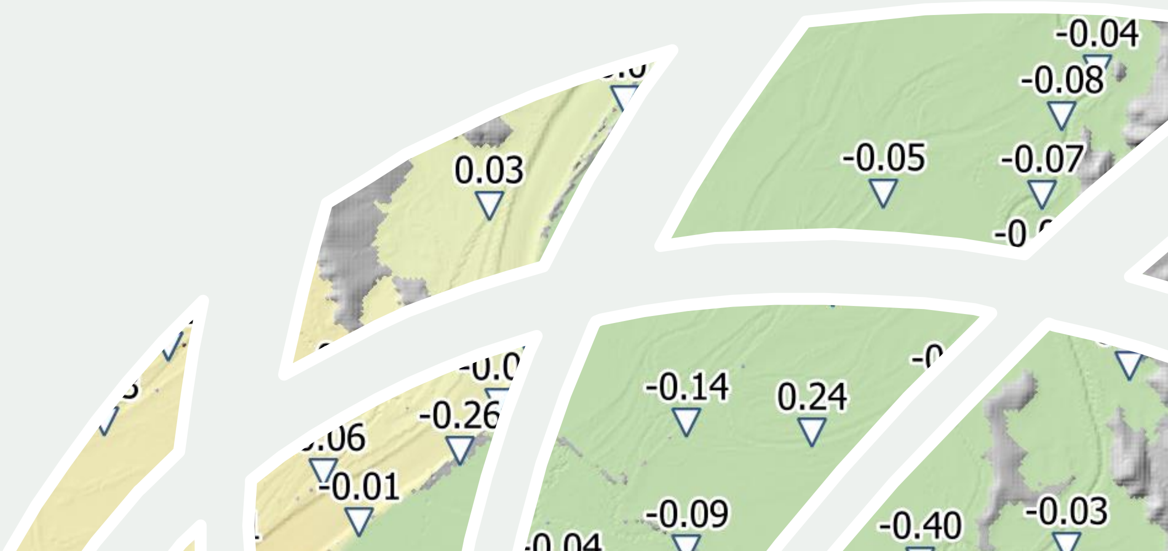
Hydraulic Model Calibration to Historical Events

Chris Huxley



Overview

1. Why is flood model calibration important?
2. Data input considerations
    - Calibration data types
    - Calibration data accuracy
    - Model input quality control
3. Model design
    - User decisions impacting calibration accuracy
    - Case study examples
4. Model calibration reporting
    - Types and common summary statistics

Why is Model Calibration Important?

Agencies commissioning projects and modellers building models have a duty of care to end users (the community) that flood modelling is fit for purpose

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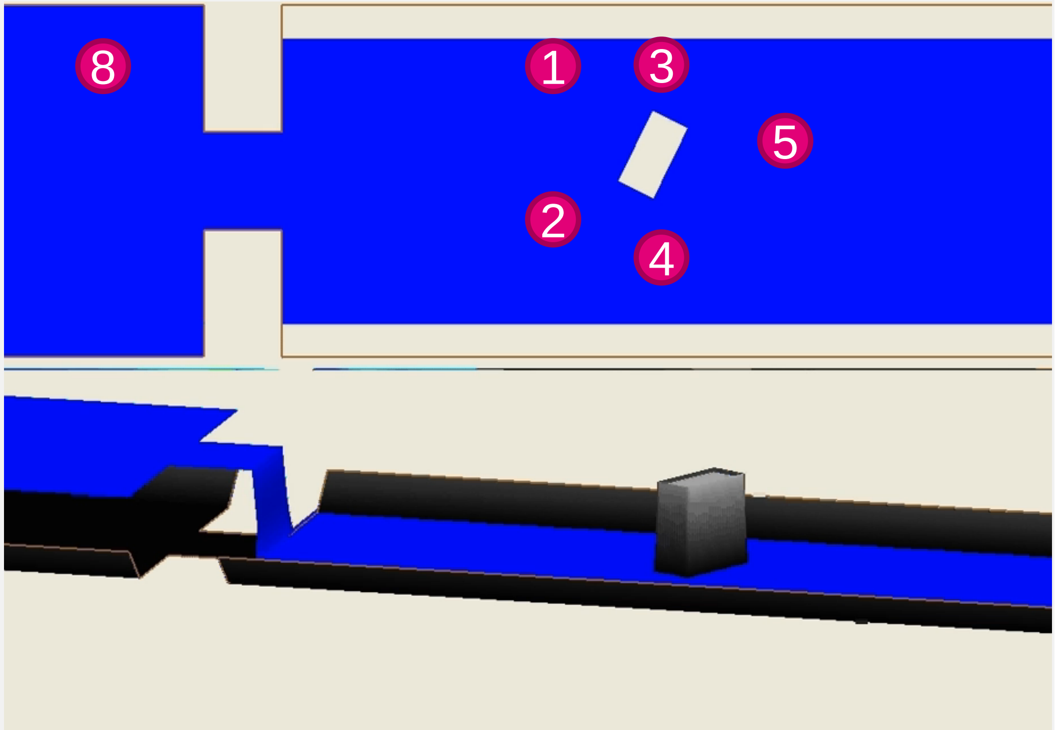
Why is Model Calibration Important?

