,000
0.5 m	12,500,000



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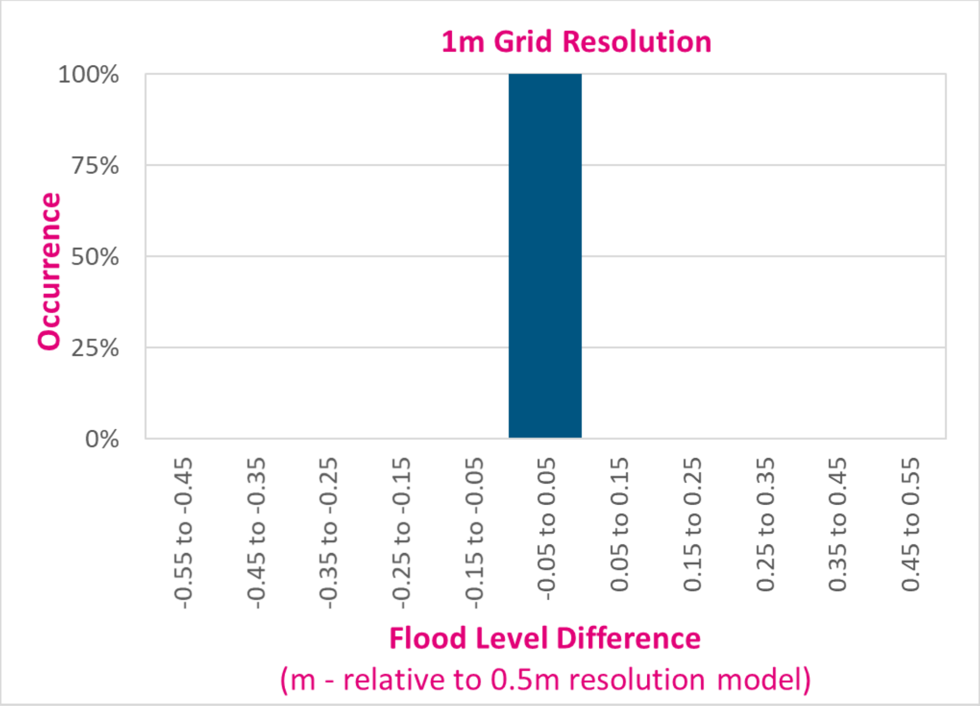
Case Study – Surfacewater Modelling Innisfail
What 2D Cell Size Resolution?

Size	Cells	
20 m	7,500	✗
10 m	31,000	✗
5 m	125,000	✗
2 m	750,000	✓
1 m	3,100,000	✓
0.5 m	12,500,000	✓



Case Study – Surfacewater Modelling Innisfail
What 2D Cell Size Resolution?

Size	Cells		CPU (2017)	GPU (2017)
20 m	7,500	✗	~~0:12 hr~~	~~0:02 hr~~
10 m	31,000	✗	~~0:15 hr~~	~~0:03 hr~~
5 m	125,000	✗	~~1:32 hr~~	~~0:05 hr~~
2 m	750,000	✓	15:19 hr	0:20 hr ✓
1 m	3,100,000	✓	~~6 days~~	1:55 hr ✓?
0.5 m	12,500,000	✓	~~~48 days~~	18:30 hr

Number Simulations

ARR 2016
(Monte Carlo Approach)

10 AEPs
x 10 Durations
x 10 Storm Patterns

= 1,000
Simulations!

