

RainGain: International Workshop on Urban Pluvial Flood Modelling

Formulation of a fast 2D urban pluvial flood model using a cellular automata approach

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Outline

- Introduction / Research project
- Model(s) Introduction
- Results
 - Two EA Benchmark Test Cases
 - Torquay Test Cases (8m / 4m resolution)
 - Very Large Test Case (~14 million cells)
- Summary

Introduction

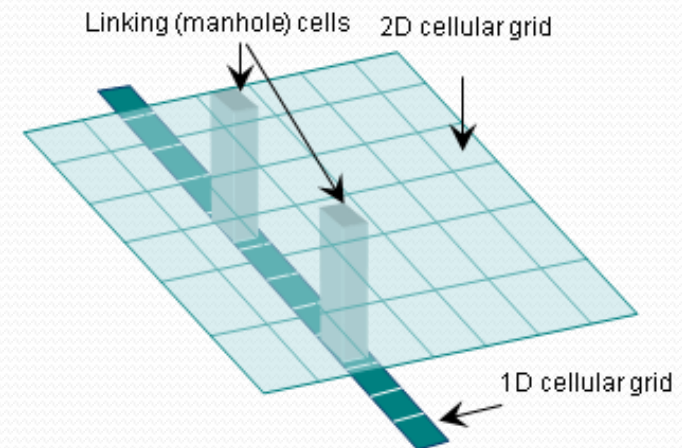
- Needs for efficient 2D flood modelling
 - High resolution real time flood forecasting
 - Uncertainty analysis for large scale (e.g. continental)

Introduction

- Approaches
 - Improved numerical schemes
 - Parallel computing (MPI, OPEN-MP, GPU)
 - Grid coarsening
 - Simplification

CADDIES: Cellular Automata Dual-DrainagE Simulation

- Funded by the UK EPSRC & industry (2010-2013)
- Rapid, simplified dual-drainage modelling algorithms
- Realistically capture the nature of flood dynamics over large urban areas



EPSRC

Engineering and Physical Sciences
Research Council



Halcrow



mouchel

City of Bradford MDC
www.bradford.gov.uk

UKWIR

SOUTH WEST WATER



United Utilities

UNIVERSITY OF
EXETER
Centre for Water Systems

TORBAY
COUNCIL

raa
Richard Allitt Associates Ltd
CONSULTING ENGINEERS

NORTHUMBRIAN
WATER

YorkshireWater

CADDIES Team



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Dr Edward Keedwell



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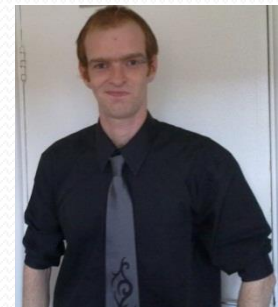
Dr Bidur Ghimire



Dr Michele Guidolin



Miss Rebecca Austin



Mr Mike Gibson



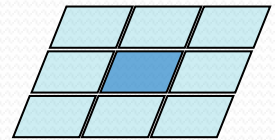
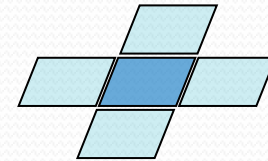
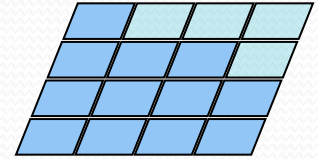
BUILDING A BETTER



Models

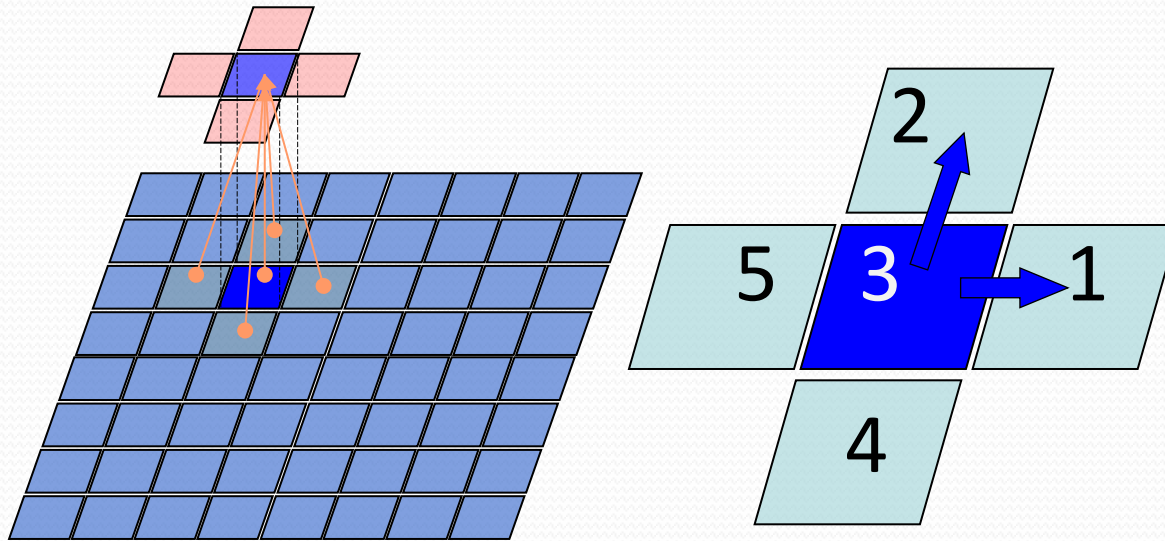
Cellular Automata

1. Discrete space
2. Cell states: discrete, continuous
3. Neighbourhood type
4. Local rules (deterministic and uniform)
5. Independent cell state updating (parallel)



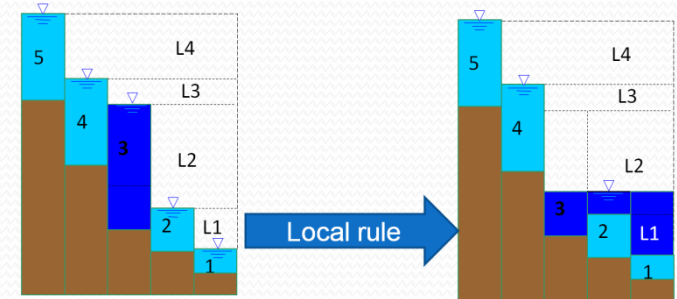
CADDIES 2D Models

- The 2D CA models describes the surface flow using discretised cell states



CADDIES 2D Models

- **CA2D: First model (2011/2012)**
 - Ranking technique to compute the volume of water transferred
 - Expensive sorting algorithm to rank
 - Oscillation problem
 - Ghimire et al., 2013, J. Hydroinformatics

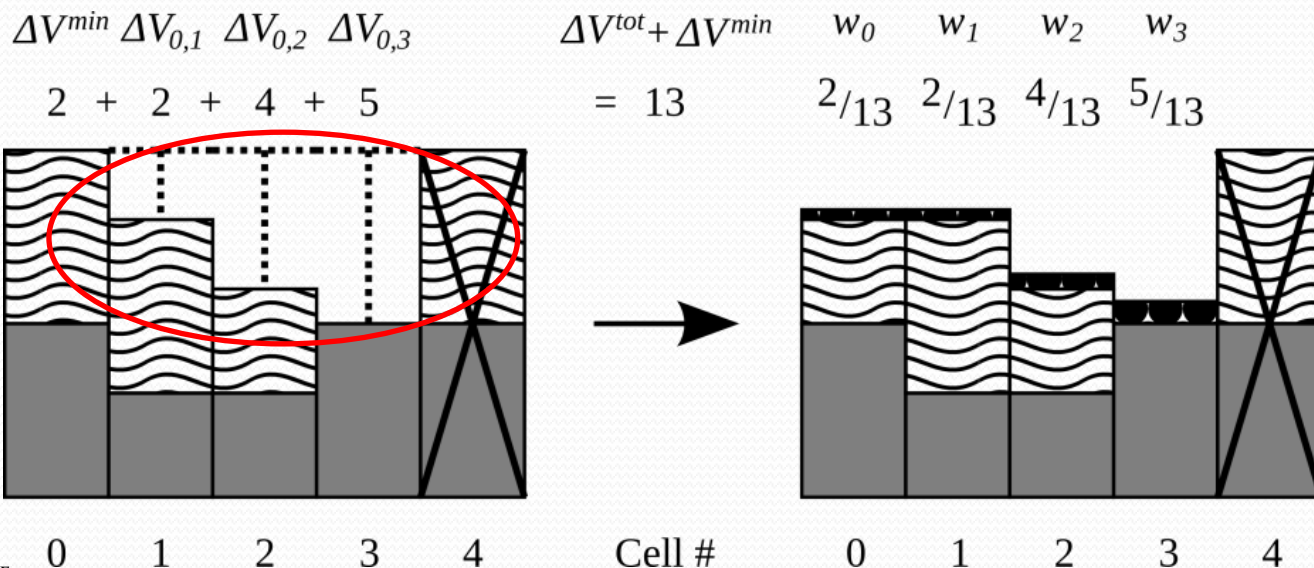


CADDIES 2D Models

- Weighted CA2D:
Quicker weight-based system to compute the volume of water transferred
 - Manning's equation applied to limit flux
 - Quicker with same accuracy of CA2D

