Is Direct Rainfall (Rain on Grid) Accurate?

Webinar: 17th February 2021

Presentation Introduction
Agenda

Background

- Catchment Simulation Approaches
- What is Direct Rainfall (Rain on Grid)?

Benchmarking Case Studies

- Case Study 1 – Urbanised; Flood Rainfall
- Case Study 2 – Large Rural; High Rainfall
- Case Study 3 – Small Rural; Low Rainfall

Background
Modelling Rainfall-Runoff is Complicated

Converting rainfall to runoff

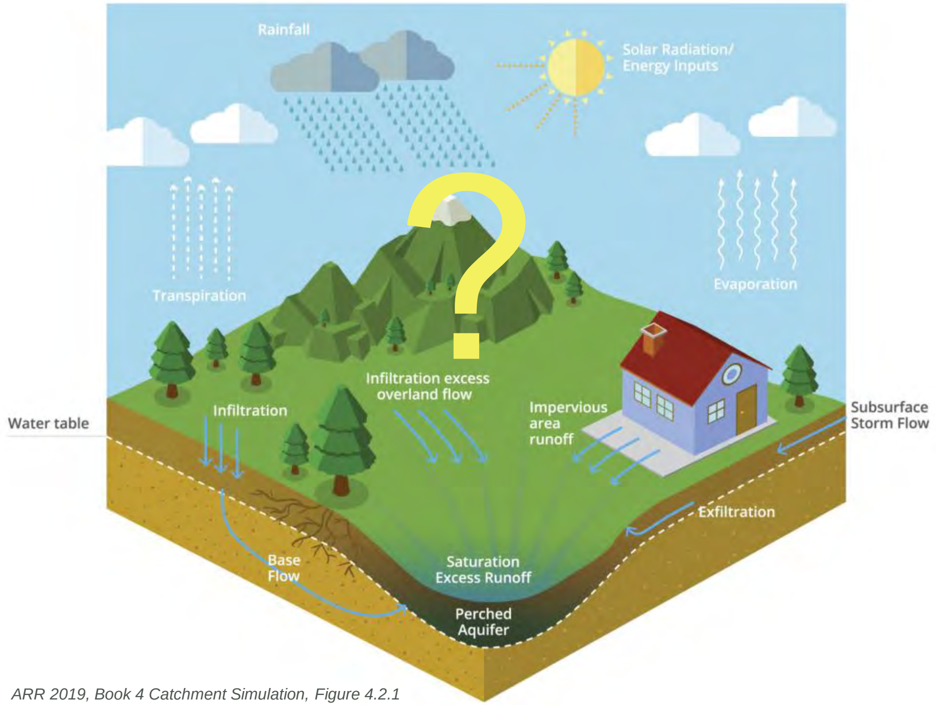
- Hydrology or Catchment Simulation
  - Many approaches analytical and empirical
  - Many unknowns and approximations

Propagating runoff causing inundation

- Hydraulics
  - Based on physics of fluid flow

Direct Rainfall Modelling

- Uses hydraulics to do both
- Is this accurate?



ARR 2019, Book 4 Catchment Simulation, Figure 4.2.1

Background
Catchment Simulation Approaches

Lumped
$Q = f(\theta)$

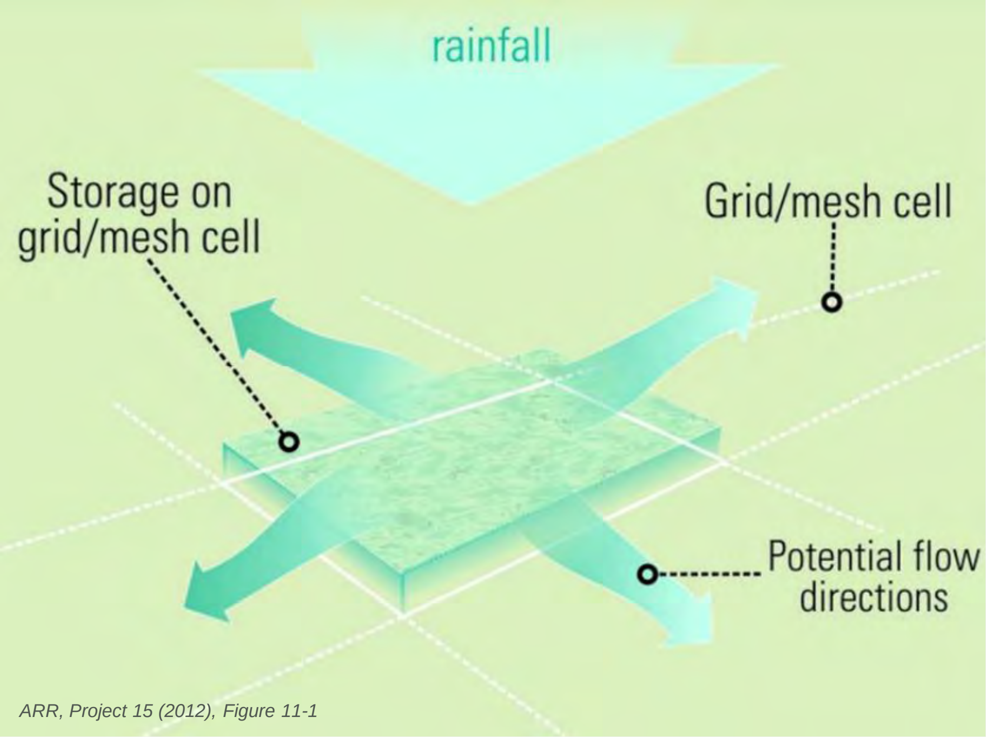
Semi-distributed
$Q = f(\theta_A, \theta_B, \theta_C)$

Distributed
$$Q = f(\theta_{A1}, \theta_{B1}, \theta_{C1}, \theta_{A2}, \theta_{B2}, \theta_{C2}, \ldots\ \theta_{AN}, \theta_{BN}, \theta_{CN})$$

ARR 2019, Book 4 Catchment Simulation, Figure 4.2.5

Background
What is Direct Rainfall?

- Rainfall depth is applied to each 2D cell / mesh element
- Runoff from cell dependent on:
  - Cell area
  - Rainfall depth
  - Rainfall / Infiltration Losses
  - Roughness
  - Surrounding levels / slope



ARR, Project 15 (2012), Figure 11-1

Background
Direct Rainfall Pros

Direct Rainfall Pros

- No need for catchment delineation, which can be difficult in areas of flat terrain
- Ability to model cross catchment flows that occur in larger events
- Simplified modelling process (1 model rather than 2)
- Better representation of flow contributions to inlet pits in urban drainage studies

Background
Direct Rainfall Cons

Direct Rainfall Cons

- Requires ‘decent’ DEM
- Much slower run times compared to lumped or semi-distributed hydrology models
- Industry acceptance of direct rainfall approach
- Are industry standard parameters valid at very shallow depths, e.g. Manning’s n?
- Need to filter shallow depths

Preparing to talk to a hydrologist
about direct rainfall

Background
Direct Rainfall History in TUFLOW

- 2006 First application, Sydney urban catchments, Depth varying n
- 2010 Soil infiltration and impervious surfaces added to TUFLOW
- 2013 GPU solver offering stability and speed
- 2014 Depth varying roughness based on the “Law of the wall”
- 2017 TUFLOW HPC ability to model urban drainage in GPU
- 2020 Sub Grid Sampling (SGS) substantially improves routing

Case Study 1 – Urban
Newcastle, Australia

Throsby, Cottage and CBD Flood Study completed in 2007

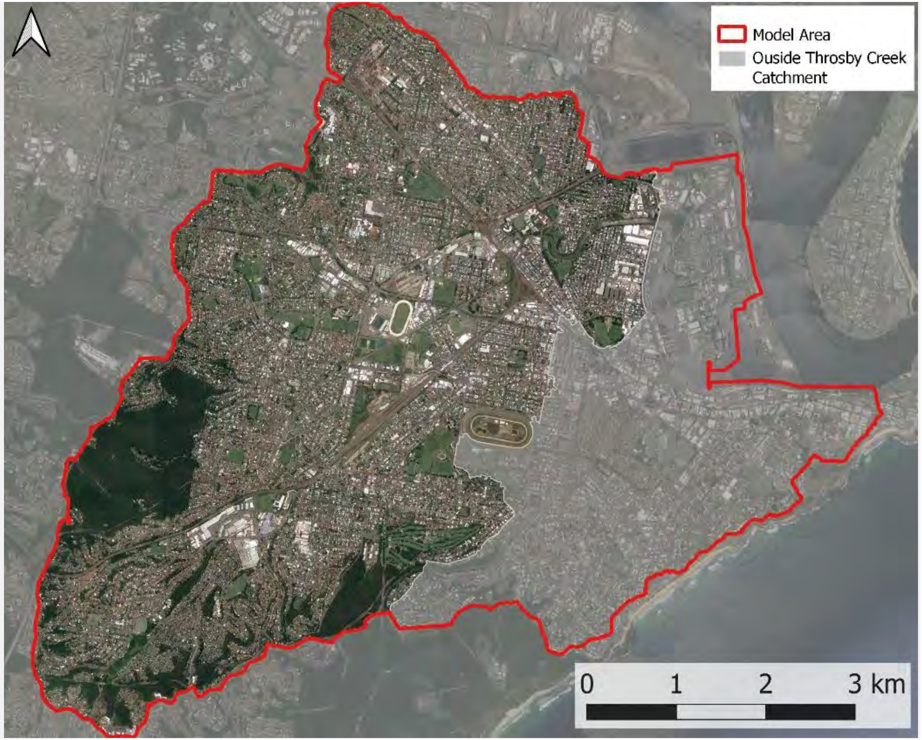
- Detailed flood investigation incorporating:
  - Data compilation, review, and acquisition of missing data
  - Develop and calibrate hydrologic and hydraulic models
  - Design event selection, modelling and mapping

Excellent calibration datasets, especially 1990 flood

Very high-quality input datasets

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)



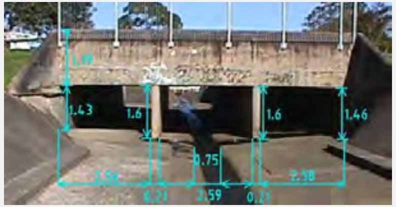
Case Study 1 – Urban
Throsby Creek Flood Study

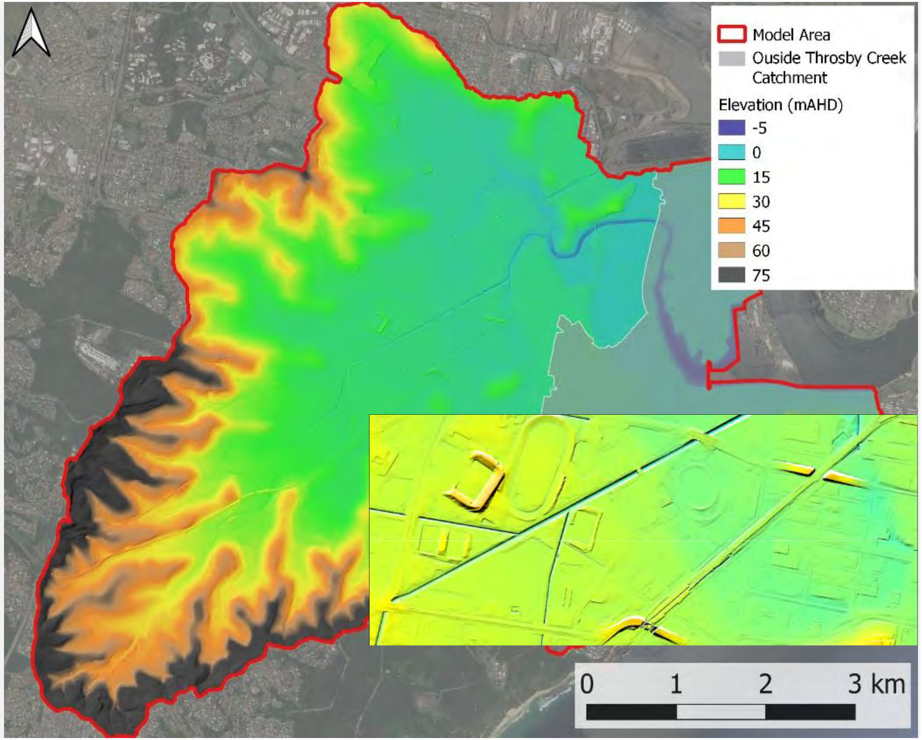
Very High-Quality DEM

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

Excellent Hydraulic Structure Data

- Detailed field survey





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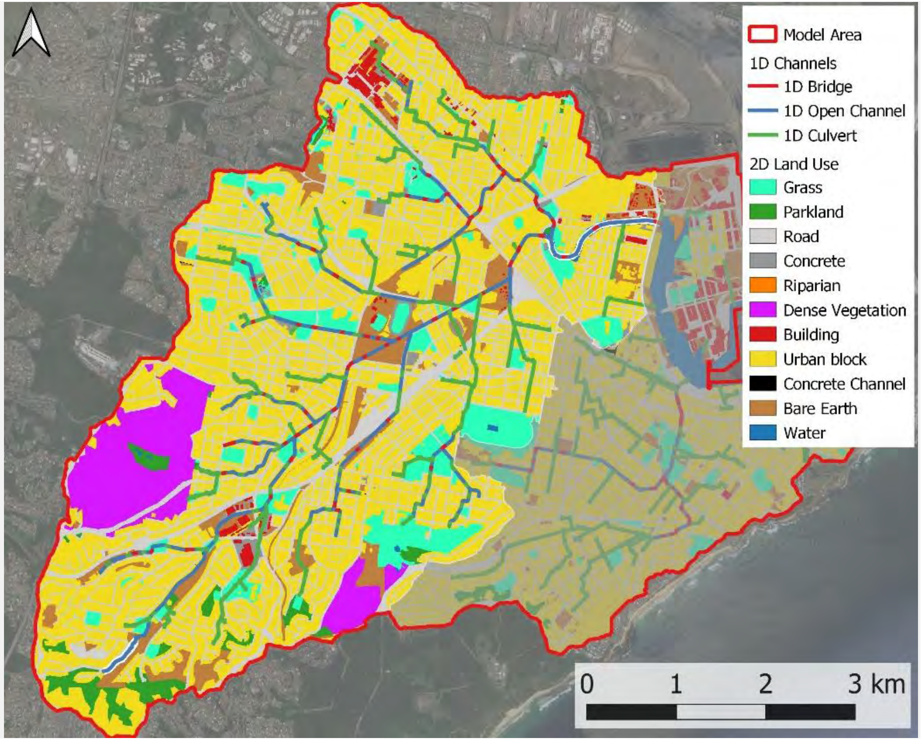
Case Study 1 – Urban
Throsby Creek Flood Study

Detailed land-use mapping



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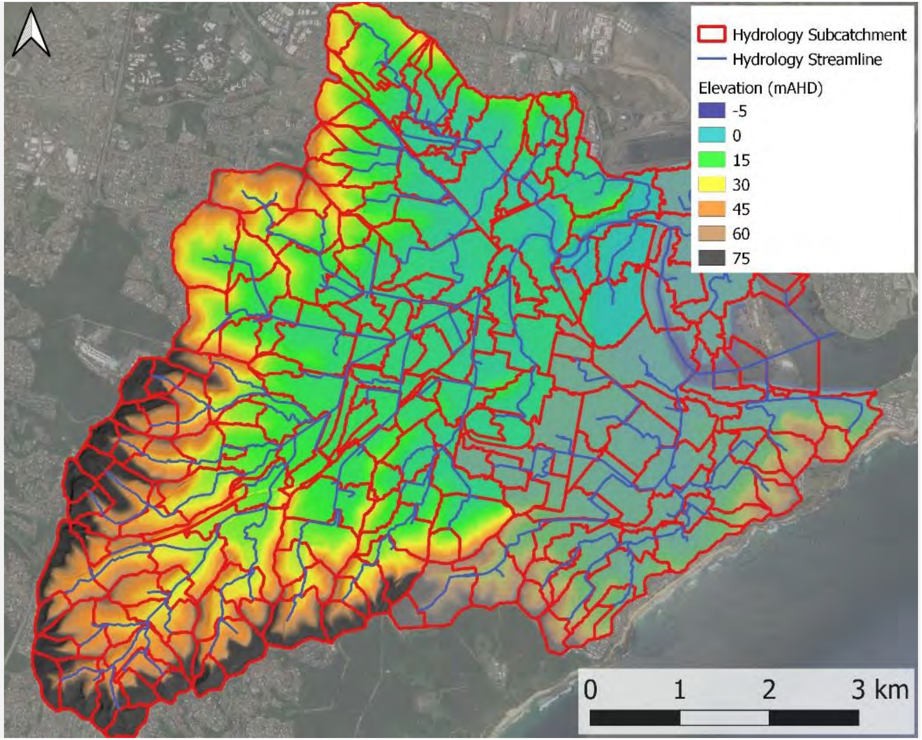
Case Study 1 – Urban
Throsby Creek Flood Study