Flood model results can be incredibly convincing!

Calibration is the only true way to verify that the models we develop are an accurate representation of the real world situation

How wrong is your flood model?
www.tuflow.com/library/webinars



Calibration Workflow

1 Confirm input data accuracy

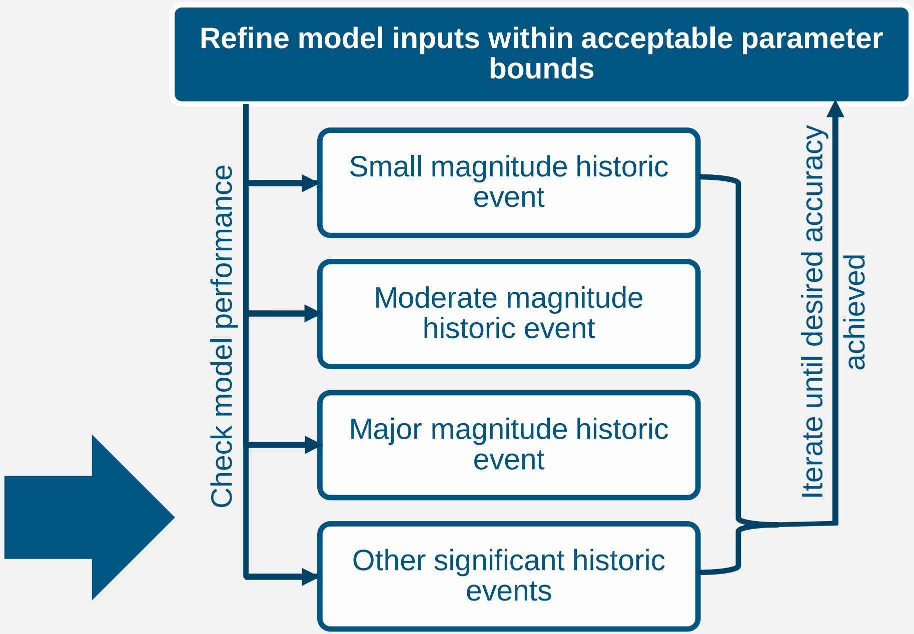
Calibration data and model inputs

2 Develop base model with appropriate features

Cell size, hydraulic control breaklines, industry standard Manning's n and bend losses etc.

3 Calibrate model to multiple historic events

Various event magnitudes



LinkedIn Discussion

"In 2013 Seqwater undertook a study of the Brisbane R which calibrated a suite of flood hydrologic models to 35 flood events dating from 1893. An objective method of determining model parameters was developed which included data quality, rating reliability, event magnitude, peak ratio, volume ratio and goodness of fit (Nash-Sutcliffe)… I've adopted this approach in 100s of models and 1000s of events throughout Australia.

It's easy to calibrate an event but far more difficult to calibrate a model."

Terry Malone (April 2020) – ex SEQ Water, Sun Water, BoM

Calibration of a model to multiple historic events is important to ensure a model can perform adequately for a range historic event magnitudes

LinkedIn Discussion
Model Calibration Cost?

What is a reasonable cost for model calibration, relative to the total project budget during a standard flood study?