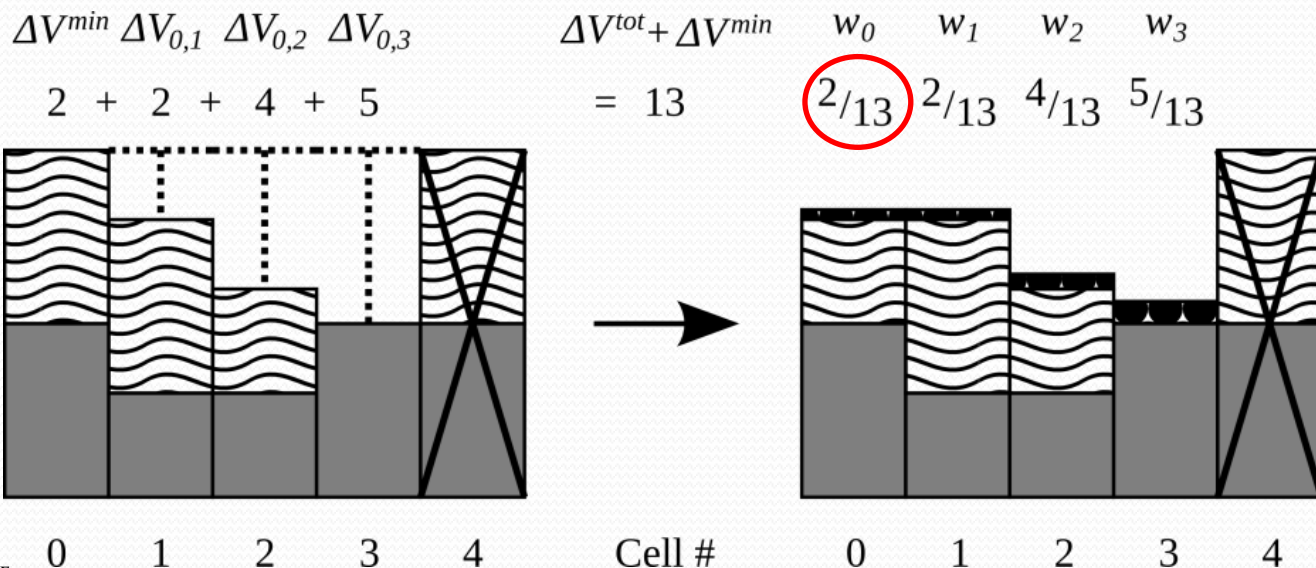
WCA2D Methodology

- For each neighbour cell:
 - Compute a weight that depends on the difference in water volume with the main cell



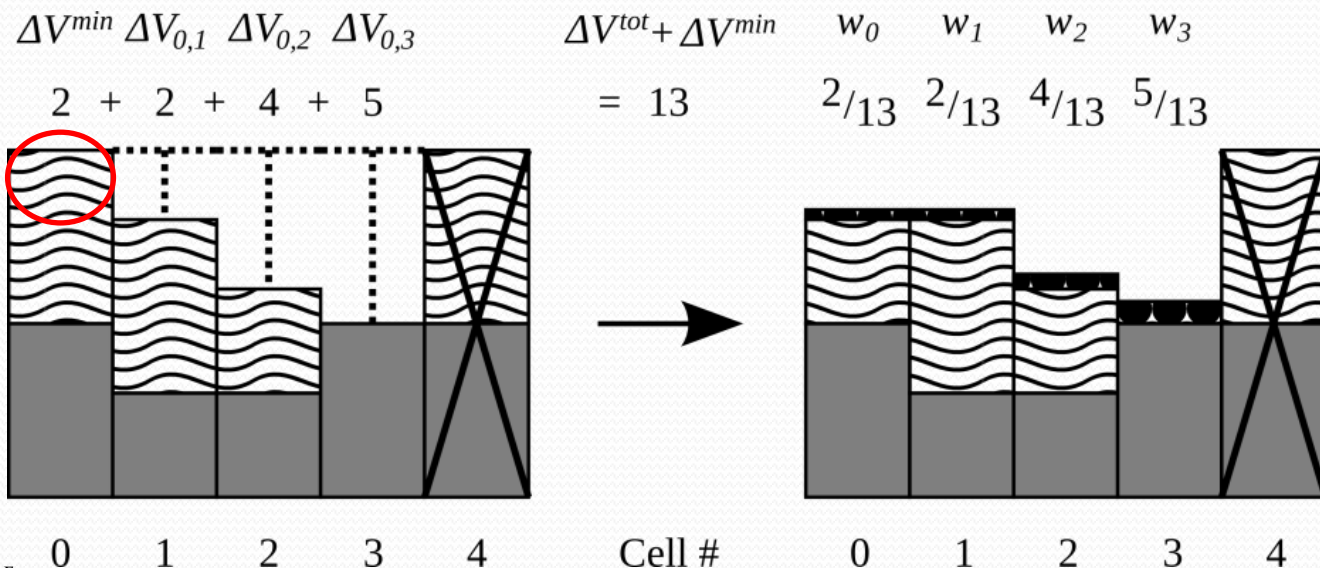
WCA2D Methodology

- For each neighbour cell:
 - The central cell is given the smaller weight between the neighbour cells (min oscillations)



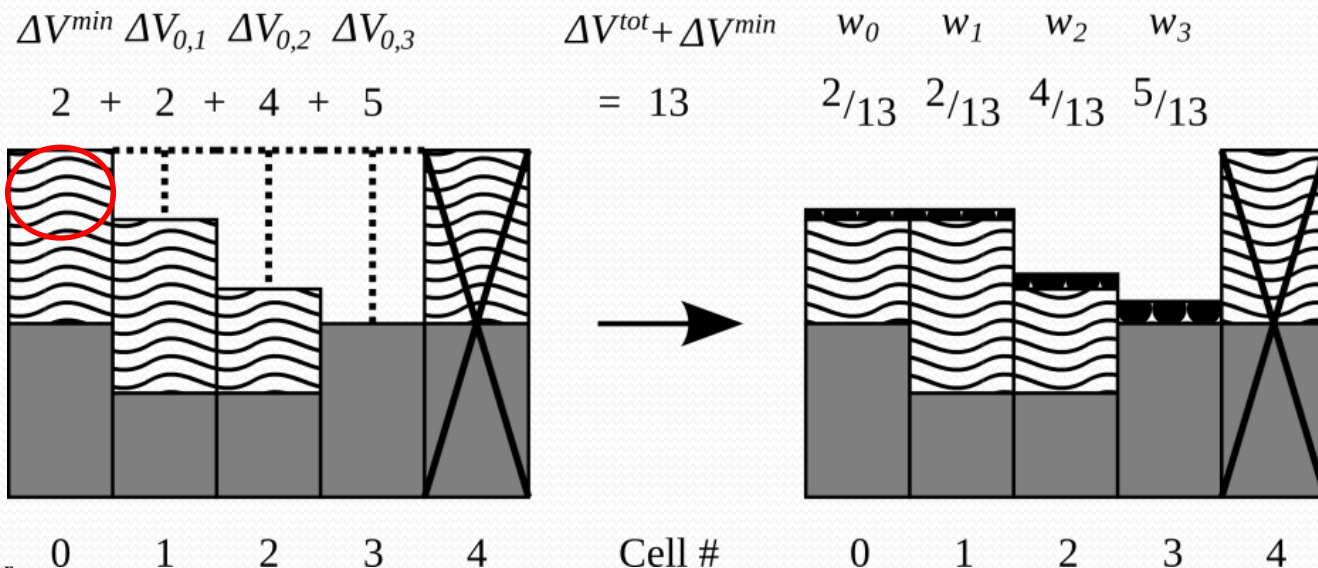
WCA2D Methodology

- For each neighbour cell:
 - Each cell receives the volume that is the total transferrable volume multiplied by its weight



WCA2D Methodology

- The total transferrable volume is the smaller water level difference, between the central cell & its lower neighbour cells, multiplied by its area

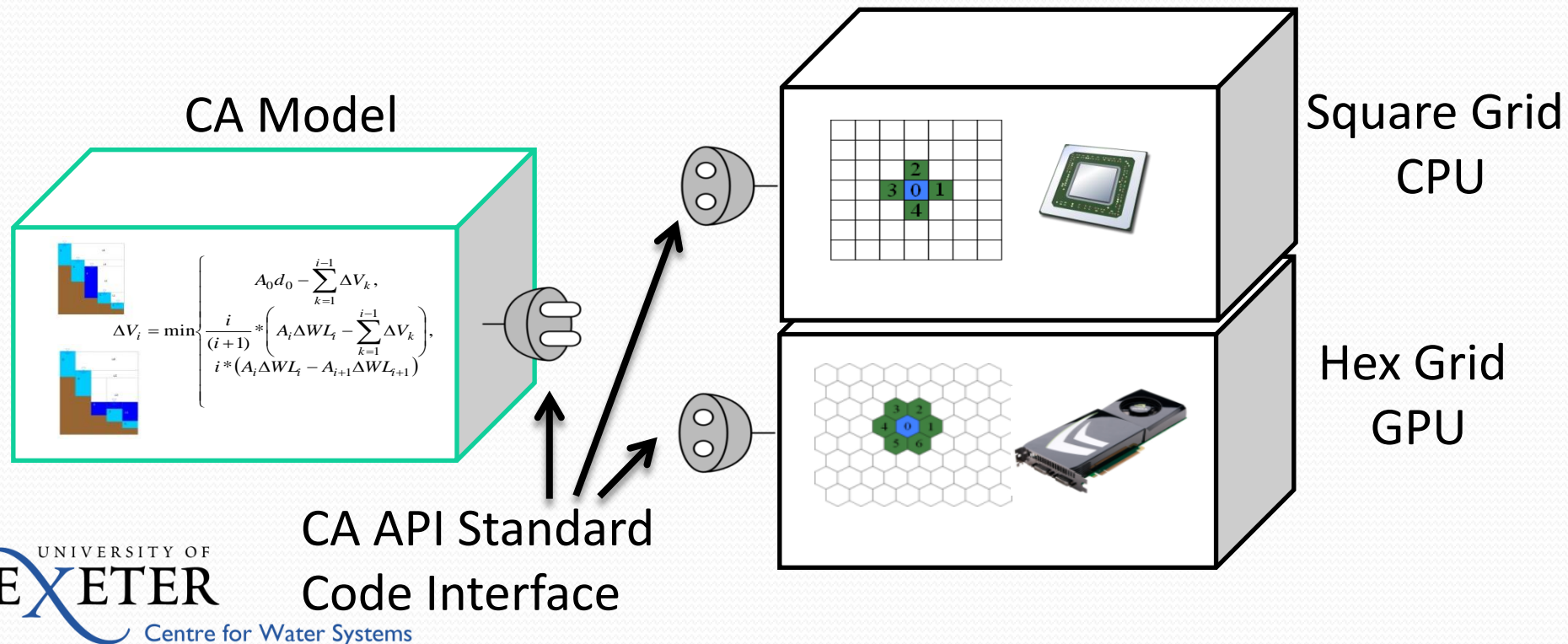


WCA2D Methodology

- The volume transferred between cells is capped by the Manning's formula
- The calculation is only applied to the neighbour cell with the largest weight to save computational cost
- Calculated once per cell.