Hydrology Model

- Highly detailed WBNM model (semi-distributed approach)
- 198 sub-catchments
  - Area, % impervious, lag parameter, impervious lag parameter, rain gauge weightings, pervious initial loss, pervious continuing loss, impervious initial loss
- 135 flowpaths to route flow
  - Lag parameters



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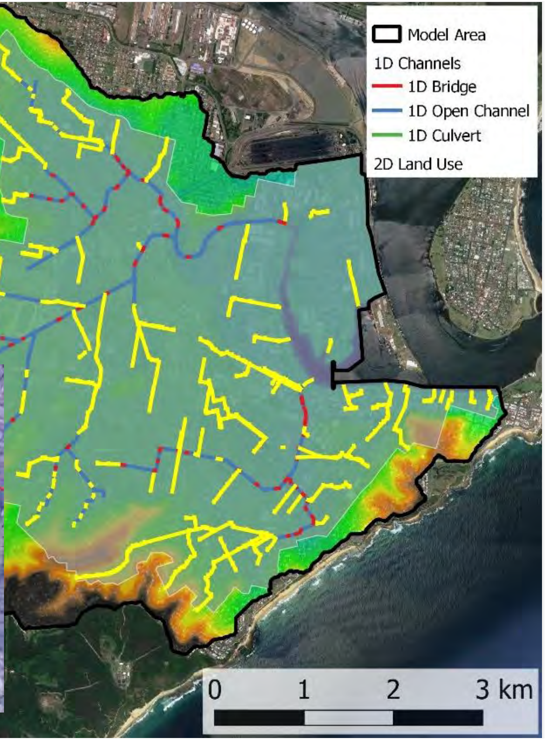
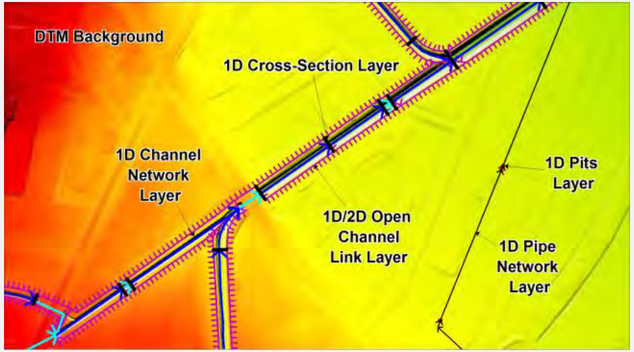
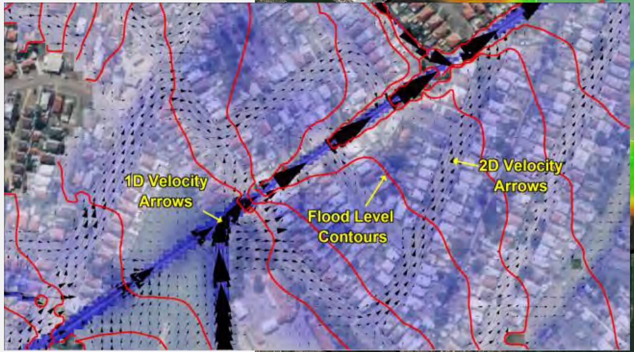
Case Study 1 – Urban
Throsby Creek Flood Study

Hydraulic Model

- TUFLOW (2007 version)
- 10 m 2D cell size
- 1D network for open channels, bridges, culverts, and pipes

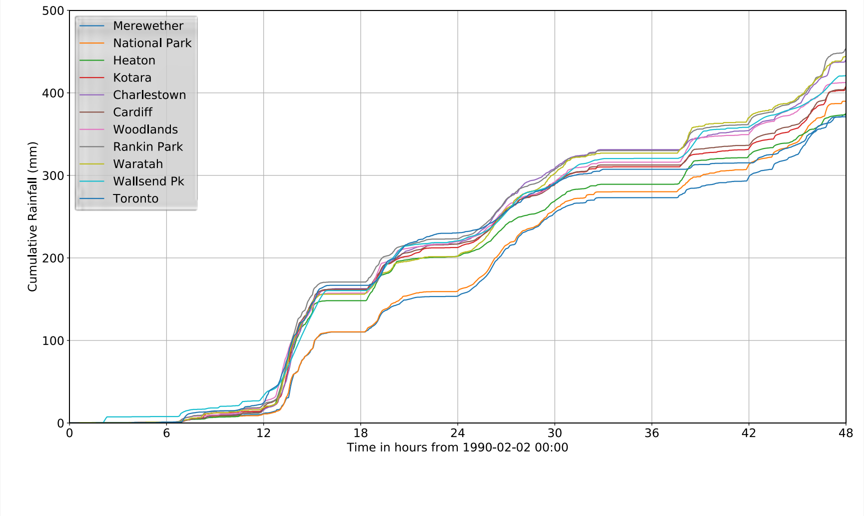


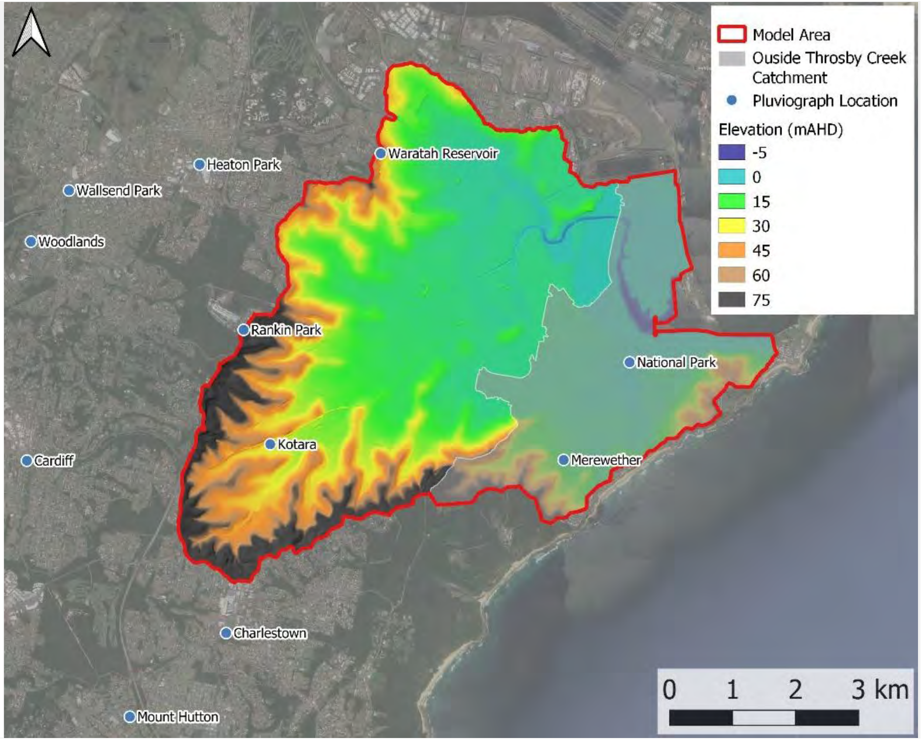




Case Study 1 – Urban
1990 Flood – Recorded Rainfall

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





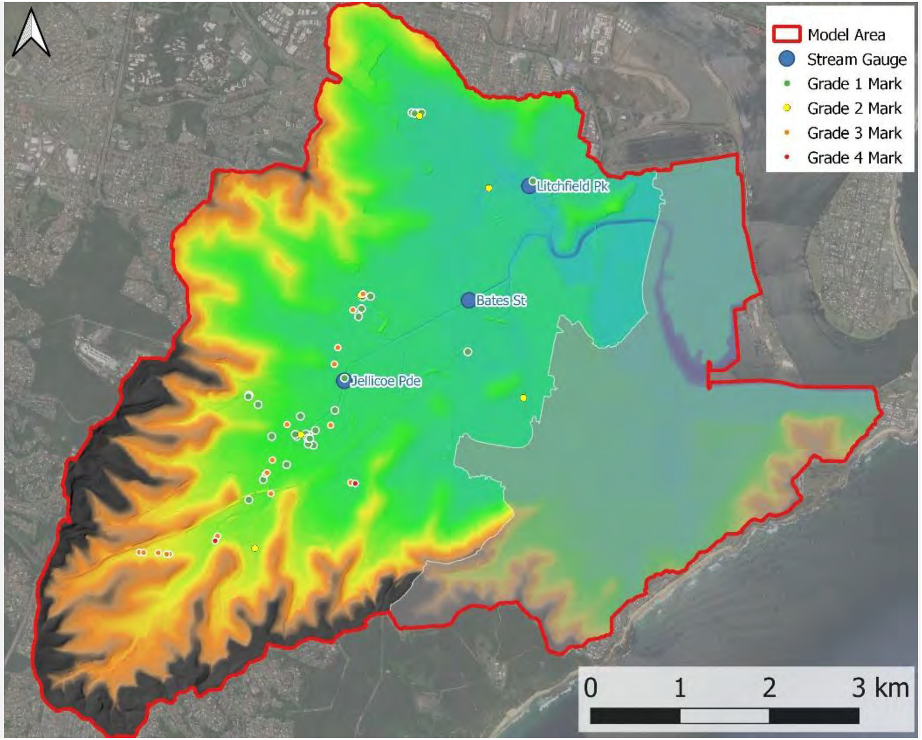
Case Study 1 – Urban
1990 Flood – Recorded Water Levels

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)



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Case Study 1 – Urban
Objective for this Webinar

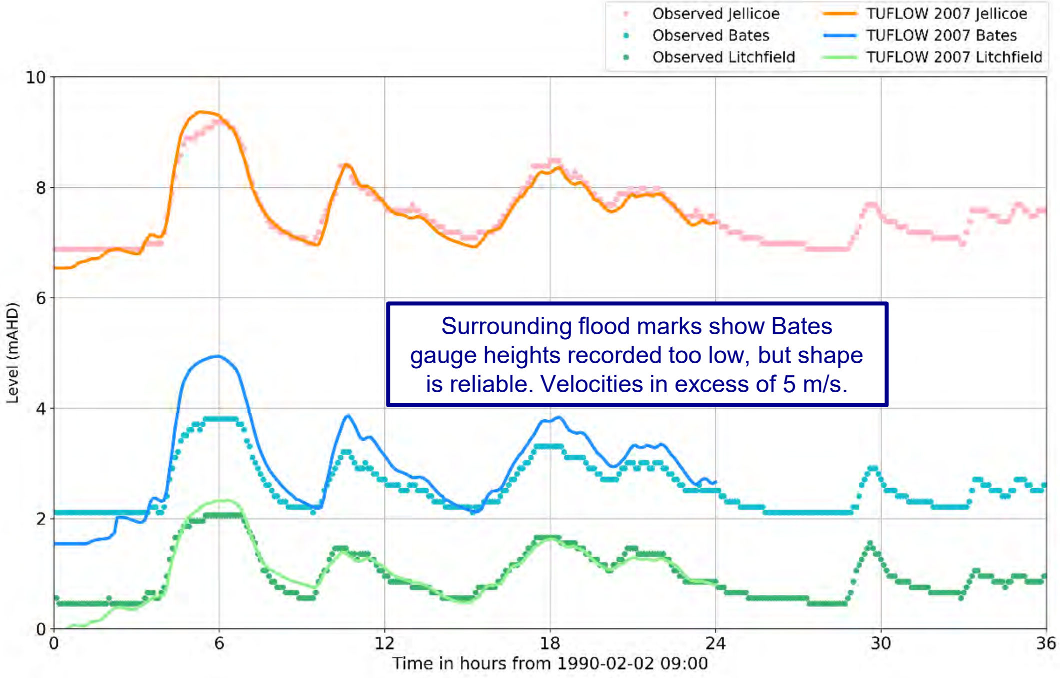
What happens if hydrology model is replaced by direct rainfall?

Process

- Update 2007 model to latest industry practices
  - Upgrade from 2007 version of TUFLOW to latest 2020 release
  - Switch from TUFLOW Classic (Finite Difference, CPU) to TUFLOW HPC (Finite Volume, GPU)
- Compare results for 1990 flood calibration
- Detailed recalibration not performed

Case Study 1 – Urban
Calibration Check – Hydrology / Hydraulic Model

Gauge calibration



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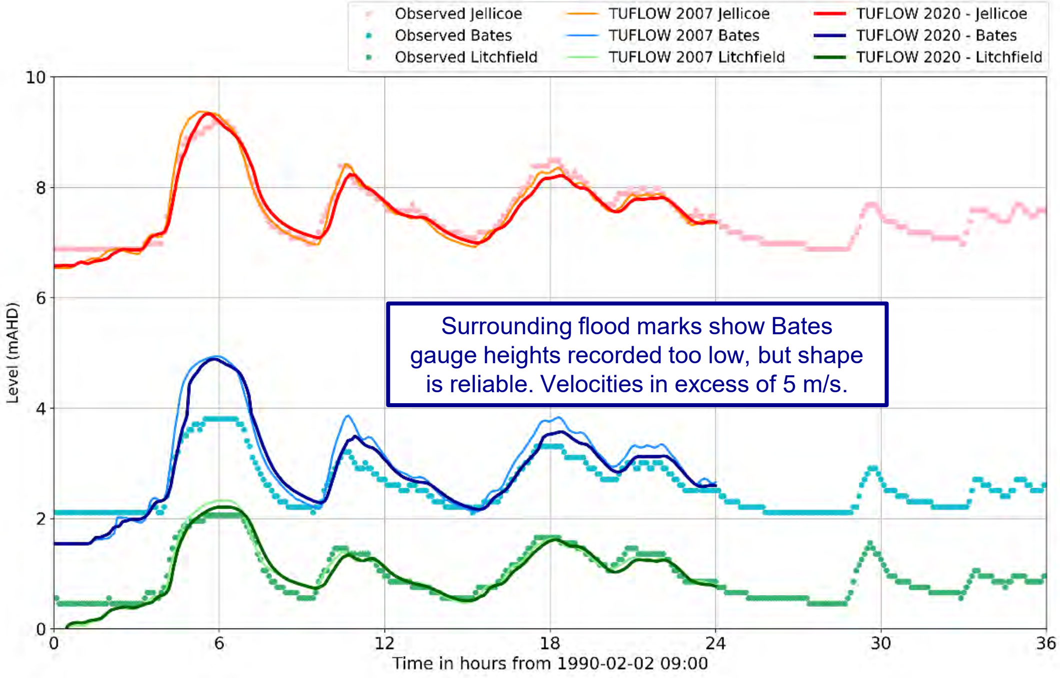
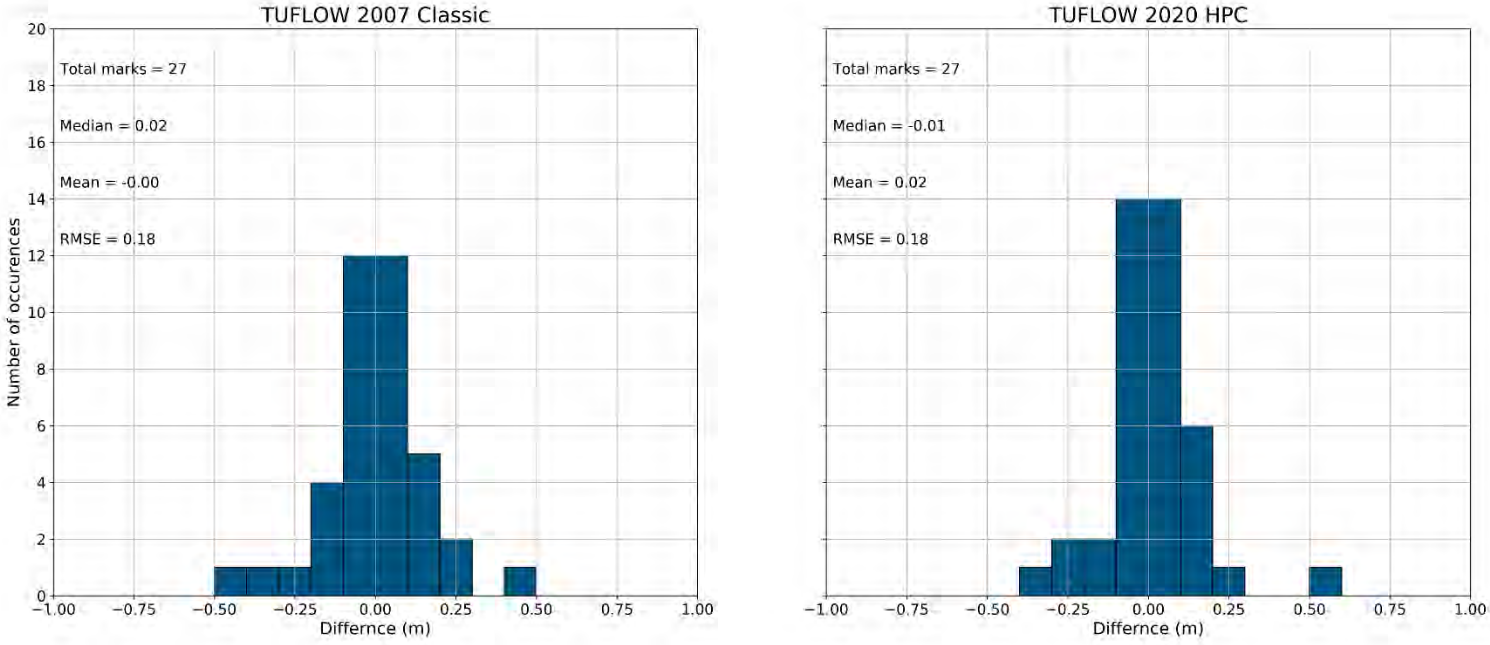
Case Study 1 – Urban
Calibration Check – Hydrology / Hydraulic Model