1. I don't have enough hands-on calibration experience to answer this question
2. 10%
3. 20%
4. **30%**
5. 40%
6. 50%

The upfront cost of calibration is far less than the potential follow-on costs/damages resulting from inaccurate uncalibrated modelling

Modelling

Potential Sources of Calibration Error

Systematic consideration of all potential sources of error is key to developing an accurate flood model

1. Data Issues
   - Recorded flood calibration data
   - Boundary condition inputs
   - Model geometry inputs
2. Model Build / User Error
   - Model input data interpretation
   - Model design
3. Software Assumptions / Applicability
   - Hydrology model
   - Hydraulic model

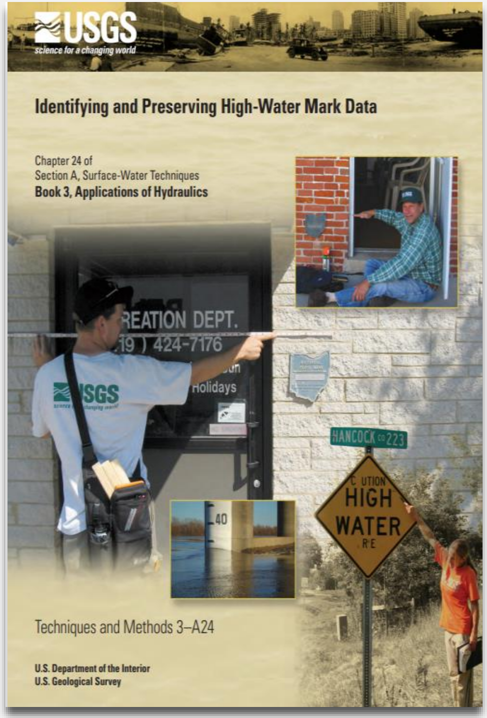
Calibration Data

Calibration Data Types

- Surveyed peak flood levels
  - Maximum height gauges
  - Water marks on buildings
  - Debris lines
- Continuous water level gauges
- Velocity gauging
- Anecdotal evidence
- Flood extent aerial imagery

Counties, Catchment Management Authorities, Councils, Cities take note!

- Collection and cataloging of these data immediately after an event is preferred
- Interagency coordination is beneficial



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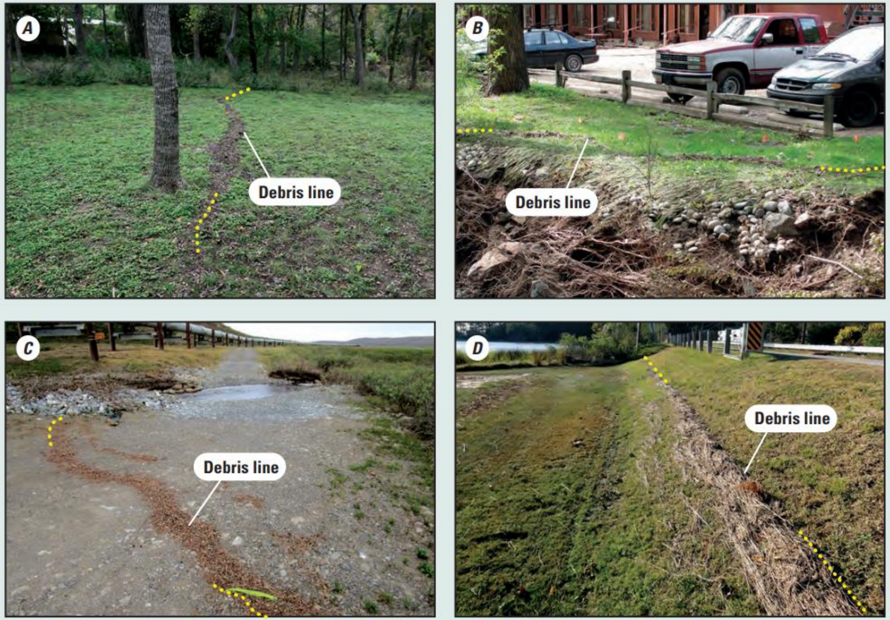
Calibration Data Preparation
Peak Flood Level Data

- Understand peak level reliability (1 = high, 2 = medium, 3 = low)