CADDIES Software Platform

- Integrates the numerical models with modern computing techniques



Results

EA Benchmarks

Benchmarking model

Urban Inundation Model (UIM), a physically based non-inertial 2D model based on shallow water equations

$$\frac{\partial d}{\partial t} + \frac{\partial ud}{\partial x} + \frac{\partial vd}{\partial y} = q$$

$$\frac{\partial(d+z)}{\partial x} + \frac{n^2 u \sqrt{u^2 + v^2}}{d^{\frac{4}{3}}} = 0$$

$$\frac{\partial(d+z)}{\partial y} + \frac{n^2 v \sqrt{u^2 + v^2}}{d^{\frac{4}{3}}} = 0$$

where,

q : lateral source term

u : velocity in x-direction

v : velocity in y-direction

d : flow depth

z : bed elevation

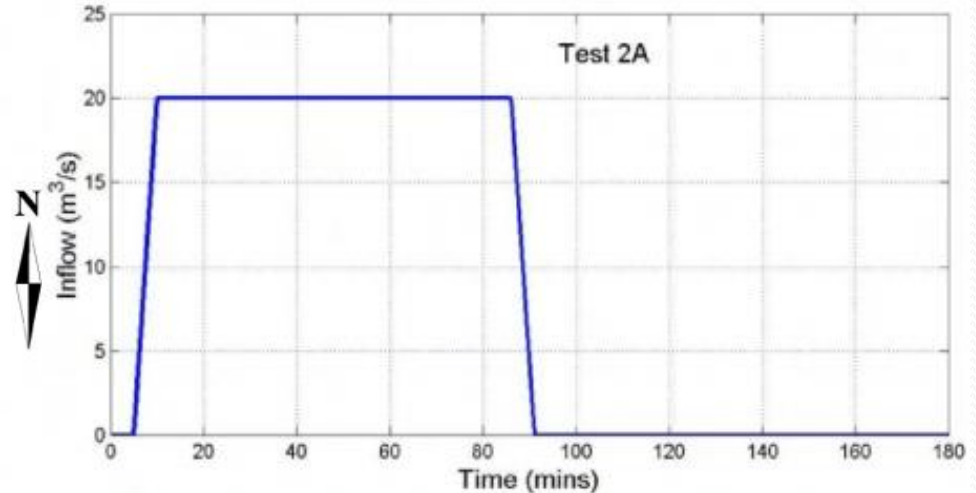
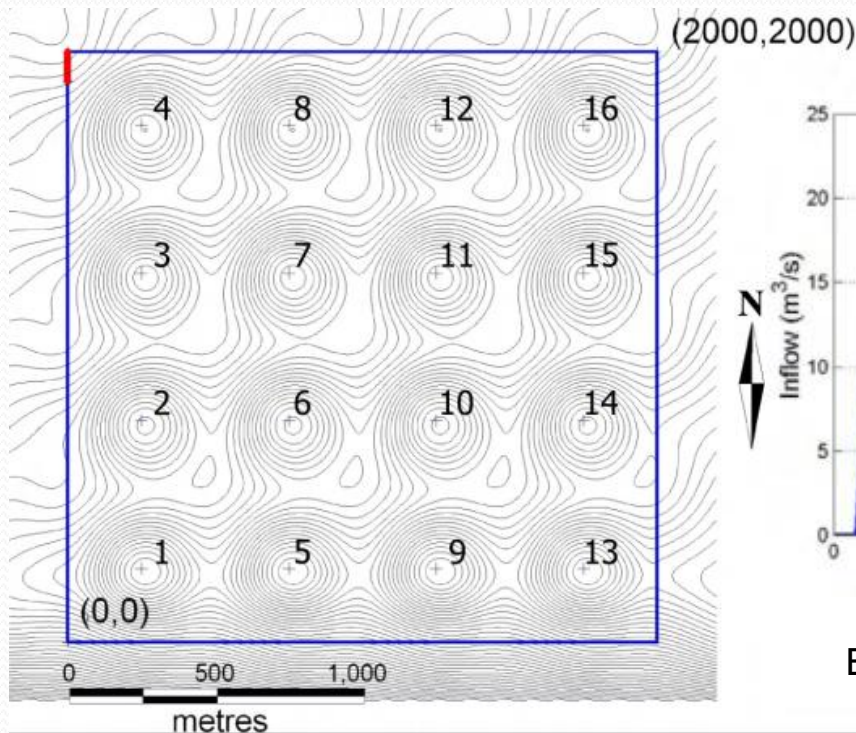
n : Manning's Roughness

x, y, t : space and time coordinates

EA Benchmarks Test cases

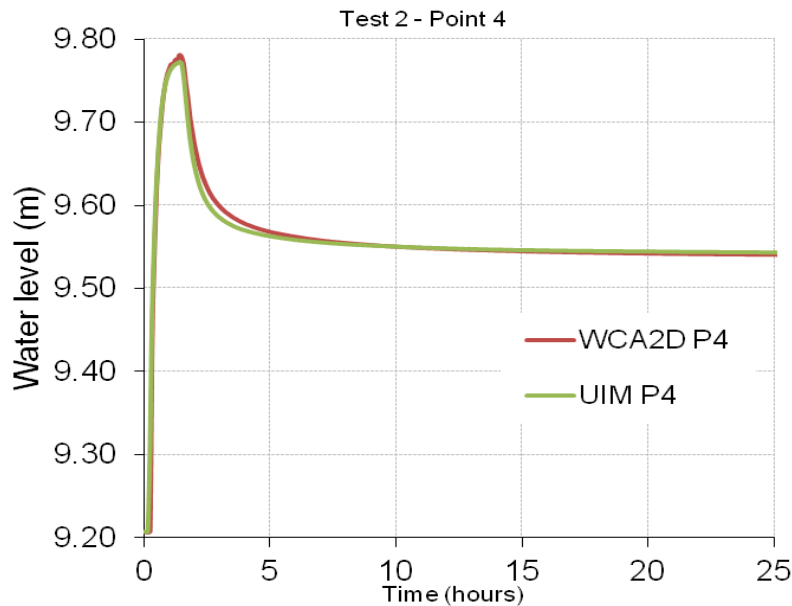
EA Benchmarking TEST2

Terrain (plan) gently sloping (NW to SE) area with 4x4 matrix of ~0.5m deep depressions