Game Changers
2D Solution Enhancements

Sub-Grid-Sampling

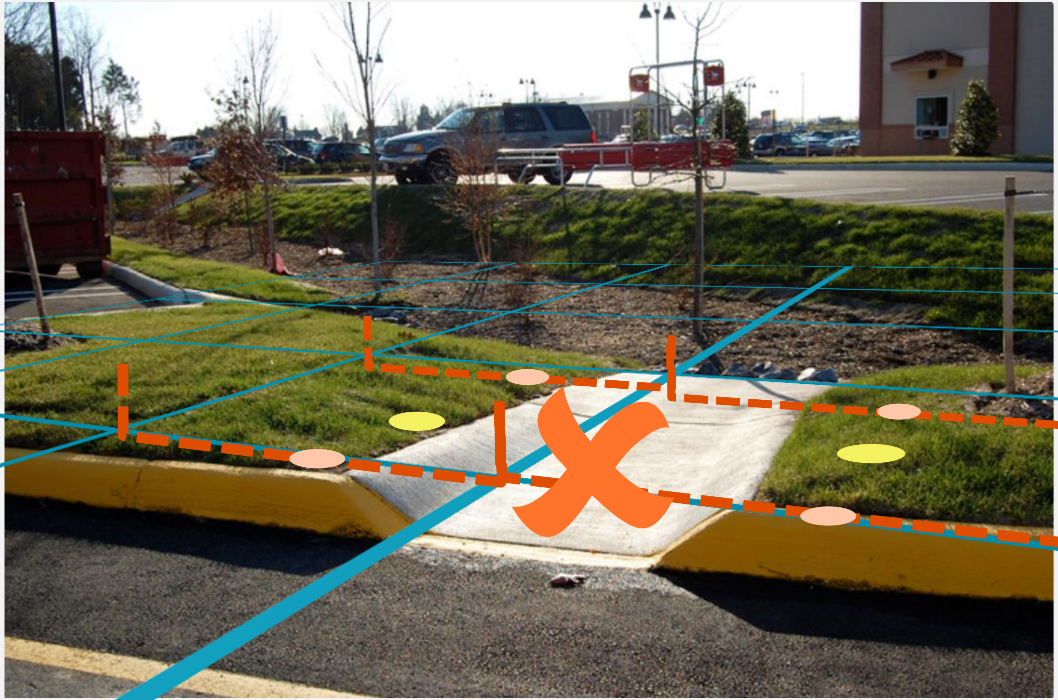
Quadtree Grid

Sub-grid turbulence (eddy viscosity) approach

2D Solution Enhancements
Sub-Grid-Sampling (SGS)

2D Original Approach

- Cell storage based on one elevation (imagine a square tub)
- Cell faces rectangular flow area
- OK if grid resolution sufficiently fine

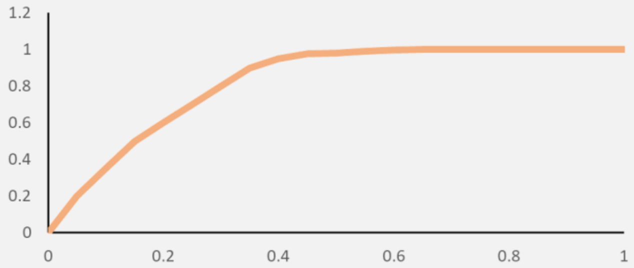


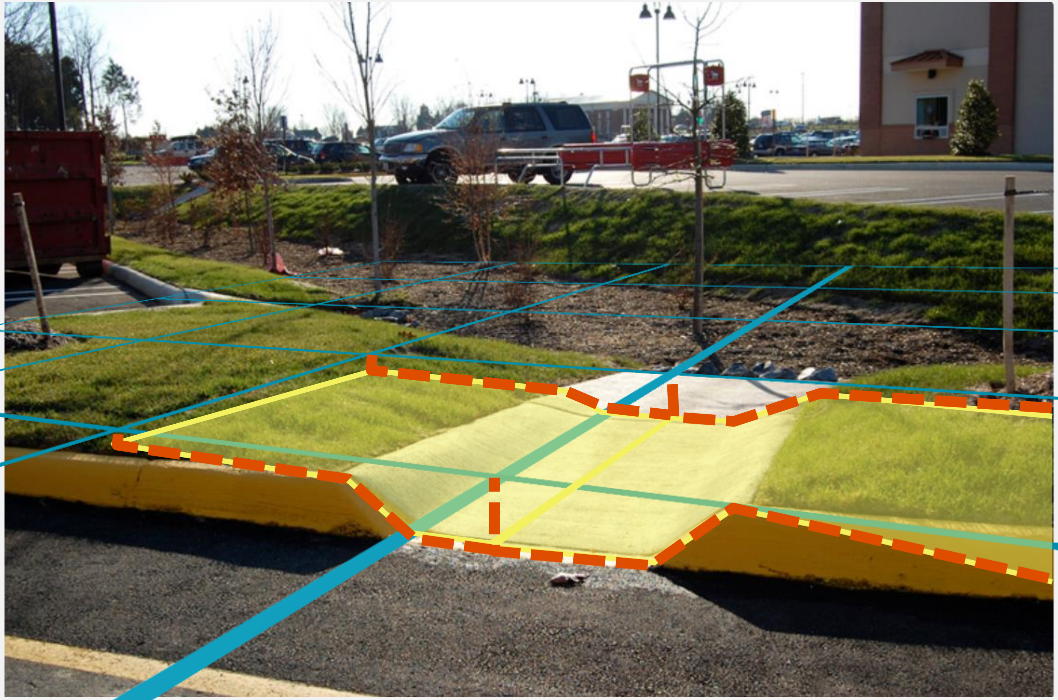
https://ww[…]rdenvisit.com/blog/suds-lid-wsud-urban-drainage-systems-and-landscape-architecture/