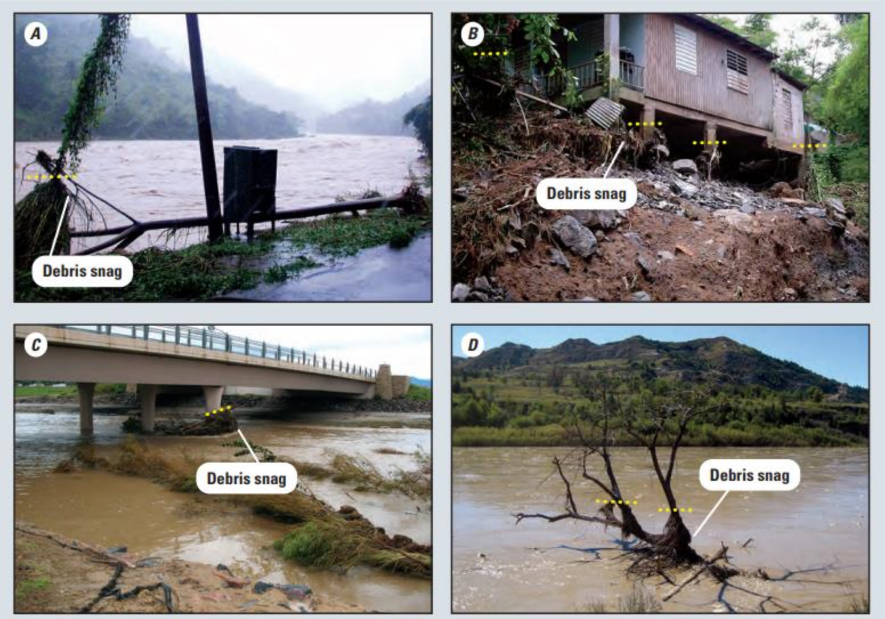


Identifying and Preserving High Water Mark Data (USGS, 2016)

Calibration Data Preparation
Peak Flood Level Data

- Understand peak level reliability (1 = high, 2 = medium, 3 = low)

Debris snags (sometimes called “trash snags” or “flood trash” in urban settings) are formed when coarse debris collects on an obstruction in the water, such as a structure, pole, fence, guy wire, tree, boulder, or bush (fig. 23). Note that some piles may be taller than others, leading to a large amount of uncertainty regarding the actual peak water surface. Large pileups can result from deposition of new materials at different stages as the water recedes. Conversely, the pileups may also result from swift flow forcing new material on top of older material. When swift flow encounters obstructions, water may run up higher on the upstream side of the object and draw-down lower on the downstream side, as shown in figure 24. This can also cause coarse debris to pile up higher than the flood peak surface, so these piles should be assigned a suitably large uncertainty or remain unused.



Identifying and Preserving High Water Mark Data (USGS, 2016)

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Calibration Data Preparation
Peak Flood Level Data

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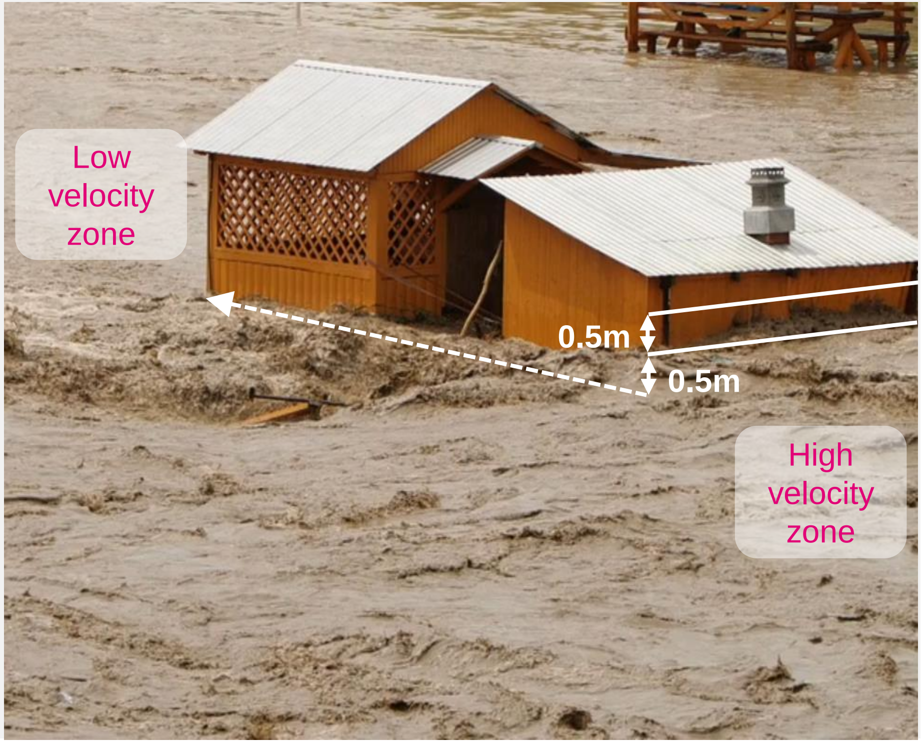


Calibration Data Preparation
Peak Flood Level Data

- Understand peak level reliability (1 = high, 2 = medium, 3 = low)

If surveying levels marked on a building from a past event, check the structure has not been raised since the flood!