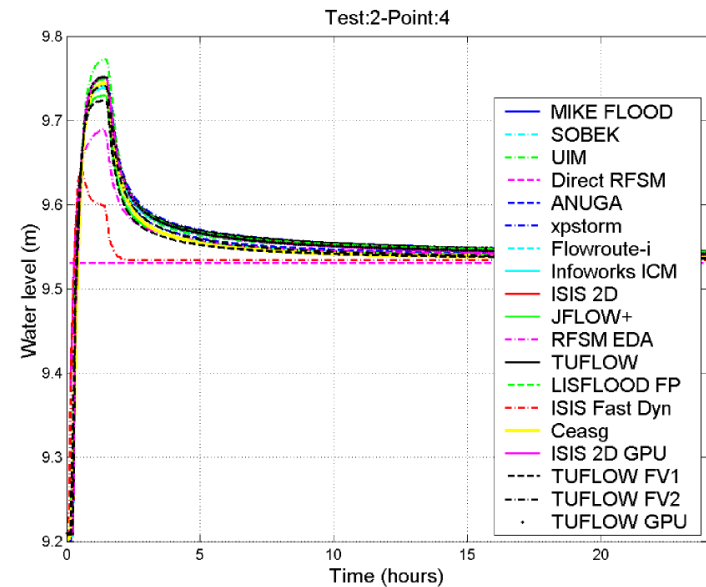


Boundary Condition: Inflow

Results: WCA2D – EAT2

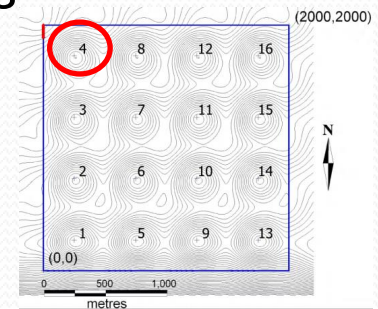


WCA2D And UIM

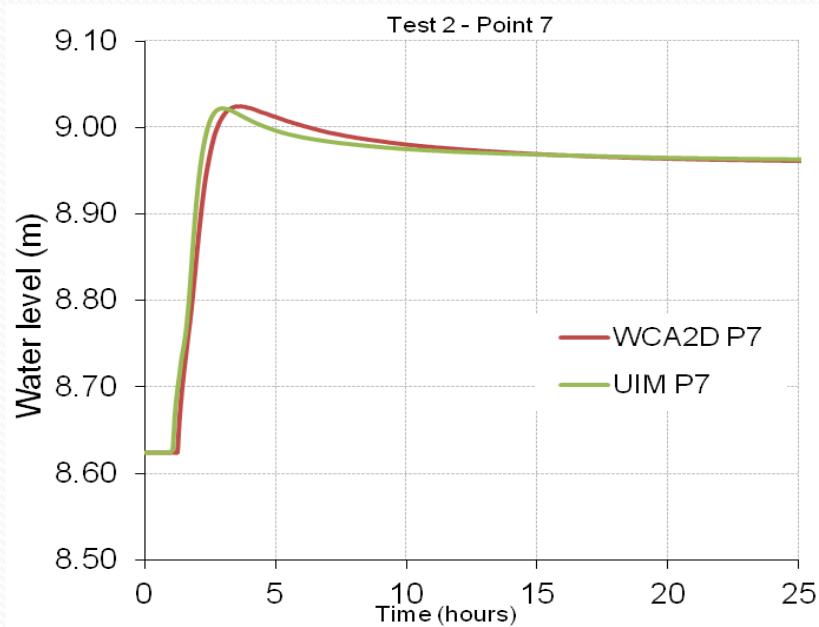


Multiple Models

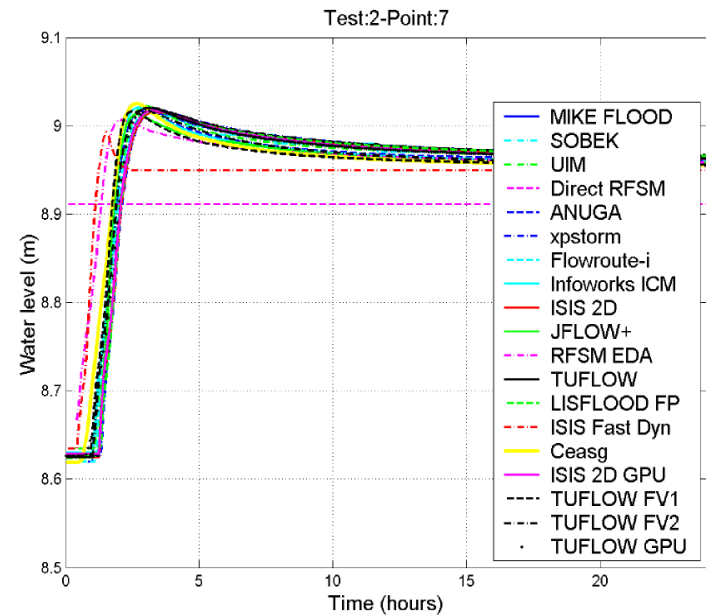
Point 4



Results: WCA2D – EAT2

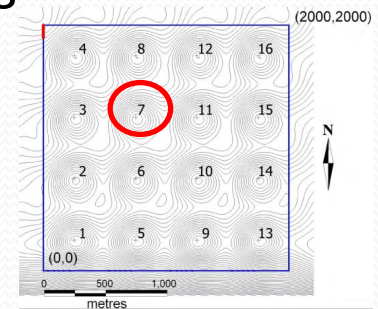


WCA2D And UIM

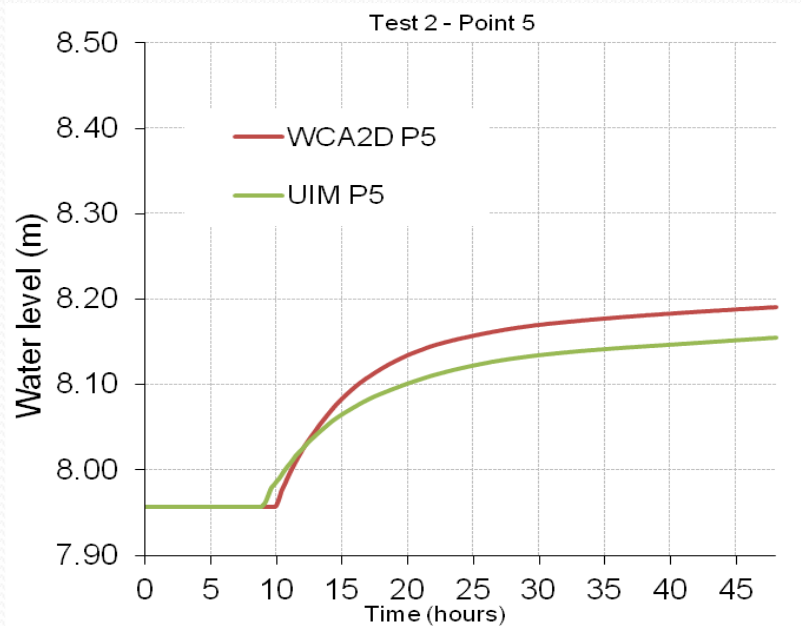


Multiple Models

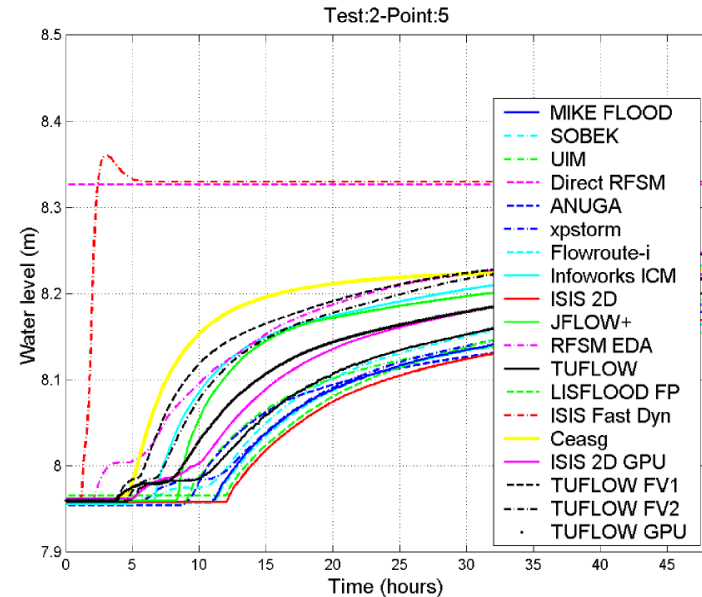
Point 7



Results: WCA2D – EAT2

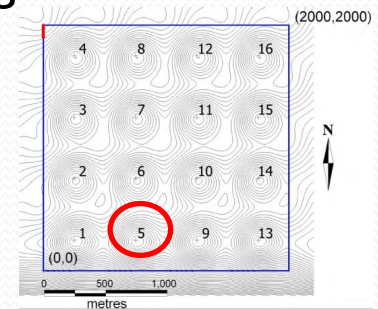


WCA2D And UIM



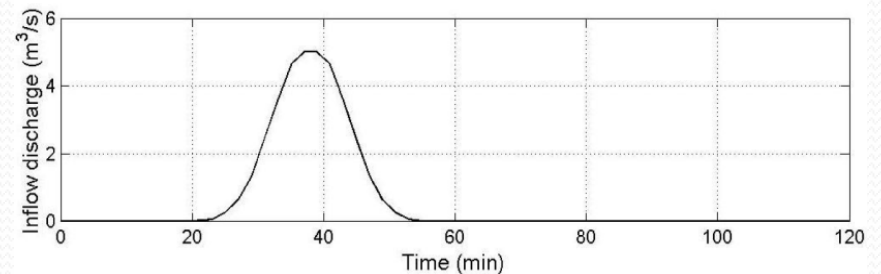
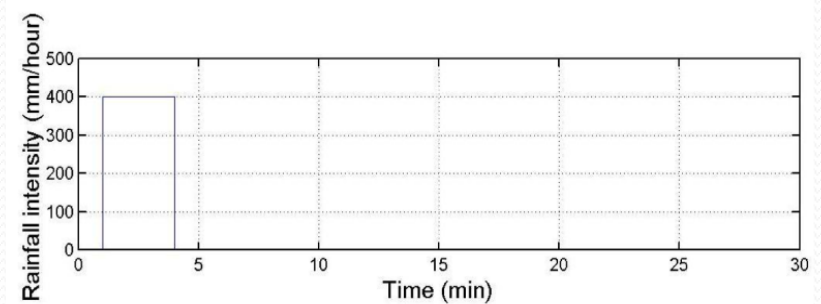
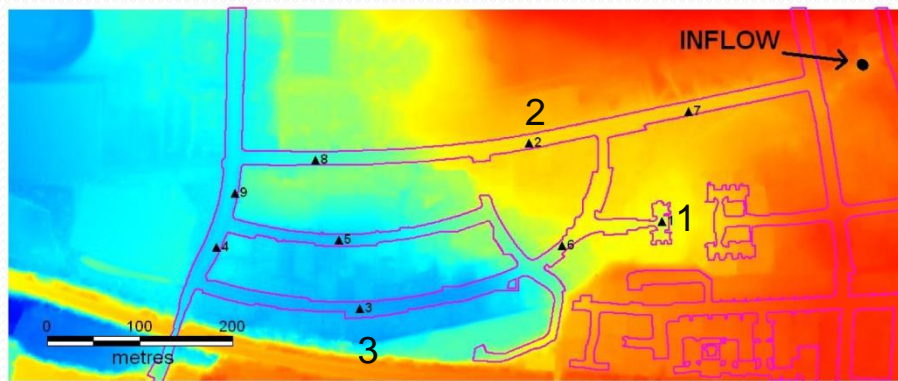
Multiple Models