Gauge calibration



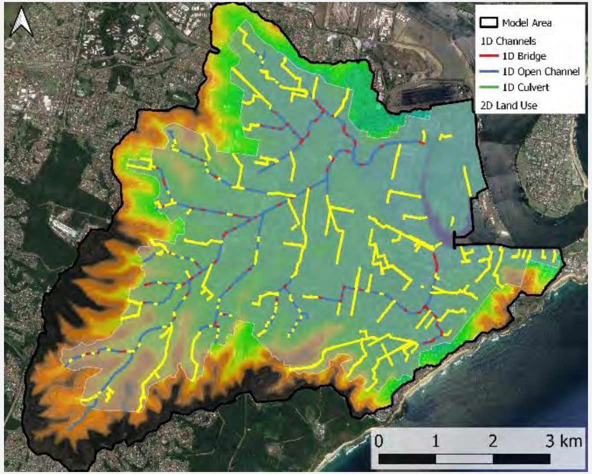
Case Study 1 – Urban
Calibration Check – Hydrology / Hydraulic Model

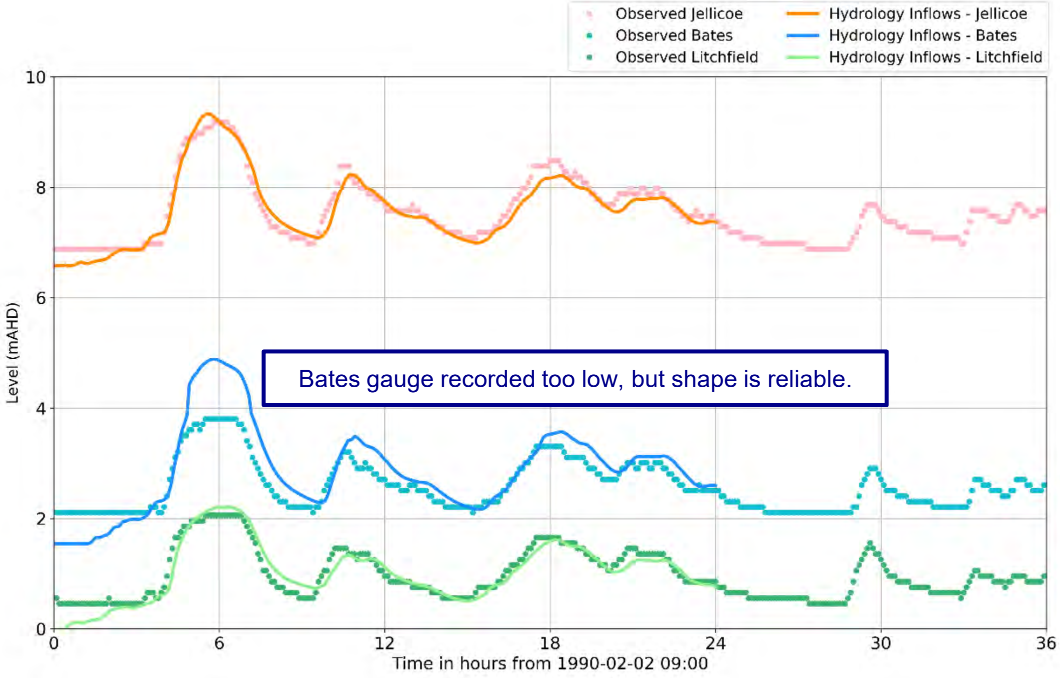
Grade 1 Flood mark calibration



Case Study 1 – Urban
Direct Rainfall Comparison

- Extended 2D model to whole of catchment
- Direct rainfall with IDW interpolation from 9 rainfall gauges





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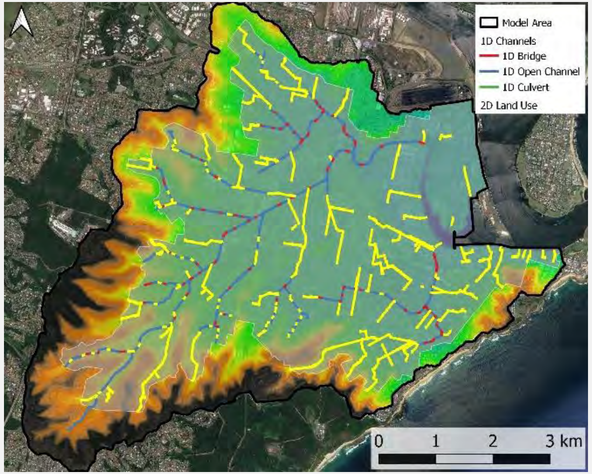

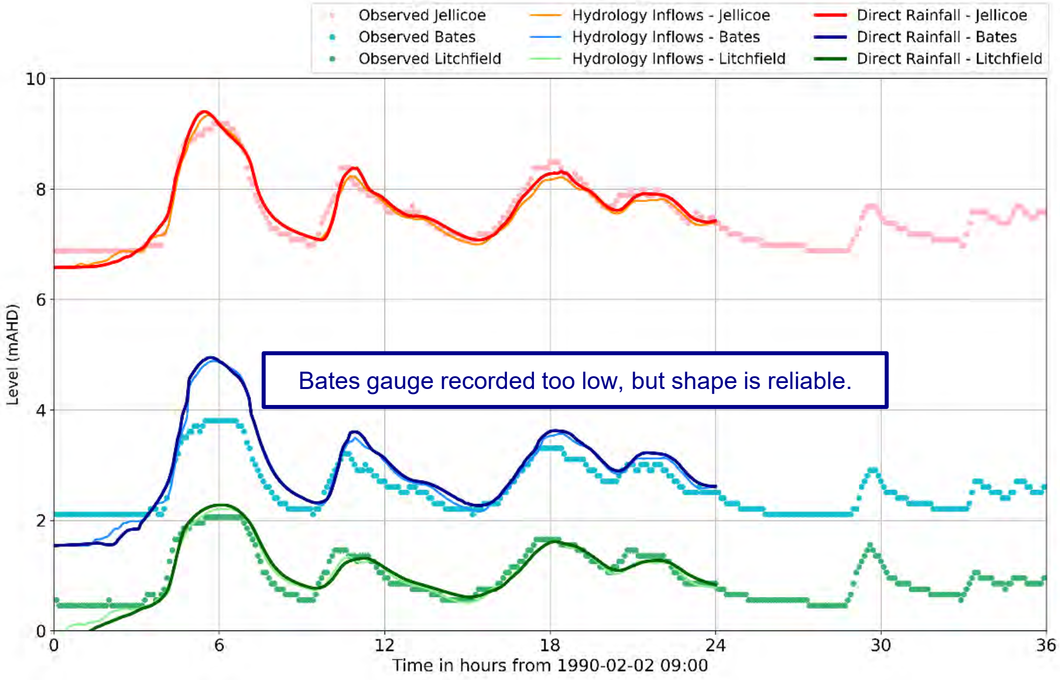

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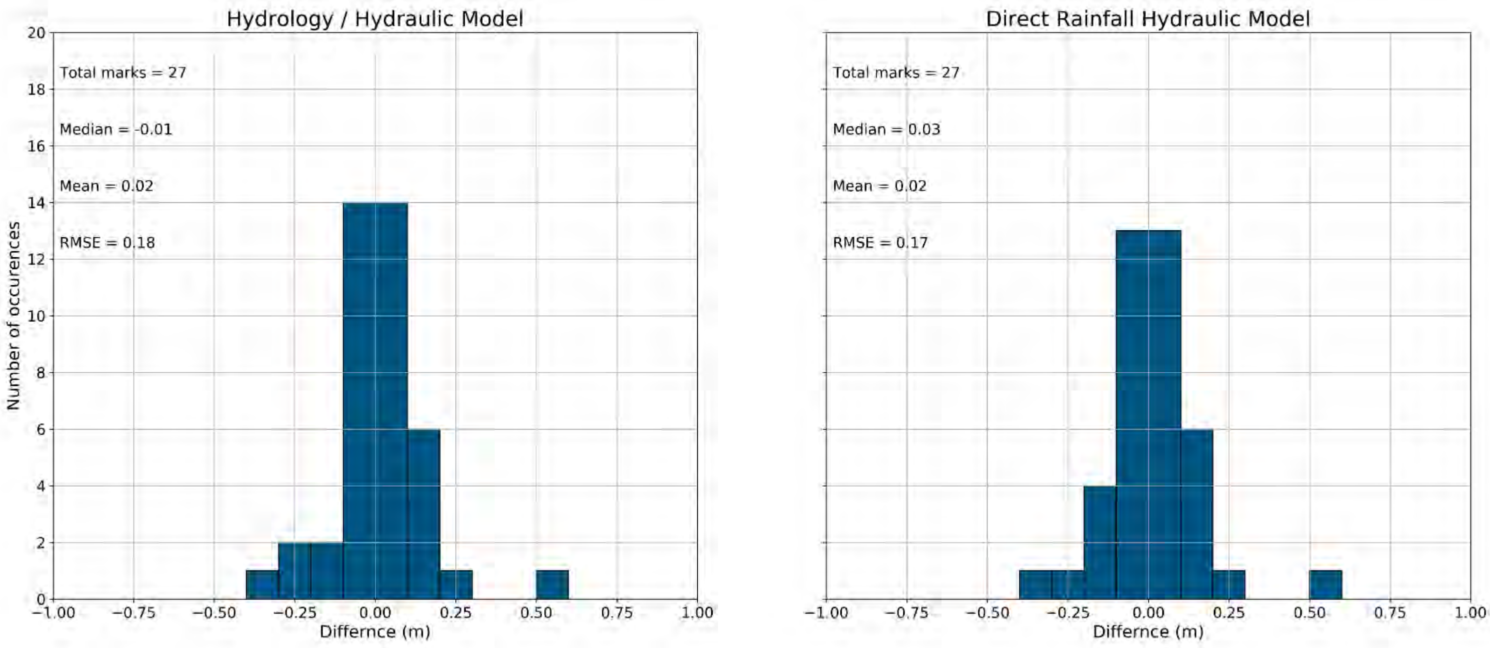
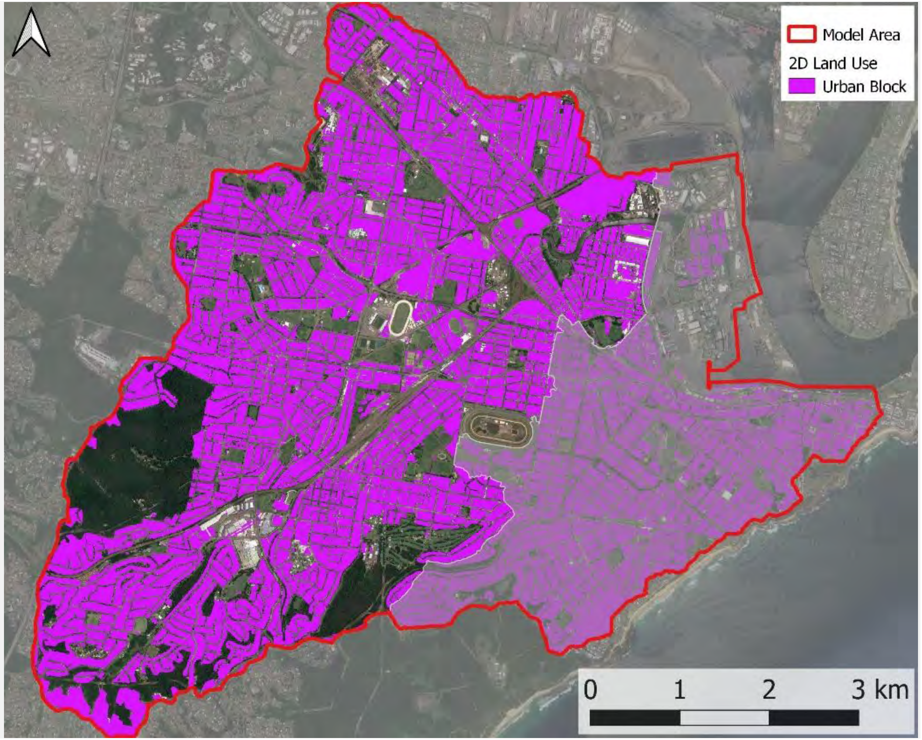


Case Study 1 – Urban
Manning's n for Buildings?

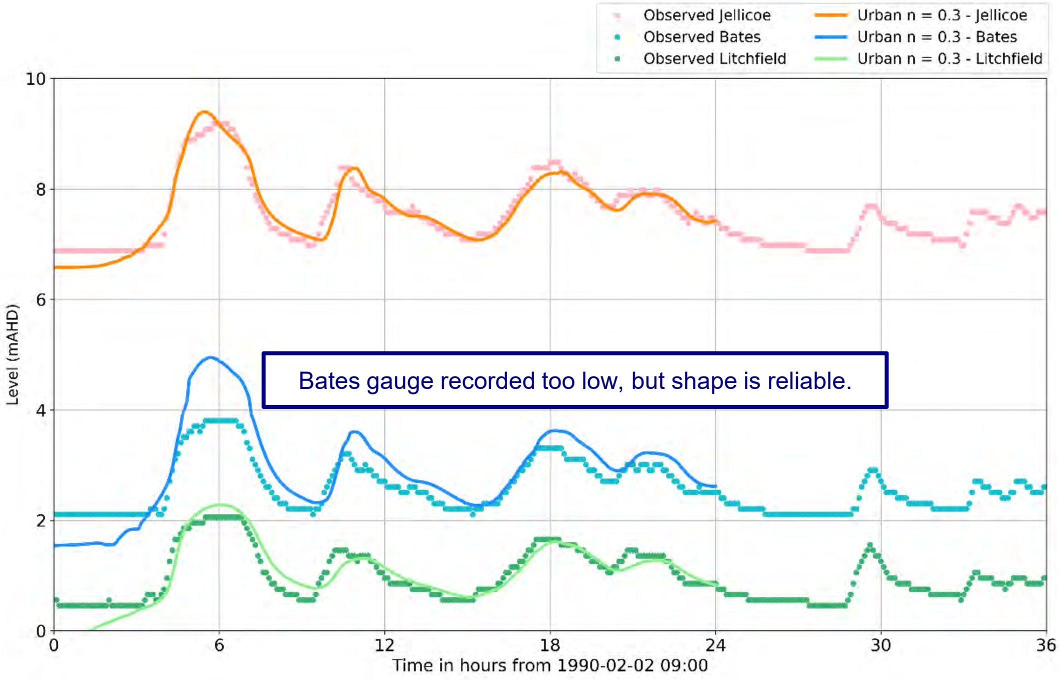
- Predominant land use is urban block
- Original model used Manning's n of 0.3 to account for blockages from buildings, fences
- Roads modelled separately using n of 0.02
- For direct rainfall need to allow rapid runoff for rain falling on buildings, driveways, etc
  - 0.3 is too high for runoff from buildings, driveways



Case Study 1 – Urban Manning’s n for Buildings?

