Next Generation 2D Hydraulic Modelling

Webinar: 15th July 2021

Phillip Ryan / Bill Syme

Presentation Introduction
Agenda

Background

- What is 1D and 2D linked modelling?
- Why use 1D/2D linked modelling?

Benchmarking Case Studies

- Compound Trapezoidal Channel
- Urban Catchment, Open Concrete Drains

Open Channel Modelling
1D or 2D?

1D Equations

- Quick to simulate but slow to setup
- Assumptions, assumptions, assumptions…

2D Equations

- Much closer to reality

Consideration	1D Dynamic Equations	2D Dynamic Equations
Delineation of flow paths	Manually defined	Not needed
Terrain/Bathymetry (Elevations) Surface roughness (Manning's n)	Lumped at cross-sections	2D Cell or SGS resolution
Hydraulic computations (water levels, velocities)	Lumped at cross-sections (depth/width averaged)	2D Cell resolution (depth averaged)
Energy losses due to change in flow direction (e.g. bend or junction)	User defined, lumped	Included (excludes any 3D losses)
Energy losses due to sub-element turbulence	Not included	Included (not all 2D dynamic solvers)
Run-time	Fast	Much slower (small 2D cells in-bank)
Flood mapping	User defined – approximate	Standard output

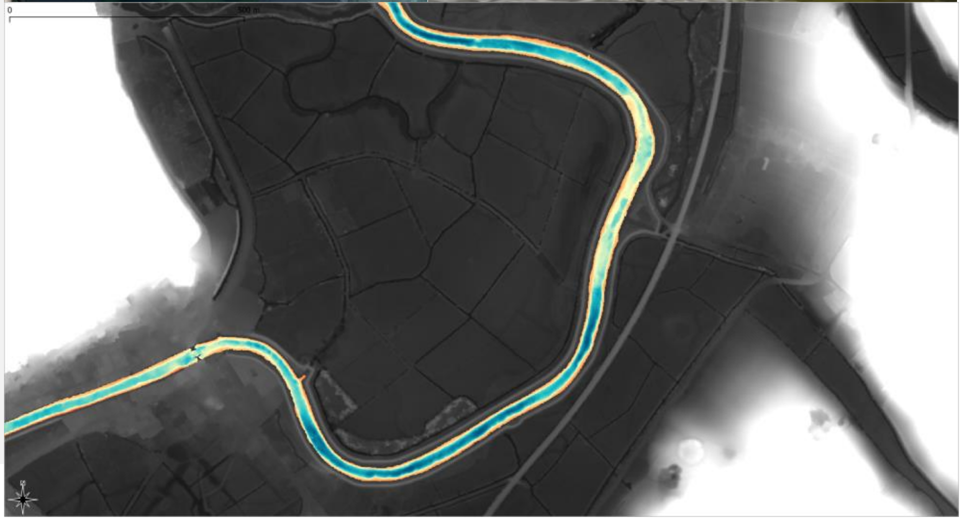
Open Channel Modelling
Topography

1D Cross-Sections

- Slow to setup
- Expensive to survey

2D High Resolution DTM

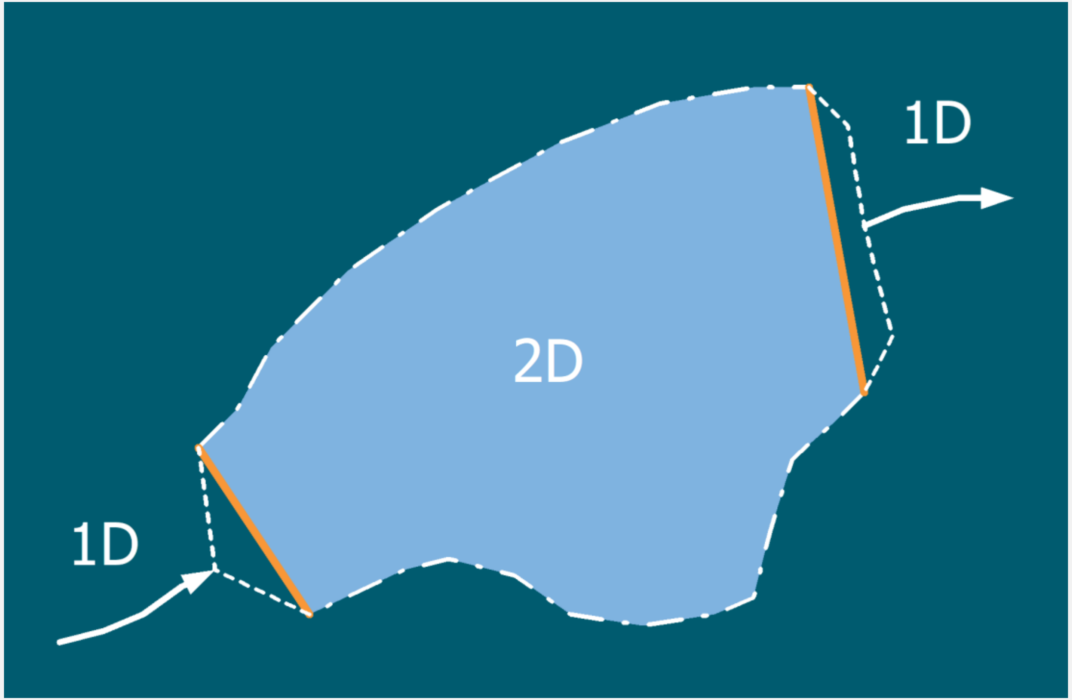
- Today, quicker/cheaper using laser side scanning than a cross-section survey
- Easy to set up in a 2D Model



History 1D/2D Linking
Early Days (Starting ~1990)

Objective

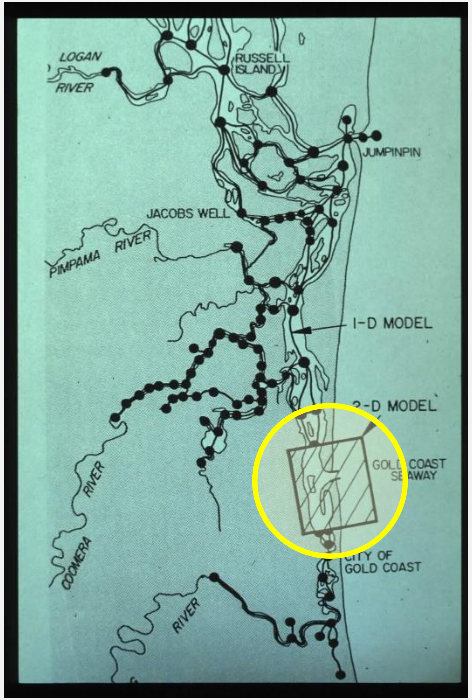
- Use 1D to propagate water to/from area of interest (2D)
- 2D models were VERY slow
  (10,000 cells was big!)
- 1D/2D allowed modelling the whole system as one
  (rather than transferring boundaries)

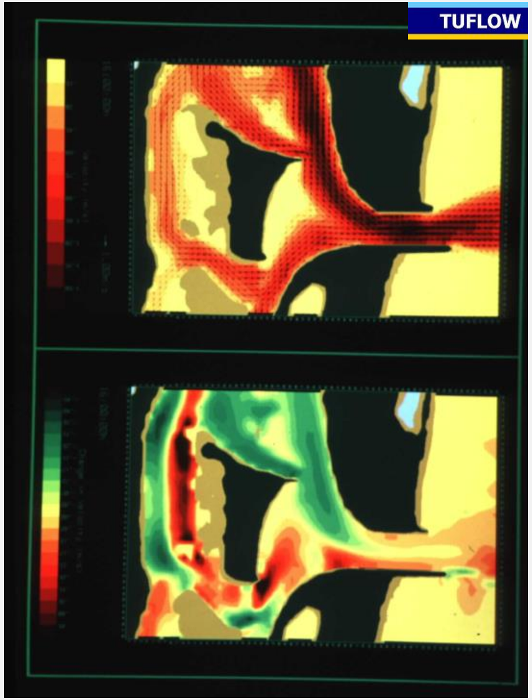


TUFLOW

History 1D/2D Linking
Early Days (Starting ~1990)

Example from 1990

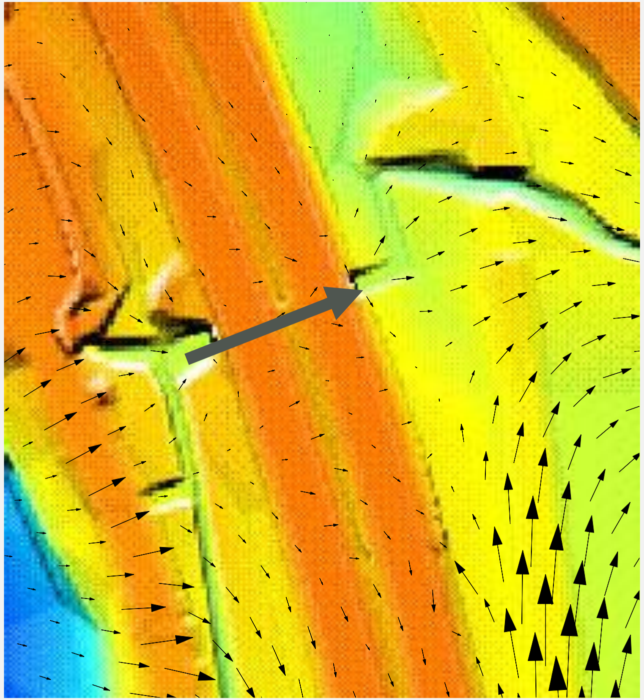




History 1D/2D Linking
1D Culverts (Starting ~1998)

Objective

- Convey water through conduits that can not be modelled in 2D
- Example: culvert through an embankment



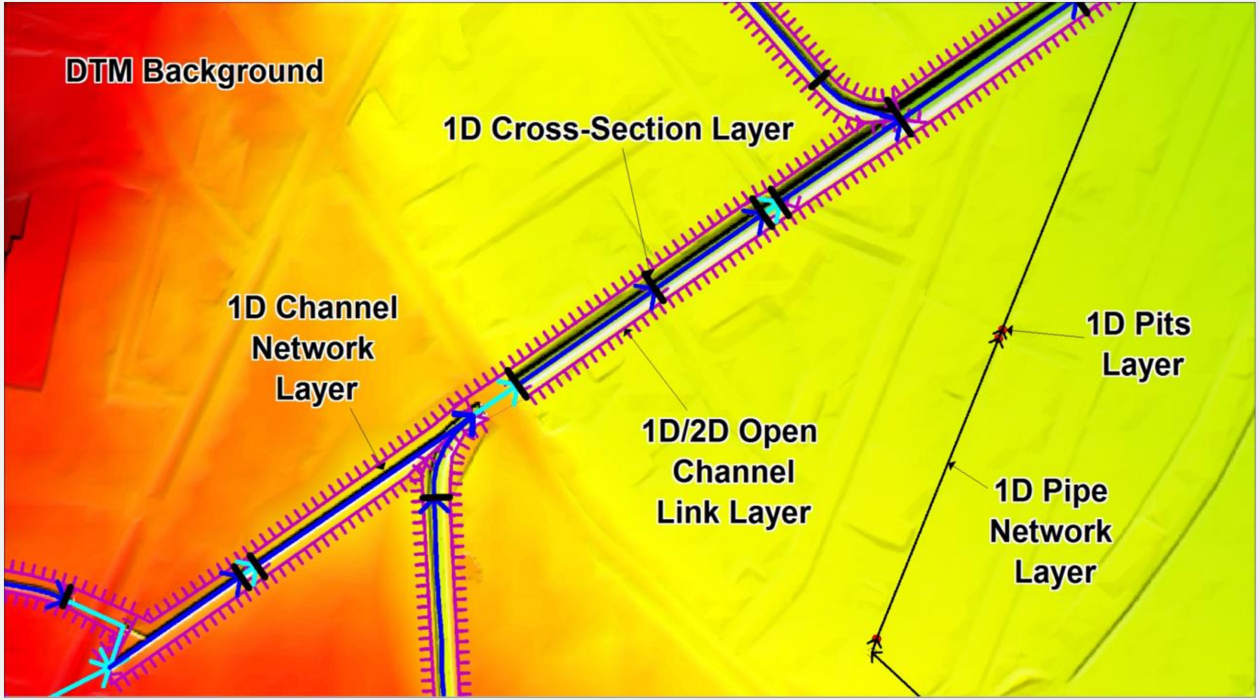
TUFLOW

History 1D/2D Linking
1D Cut Through 2D (Starting ~2001)

Objective

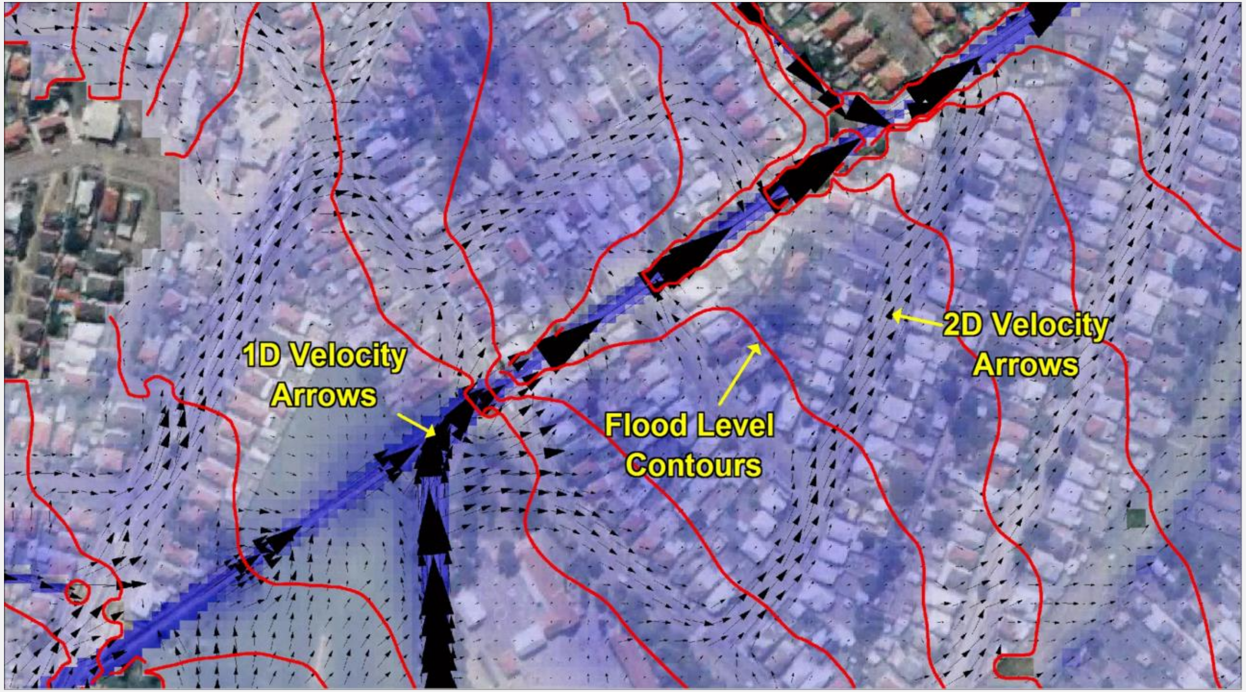
- Good representation of narrow open channels
- 2D representation
  - Very long run times
  - May not have been able to handle the hydraulics

Throsby Creek, NSW, 2006



History 1D/2D Linking
1D Cut Through 2D (Starting ~2001)