Point 5



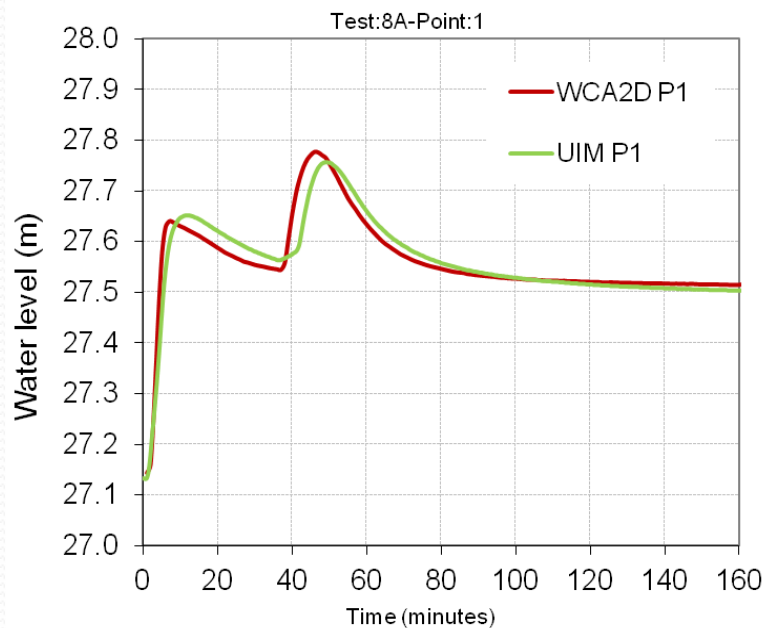
EA Benchmarking TEST8a

Terrain an approximately 0.4 km by 0.96 km urban area in Glasgow, UK

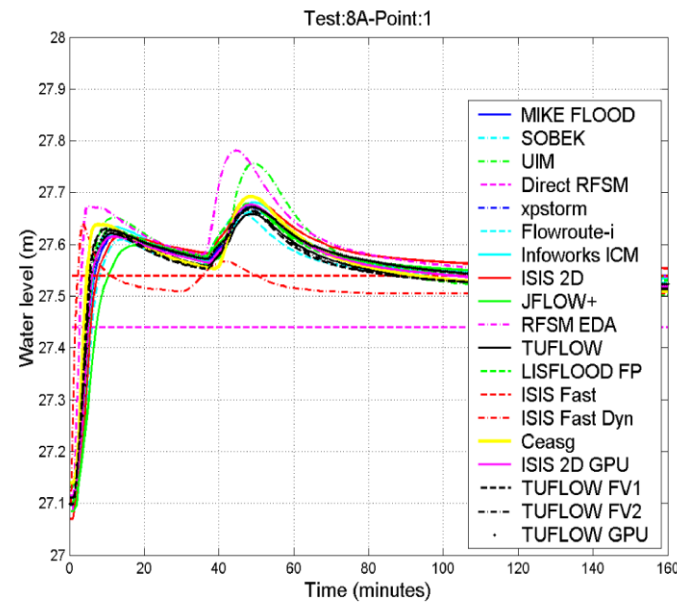


Boundary Condition : Rain (top), Inflow (bottom)

Results: WCA2D – EAT8a

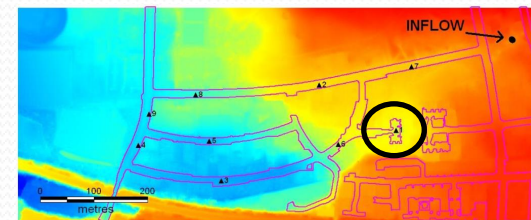


WCA2D And UIM

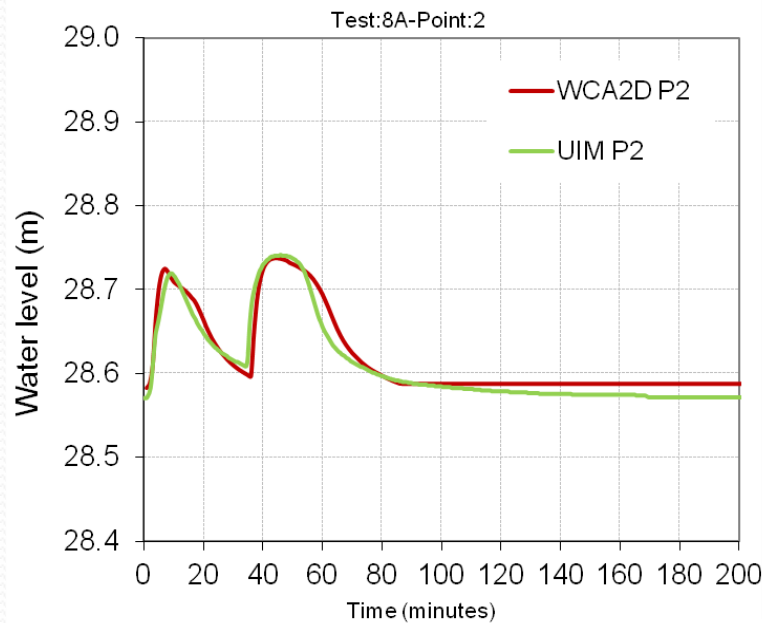


Multiple Models

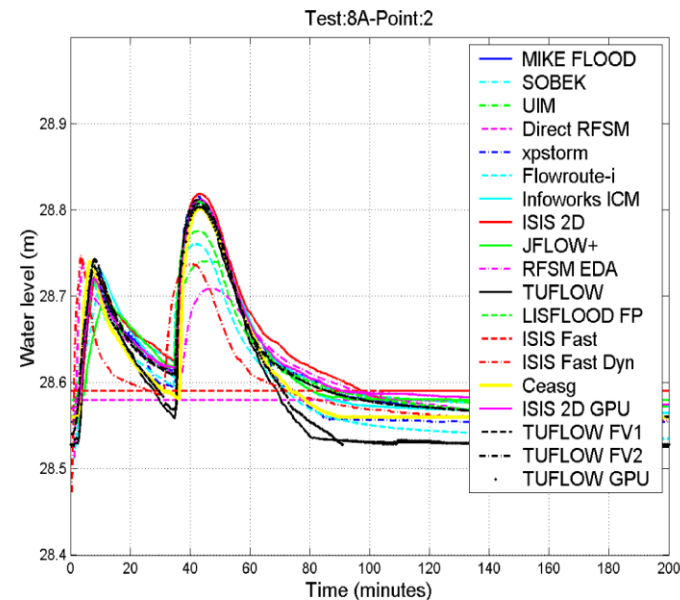
Point 1



Results: WCA2D – EAT8a

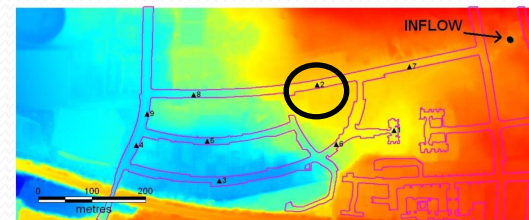


WCA2D And UIM

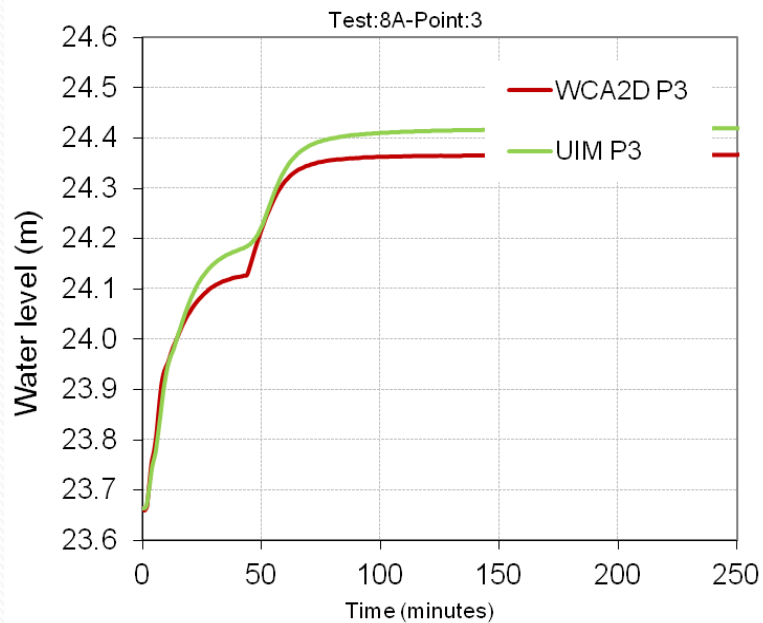


Multiple Models

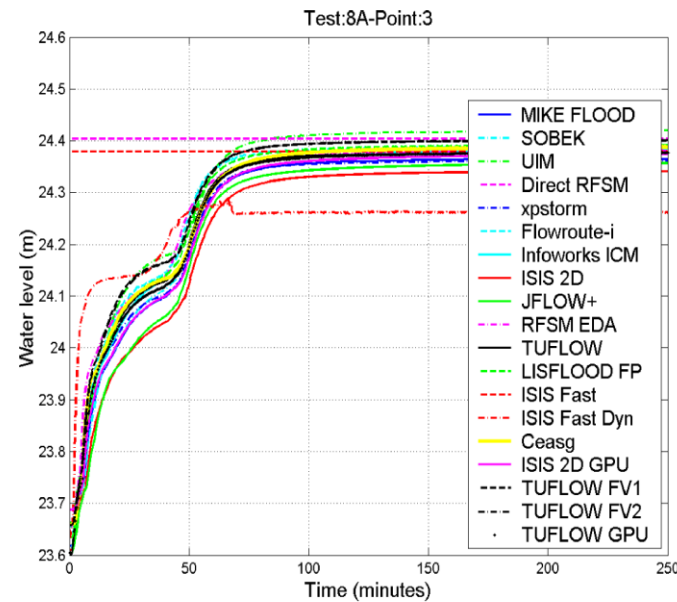
Point 2



Results: WCA2D – EAT8a

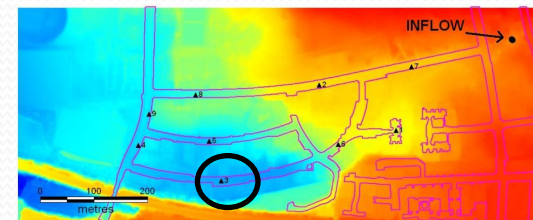


WCA2D And UIM



Multiple Models

Point 3



Computation Time

- EA report contains run times
- Achieved using different hardware
- Table shows the minimum, median and first quartile run time obtained by all models