Figure 5. A stain line on a wood door that has absorbed floodwater. Note the seed line below the stain line, indicating the true high-water elevation at this location and the amount that could be overestimated because of porous material wicking.

Identifying and Preserving High Water Mark Data (USGS, 2016)

Calibration Data Preparation
Peak Flood Level Data

- Understand peak level reliability (1 = high, 2 = medium, 3 = low)

Mud line identification presents several pitfalls that can be avoided with proper awareness. The "Paria River, Arizona" narrative illustrates some of these pitfalls. High-velocity, high-sediment-load rivers can paint lines on structures such as bridge piers; however, the lines may generate misleading high-water marks because of waves, pileup, and drawdown generated by the structures themselves (fig. 22). Hydrographers should note the variability in mud-line elevations on a large structure, especially in the upstream to downstream direction, before determining if the mud lines should be used as high-water marks. If highly-variable mud lines must be used, recording the measured amount of variability is important, as described in the Evaluation section of this manual. For smaller obstructions where runup is evident on the upstream side and drawdown is evident on the downstream side, a mark can be assumed halfway between the two extremes.

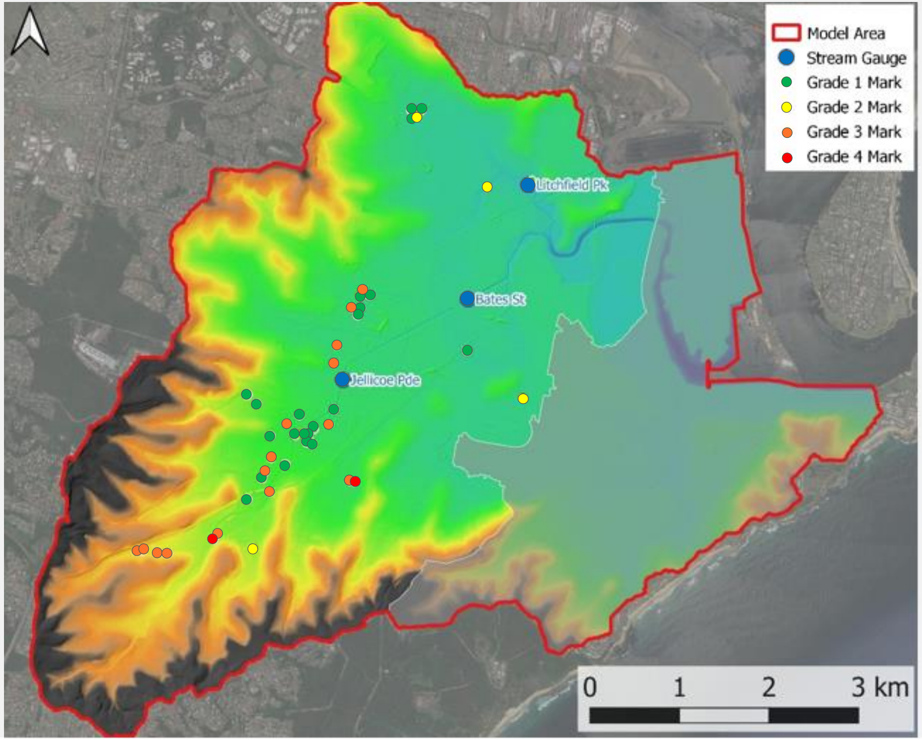
As with wash lines, care should be taken with mud lines to watch for receding soil saturation that may masquerade as mud lines and underestimate the actual peak water surface.

Figure 21. A rapid-water mud line of a different color than the existing bed sediment. Photograph by Jon Mason.