Throsby Creek, NSW, 2006



Background

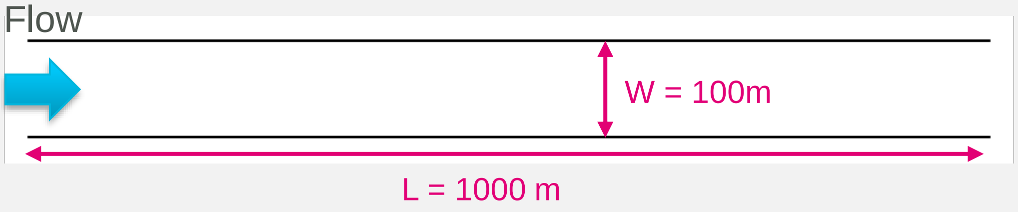
What has changed recently

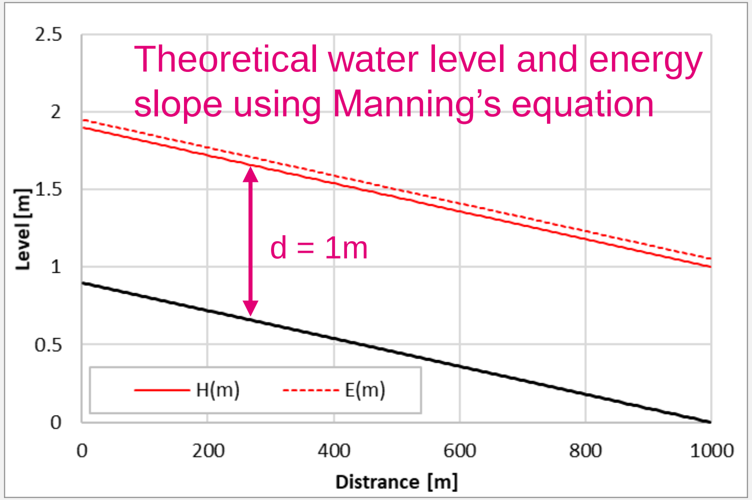
- In bank bathymetry getting better / cheaper
- Sub-Grid Sampling (SGS) of
  - Elevations
  - Material (Manning's n)
- Structure losses account for approach / departure velocities in 2D
- Quadtree solver, allowing easy setup of flexible cell sizes

SGS Benchmarking – Manning’s Equation Rectangular Channel Test

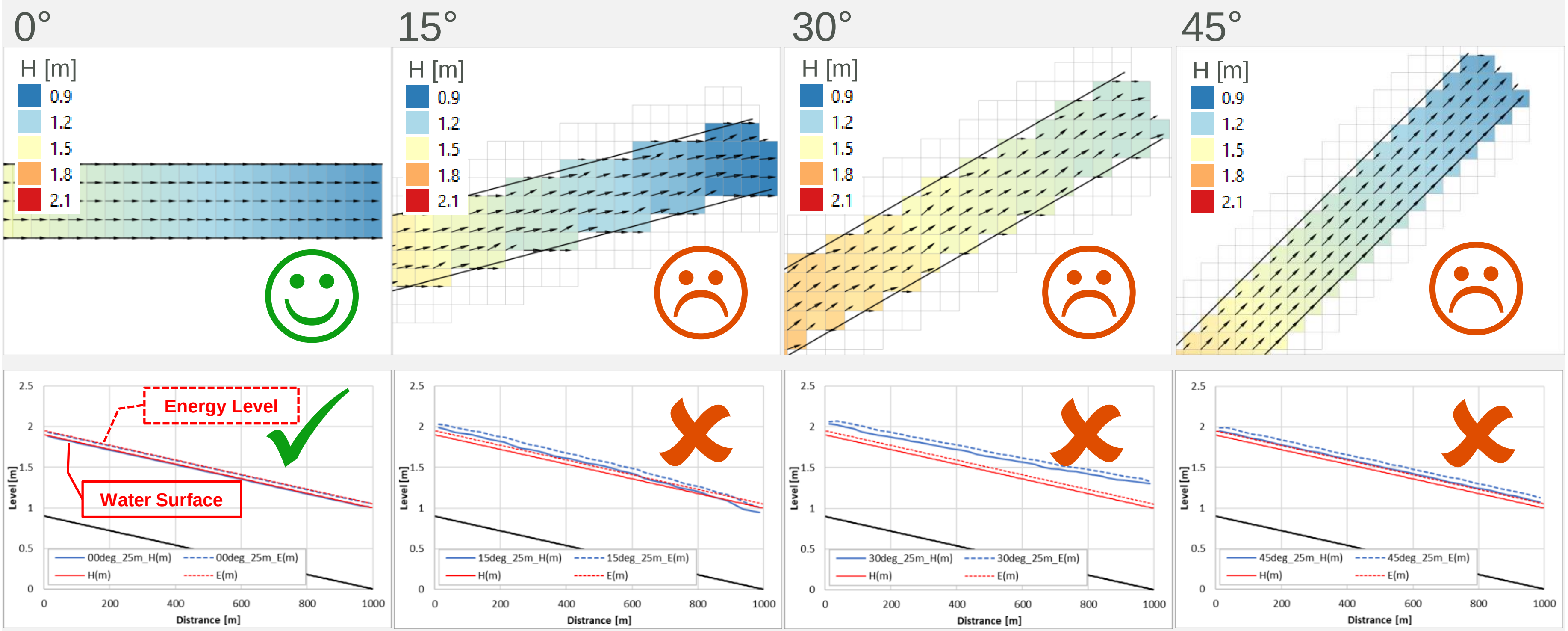
- Rectangular channel with length of 1000m and width of 100m
- Flow rate = 100 m^3/s
- Depth = 1 m
- Slope = 0.0009
- Manning’s n = 0.03

Uniform flow of U = 1m/s, d = 1m



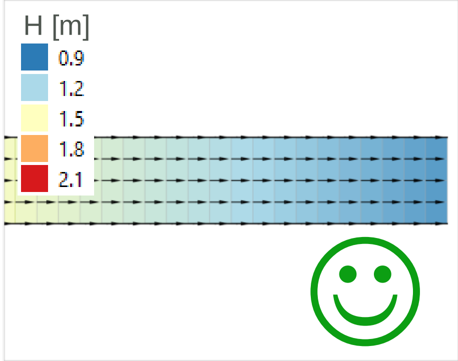


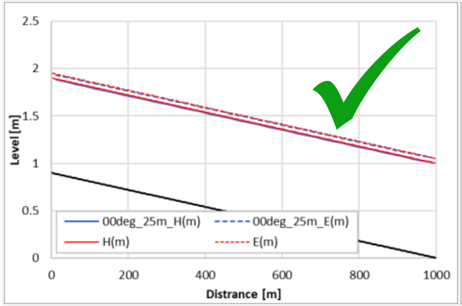
SGS Benchmarking – Manning's Equation
Rotated Channel Test – Without SGS



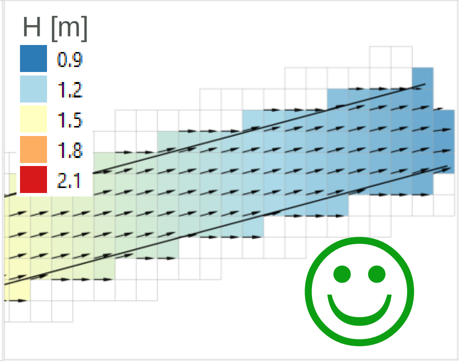
SGS Benchmarking – Manning’s Equation
Rotated Channel Test – With SGS

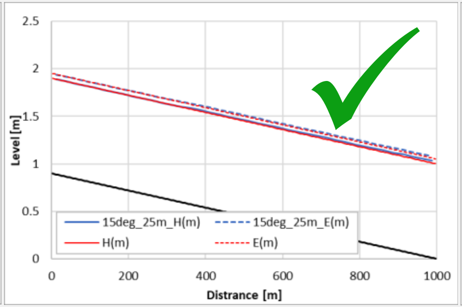
0°



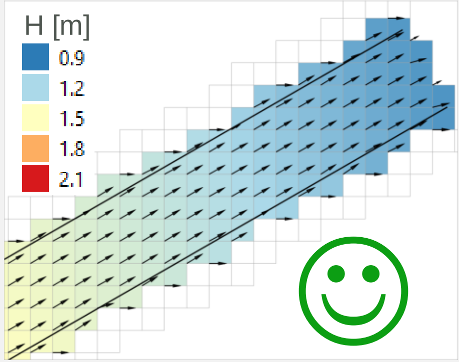


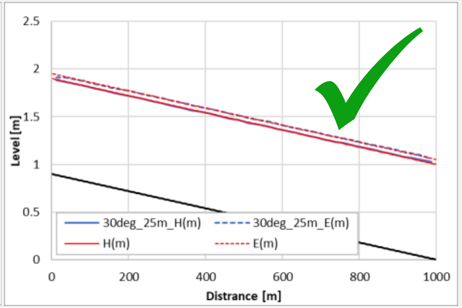
15°



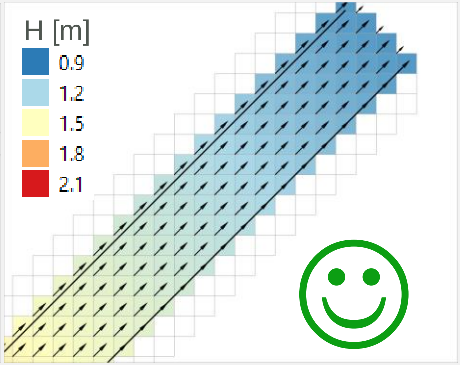


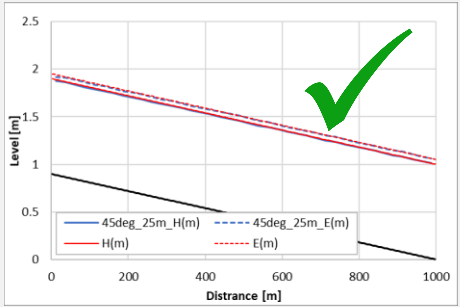
30°





45°

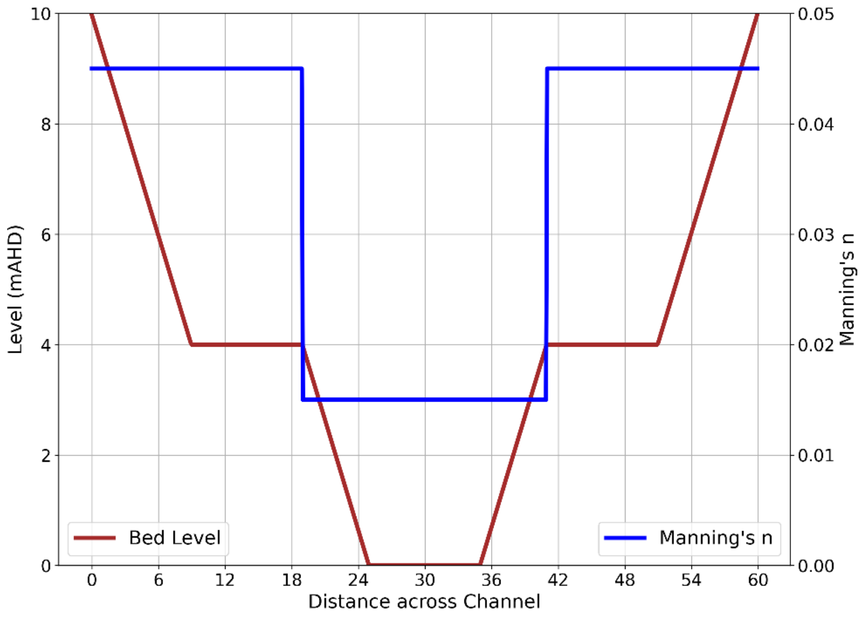




Compound Trapezoidal Channel

Test model:

- 10 m wide, 4 m deep, concrete channel
  - Manning’s n = 0.015
  - Batter slope 1.5:1 (H:V)
- 10m floodplain each side
  - Manning’s n = 0.045
  - 6 km long x 60 m wide
- Downstream WL boundary, upstream flow



TUFLOW

Compound Trapezoidal Channel
1D Parallel Channel Analysis

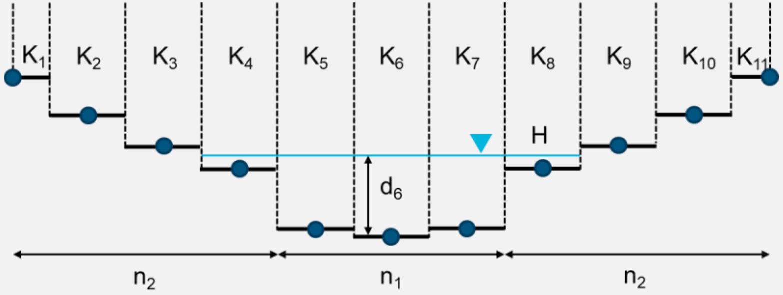
Flows – Parallel Channel Analysis

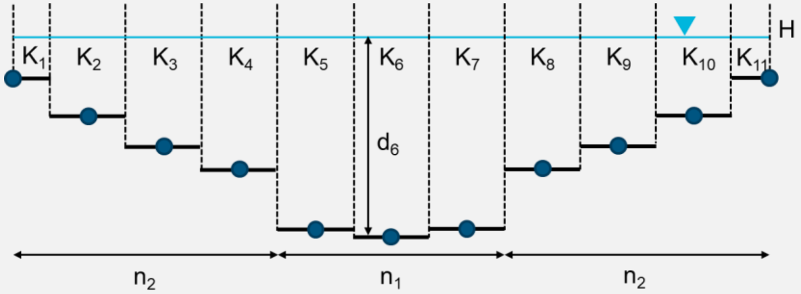
$$K(H) = \Sigma K_i = \Sigma \frac{1}{n_i} A_i d_i^{\frac{2}{3}}$$