	Run Time	
	EAT2	EAT8a
Minimum	2 s	66.0 s
Median	12.1 s	297.5 s
1 st Quartile	9.6 s	88.5 s
WCA2D GPU	5.0 s	33.9 s

Results

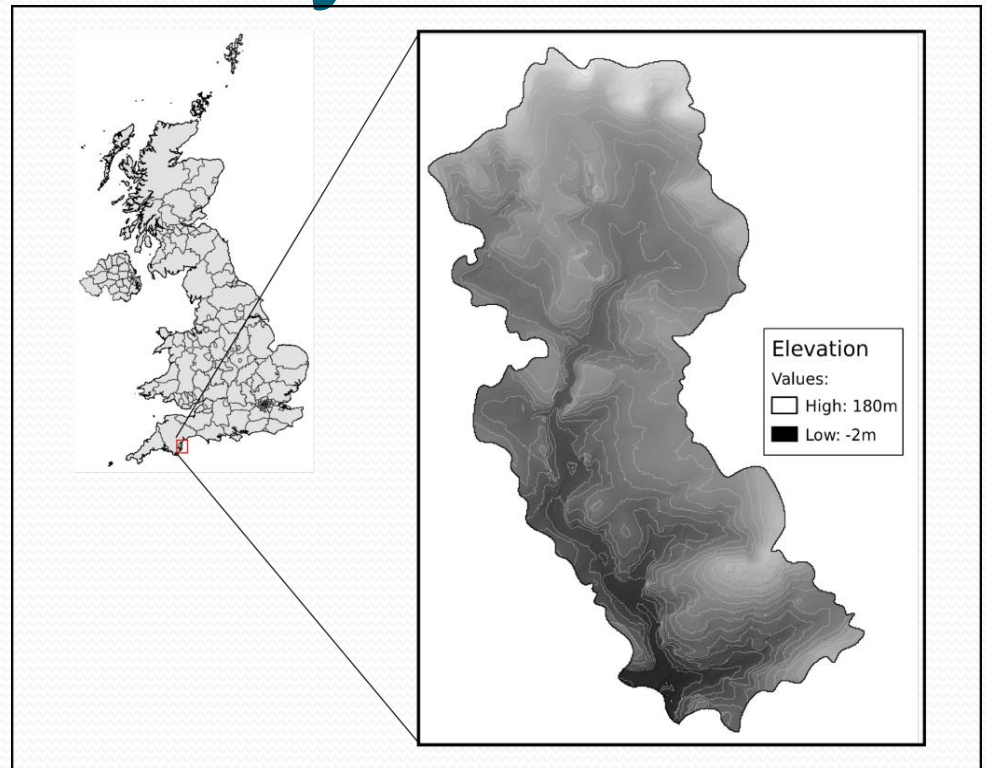
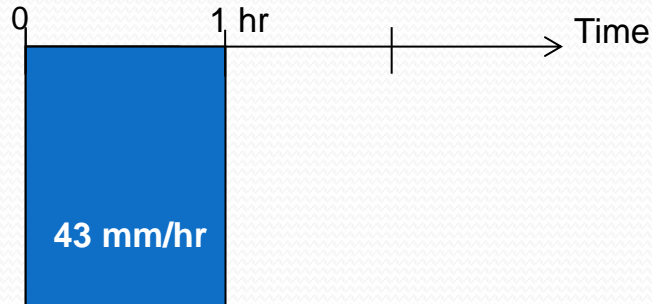
Torquay test cases