2D Solution Enhancements
Sub-Grid-Sampling (SGS)

2D Sub-Grid-Sampling

- Cell surface area (storage) varies with depth
- Cell face flow area varies with depth
- Utilises higher resolution DEM elevation data





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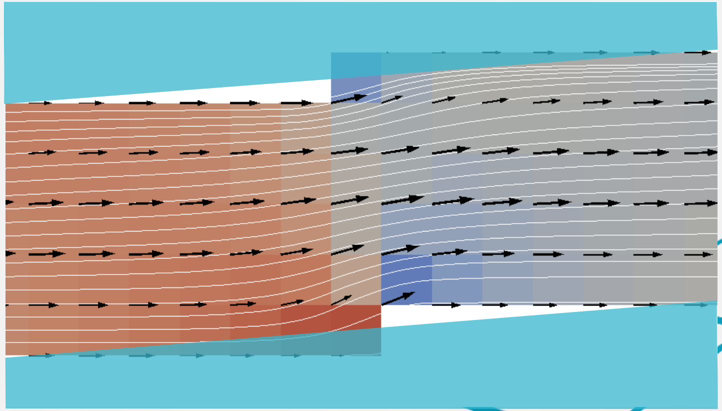
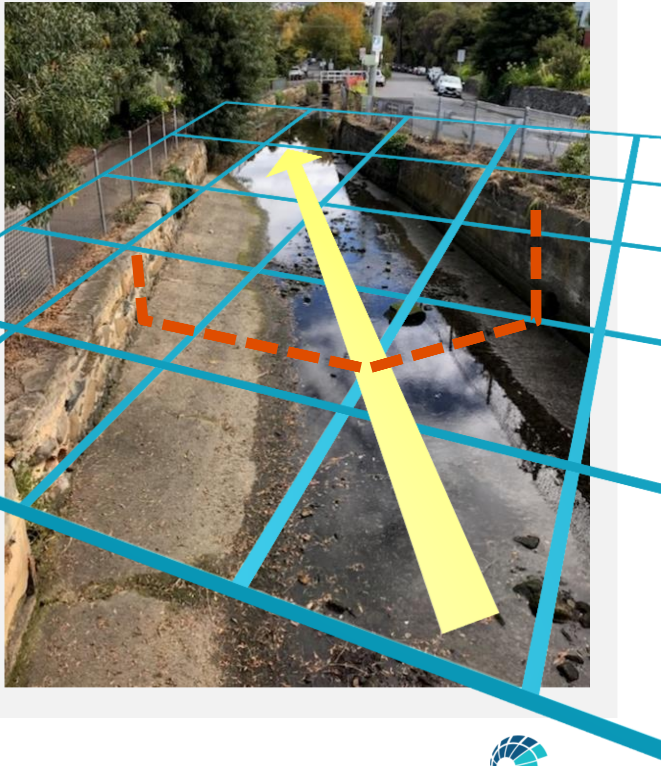
2D Solution Enhancements
Deep Sided Channels Unaligned to Grid