A_i is the flow area for the segment

d_i is the depth for the segment

$$Q = K_{total} s^{\frac{1}{2}}$$





TUFLOW

Compound Trapezoidal Channel
1D Parallel Channel Analysis

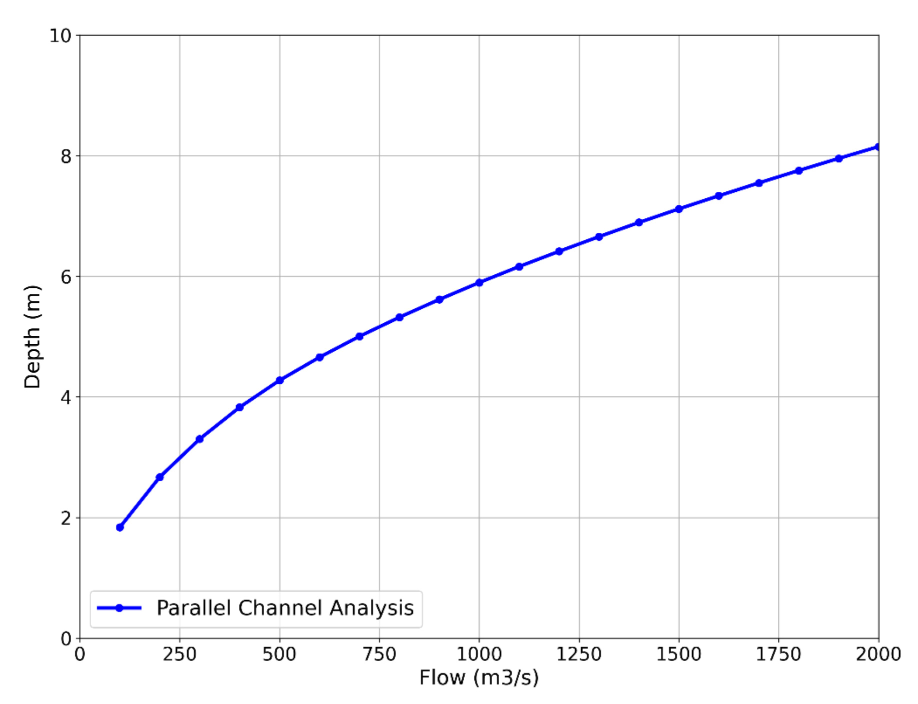
Flows – Parallel Channel Analysis

$$K(H) = \Sigma K_i = \Sigma \frac{1}{n_i} A_i d_i^{\frac{2}{3}}$$

A_i is the flow area for the segment

d_i is the depth for the segment

$$Q = K_{total} s^{\frac{1}{2}}$$



TUFLOW

Compound Trapezoidal Channel
1D Parallel Channel Analysis

Run at range of cell sizes from 60 m down to 2 m

Run for 500 m^3/s event

Parallel channel analysis predicts depth of 4.27 m

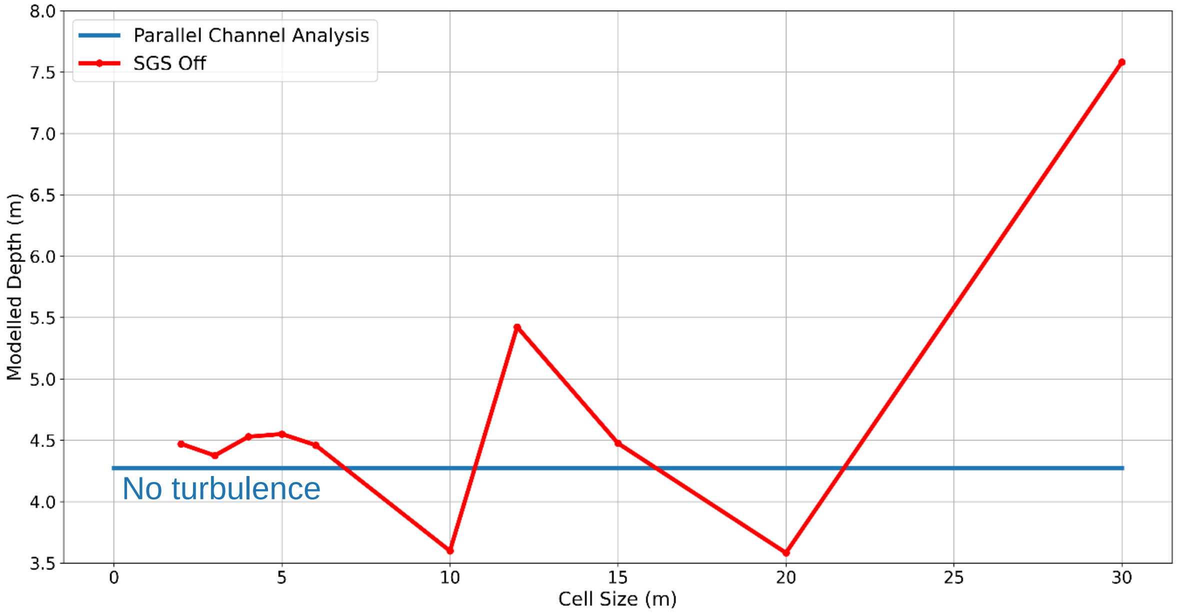
Expecting shallow depth on overbank areas

Compound Trapezoidal Channel
No Turbulence

Modelled Results

Turbulence Off

- 1D parallel channel analysis does not model turbulence (i.e. shear between main channel and overbank)

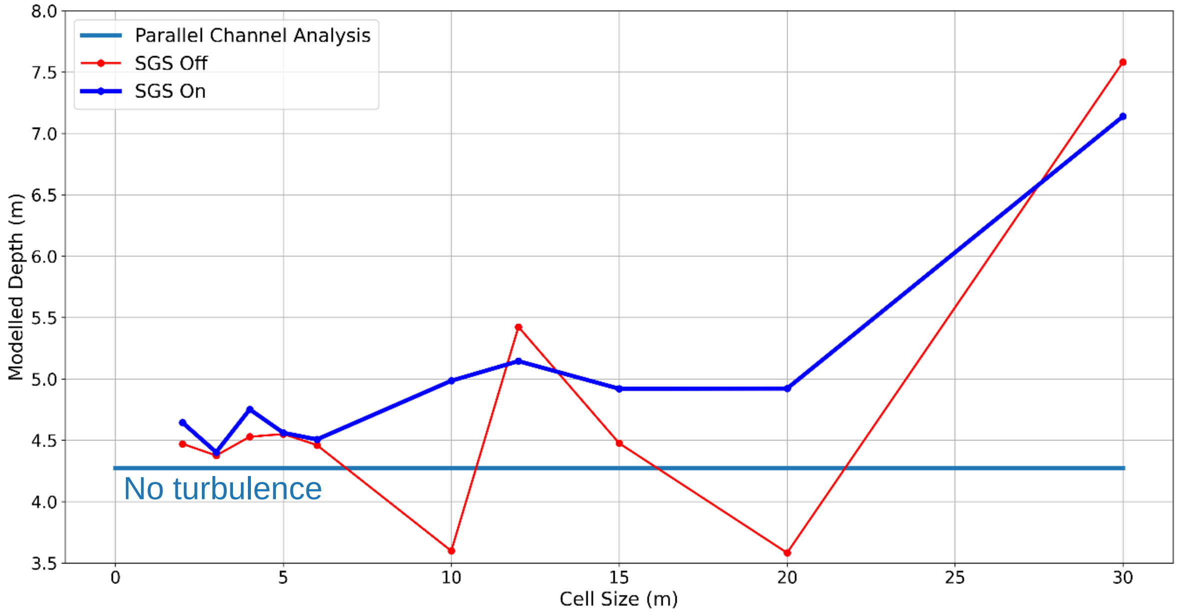


Compound Trapezoidal Channel
No Turbulence

Modelled Results

Turbulence Off

- 1D parallel channel analysis does not model turbulence (i.e. shear between main channel and overbank)

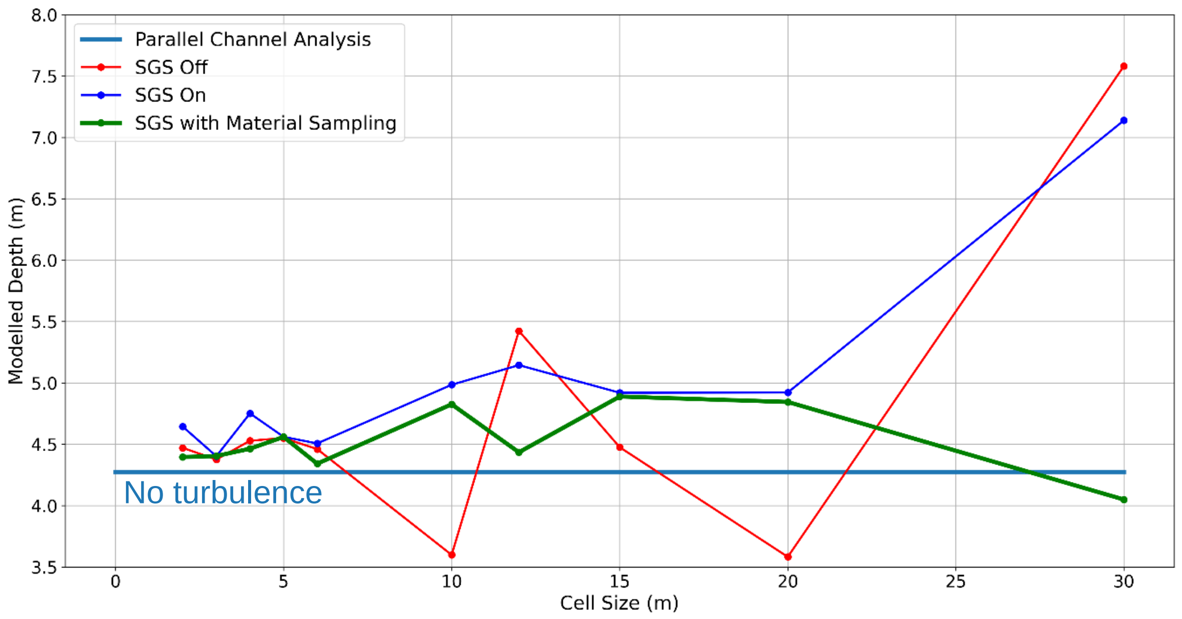


Compound Trapezoidal Channel
No Turbulence

Modelled Results

Turbulence Off

- 1D parallel channel analysis does not model turbulence (i.e. shear between main channel and overbank)



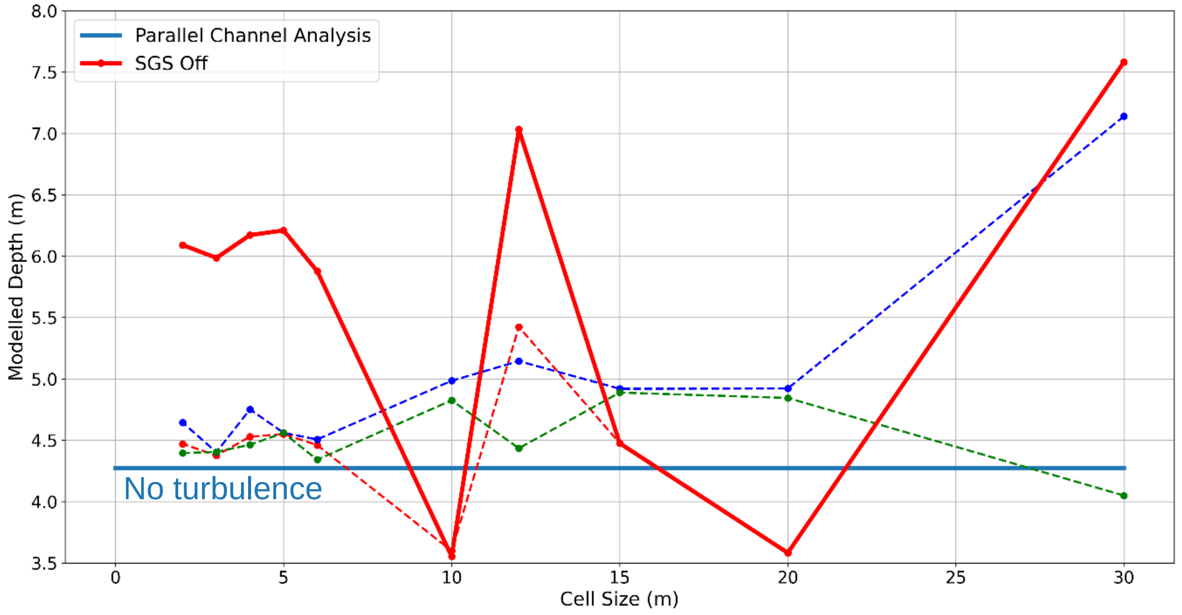
TUFLOW

Compound Trapezoidal Channel
Isotropic Turbulence

Modelled Results

Solid Lines:
Isotropic Turbulence On

Dashed Lines:
Turbulence Off

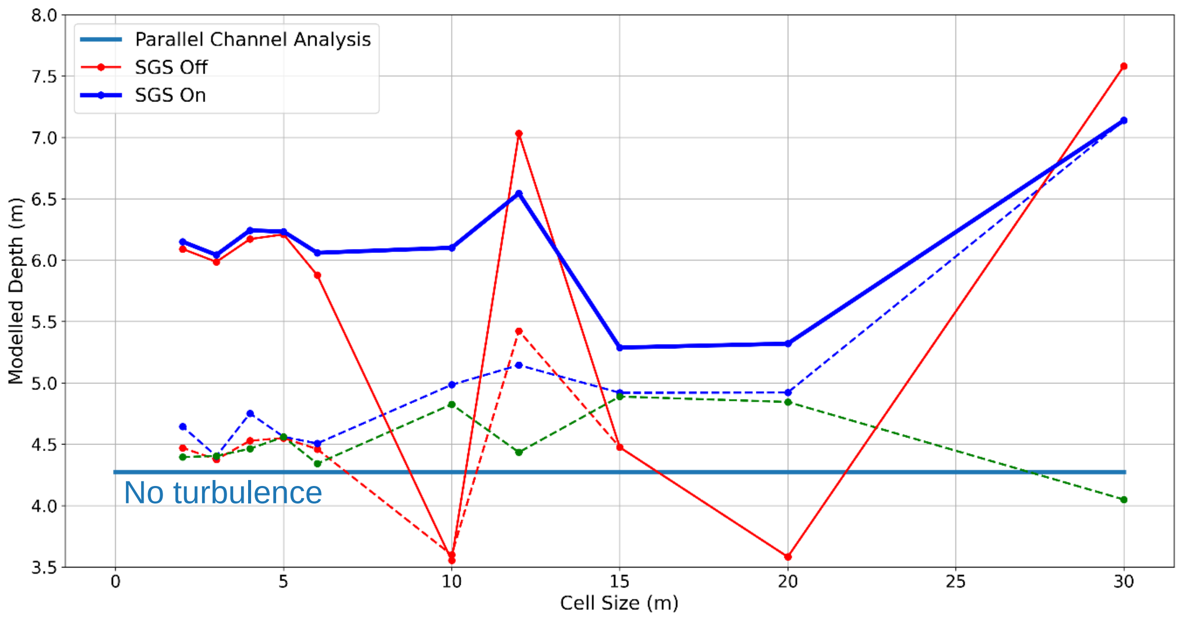


Compound Trapezoidal Channel
Isotropic Turbulence

Modelled Results

Solid Lines:
Isotropic Turbulence On

Dashed Lines:
Turbulence Off



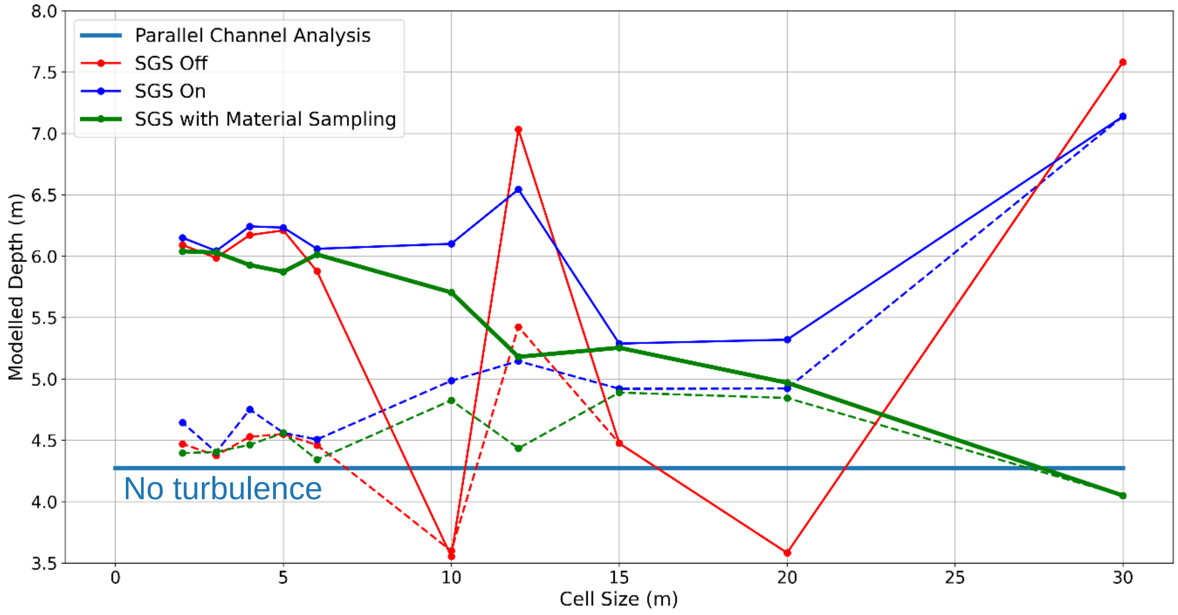
TUFLOW

Compound Trapezoidal Channel
Isotropic Turbulence

Modelled Results

Solid Lines:
Isotropic Turbulence <u>On</u>

Dashed Lines:
Turbulence <u>Off</u>



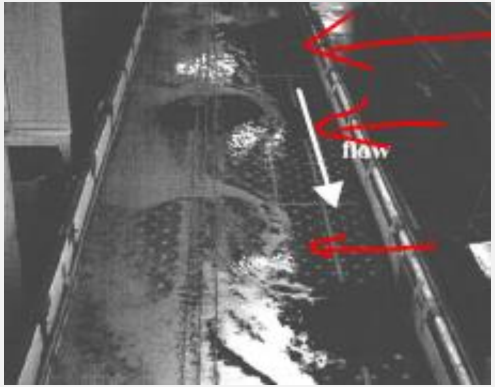
TUFLOW

Compound Trapezoidal Channel Turbulence

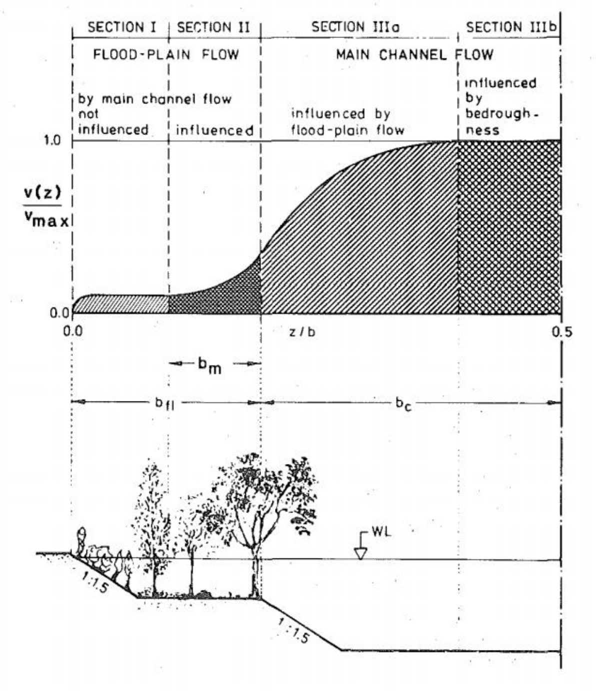
With turbulence on, the results are converging to a higher value – this is expected