Identifying and Preserving High Water Mark Data (USGS, 2016)

Calibration Data Preparation
Peak Flood Level Data

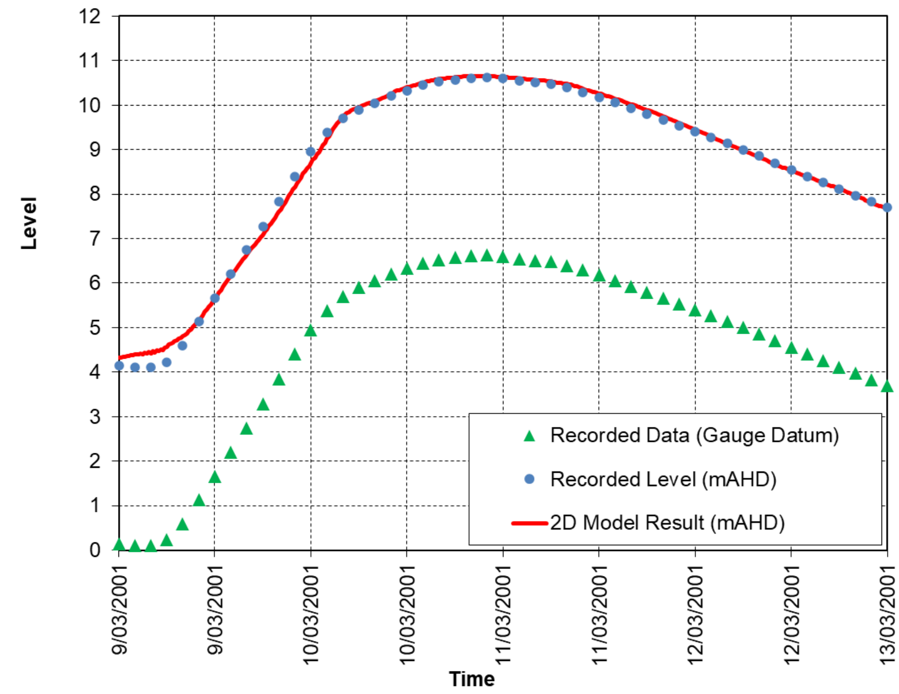
- Understand peak level reliability (1 = high, 2 = medium, 3 = low)
- Common sense check
  - Regional continuity
  - DEM verification



Is Direct Rainfall (Rain-on-Grid) Accurate? – Phillip Ryan
www.tuflow.com/library/webinars

Calibration Data Preparation
Water Level Gauges

- Confirm gauge datum (not AHD):
  - Inland gauges can use a local datum to offset base elevation



Calibration Data Preparation
Water Level Gauges

- Confirm gauge datum (not AHD):
  - Inland gauges can use a local datum to offset base elevation
  - Coastal gauges can use Lowest Astronomical Tide (LAT) as datum for navigation purposes