- One approach is to use a depth varying Manning’s n

Depth (m)	Manning's n
0.1	0.02
0.3	0.30



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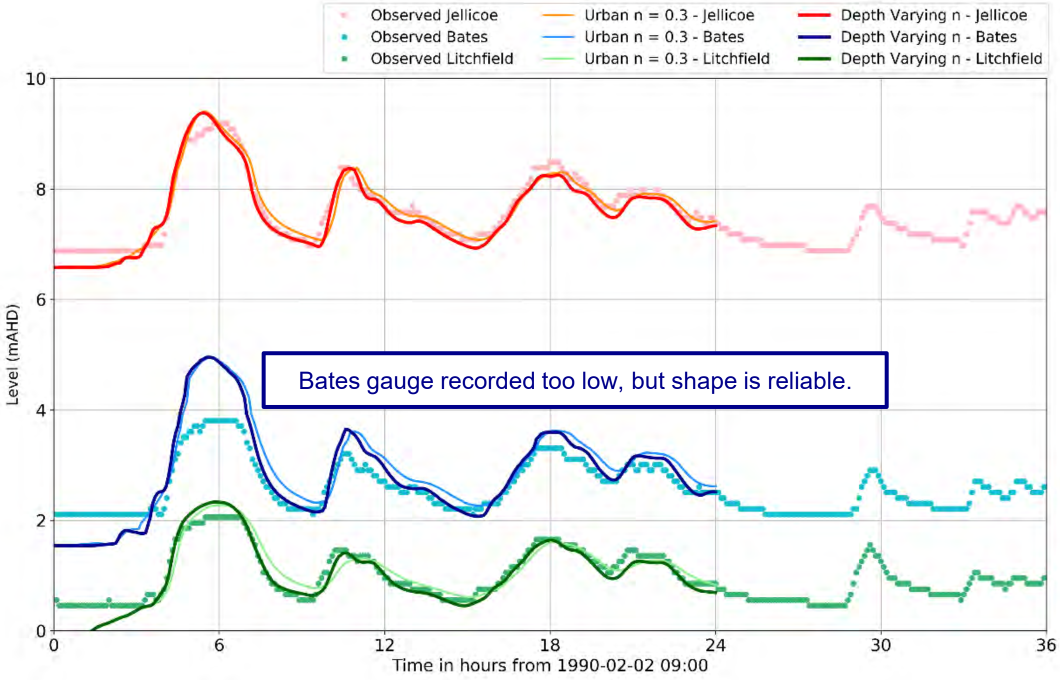

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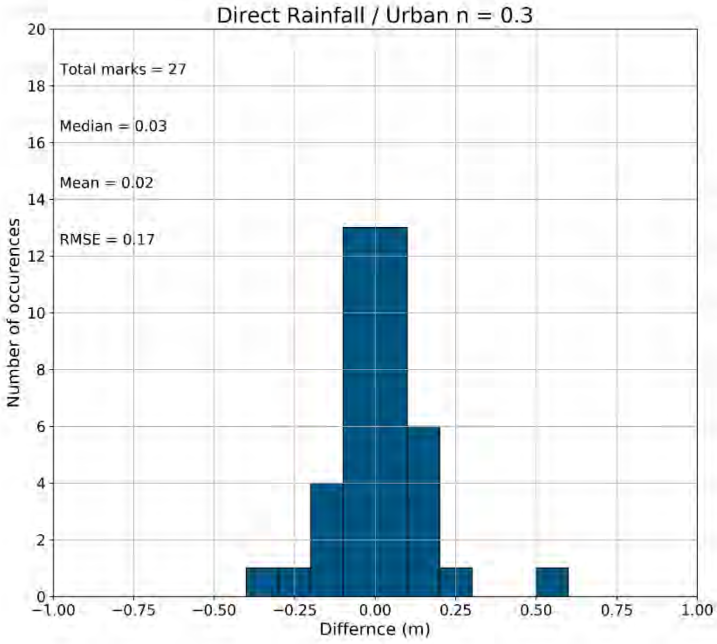
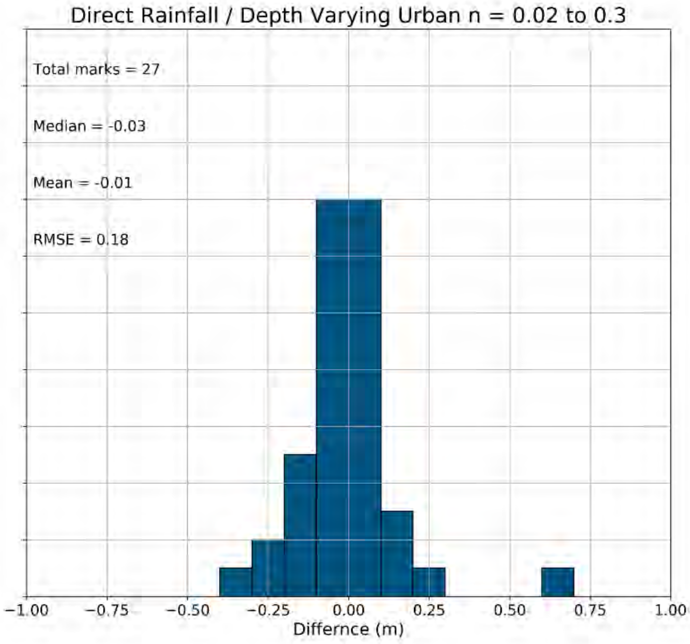
Case Study 1 – Urban Manning’s n for Buildings?





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Case Study 1 – Urban Conclusions

- Direct rainfall produced similar quality calibration to original study with no changes required – somewhat surprised!
- High-quality calibration demonstrates direct rainfall a valid approach for this case study
- Original hydrology model was of a high resolution (~200 sub-catchments)
  - May better align with high resolution of direct rainfall approach?
- Using depth varying n for urban areas (excluding roads)
  - Improved runoff response – better match to recorded hydrograph shapes
  - Had negligible benefit to calibration against peak flood level marks

Case Study 2 – Rural Model Overview

South Johnstone River Catchment

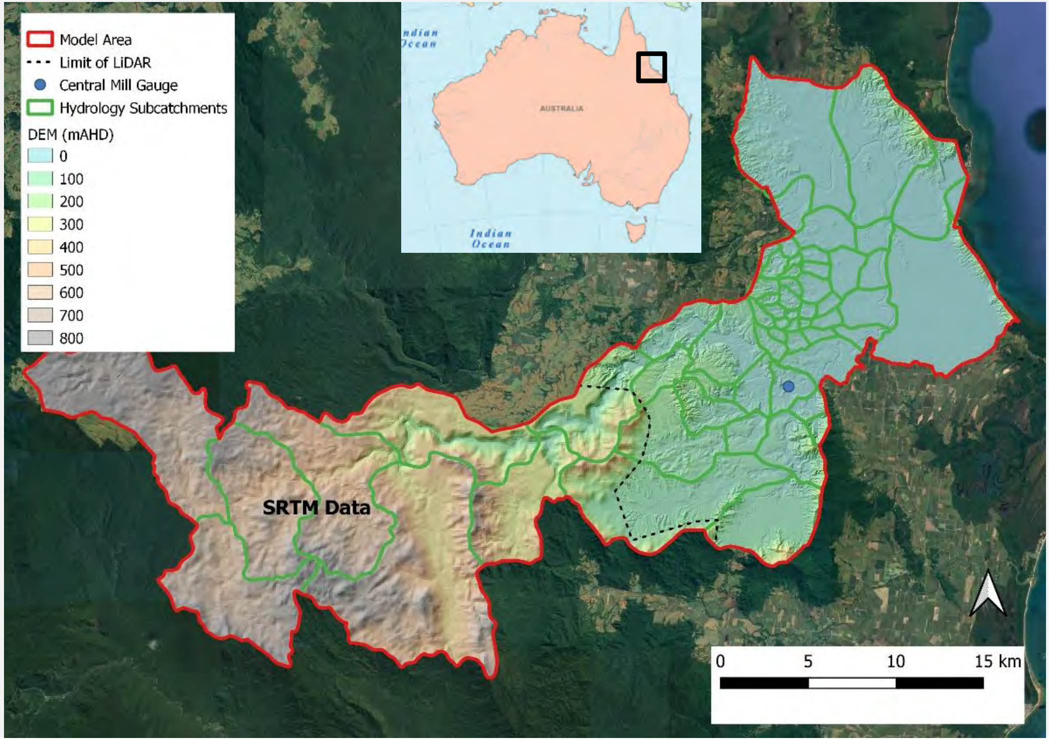
- Steep mountainous headwaters + well developed coastal floodplain

Input Data

- Satellite sourced elevation data in upper catchment (SRTM)
- LiDAR elevation and bathymetry in lower catchment
- Good rainfall pluvio coverage

Validation data

- Gauge data and BoM hydrology model



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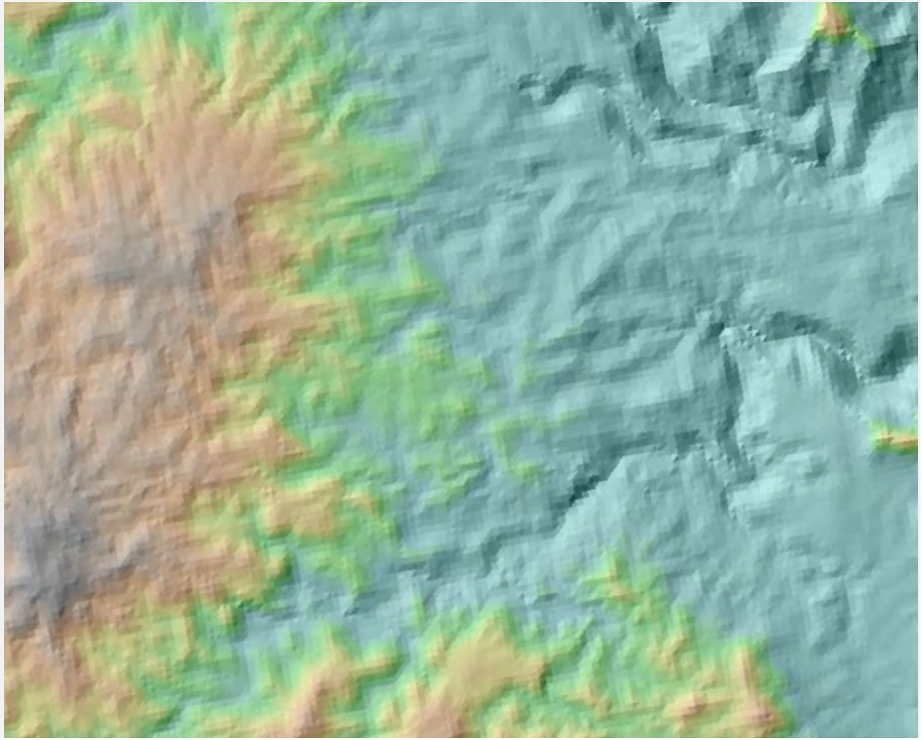
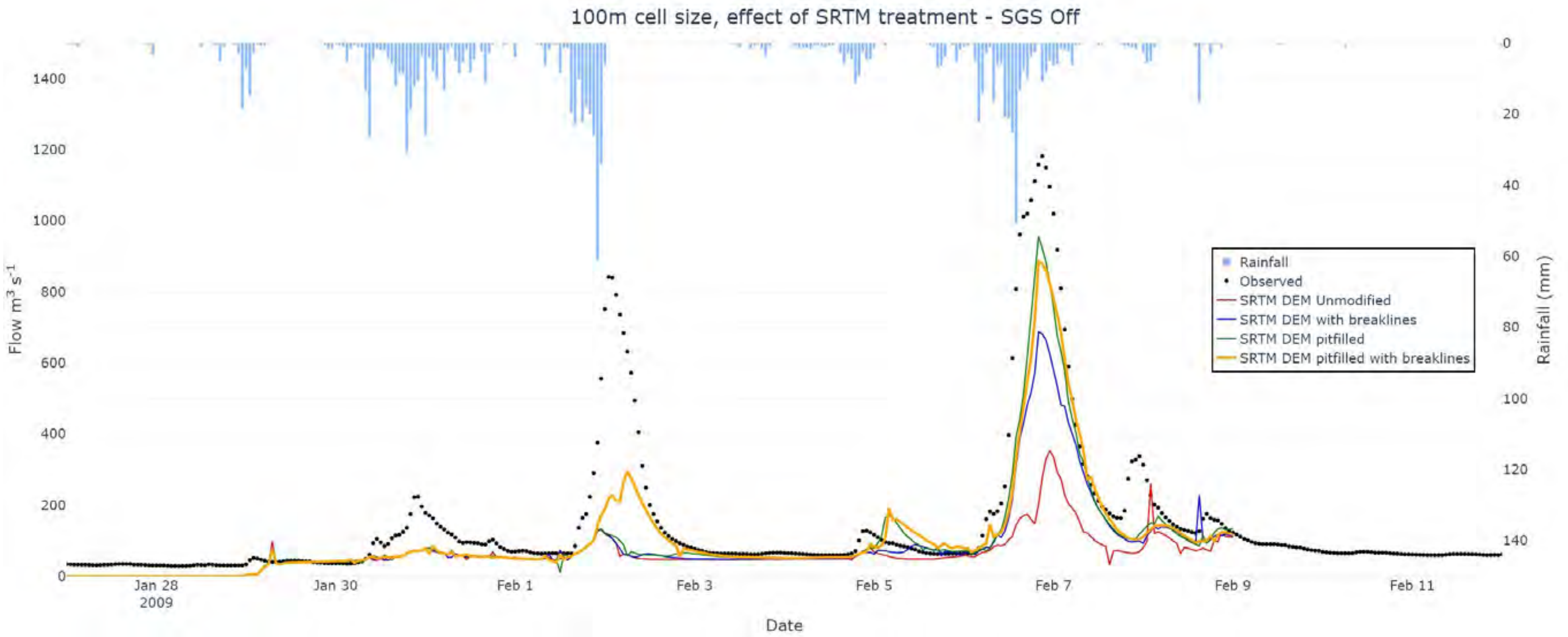
Case Study 2 – Rural
Original Treatment of SRTM DEM

Original Study

- Coarse resolution of SRTM data caused artificial storages
- Tested four treatments of SRTM DEM
  - DEM only – no changes
  - DEM + Breaklines
  - Pit filled DEM
  - Pit filled DEM + Breaklines

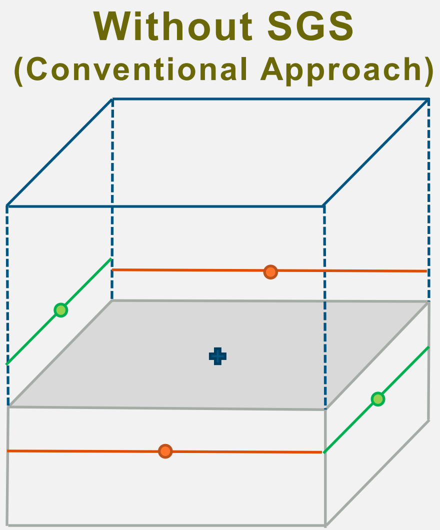


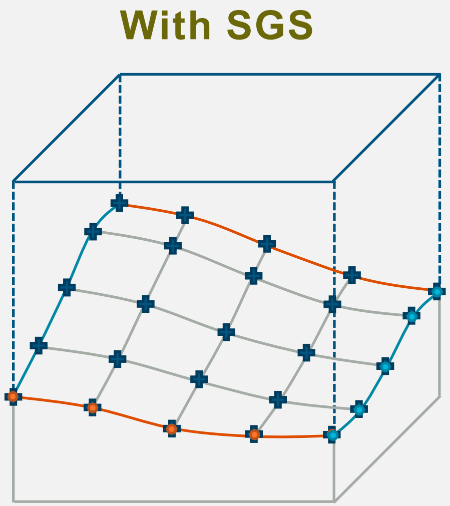
Case Study 2 – Rural
Testing of SRTM DEM Treatments



Case Study 2 – Rural
Sub-Grid Sampling (SGS) – Will it Help?