Parallel Channel Analysis and 1D solvers do not account for turbulence caused by velocity variation across the channel

Ishikawa and Minoura (2011)



Ikeda et al (2000)



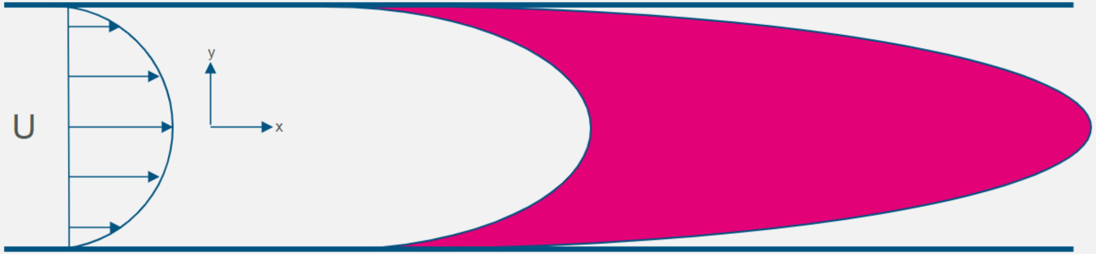
Pasche and Rouve (1985)

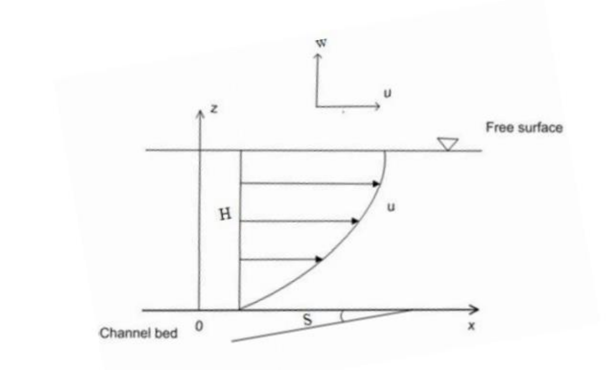
TUFLOW

Compound Trapezoidal Channel Anisotropic Turbulence

What is anisotropic turbulence

- Separates the viscosity coefficients into longitudinal and transverse components
- Longitudinal (in the direction of flow) is stronger, therefore higher coefficient





Compound Trapezoidal Channel Anisotropic Turbulence

Flume measurements in a compound channel

- Measured velocities across channel

Anisotropic turbulence

- Longitudinal and transverse coefficients
- Best match to measurements using longitudinal coefficient >> transverse coefficient

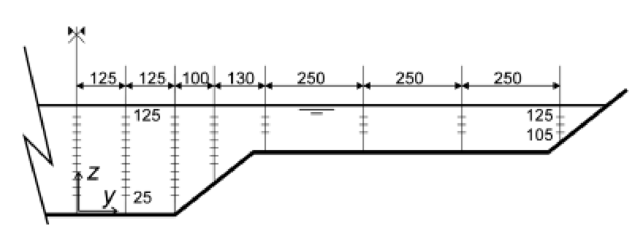
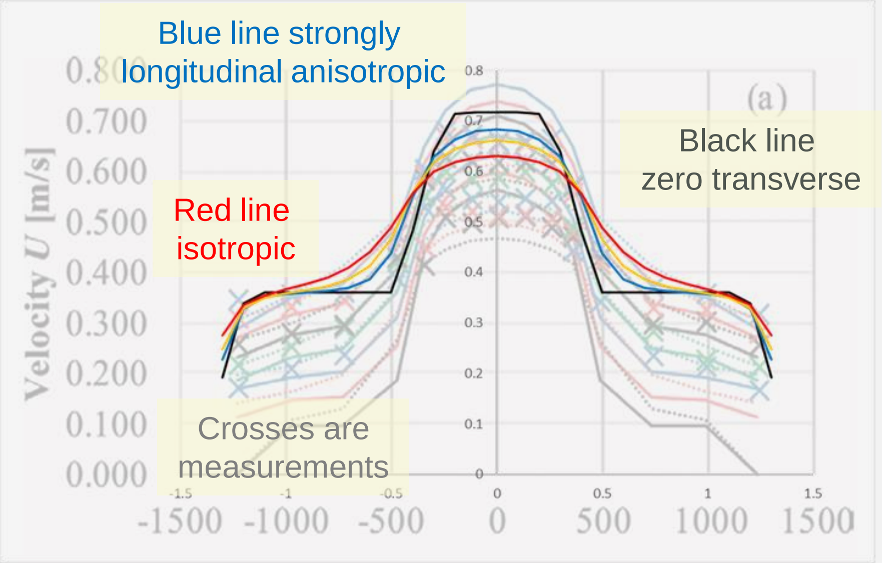


Figure 2. Velocity measurement mesh, at $H = 140$ mm. Dimensions in mm.

TUFLOW Benchmarking



2016 - Bousmar et al - Uniform flow in prismatic compound channel Benchmarking numerical models

Compound Trapezoidal Channel
Anisotropic Turbulence

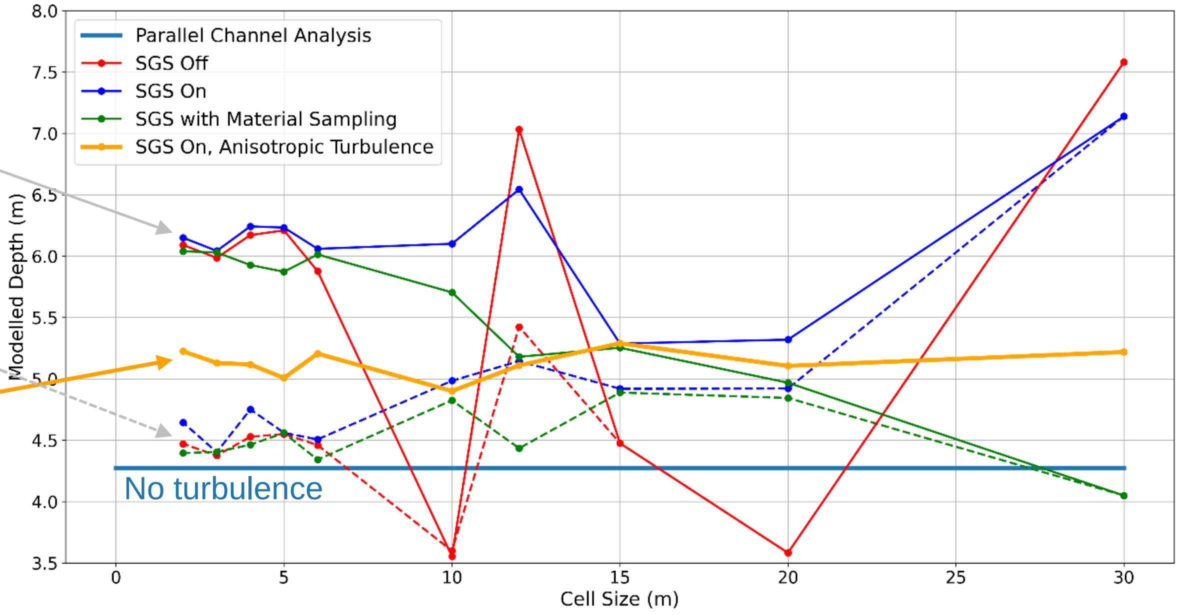
Modelled Results

Thin Solid Lines:
Isotropic Turbulence On

Dashed Lines:
Turbulence Off

Solid Yellow Line:
Anisotropic Turbulence
(New for TUFLOW 2021)

- Transverse = 0.5
- Longitudinal = 7.0



Compound Trapezoidal Channel Conclusions

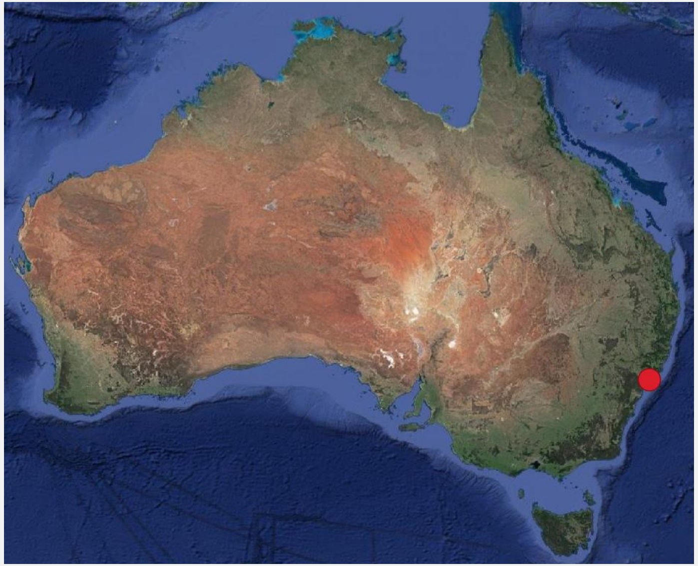
Conclusions from compound trapezoidal channel

- Channels do not need to be aligned with cells with SGS enabled
- 1D scheme and 2D without turbulence match
  (as would be expected)
- With turbulence on and velocity variation across channel, 2D provides a higher levels
  (as would be expected)
  - Requires several cells across channel to model velocity gradient
- Evidence anisotropic turbulence generates improved velocity profile
  - Literature indicates longitudinal rate >> transverse rate

Case Study 1 – Urban
Newcastle, Australia

Throsby, Cottage and CBD Flood Study completed in 2007

- Detailed flood investigation incorporating:
  - Data compilation, review, and acquisition of missing data
  - Develop and calibrate hydrologic and hydraulic models
  - Design event selection, modelling and mapping



Excellent calibration datasets, especially 1990 flood

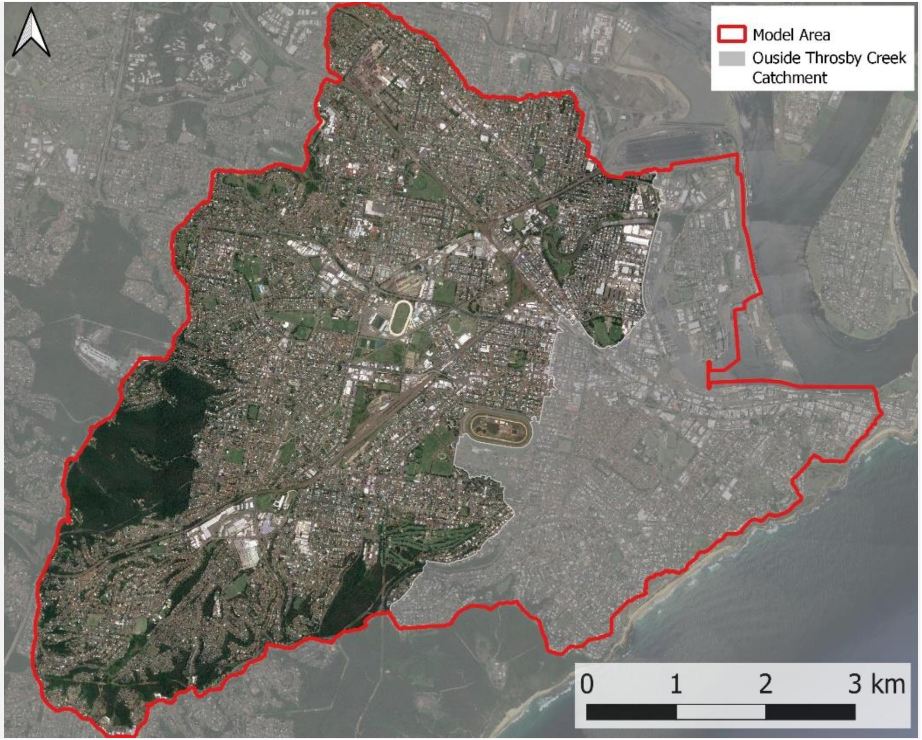
Very high-quality input datasets

Previous webinar: direct rainfall c.f. hydrology

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

Case Study 1 – Urban
Throsby Creek Flood Study

- Throsby Creek covers a significant portion of the City of Newcastle, NSW, Australia
  (Population: 450,000)
- Highly urbanised catchment
- Heavily engineered
  (Concrete open channels and culverts)
- Calibration to 1988 and 1990 events
  - 1990 ~ 1 in 80-year event
  - Confirmation post study to 2007 event (~1 in 100)



TUFLOW

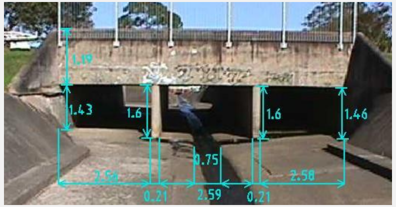
Case Study 1 – Urban
Throsby Creek Flood Study

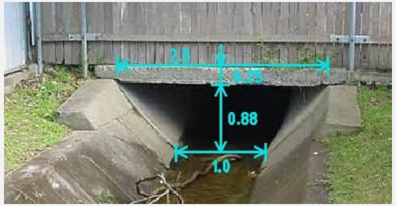
Very High-Quality DEM

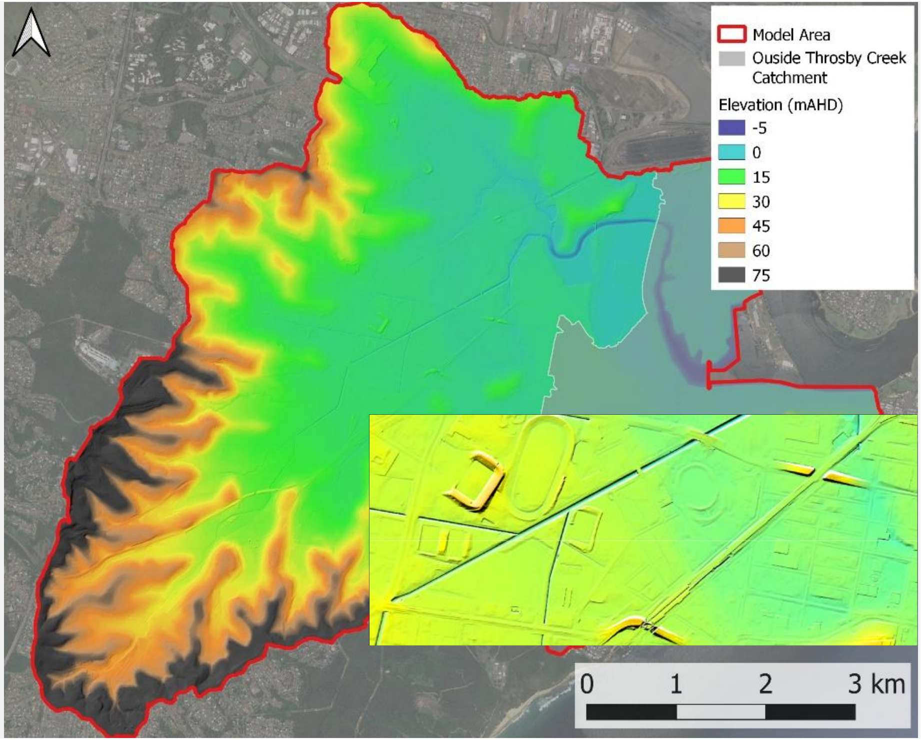
- High resolution photogrammetry
- Longitudinal field survey of all open channels