Torquay case study

Boundary Condition

Open boundaries

Rainfall: 43 mm/hr

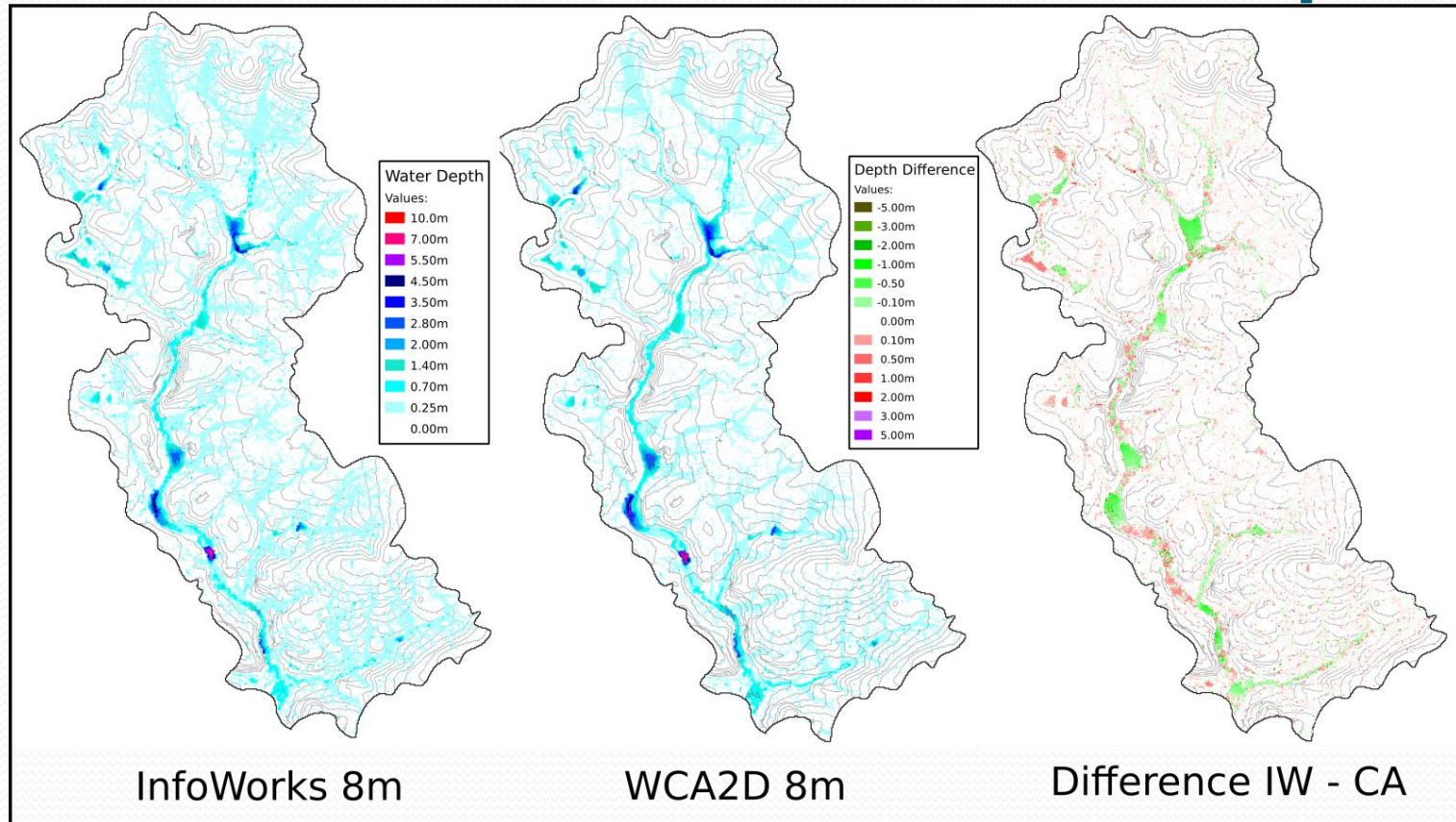


- 8m resolution: ~120,000 cells
- 4m resolution: ~500,000 cells

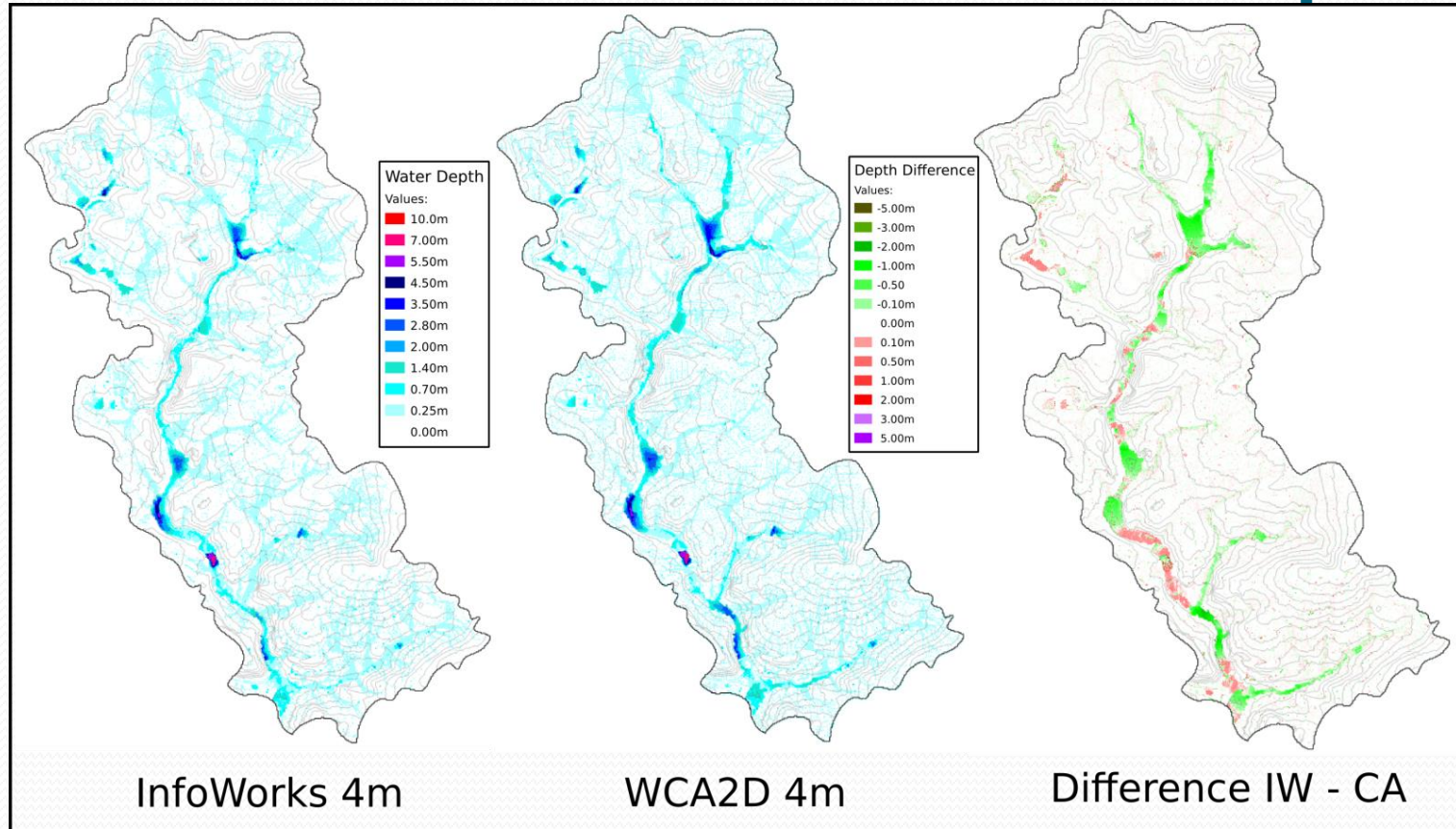
Results analysis

- Compared WCA2D
 - InfoWorks ICM 3.0
 - UIM
- Using three metrics:
 - Maximum absolute error (MAD)
 - Root mean square error (RMSE)
 - Nash-Sutcliffe Efficiency (NSE)

Maximum Inundation Depth



Maximum Inundation Depth

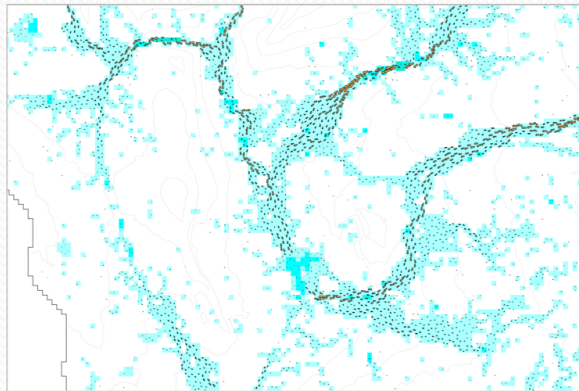


Results vs InfoWorks

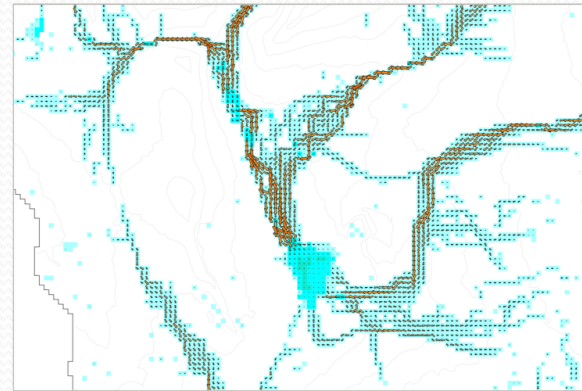
Models comparison time / attribute	IW 8m – WCA2D 8m			IW 4m – WCA2D 4m		
	MAD	RMSE	NSE	MAD	RMSE	NSE
30 Min.	1.93 m	0.09 m	0.24	2.59 m	0.06 m	0.75
60 Min.	2.83 m	0.13 m	0.77	3.50 m	0.12 m	0.85
90 Min.	3.41 m	0.20 m	0.93	4.22 m	0.37 m	0.83
120 Min.	6.47 m	0.26 m	0.95	4.90 m	0.42 m	0.88
360 Min.	5.89 m	0.26 m	0.96	3.84 m	0.30 m	0.95
720 Min.	5.81 m	0.27 m	0.97	4.21 m	0.18 m	0.98
Max. Depth	6.55 m	0.14 m	0.88	4.43 m	0.17 m	0.85
Max. Speed	3.26 m/s	0.37 m/s	0.70	3.81 m/s	0.46 m/s	0.65

- $NSE > 0.75$ satisfactory agreement
- $NSE > 0.95$ good agreement
- Only water depth at 30m for 8m test case and maximum speed non satisfactory

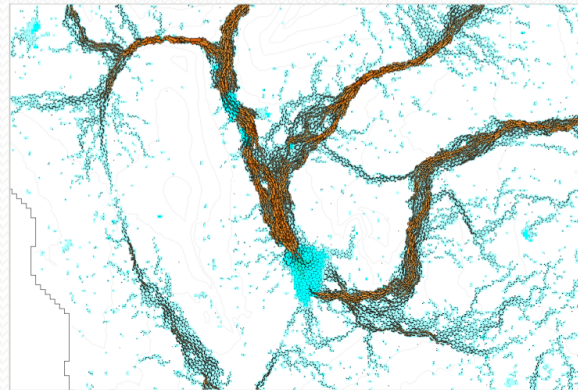
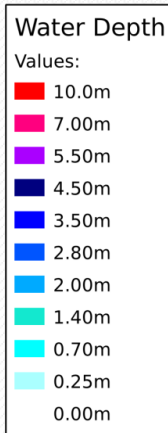
Depth and Velocity at 30 min



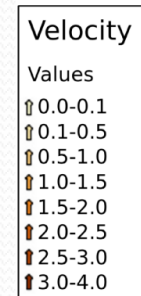
InfoWorks 8m



WCA2D 8m



InfoWorks 4m



Computation Time

	WCA2D 8m		IW 8m		WCA2D 4m		IW 4M	
Type	OMP	GPU	OMP	GPU	OMP	GPU	OMP	GPU
Time	182 s	41 s	698 s	211 s	982 s	249 s	3241 s	989s
Sp vs IW	3.83	5.14	---	---	3.30	3.97	---	---

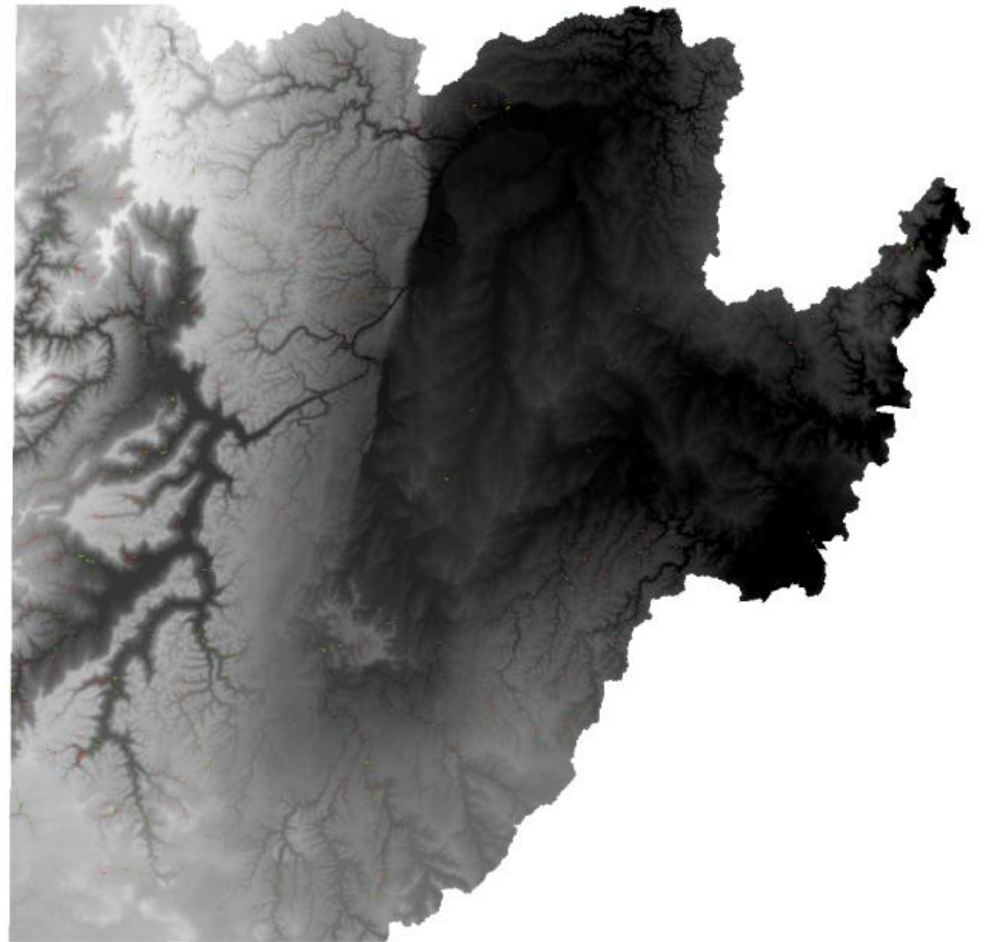
- Simulations performed on multi-core CPU (OMP) and GPU
- WCA2D is from over 3 times to over 5 times faster than InfoWorks