- Re-run using TUFLOW 2020's new SGS function
- For TUFLOW 2021, SGS also samples material (Manning's n) values





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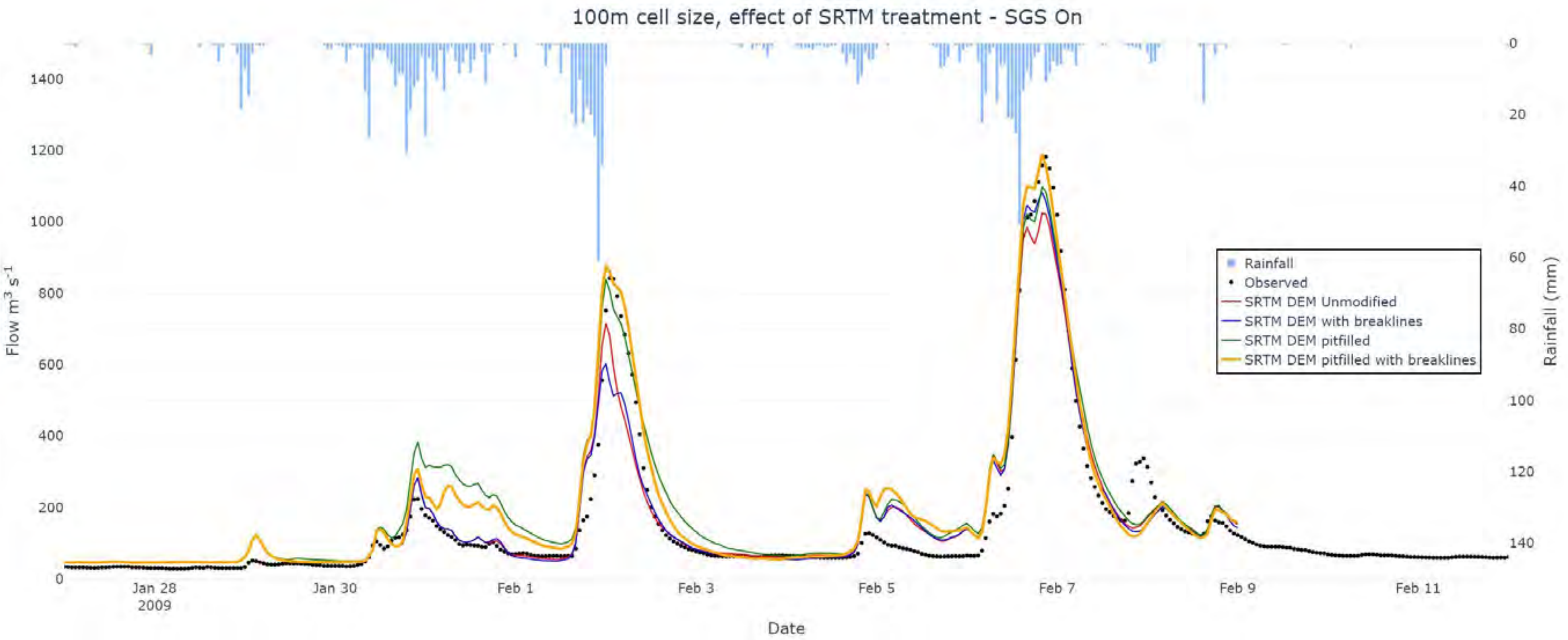
Case Study 2 – Rural
Testing of SRTM DEM Treatments – SGS

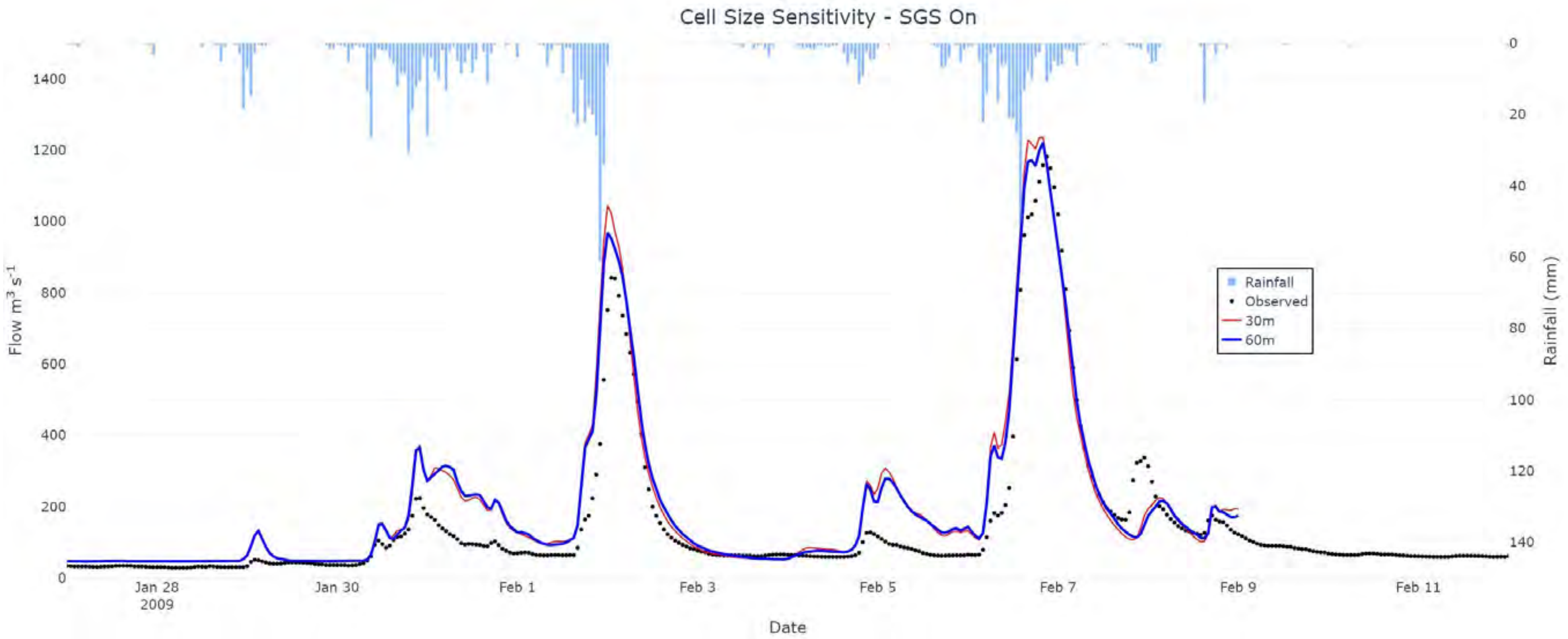


Case Study 2 – Rural
Cell Size Sensitivity

Results Convergence Testing

- Run with cell sizes from 120 to 30 m
- As cell size reduces, results should converge
- Key quality control task for all 2D/3D models
- Also helps set the largest cell size that should be used

Case Study 2 – Rural
Cell Size Sensitivity – SGS On



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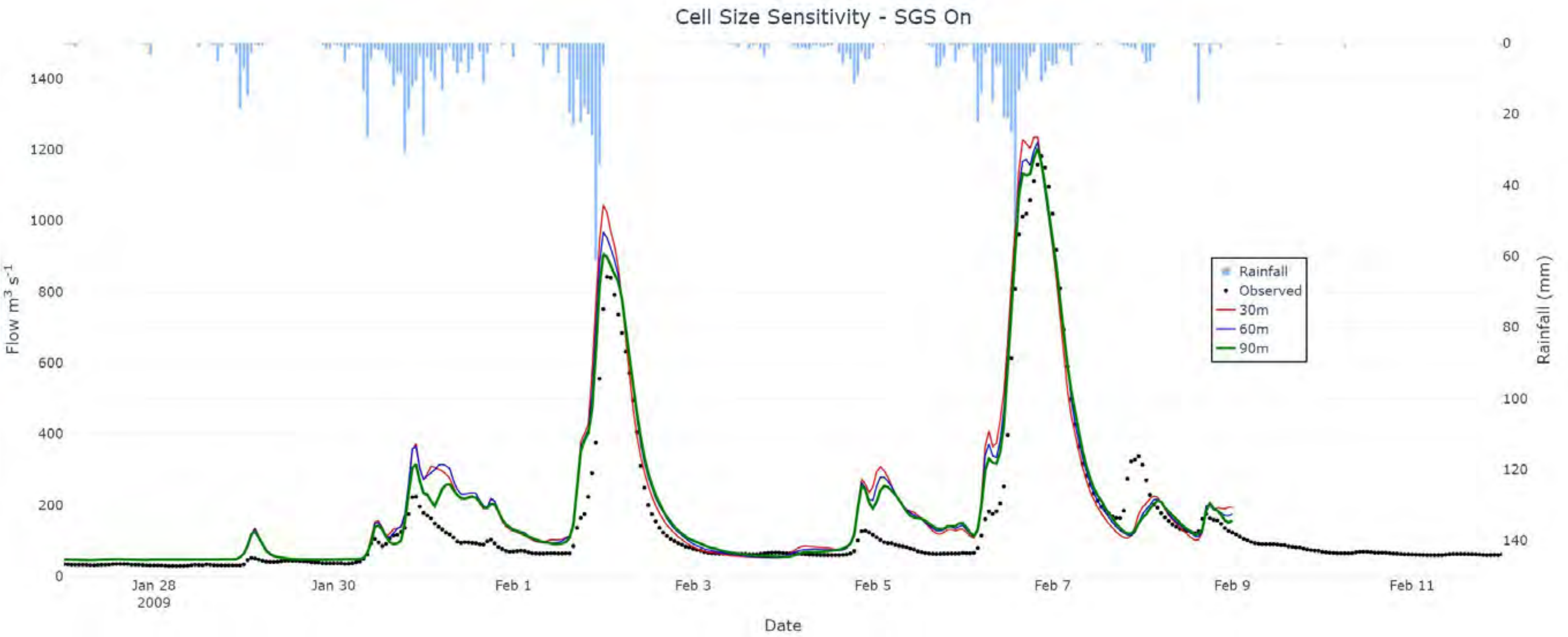

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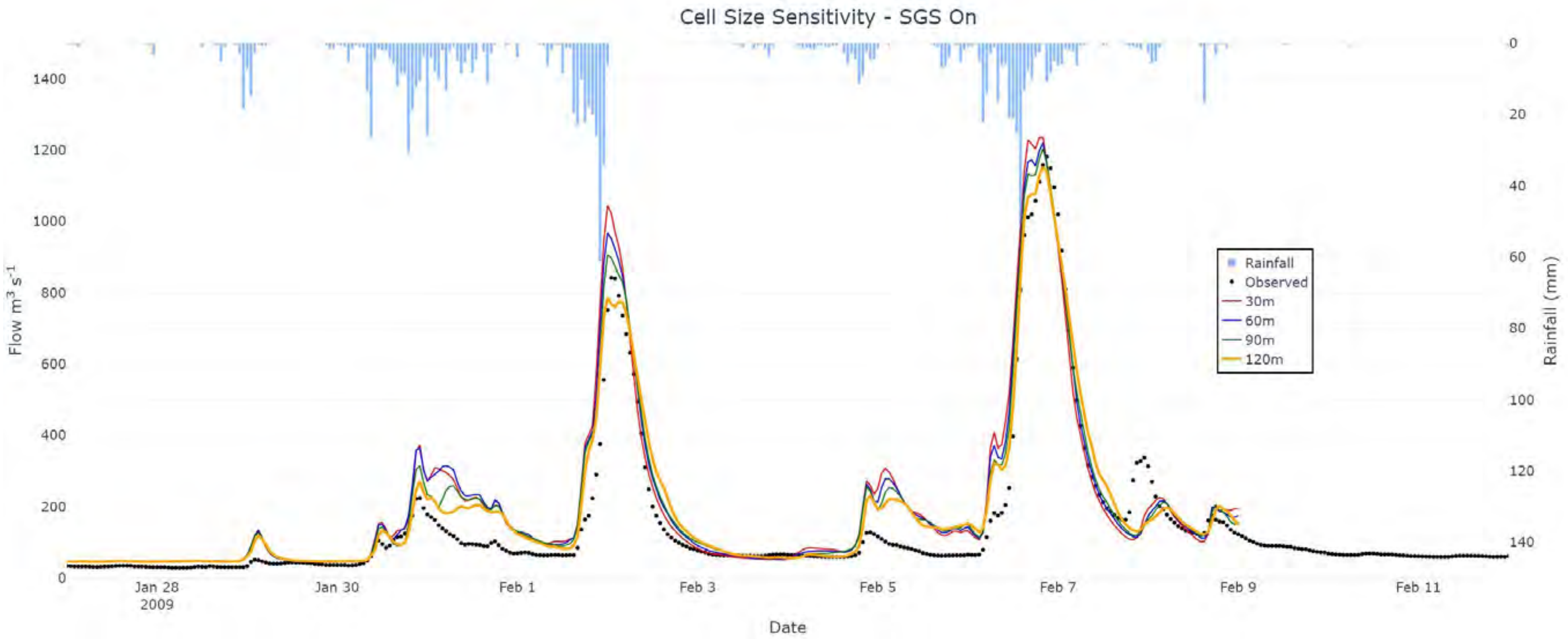

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Case Study 2 – Rural
Cell Size Sensitivity – Run times

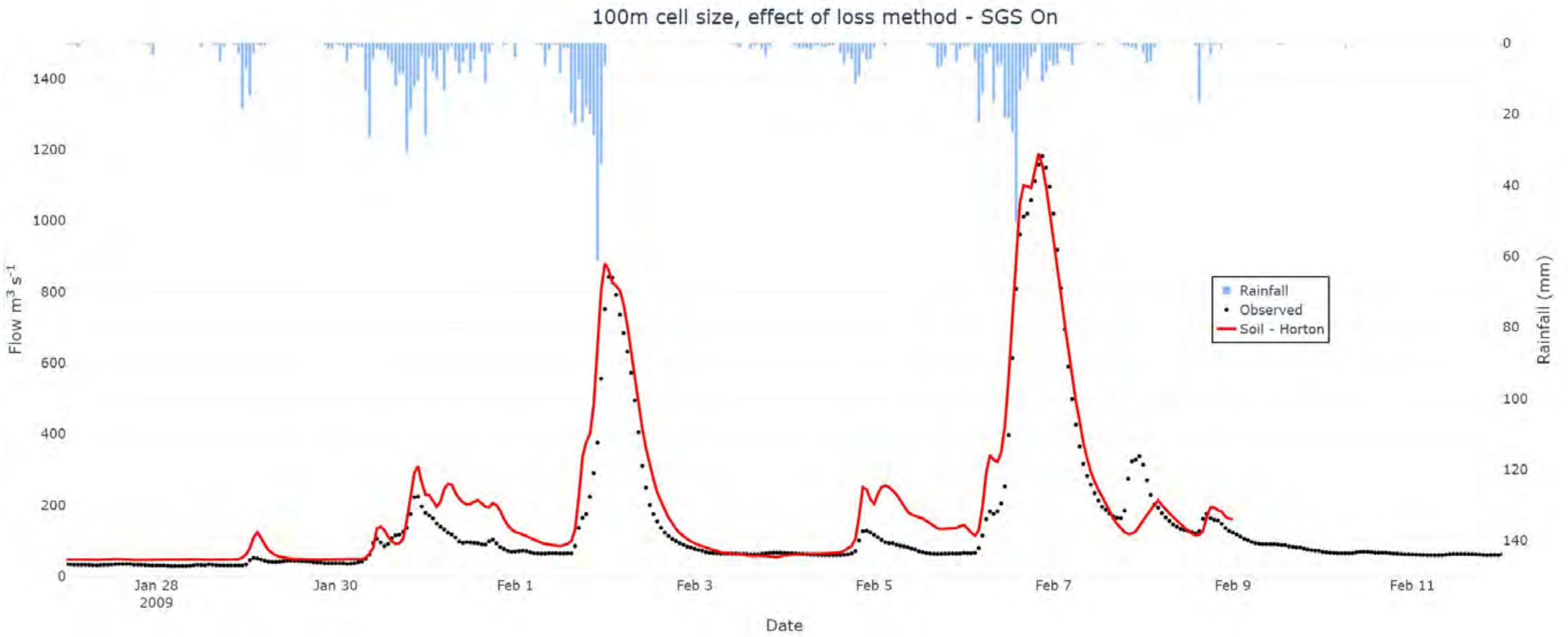
- Event duration is 27 days
- Run times for single Titan XP GPU card (released in 2017)

Cell Size (m)	Number Cells	Runtime SGS Off	Runtime SGS On	Runtime Increase for SGS
120	47,000	0:03:51	0:06:23	66%
90	83,000	0:08:25	0:12:15	46%
60	188,000	0:21:42	0:33:22	54%
30	751,000	2:36:19	3:26:10	32%

Case Study 2 – Rural
Infiltration Loss Method Testing

- Soil Infiltration Tests (infiltration only occurs on wet cells)
  - Initial Loss 0 mm, Continuing Loss 2 mm/hr
  - Horton Infiltration 5 mm/hr initial, 1 mm/hr final and Horton decay rate 0.01
  - Green Ampt loss with Clay Loam Soil Type
- Excess Rainfall Test (losses removed from rainfall before applying to cells)
  - Initial Loss 0 mm, Continuing Loss 2 mm/hr