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

- Distorts streamlines
- Artificial energy losses; steepens gradient





Solutions

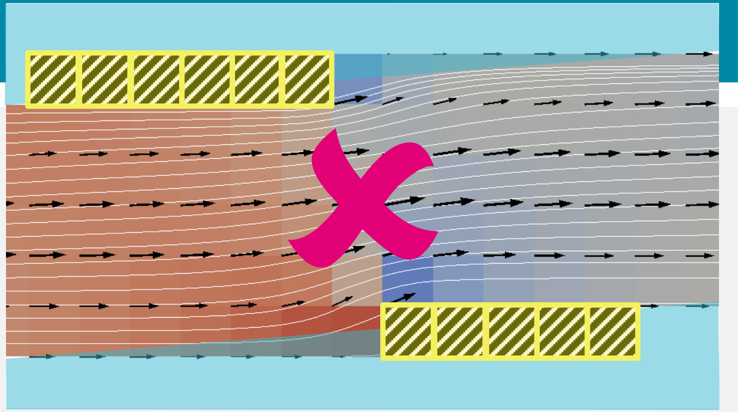
- 1D channel with cross-section (time-consuming; full 2D solution compromised)
- Flexible mesh (quadrilaterals aligned with banks)
- Much finer gridded mesh (much longer run times)
- or…

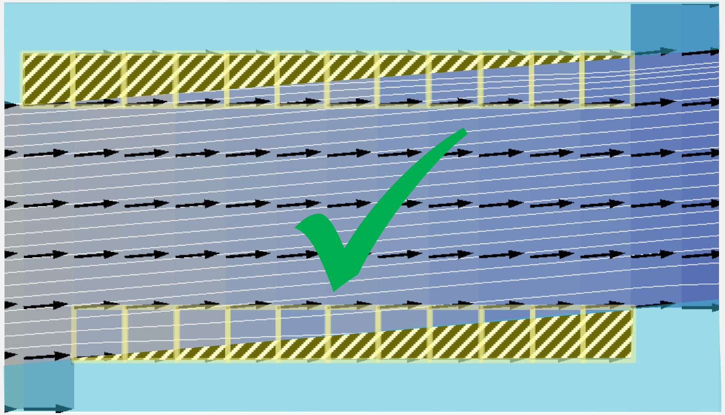
2D Solution Enhancements

Deep Sided Channels Unaligned to Grid

Solutions (cont…)

- Sub-grid-sampling
  - Cell storage and cell face flow areas adjusted
  - Streamlines parallel with banks
  - Conforming with Manning’s equation at all orientations
  - **Resolves limitation of using gridded meshes along deep sided channels ☺**
  - **Allows coarser grids to be used (faster run times!)** ☺