Excellent Hydraulic Structure Data

- Detailed field survey



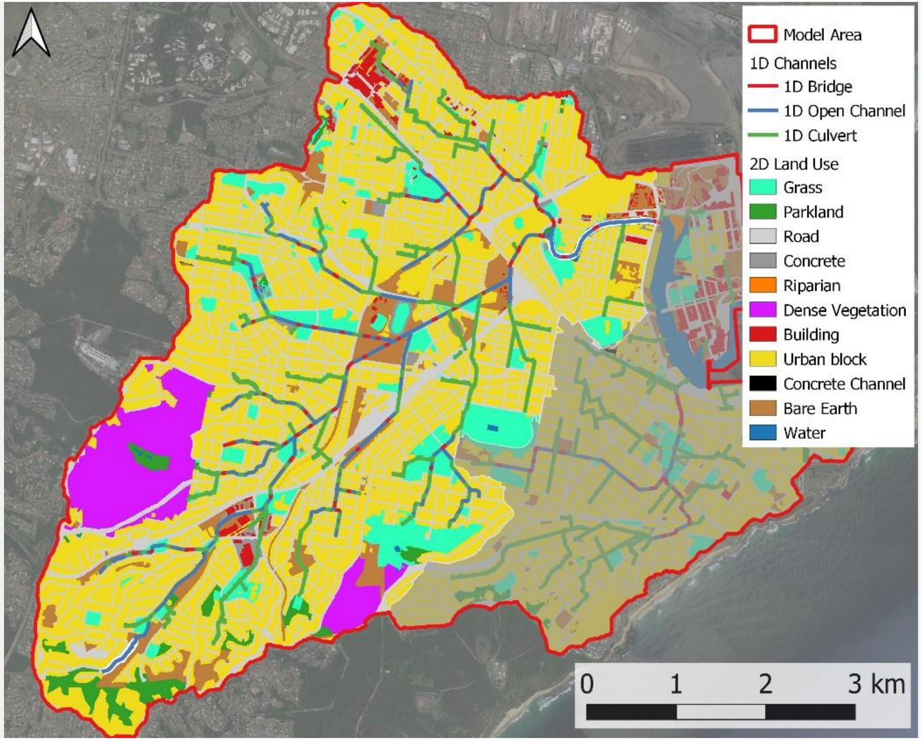




TUFLOW

Case Study 1 – Urban
Throsby Creek Flood Study

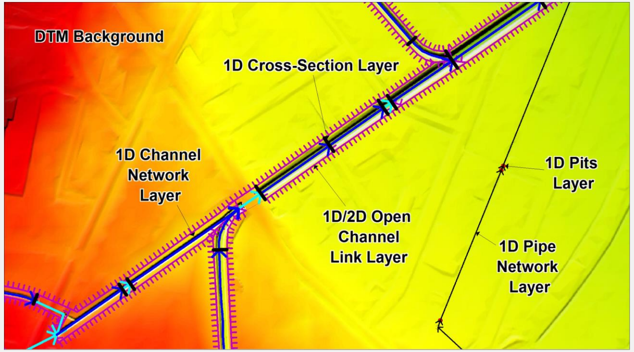
Detailed land-use mapping

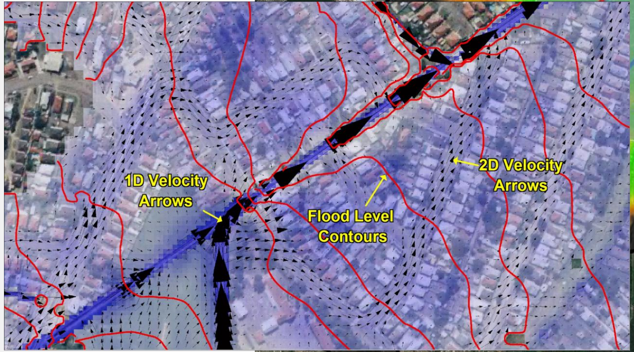


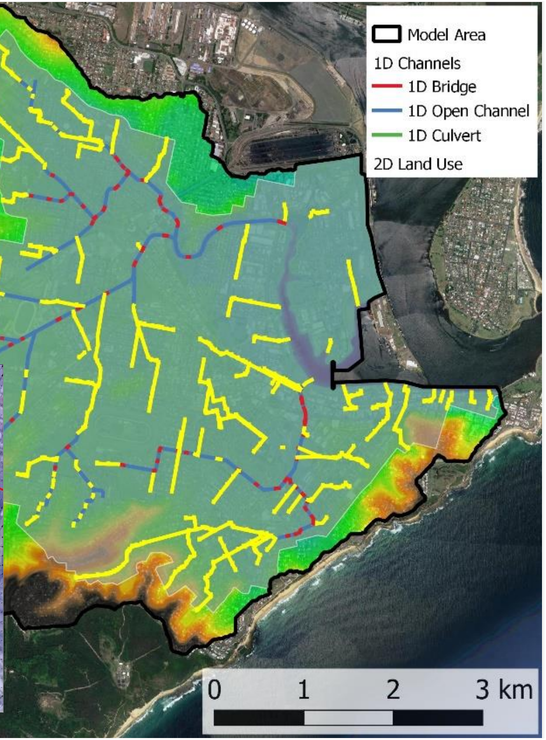
Case Study 1 – Urban
Throsby Creek Flood Study

Base Hydraulic Model

- 1D network for open channels, bridges, culverts, and pipes
- 10 m 2D cell size (SGS On)
- Direct rainfall

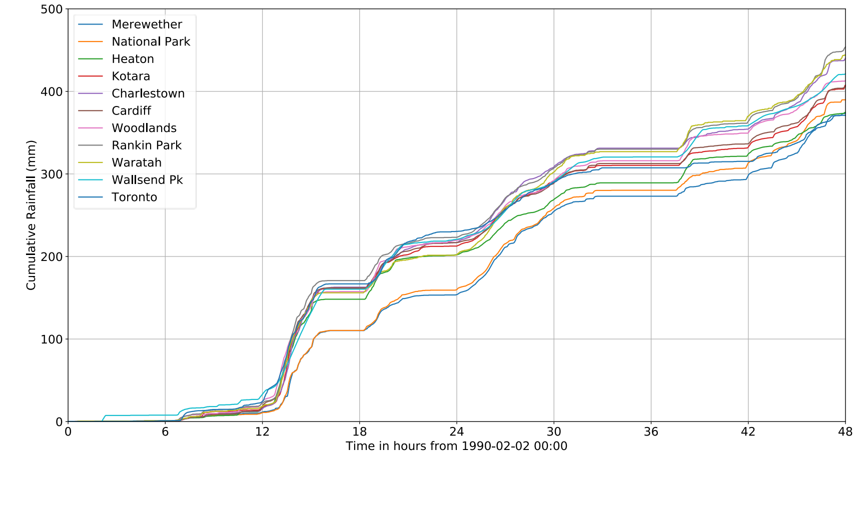


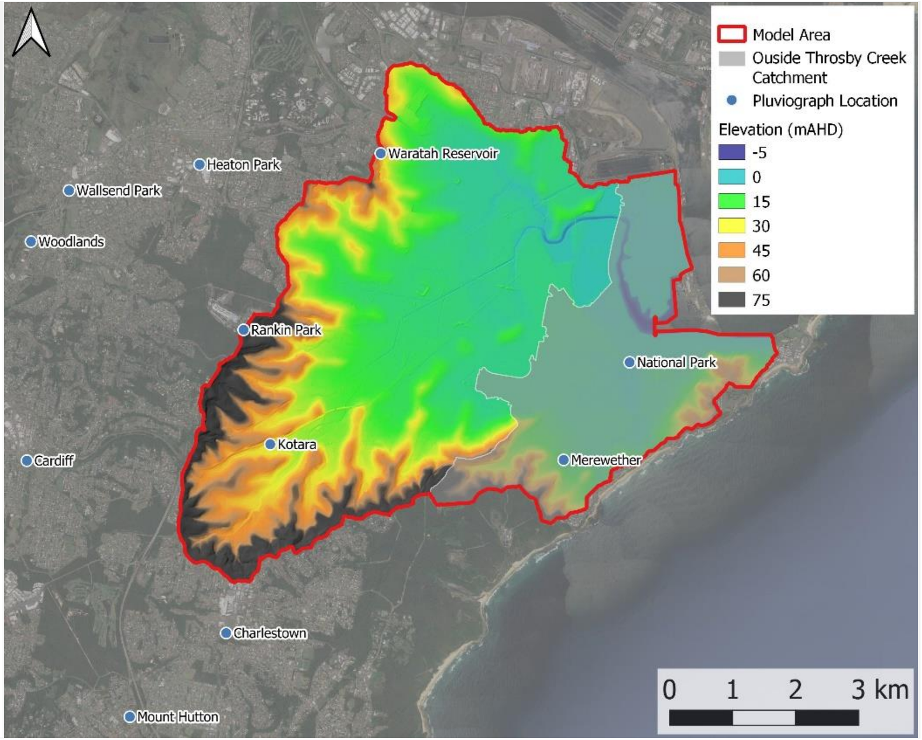




Case Study 1 – Urban
1990 Flood – Recorded Rainfall

- 11 Pluviographs
  - 7 within or close to catchment
    (this is very rare for urban catchment!)
- 370-450 mm over 48 hours





TUFLOW

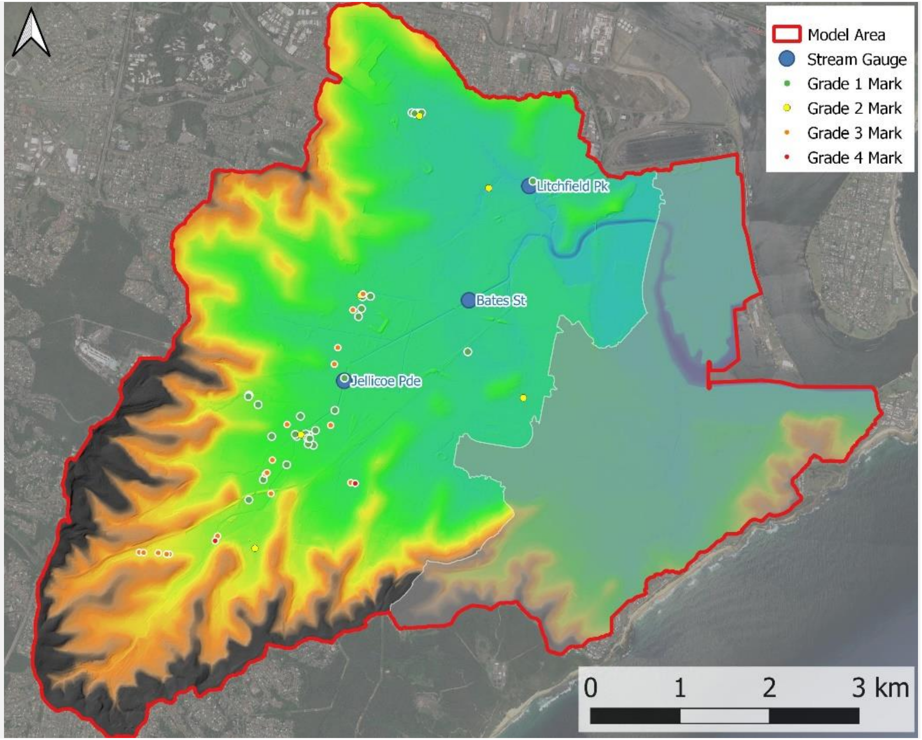
Case Study 1 – Urban
1990 Flood – Recorded Water Levels

Three in-bank stream gauges

- Very rare for urban catchments

Flood marks

- 52 peak and debris marks
- Classified as Grade 1 (accurate) to Grade 4 (least reliable)
  - 27 Grade 1 (e.g. high water mark in building)
  - 5 Grade 2 (e.g. reliable debris mark)
  - 17 Grade 3 (e.g. reliable observation, but not at peak)
  - 3 Grade 4 (e.g. rough observation)

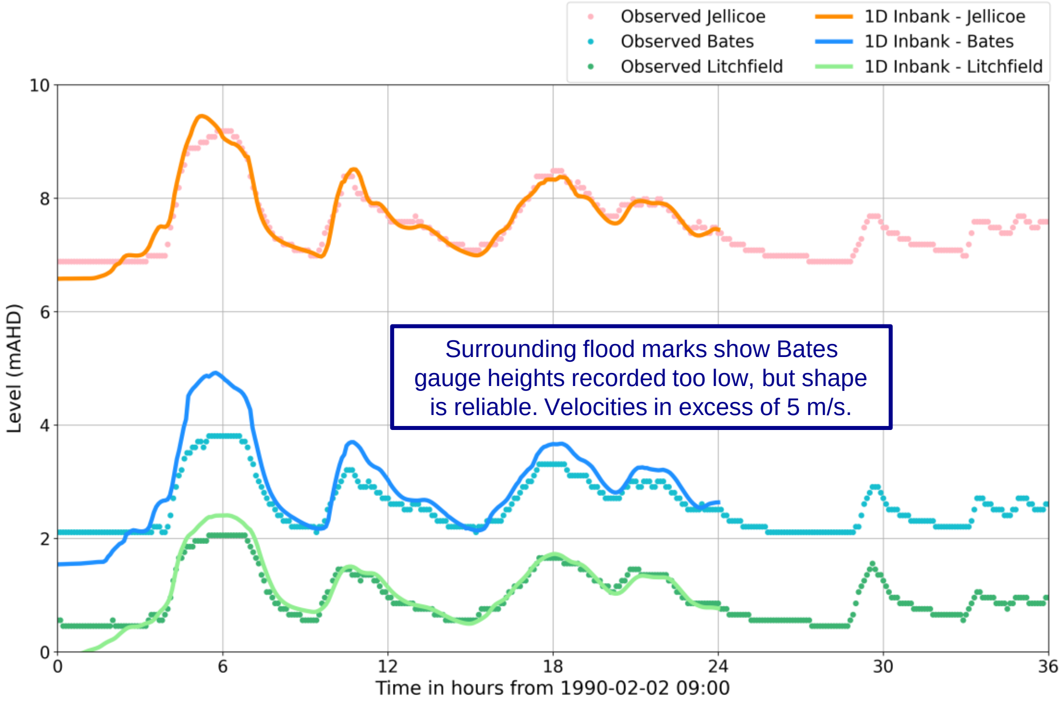


Case Study 1 – Urban
Calibration Check – 1D Inbank

Gauge calibration

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


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



TUFLOW

Case Study 1 – Urban
Objective for this Webinar

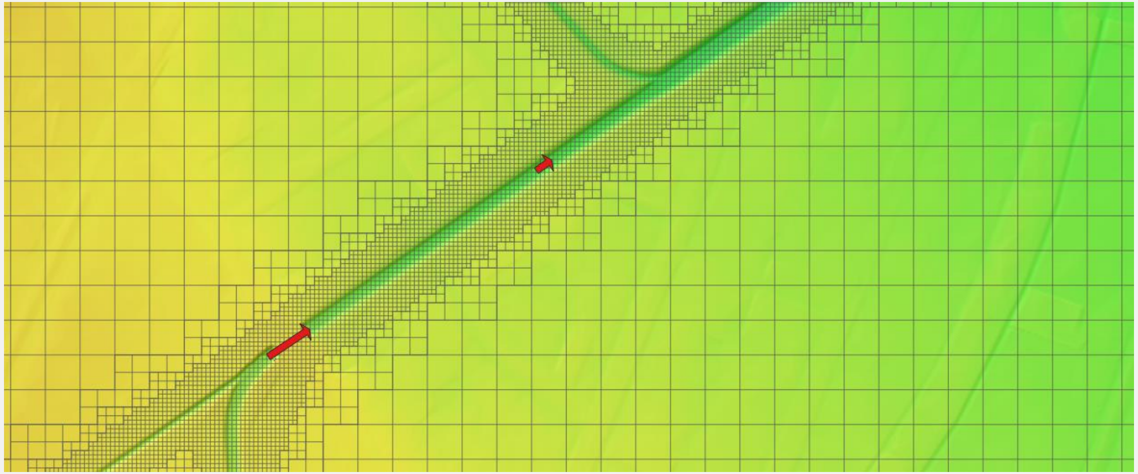
What happens if 1D in bank replaced with 2D?