Case Study 2 – Rural
Infiltration Loss Method Testing



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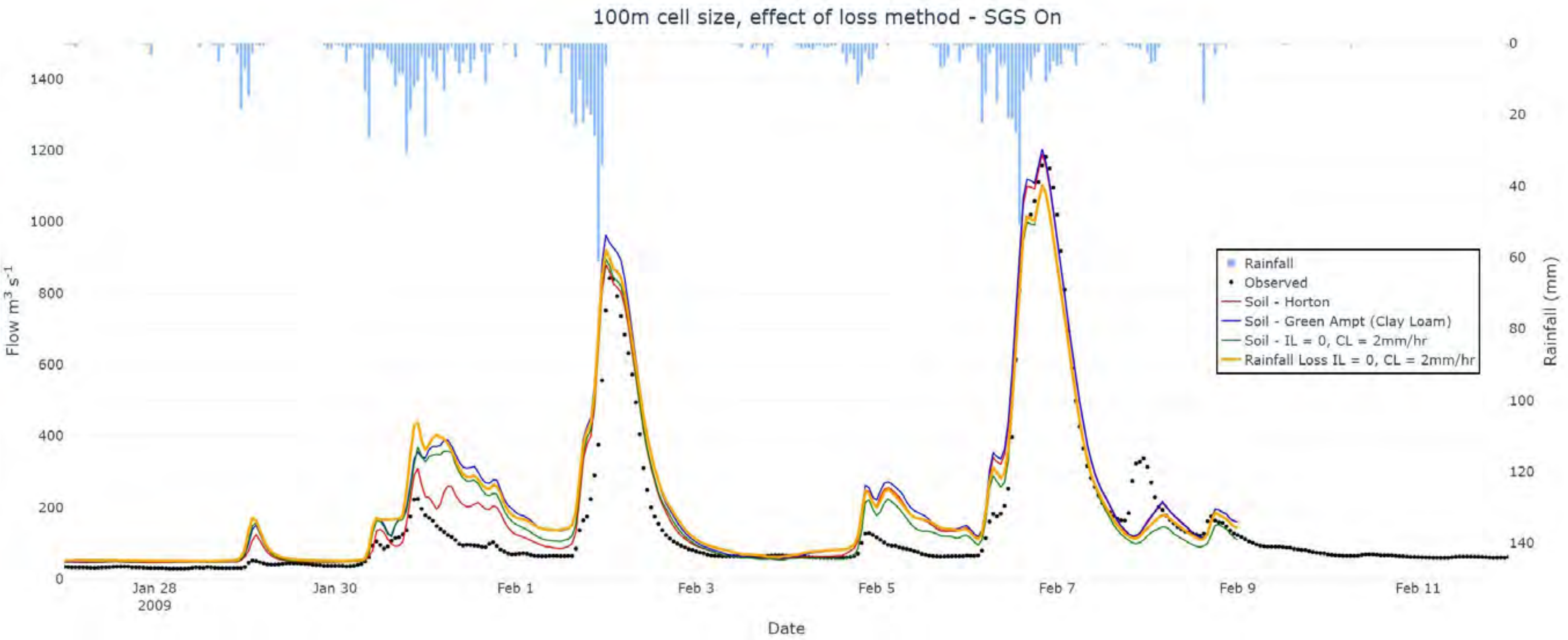
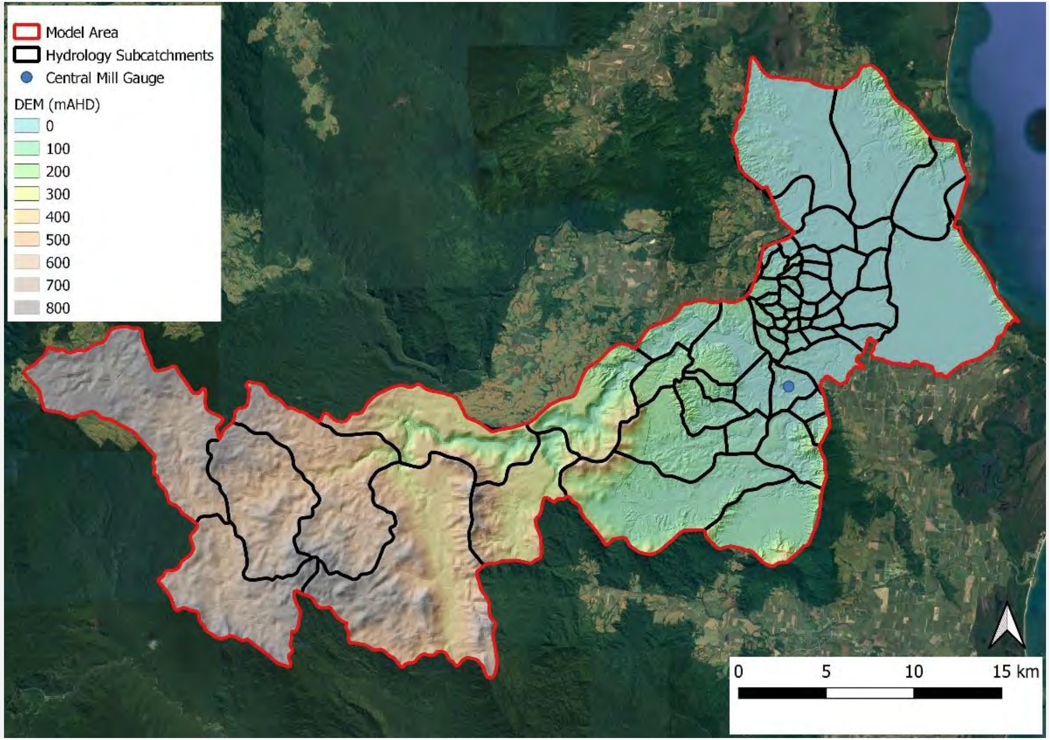


Case Study 2 – Rural
Comparison with Original Hydrology Model

- Comparison of flows with calibrated hydrology model
- Semi Distributed URBS Model



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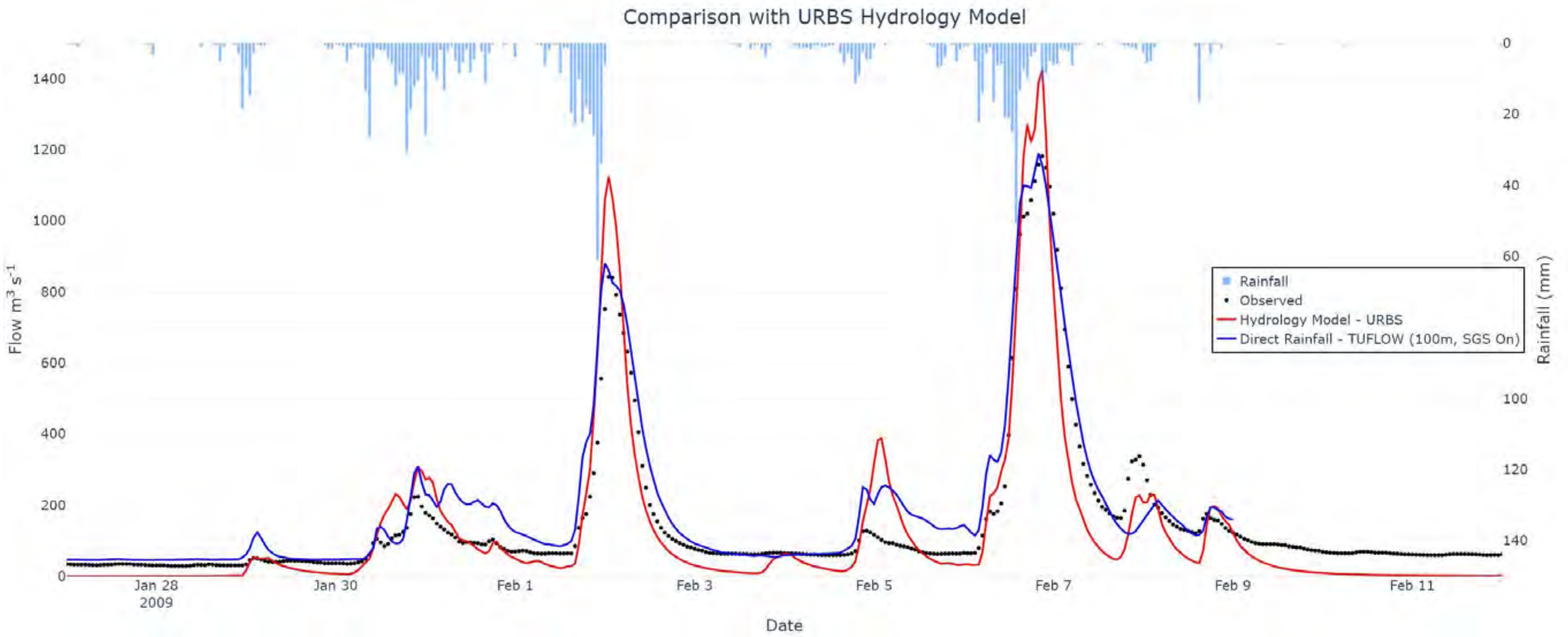


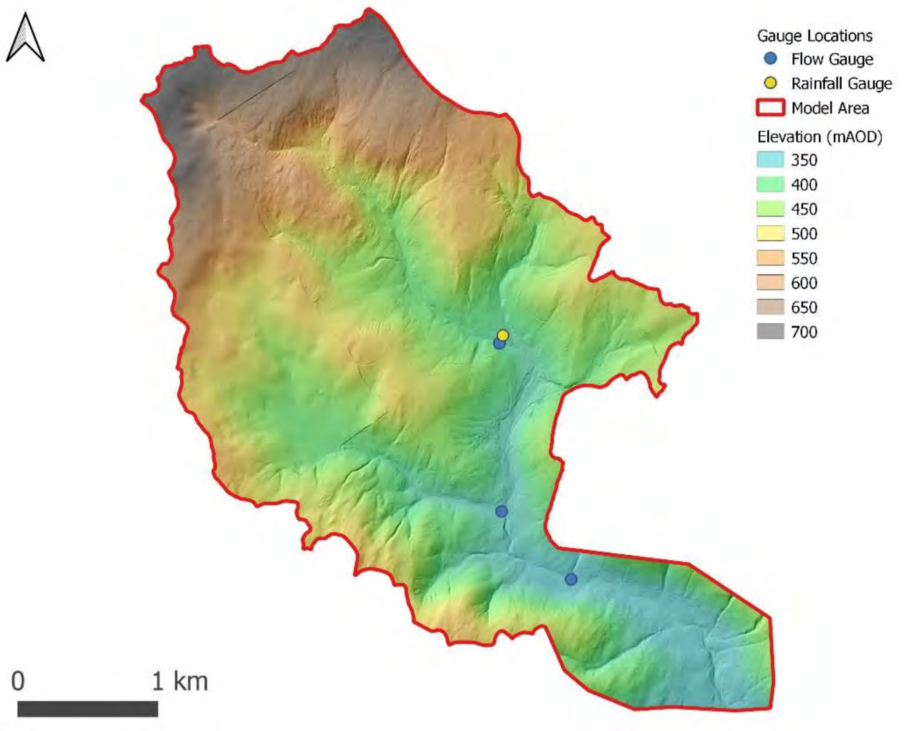
Case Study 2 – Rural Conclusions

- Direct rainfall (with SGS) produced superior calibration to semi-distributed hydrology model
- SGS essential
  - Substantially improves conveyance of water down DEM
  - Produces excellent cell size results convergence
  - Allows use of much larger cell sizes (therefore much faster run times)
- Very coarse and inaccurate DEMs (e.g. SRTM data) may still require pre-processing (e.g. pit filling)

Case Study 3 – Wales
Model Overview

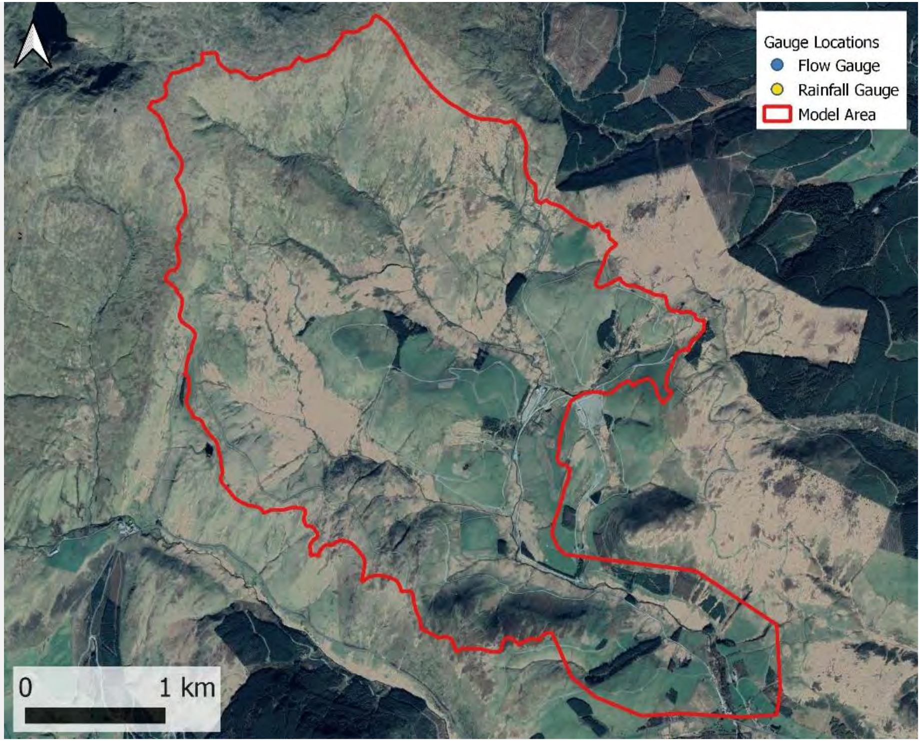
- Small Research Catchment in Wales
- Three control weirs for measuring flow
- Rainfall pluviograp within catchment

The LiDAR data used contains public sector information licensed under the Open Government Licence v3.0. The Plynlimon model contains data supplied by Natural Environment Research Council. The Plynlimon observed rain gauge and flow data was provided by the Centre of Hydrology, Bangor.



Case Study 3 – Wales
Model Overview

- Small Research Catchment in Wales
- Three control weirs for measuring flow
- Rainfall pluvio in catchment
- Predominate land use grassland

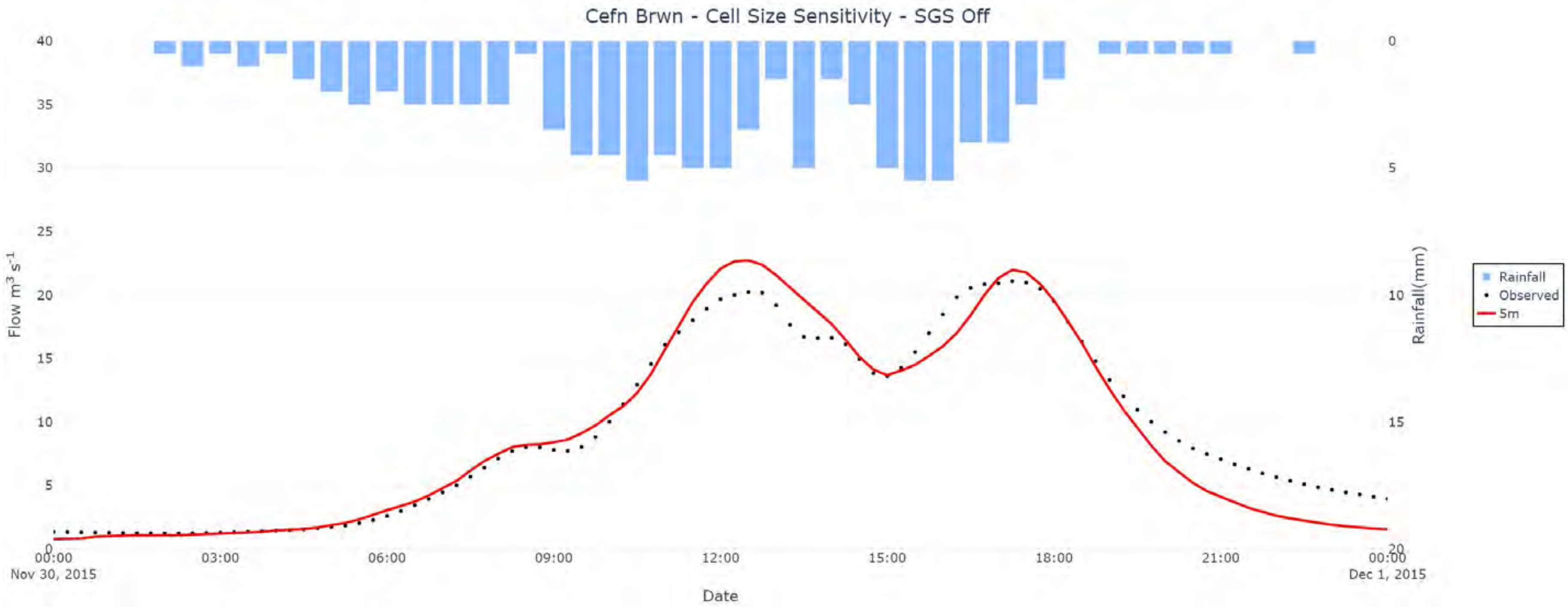


Case Study 3 – Wales
Cell Size Sensitivity – Results Convergence Testing

- Run with cell sizes from 40 to 5 m
- Test SGS on and off
- Event duration 24 hours
- Runtimes are for single Titan XP GPU card (released in 2017)

Cell Size (m)	Number Cells	Runtime SGS Off	Runtime SGS On
40	7,283	0:00:15	0:00:13
30	12,918	0:00:24	0:00:23
20	29,076	0:00:52	0:00:49
10	116,236	0:06:16	0:07:46