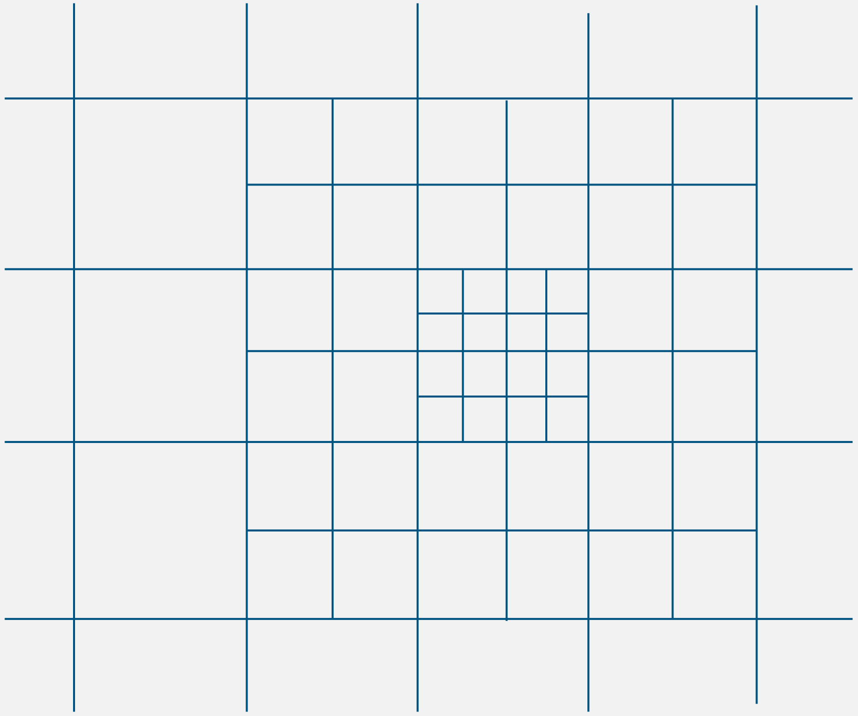




2D Solution Enhancements
Quadtree Meshes

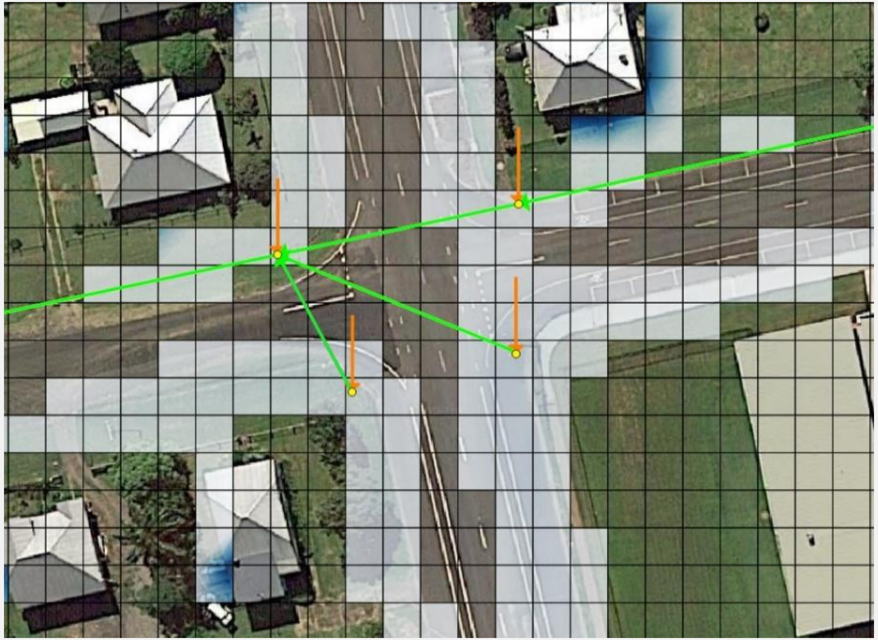
Quadtree

- Allows cells to be divided into 4
- Then these cells can be divided into 4
- And so on…
- Refinement only where necessary
- Efficient memory utilisation
- Faster simulation times
- Fast to set up