Culverts, pipes and bridges stay as 1D structures with 2D in bank

SX connections between 1D structures and 2D

Quadtree mesh:

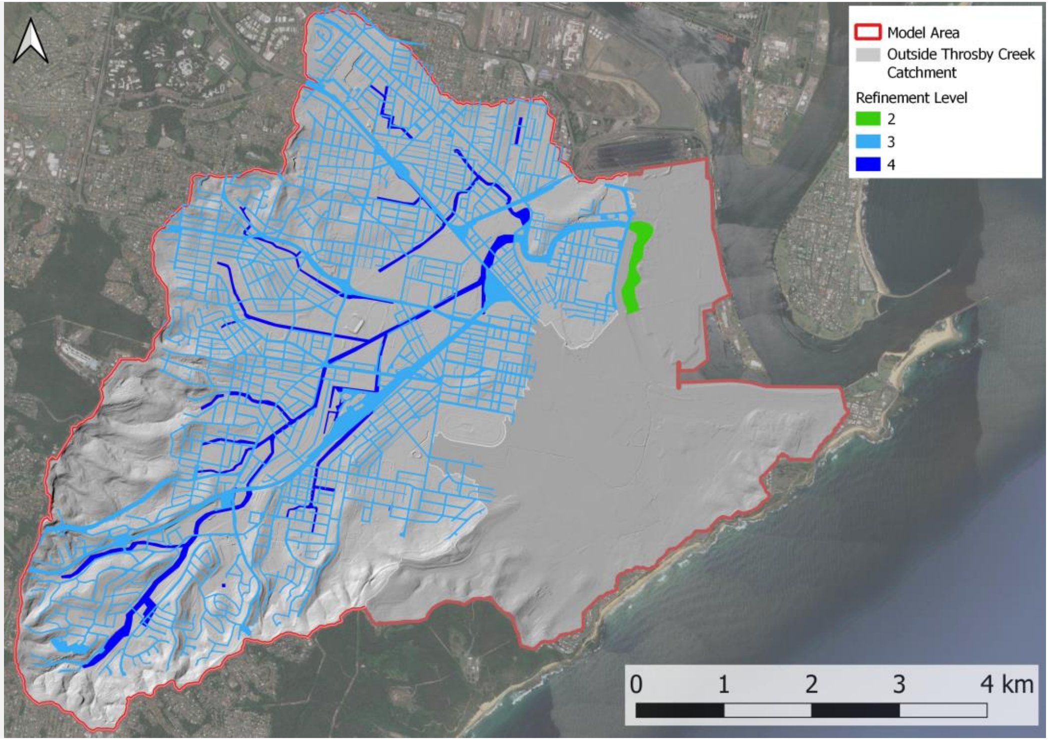
- 4 levels of refinement
- 32, 16, 8, 4m



Example results of mapping

Quadtree mesh:

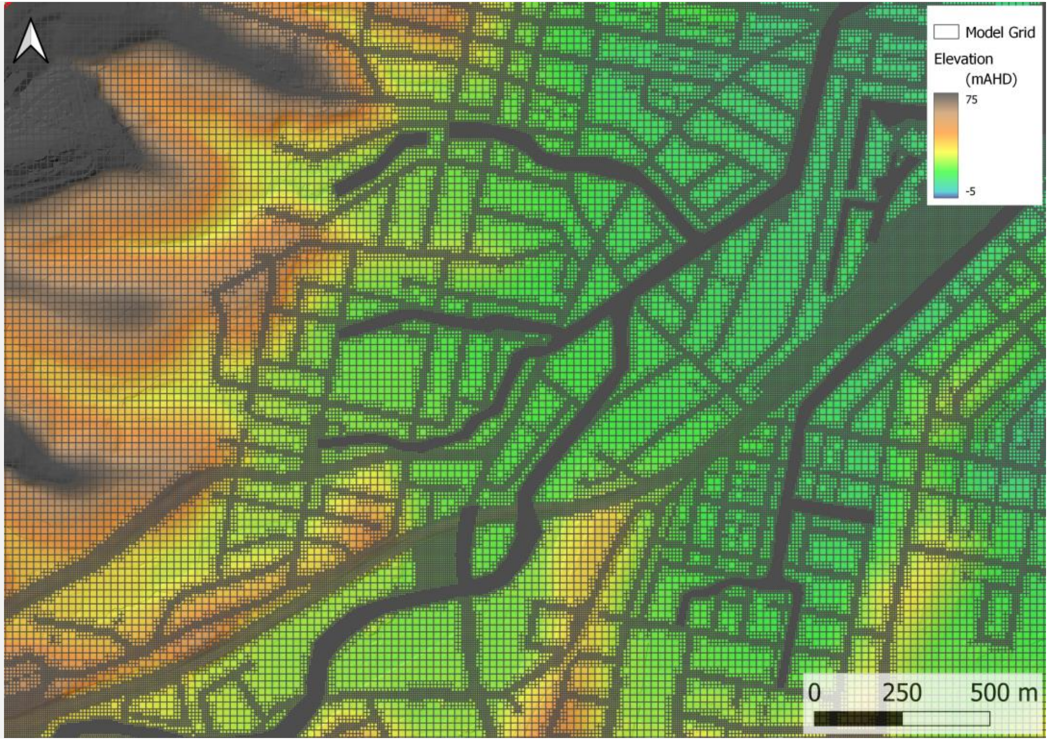
- 4 levels of refinement



Example results of mapping

Quadtree mesh:

- 4 levels of refinement

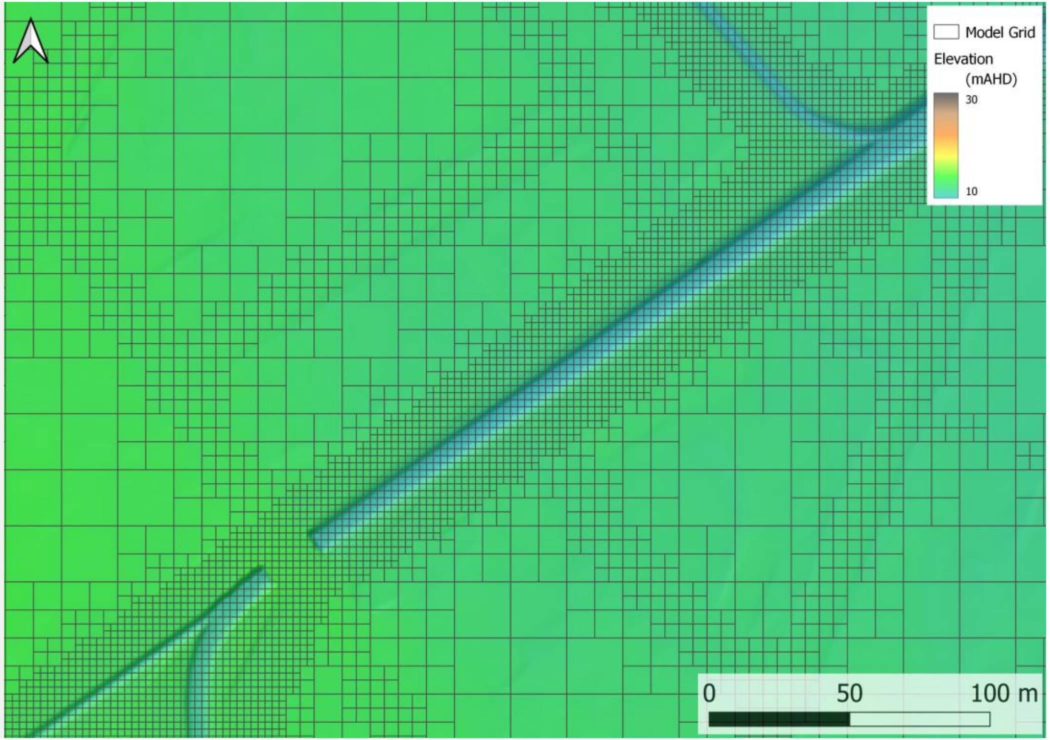


TUFLOW

Example results of mapping

Quadtree mesh:

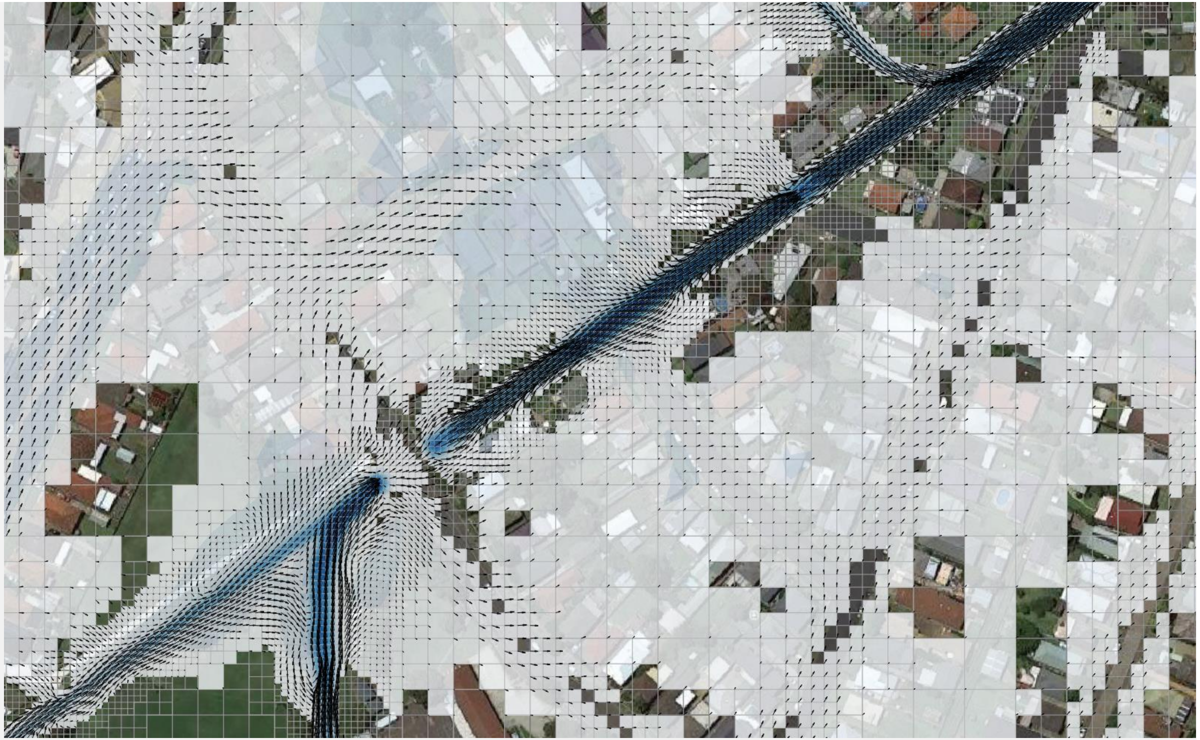
- 4 levels of refinement



Example results of mapping

Quadtree mesh:

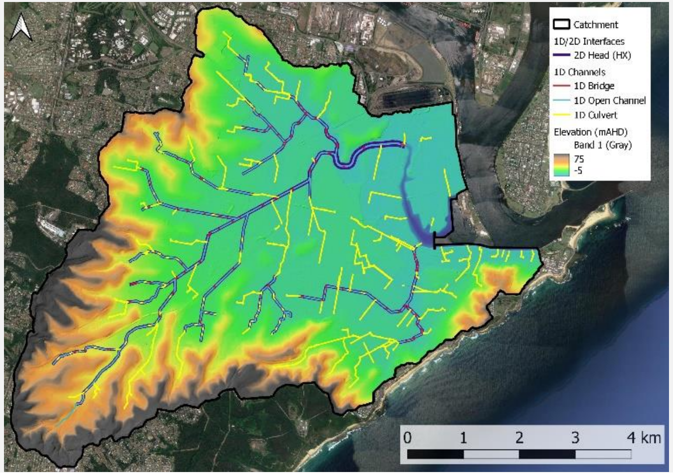
- 4 levels of refinement

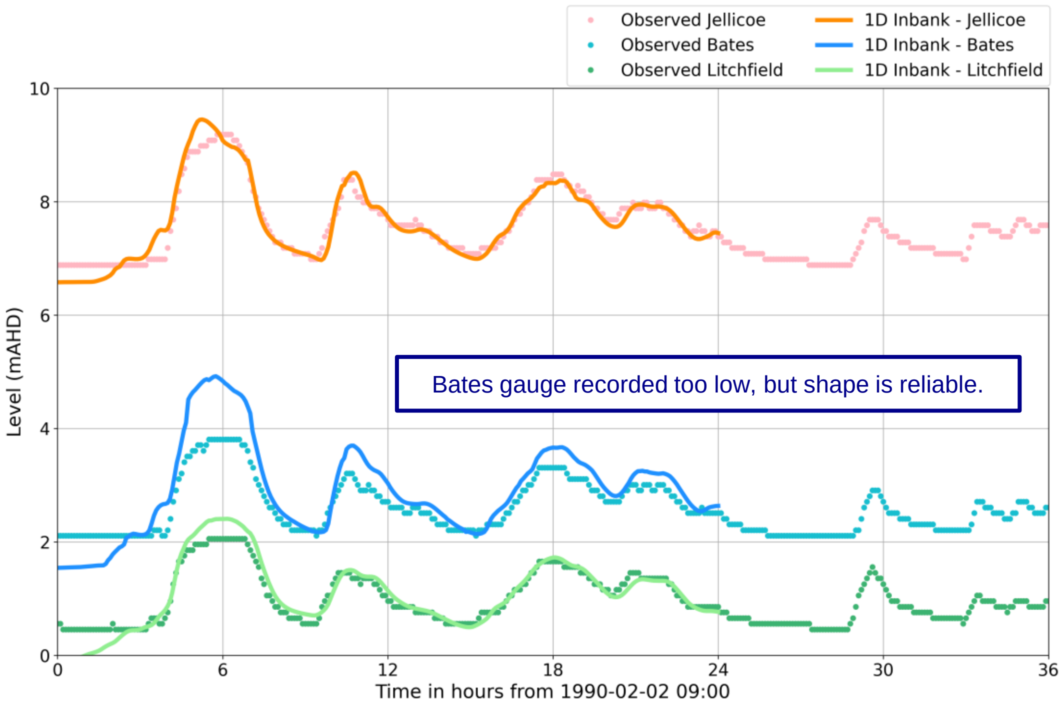


TUFLOW

Case Study 1 – Urban 2D Inbank Comparison

- Remove 1D Open Channels

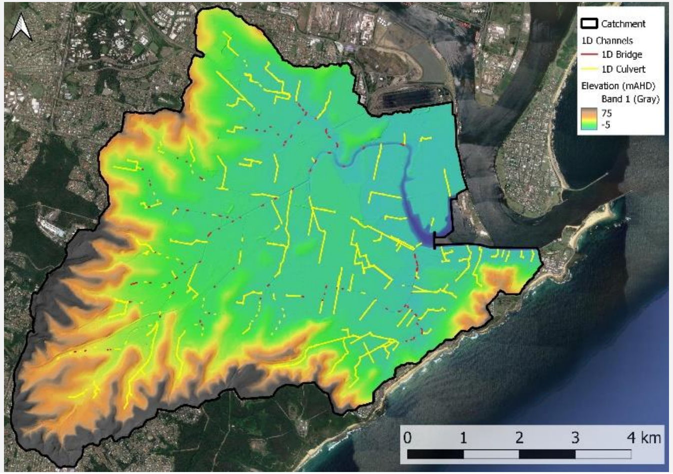


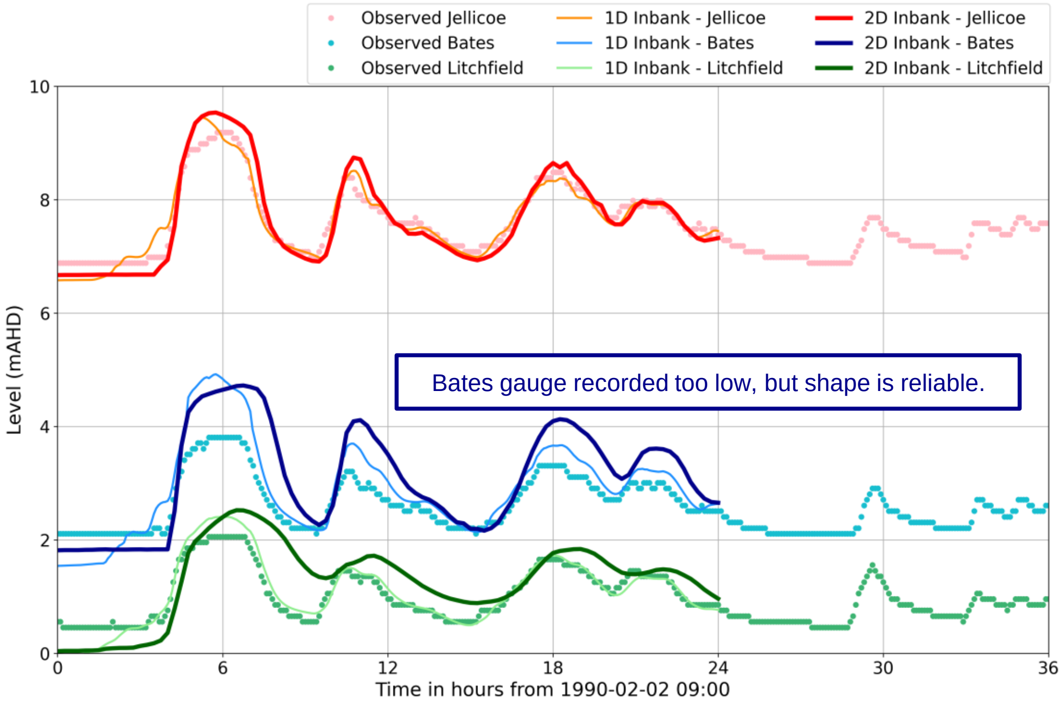


TUFLOW

Case Study 1 – Urban
2D Inbank Comparison

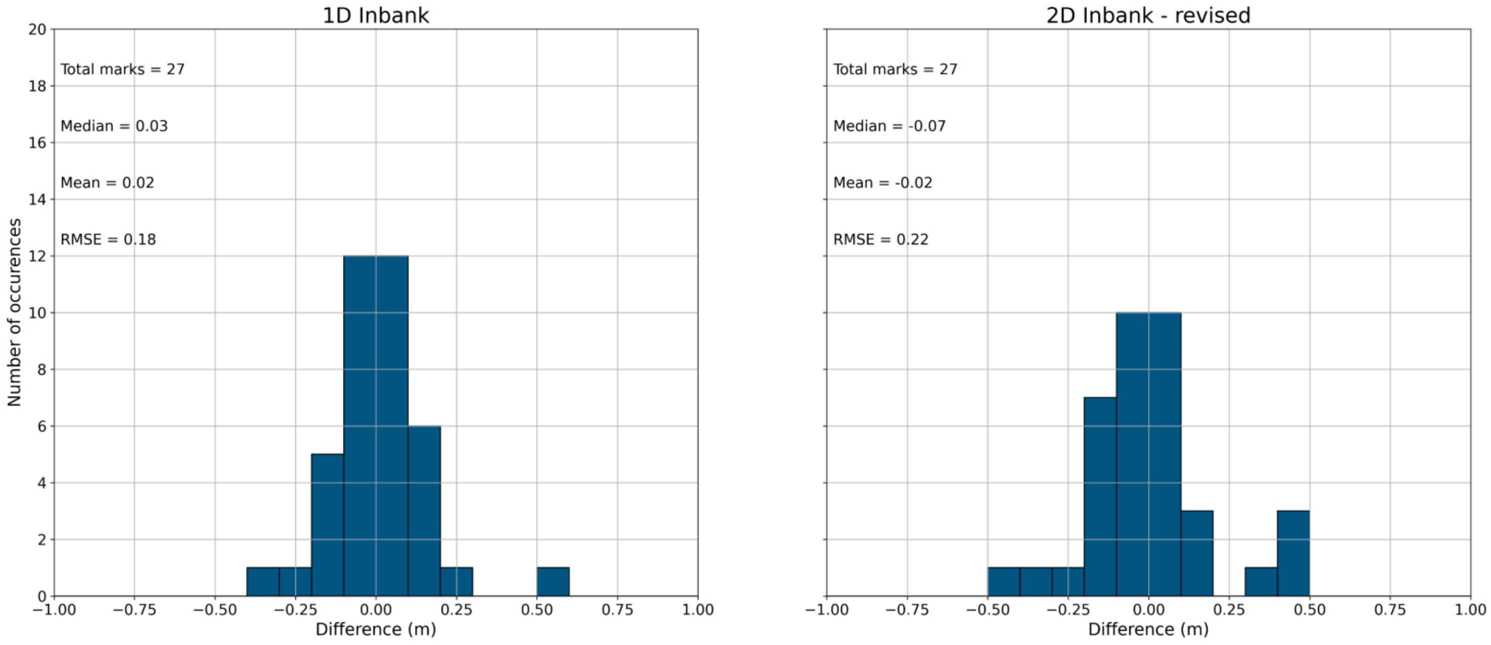
- Remove 1D Open Channels
- No Change in Manning's n values





TUFLOW

Case Study 1 – Urban
2D Inbank Comparison



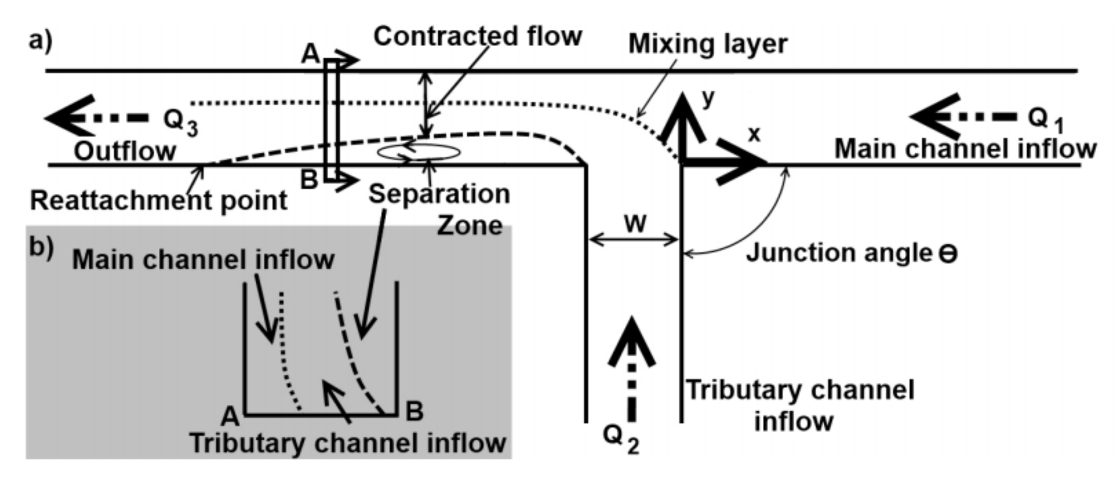
Junction and Bend Losses

Complex hydraulics at confluences

Losses varies with flow and momentum ratios

1D doesn't capture this

- Form / bend losses need to be added by user



Creëlle, et al, Ghent University, Ghent, Belgium

Junction and Bend Losses

Complex hydraulics at confluences

Losses varies with flow and momentum ratios

1D doesn't capture this

- Form / bend losses need to be added by user

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

Junction and Bend Losses

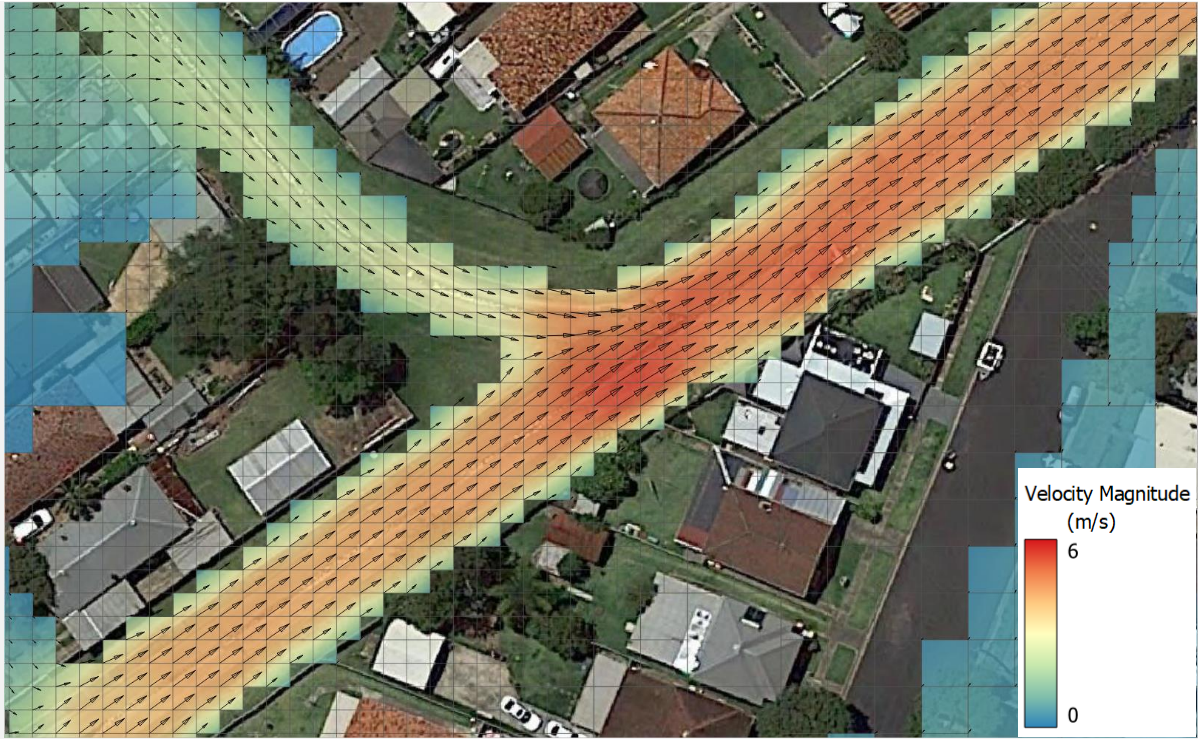
Complex hydraulics at confluences

Losses varies with flow and momentum ratios

1D doesn't capture this

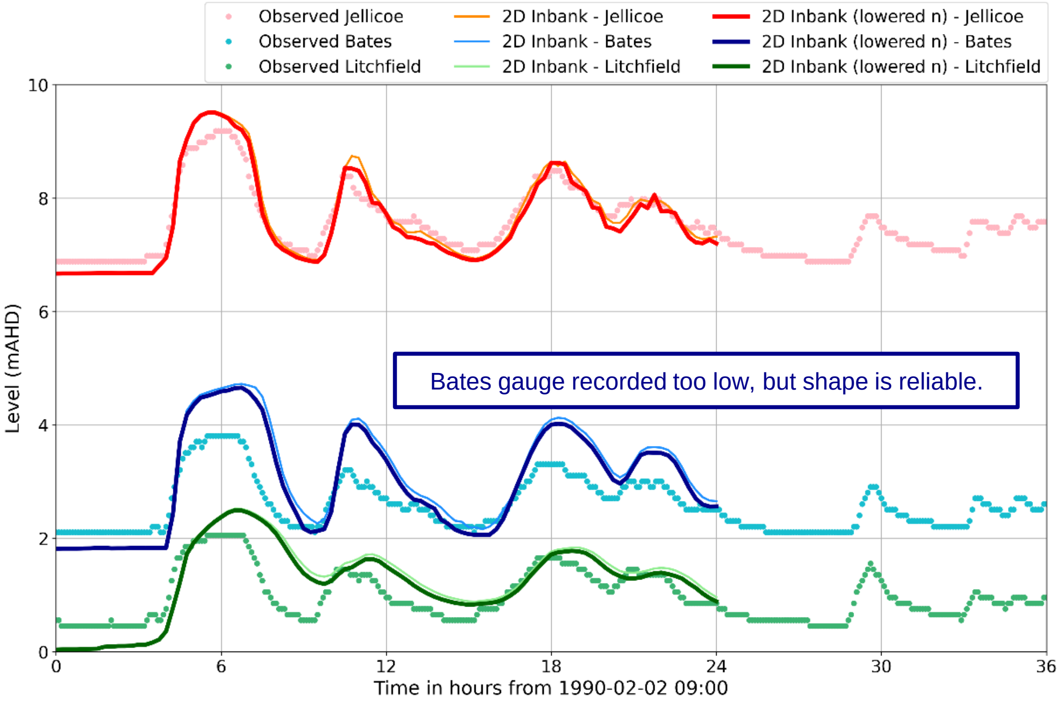
- Form / bend losses need to be added by user

2D does capture this effect



Case Study 1 – Urban
2D Inbank Comparison

- Reduced Inbank Manning's n from calibrated 1D value of 0.018 to 0.013 for 2D
- Concrete usually 0.011 to 0.015



Case Study 1 – Urban Structure Losses

Adjusting structure losses based on approach / departure velocities

- For 1D structures in TUFLOW default is to adjust losses based on

$$C_{entrance\_adjusted} = C_{entrance}\left(1 - \frac{V_{approach}}{V_{structure}}\right)$$

$$C_{exit\_adjusted} = C_{exit}\left(1 - \frac{V_{departure}}{V_{structure}}\right)^2$$

- When replacing 1D inbank with 2D, need to either
  - Manually lowering values; or
  - Dynamically adjusting based on 2D approach and departure velocities (built into TUFLOW for 2020-10-AA build)