Results

Very Large Test case

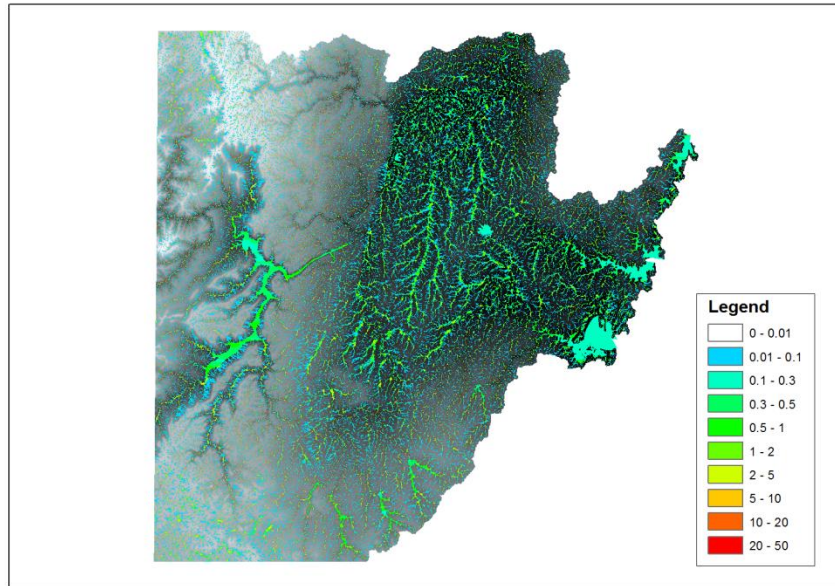
Sydney, Australia

- 3700 x 3700 cells
- ~14 million cells
- 30m x 30m



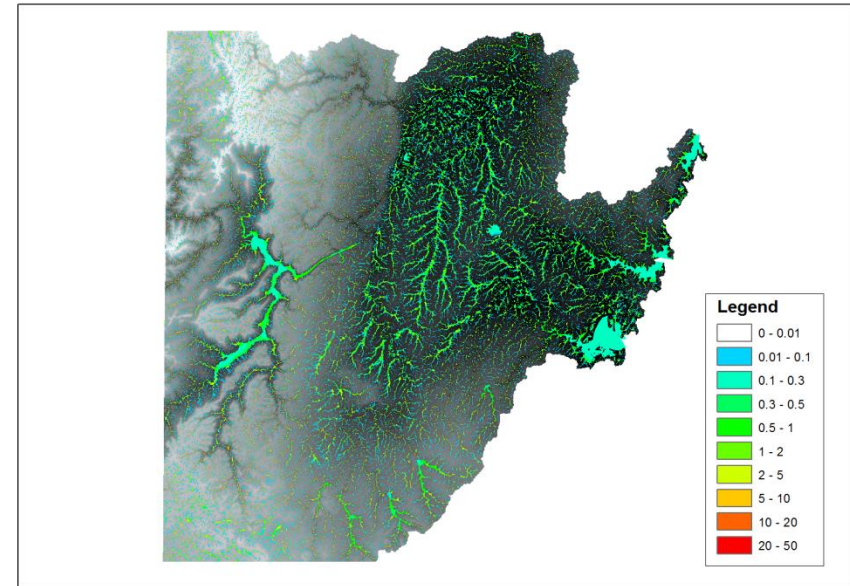
Results

UIM / Case A / Peak Values



(a)

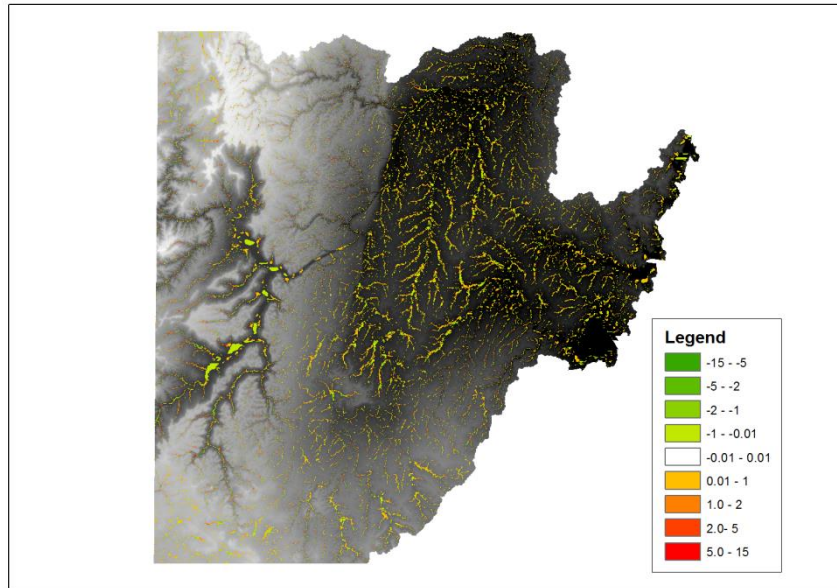
ICA2D / Case A / Peak Values



(b)

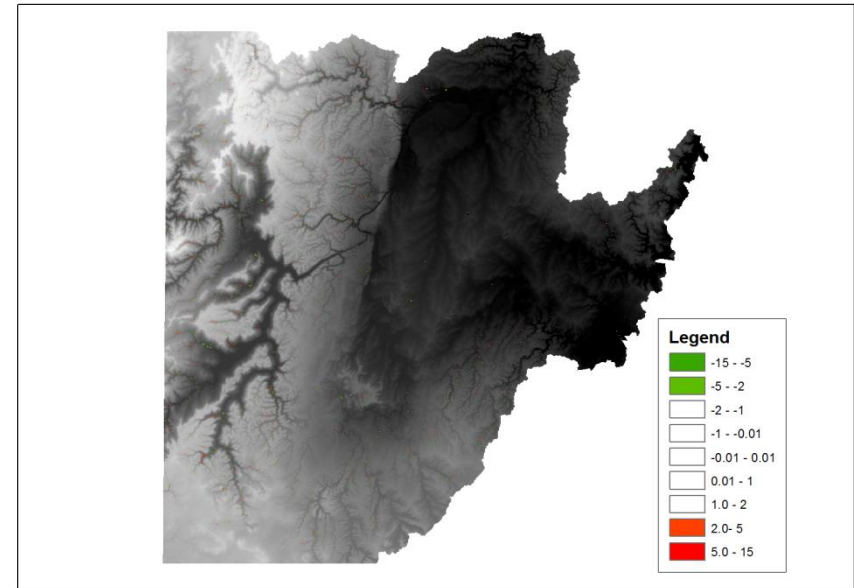
Results

Difference / ICA2D- UIM / Case A / Full Range



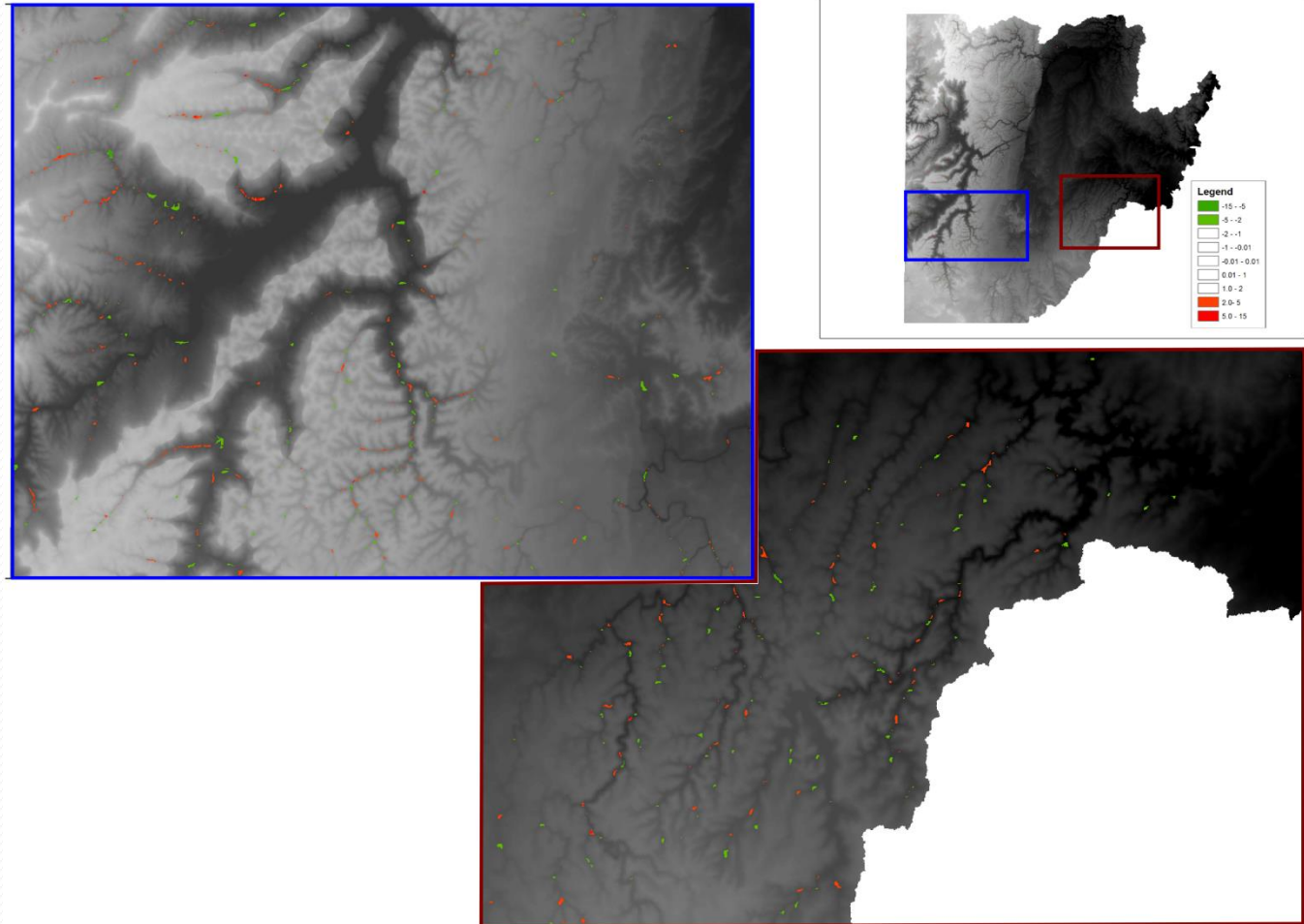
(c)

Difference / ICA2D- UIM / Case A / Over 2M



(d)

Results Zoom



Summary

- Developed a fast 2D flood model that uses a CA technique
- Produced results comparable to UIM and InfoWorks
- Run times are quicker than UIM and InfoWorks in the example showed

Thank You Questions?

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