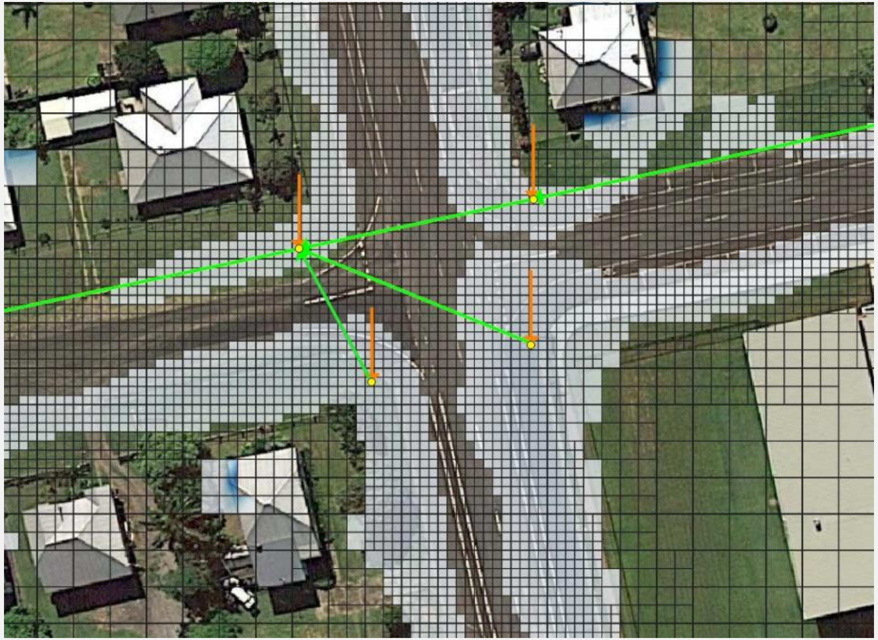


2D Solution Enhancements
Quadtree Meshes – Innisfail Model

5 m Single Domain



5m – 2.5m – 1.25m Quadtree Domain



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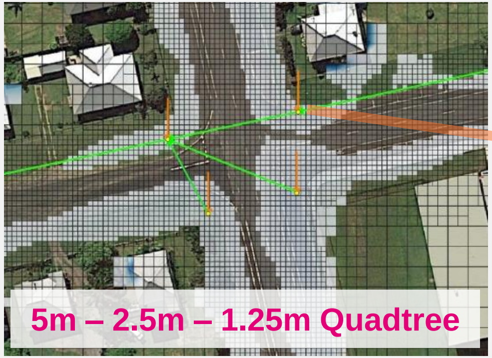
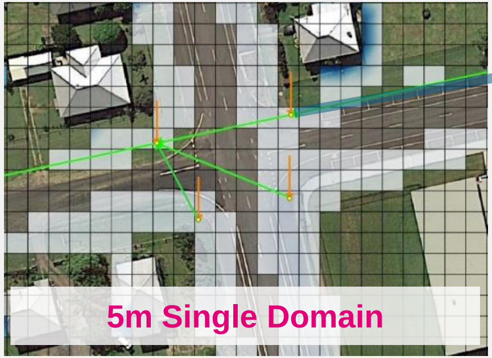
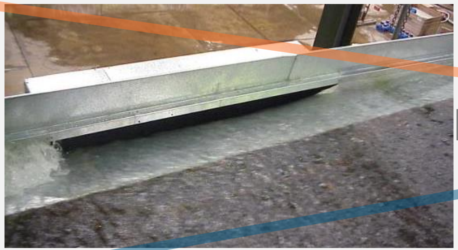
2D Solution Enhancements
Quadtree Meshes – Pit Flow Capture