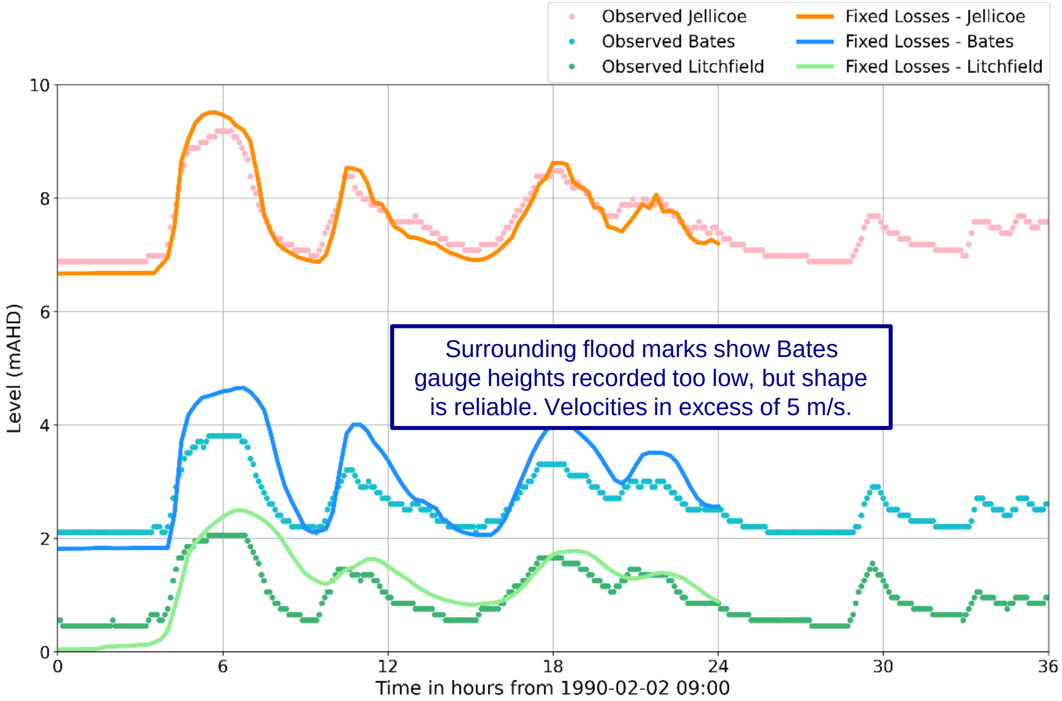
TUFLOW

Case Study 1 – Urban Structure Loss Adjustment

Gauge calibration

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

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

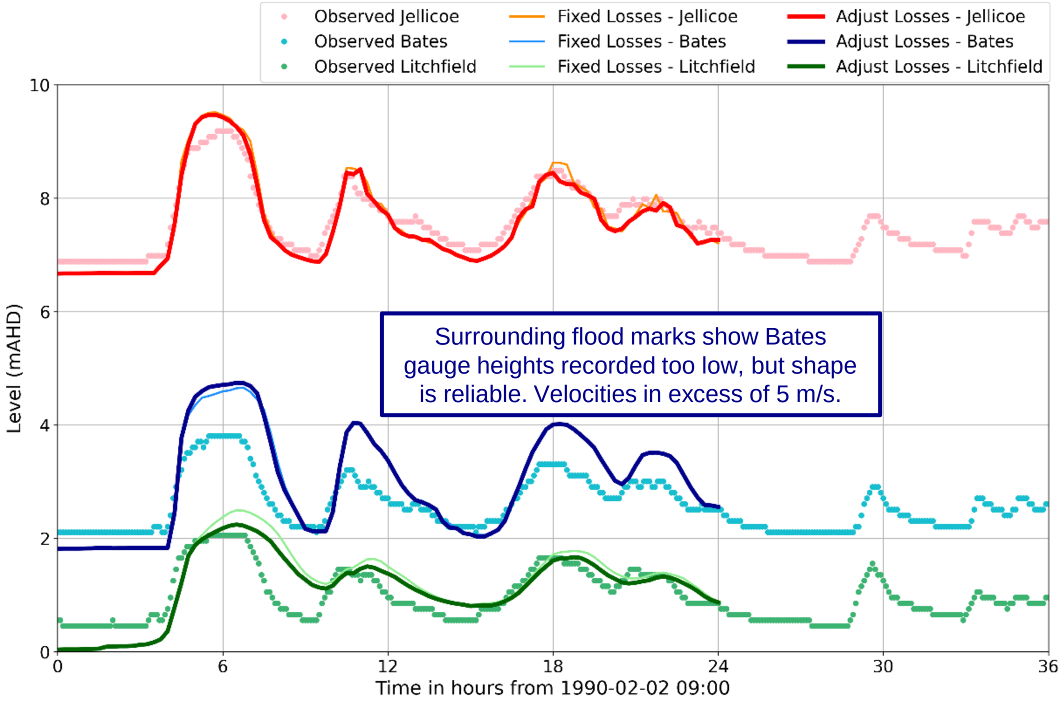


Case Study 1 – Urban Structure Loss Adjustment

Gauge calibration

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

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



TUFLOW

Case Study 1 – Urban Structure Losses

Evidence of very high velocities in channel and around structures

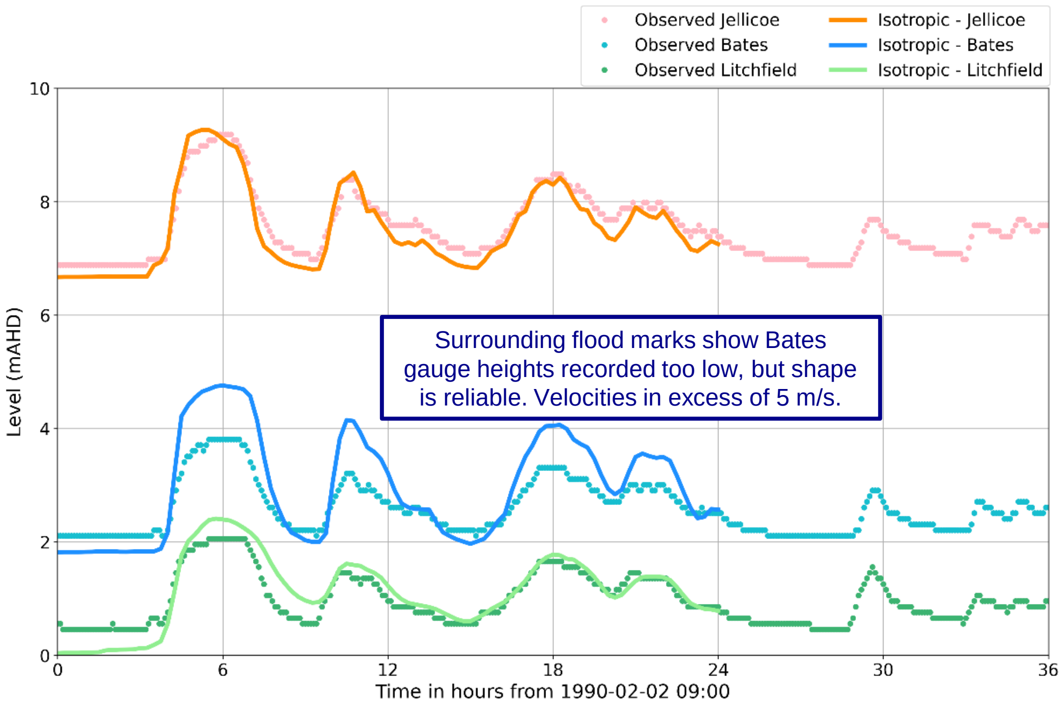
Photos taken June 2007, following significant "Pasha Bulker" storm event (~1 in 100 AEP)

TUFLOW

Case Study 1 – Urban Anisotropic Turbulence

Anisotropic Turbulence
(New for TUFLOW 2021)

- Transverse = 0.5
- Longitudinal = 7.0

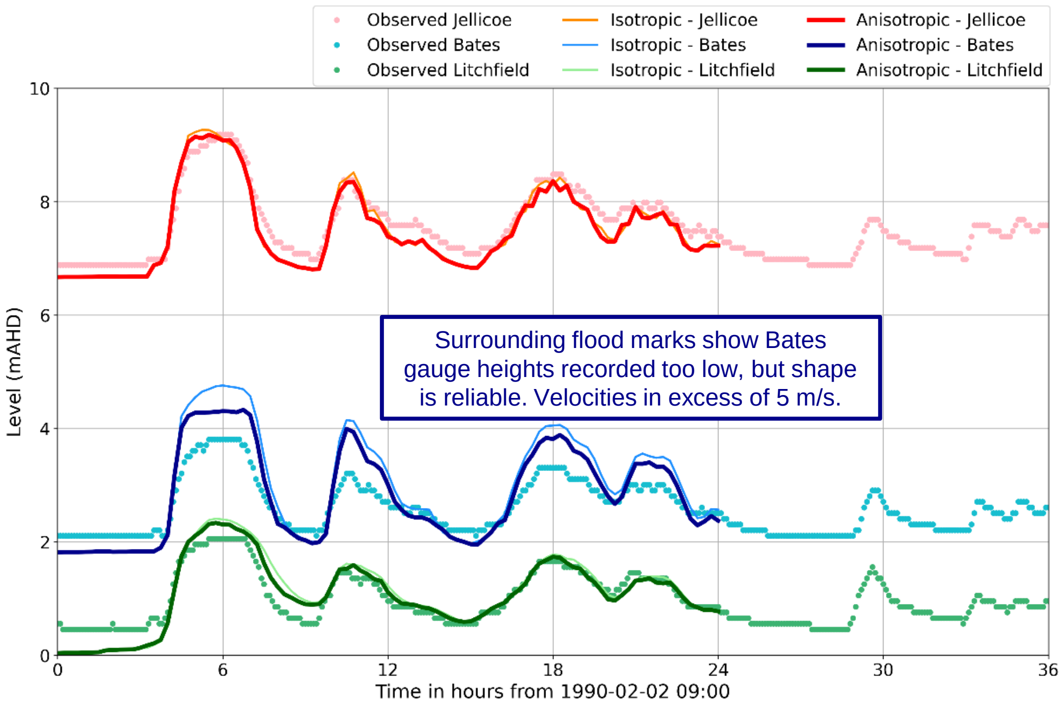


TUFLOW

Case Study 1 – Urban Anisotropic Turbulence

Anisotropic Turbulence
(New for TUFLOW 2021)

- Transverse = 0.5
- Longitudinal = 7.0

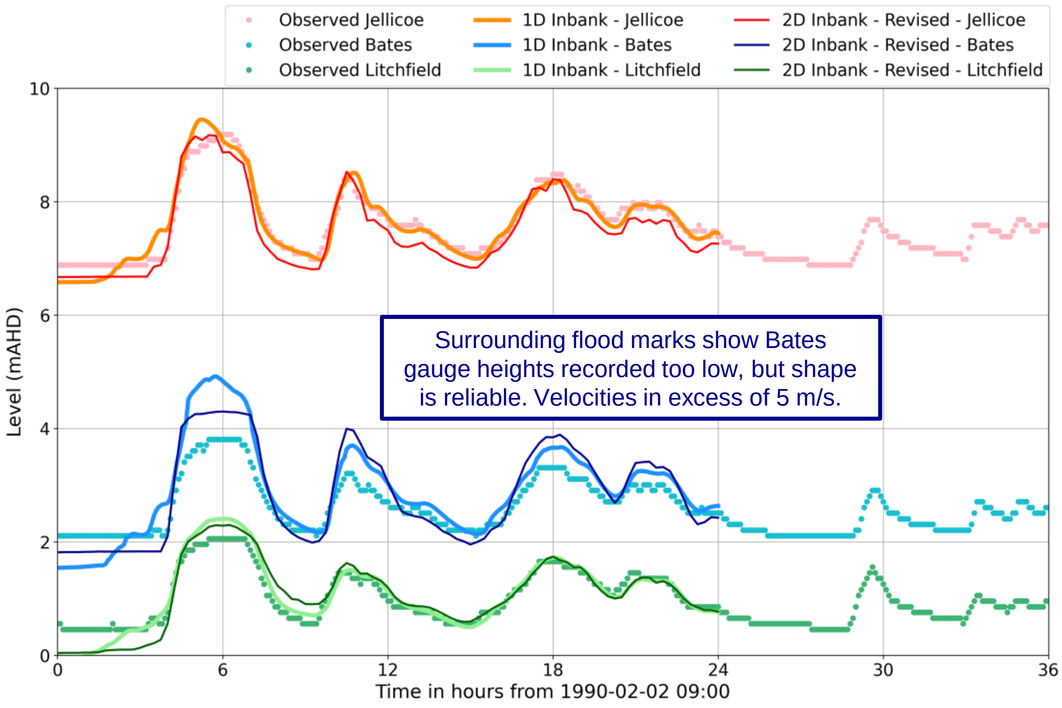


TUFLOW

Case Study 1 – Urban Revised 2D Inbank

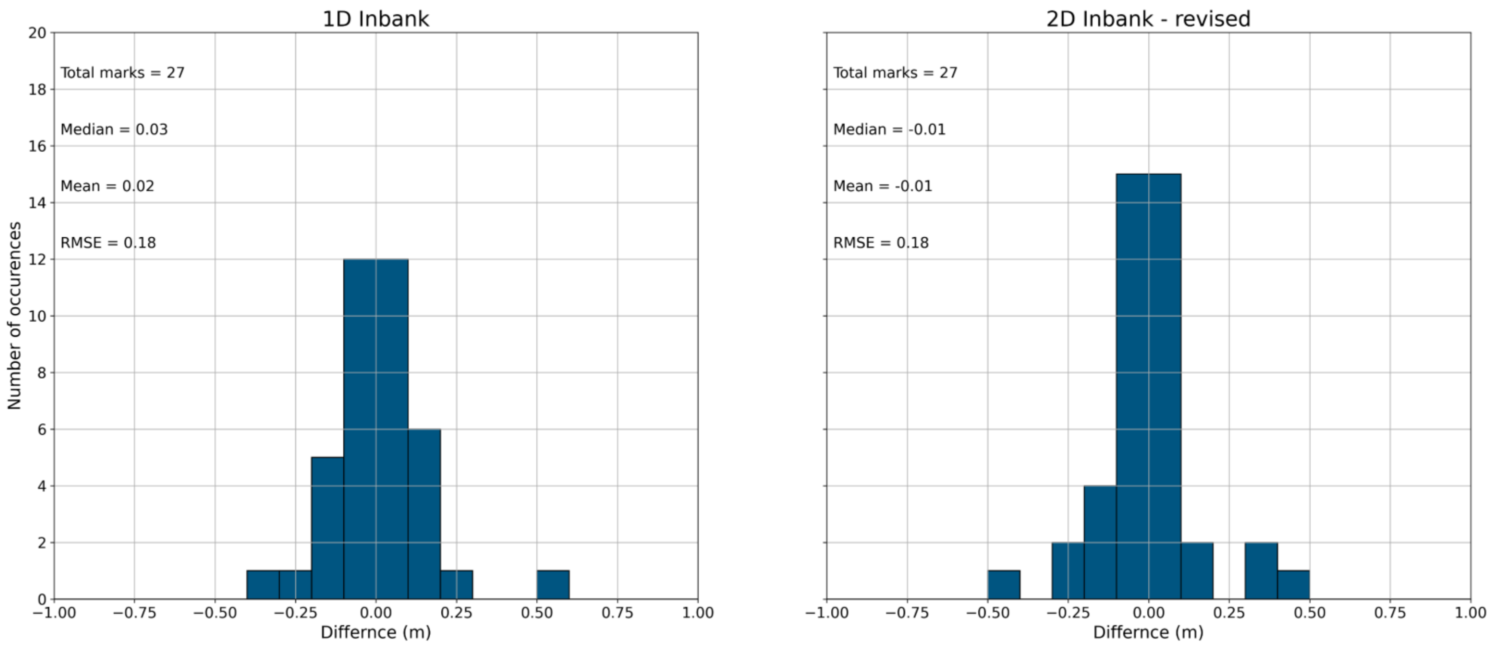
Not a detailed re-calibration

- Lowered Manning's n in channel
- Adjustment of structure losses based on 2D velocities
- Anisotropic turbulence



TUFLOW

Case Study 1 – Urban
Revised 2D Inbank



Conclusions
Pros and Cons

Pros and Cons of using 2D instead of 1D for Open Channels

Pros

- Faster to setup and more computationally accurate
- Much improved velocity computations and interaction with overbank areas
- Transfer momentum between river and floodplain fully preserved
- Much easier to produce mapping (no 1D/2D interface to deal with)

Cons

- Run-times longer (less of an issue with GPU acceleration)
- Industry may need to see more calibration case examples before becoming mainstream

Conclusions
Benchmarking Outcomes

Outcomes of Benchmarking using 2D instead of 1D for Open Channels

Highly beneficial or essential to use

- Sub-Grid Sampling (SGS)
- Quadtree or flexible mesh to create smaller cells inbank
- Dynamic adjustment of 1D structure losses according to 2D approach and departure velocities
  (as is done when using 1D approach and departure channels)

Observations

- 2D Inbank Manning's n values likely to be lower than 1D values due to turbulence effects with overbank
  (1D does not allow for turbulence or shear between inbank and overbank so need higher Manning's n value to compensate)
- Anisotropic turbulence model showing much improved calculations of velocity distribution across channels

Questions?

TUFLOW