Case Study 3 – Wales
Cell Size Sensitivity – SGS Off



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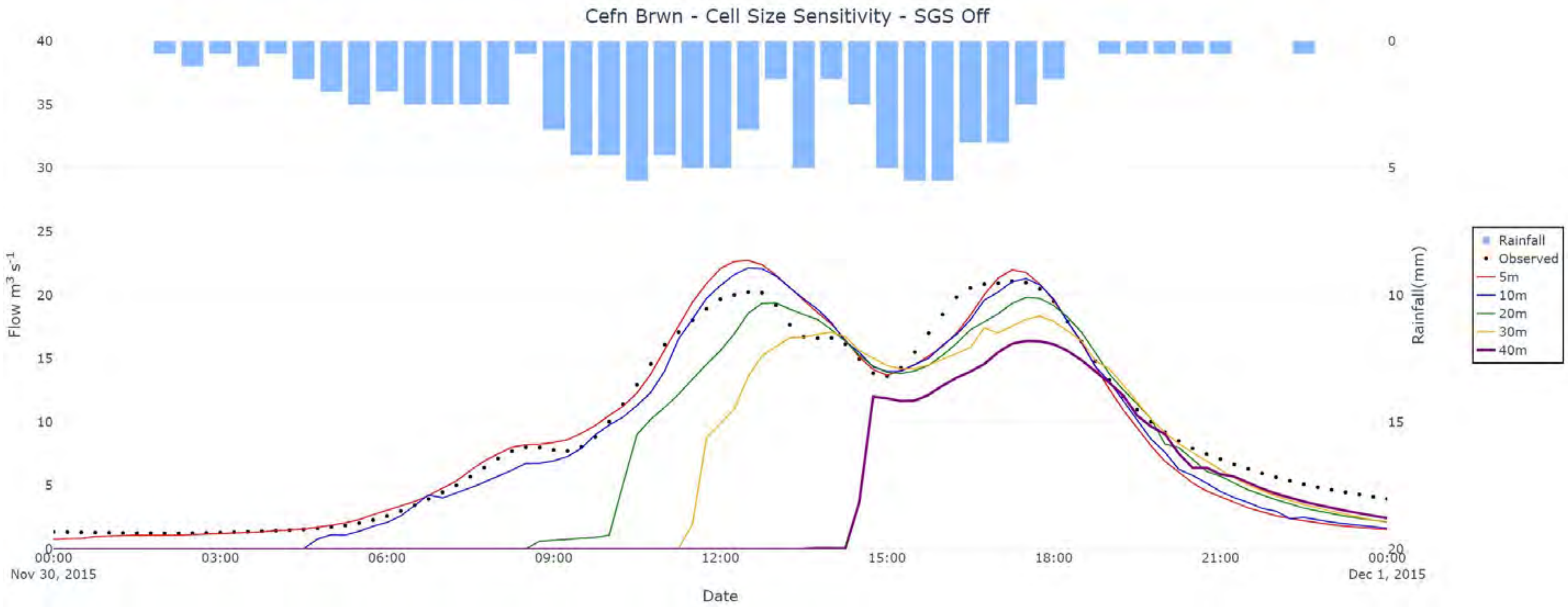
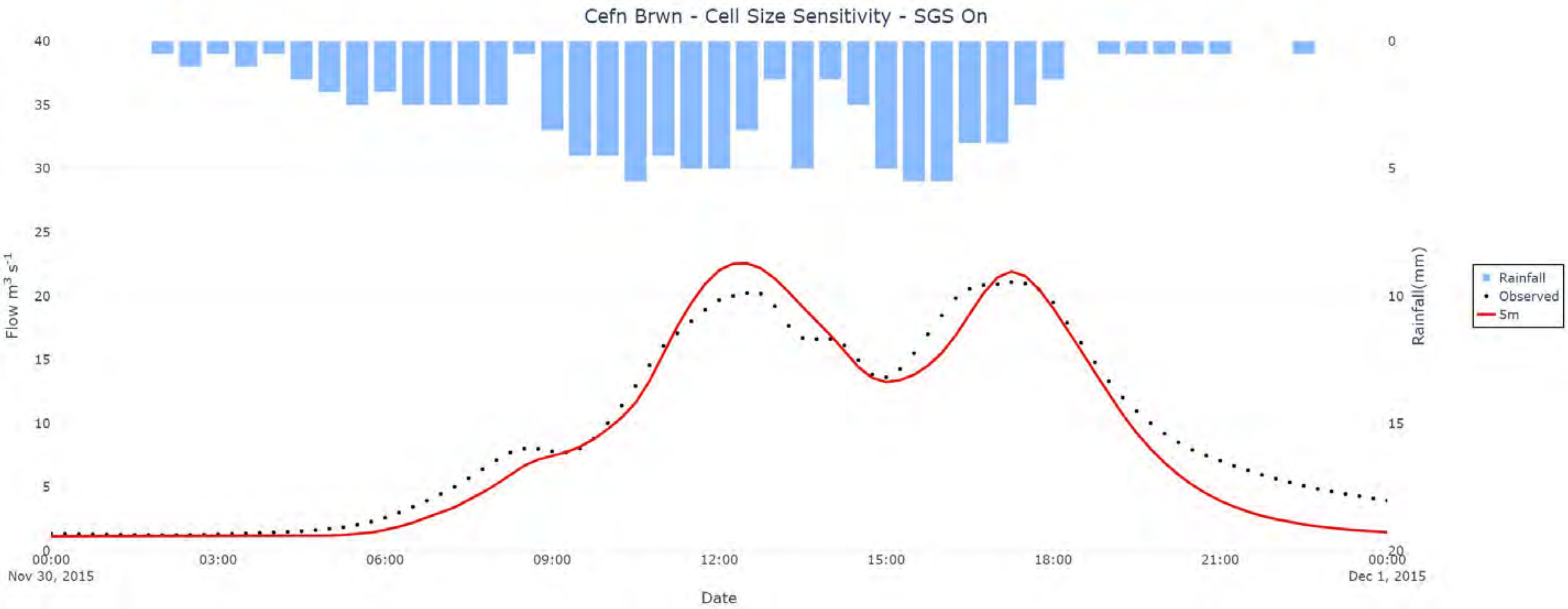
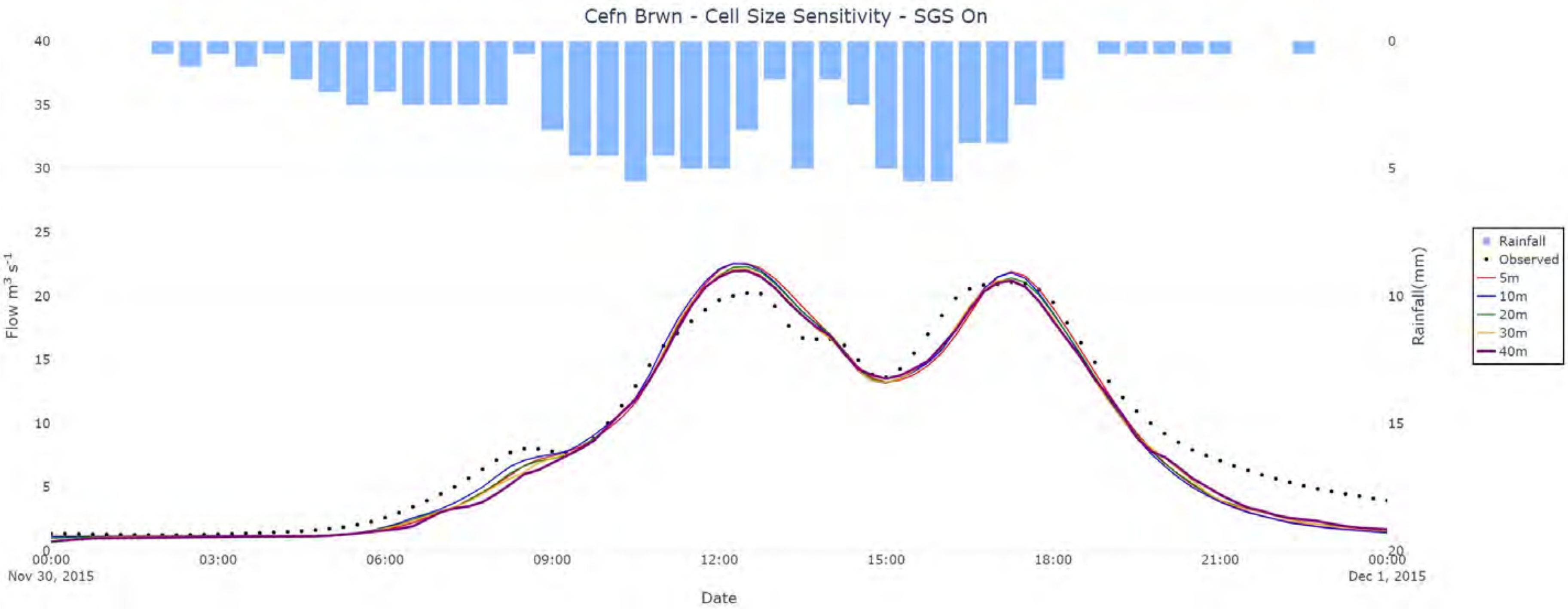
Case Study 3 – Wales
Cell Size Sensitivity – SGS Off



Case Study 3 – Wales
Cell Size Sensitivity – SGS On

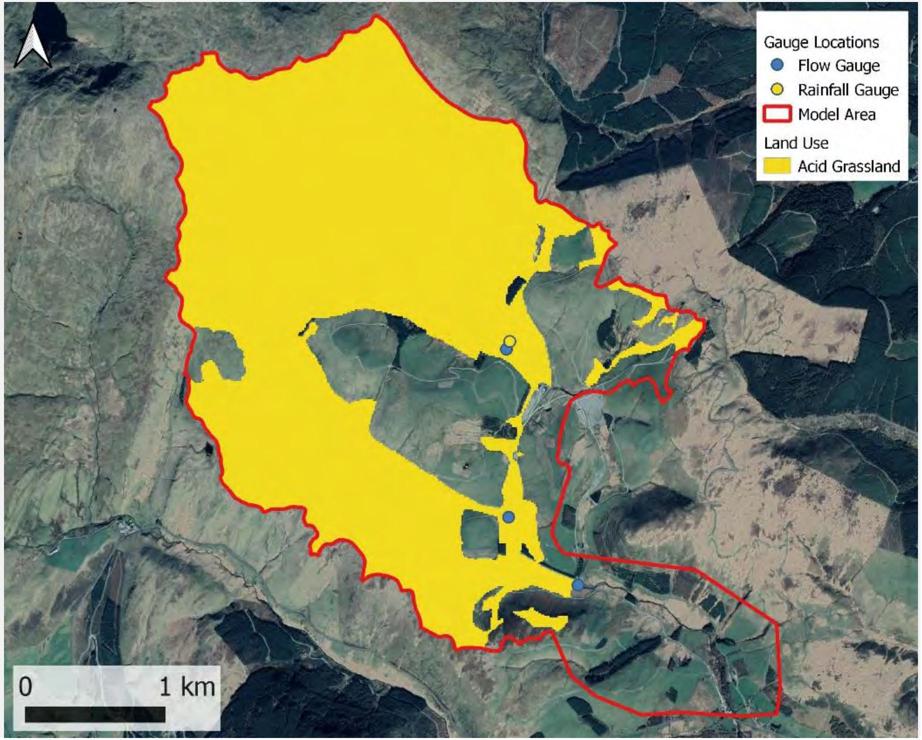


Case Study 3 – Wales
Cell Size Sensitivity – SGS On

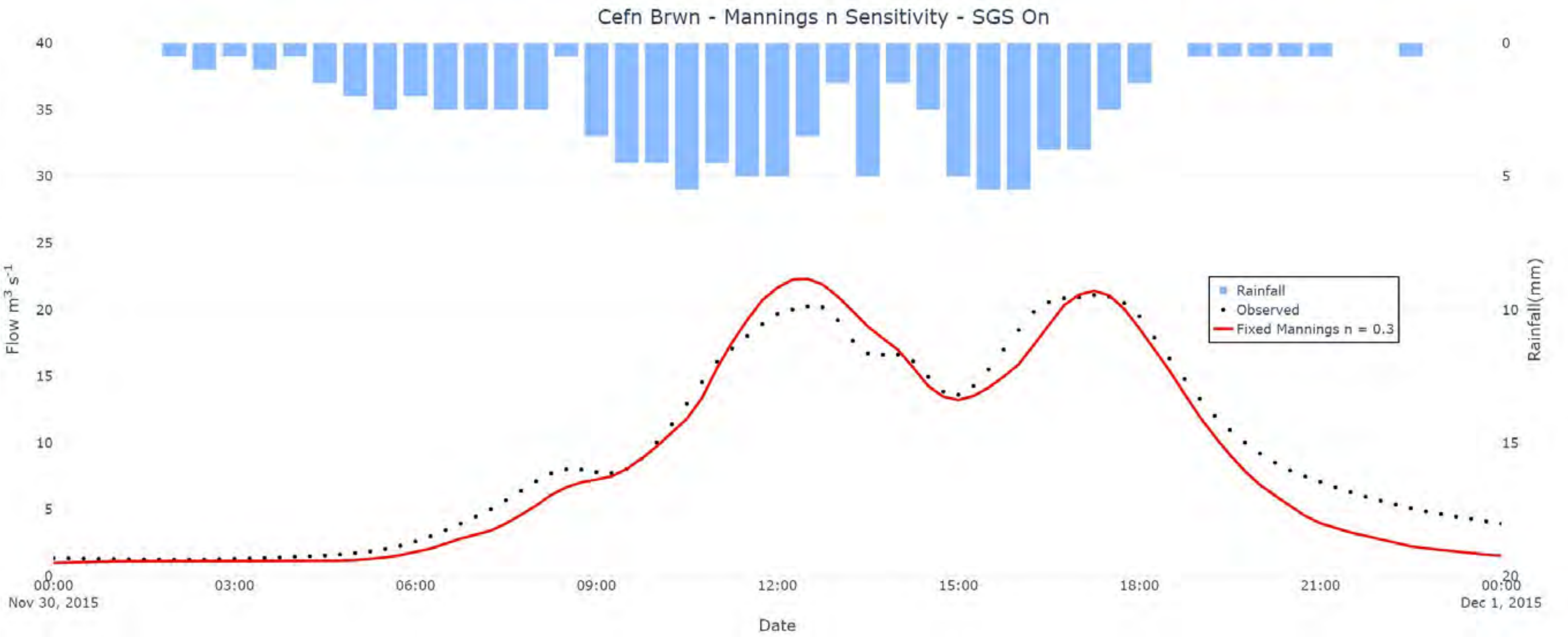


Case Study 3 – Wales
Manning's n Sensitivity Testing

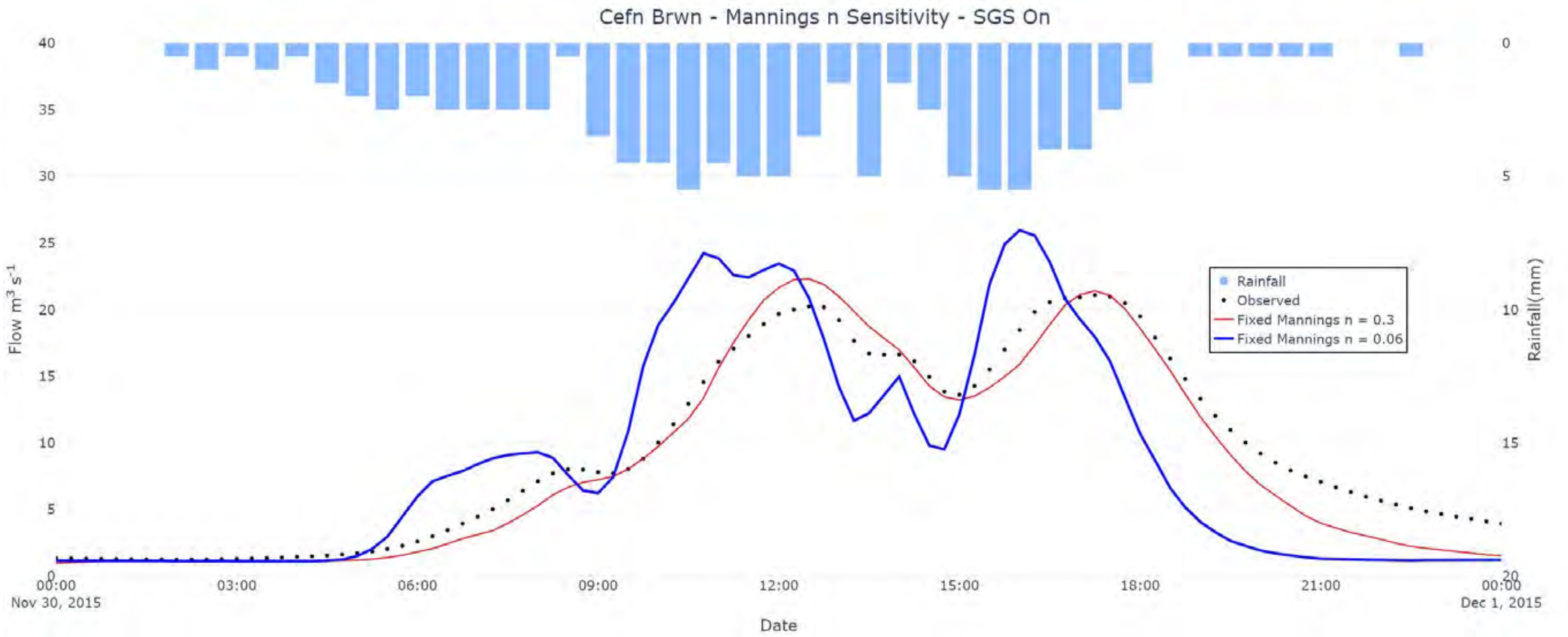
- Primary land use upstream of gauge is "acid grassland"
- Tested range of Manning's n values and approaches