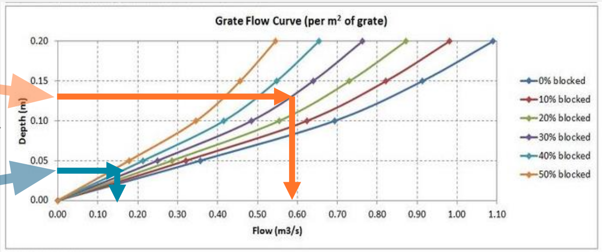


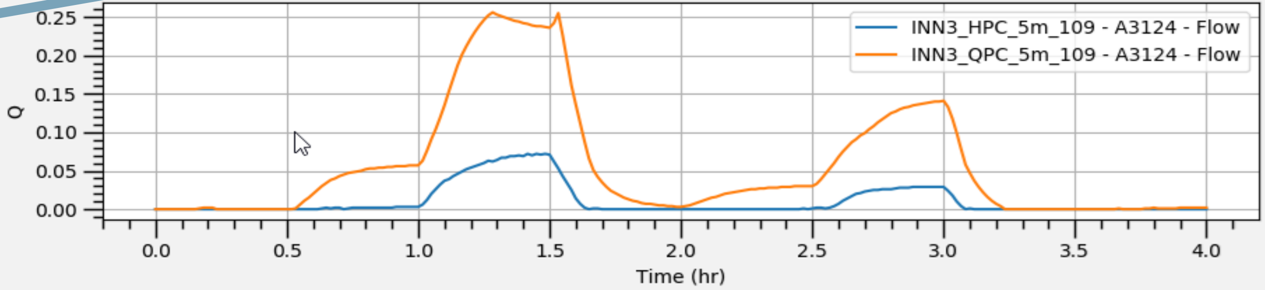


Improved pit inlet flow capture

- 2D depth at pit inlet more accurate



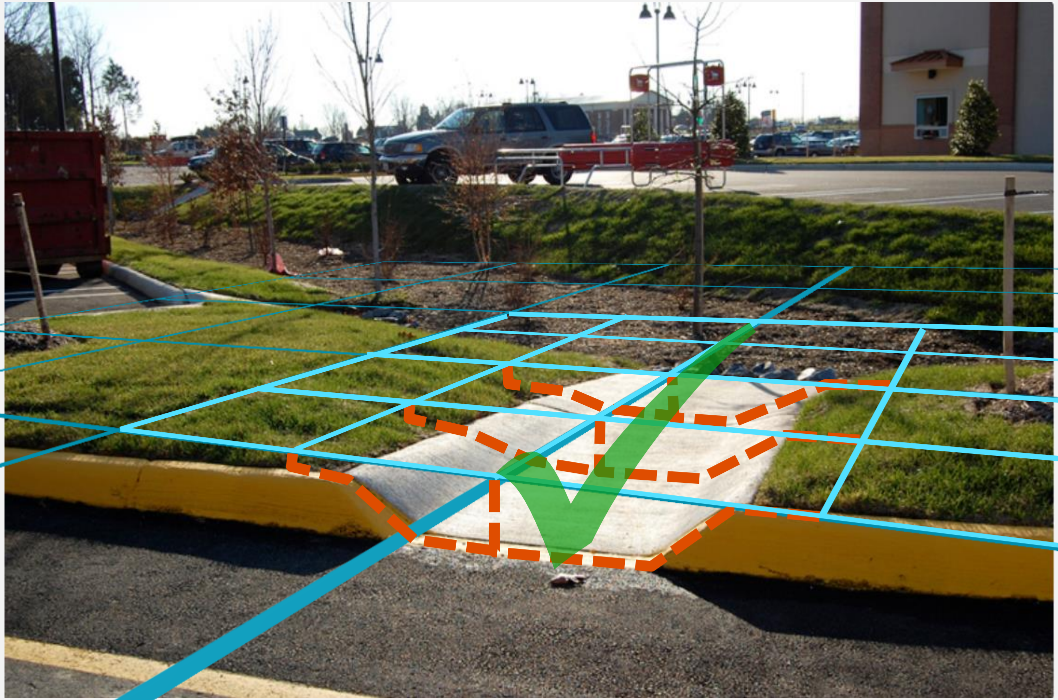




2D Solution Enhancements
Quadtree with Sub-Grid-Sampling

Best of All Worlds!

- Quadtree increases hydraulic resolution where needed
  - Complex flows
  - Critical flow paths
- Sub-Grid-Sampling
  - Resolves flow along deep-sided channels not orientated with grid
  - Models narrow flow paths (e.g. minor drainage paths)
  - Storage at DEM resolution/accuracy



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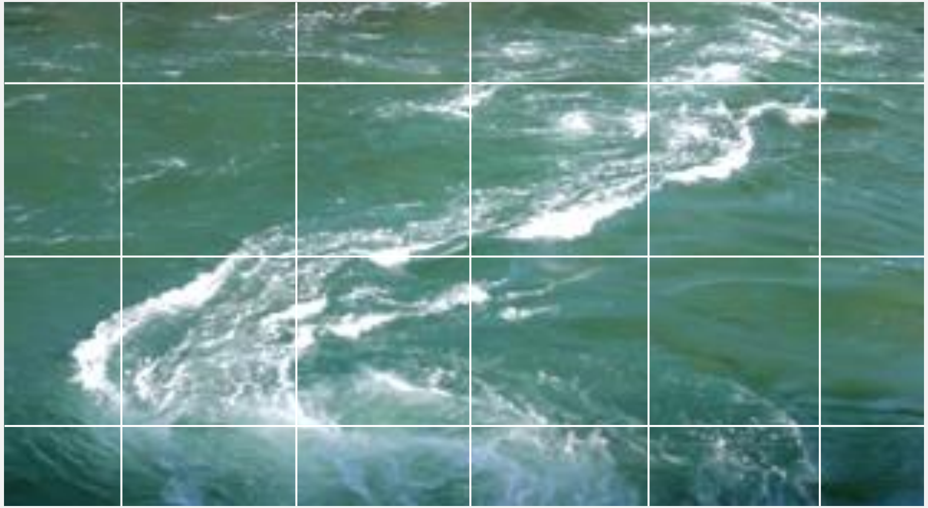
2D Solution Enhancements
Turbulence Approach

Eddy Viscosity: *"The turbulent transfer of momentum by eddies giving rise to an internal fluid friction, in a manner analogous to the action of molecular viscosity"*

Estimates losses for sub-grid (sub-cell) turbulence



2D Solution Enhancements
Turbulence Approach

2D models are becoming finer and finer

- Hardware / software enhancements
- DEM data improvements
- Quadtree / Flexible mesh

Existing turbulence approaches inappropriate (e.g. Smagorinsky)

- especially when water depth exceeds cell size
- show mesh size dependency

New approach developed and tested
(TUFLOW HPC engine developer, Greg Collecutt)

Conclusions

Urban areas are challenging to model

Benchmarking of schemes essential – know their limitations!

Calibration data and calibration of models highly beneficial

GPU acceleration a game changer

GPU with Sub-Grid-Sampling and Quadtree offer exciting opportunities

Need new cell size insensitive eddy viscosity approach

thank you

(After) 2007 Flood, Newcastle