Case Study 3 – Wales
Manning's n Sensitivity Testing – n 0.06 to 0.3



Case Study 3 – Wales
Manning's n Sensitivity Testing – n 0.06 to 0.3



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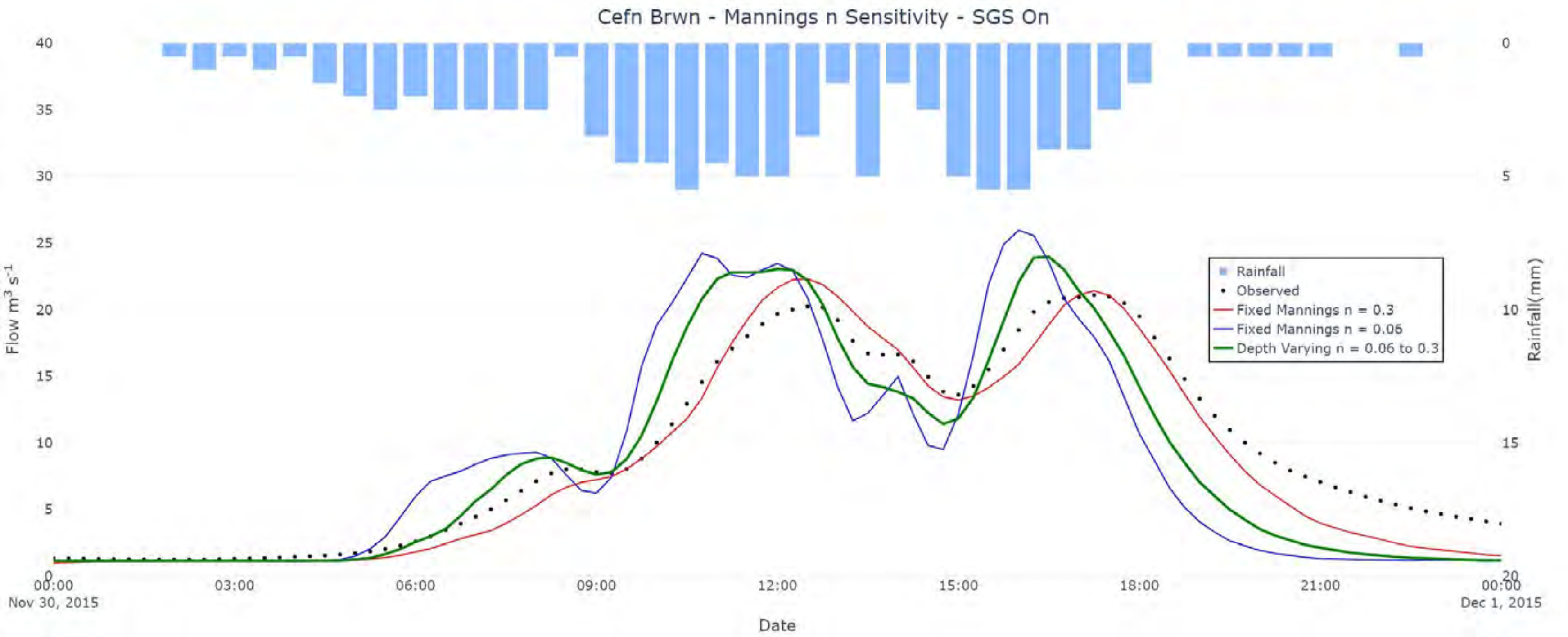
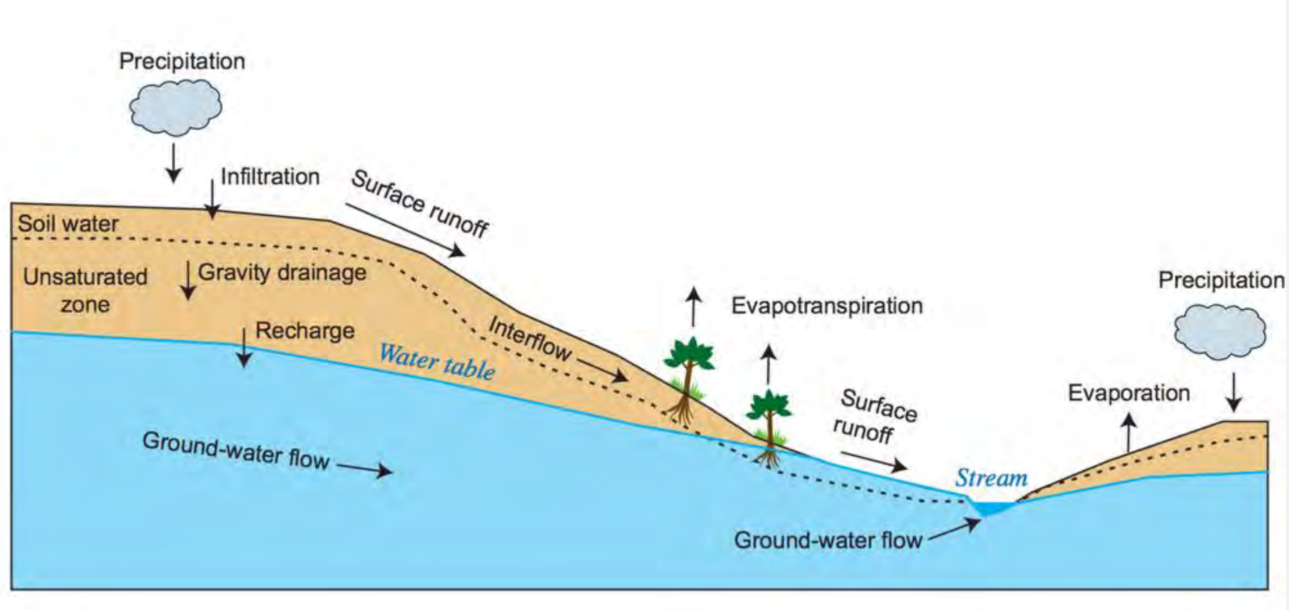
Case Study 3 – Wales
Manning's n Sensitivity Testing – n 0.06 to 0.3



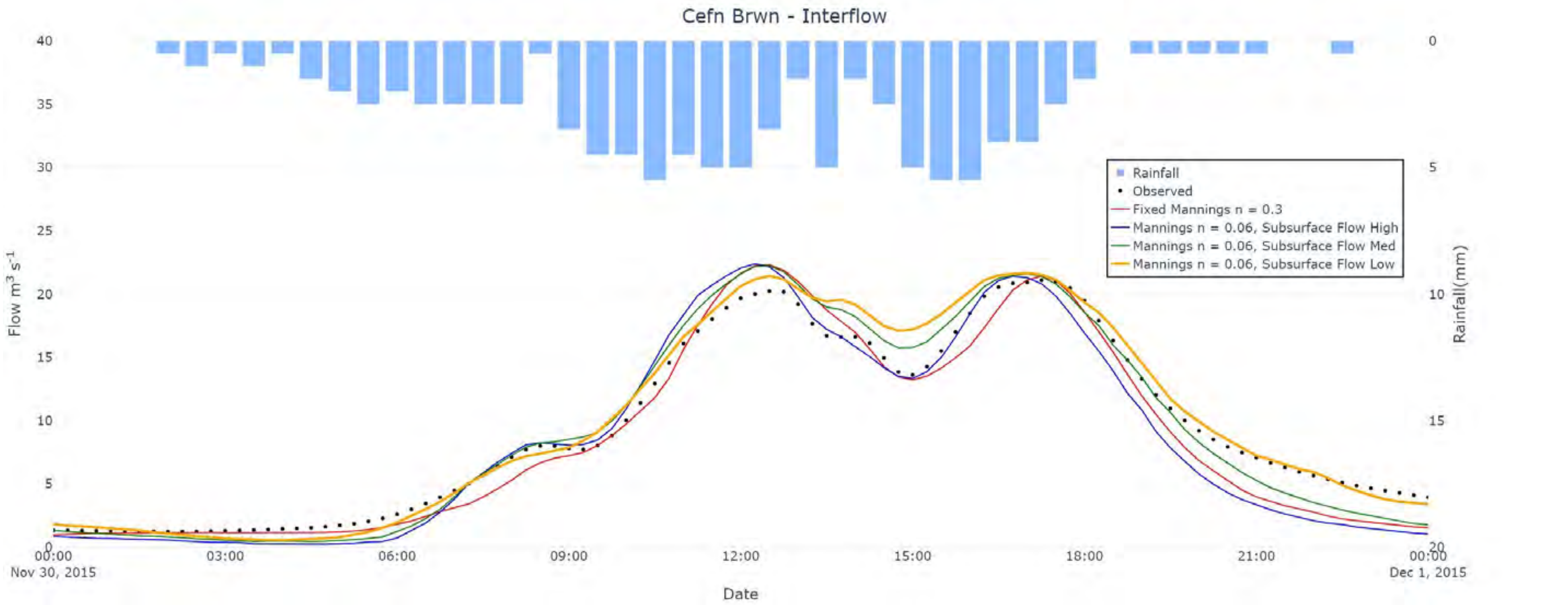
Case Study 3 – Wales
Shallow Flow Treatment?

- n = 0.3 produces best timing of peaks and attenuation of hydrograph
  - Is a high Manning's n for grassland warranted?
  - Or is some other flow mechanism at work?



Source: GSFLOW Manual (USGS)

Case Study 3 – Wales
Interflow Testing



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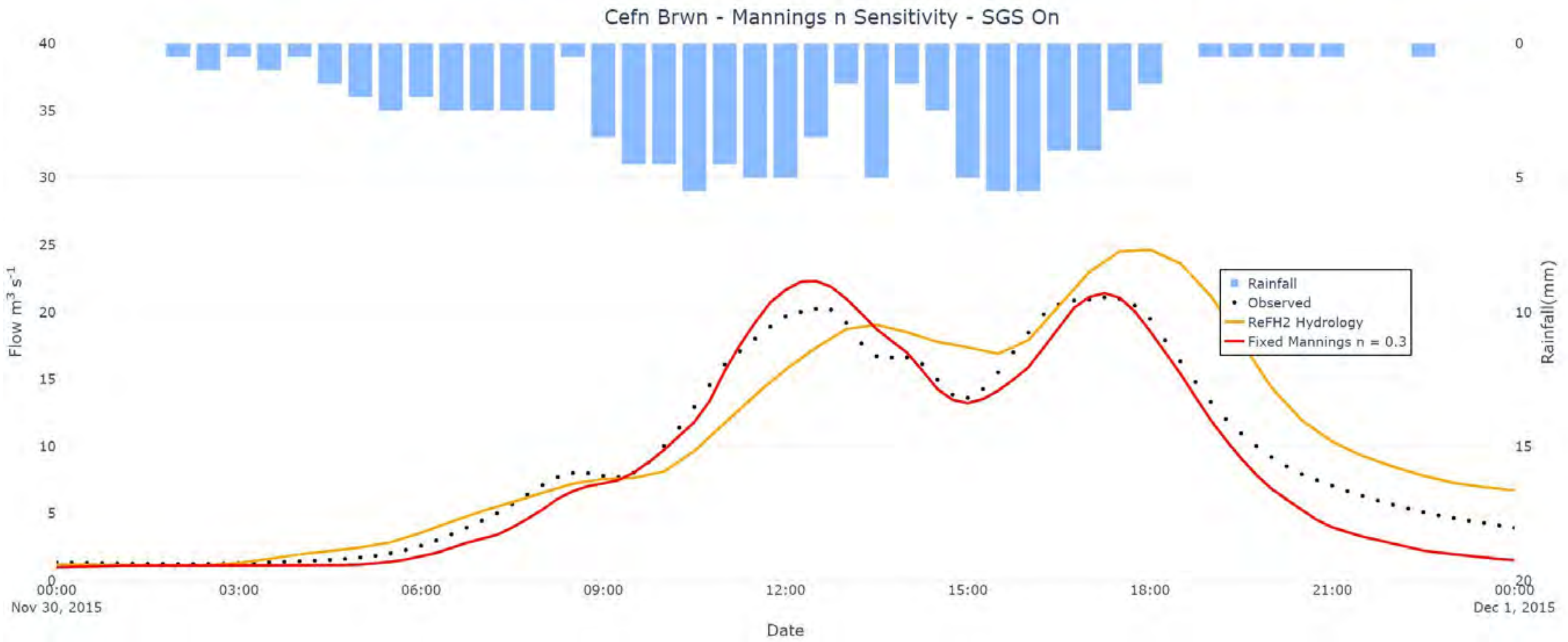
Case Study 3 – Wales
Comparison to ReFH2 hydrology

- Comparison of flows with calibrated hydrology model
- Lumped ReFH2 Model

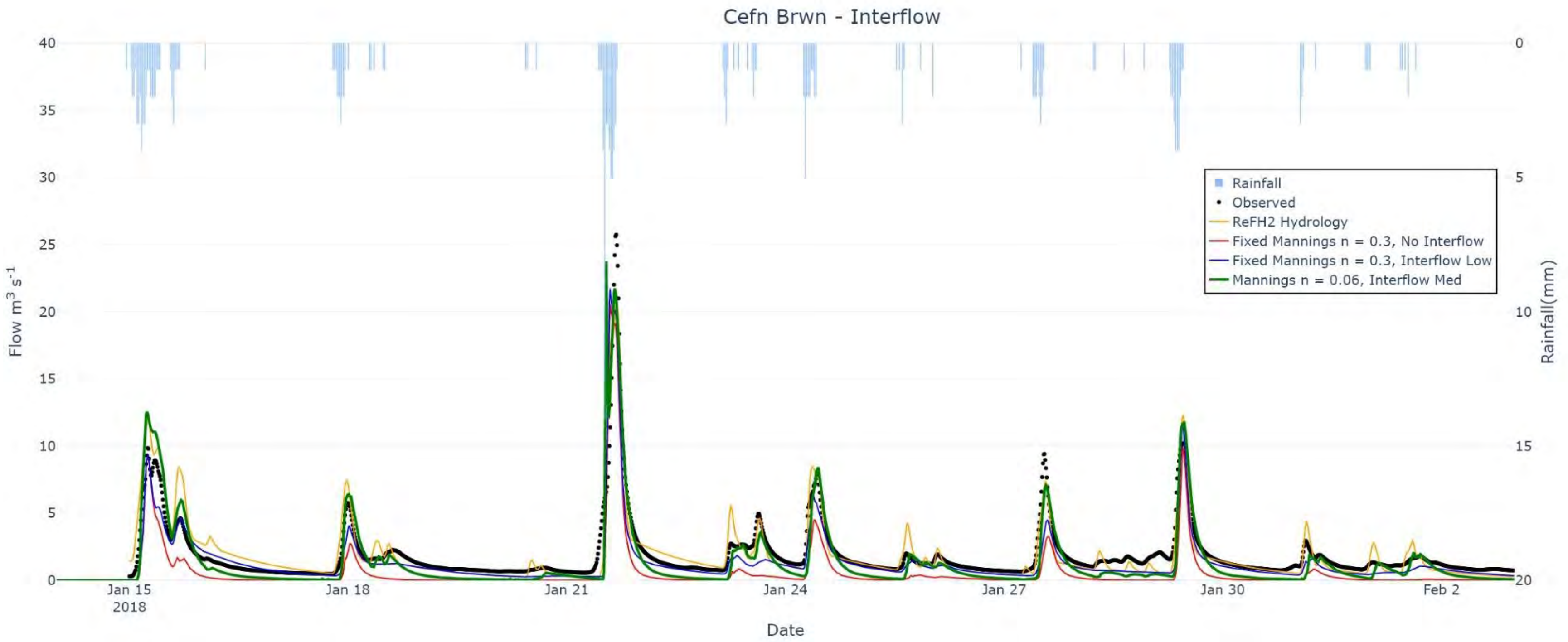
Case Study 3 – Wales
Comparison to ReFH2 hydrology



Case Study 3 – Wales
Longer Term Simulation

- Previous results were for single larger rainfall event
- What about for longer simulation?

Case Study 3 – Wales
Longer Term Simulation



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Case Study 3 – Wales
Infiltration Losses Testing – Continuous Simulation

- Rainfall intensity much lower than East Coast Australia
- 2 mm/h continuing loss results in too little flow over longer period
- However, no losses overestimates peak, poor on receding limb
- Interflow / baseflow are evidently important processes for this case study
  - Essential for longer term continuous simulations
- Interflow / baseflow capability built into TUFLOW 2021

Case Study 3 – Wales
Conclusions

Direct rainfall produced good calibration with caveats below

- SGS essential (once again)
  - Substantially improves conveyance of water down DEM
  - Produces excellent cell size results convergence
  - Allows use of much larger cell sizes (therefore much faster run times)
- Calibration only achieved with either:
  - Very high n value for very shallow flows through grasslands
    – reasonable match to peaks and timing

  or

  - Industry standard Manning's n with sub-surface interflow (baseflow) feature
    - improves calibration to catchment response and hydrograph shape after peak

Presentation Conclusions

Calibrate, calibrate, calibrate

- Other 2D software likely to perform differently, so benchmarking to calibration data sets essential

Test, test, test

- Cell size results convergence testing essential

Case studies show direct rainfall using TUFLOW HPC is a viable alternative to traditional hydrologic approaches provided

- Sub-Grid Sampling (SGS) is used
- Depth varying n values beneficial (e.g. buildings)
- Infiltration loss modelling needed for low rainfall intensity areas
- Sub-surface interflow feature needed for low rainfall, pervious catchments