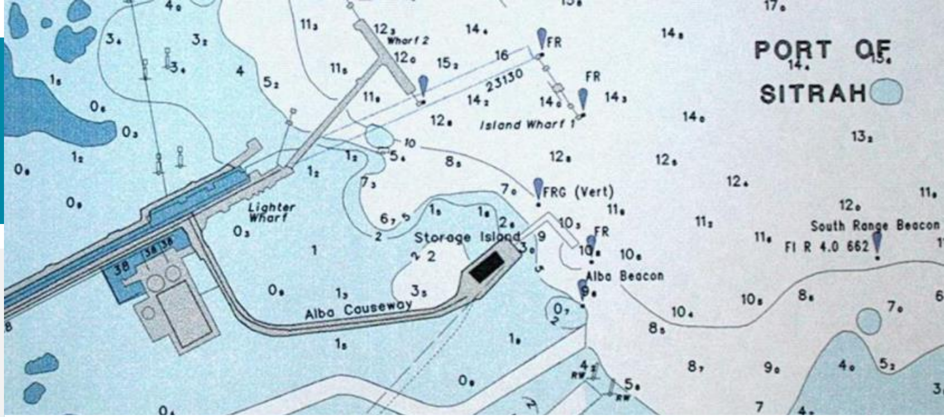
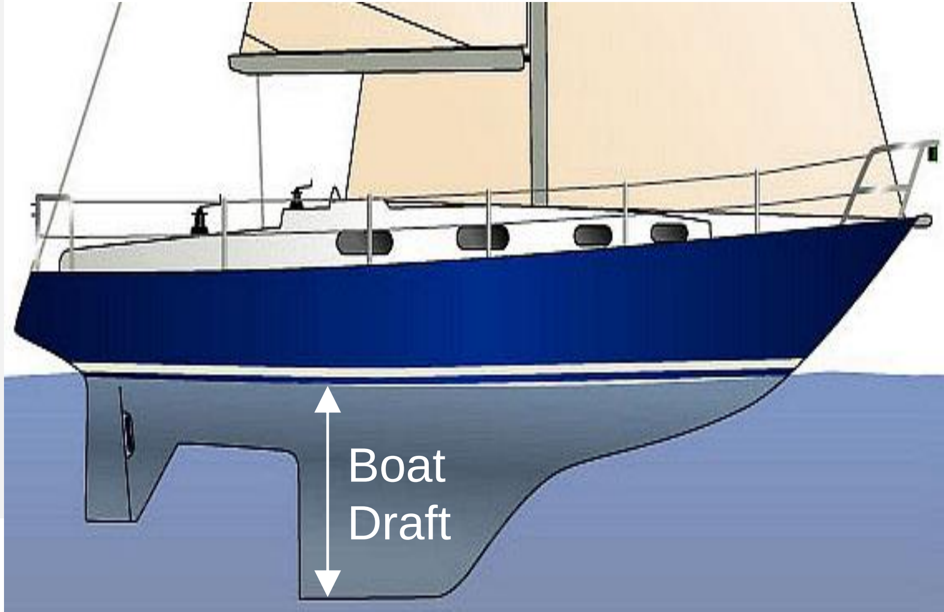
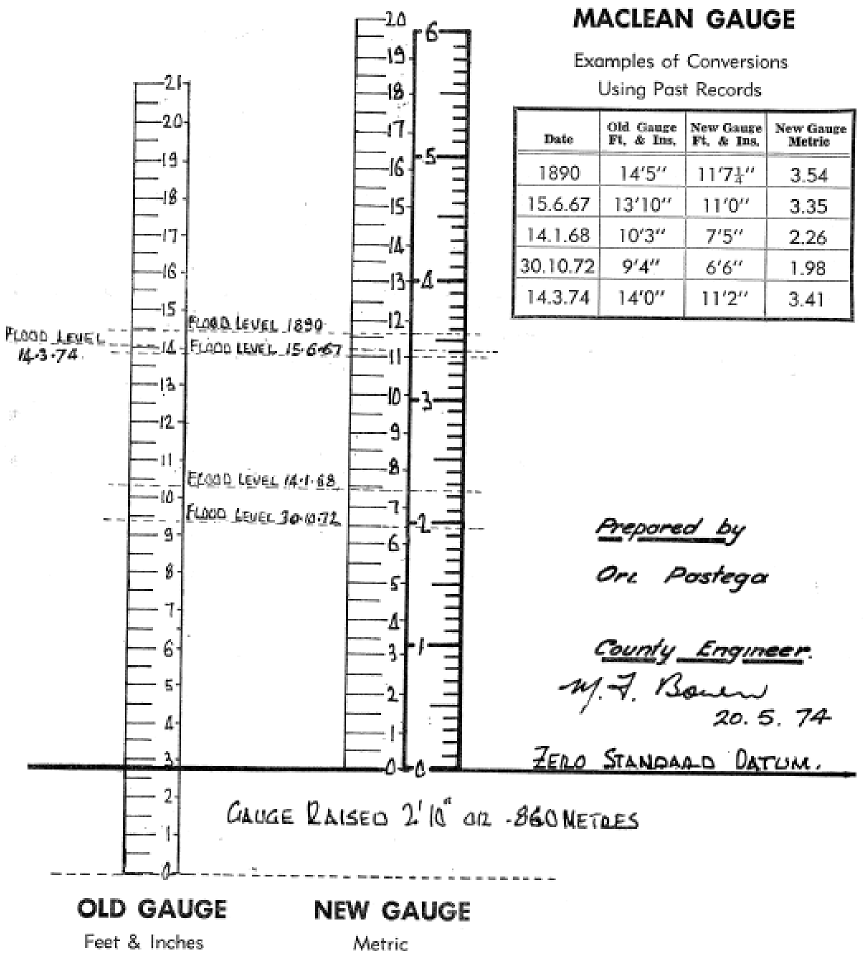


Chart depth + tide level (LAT datum) = available depth for boat draft



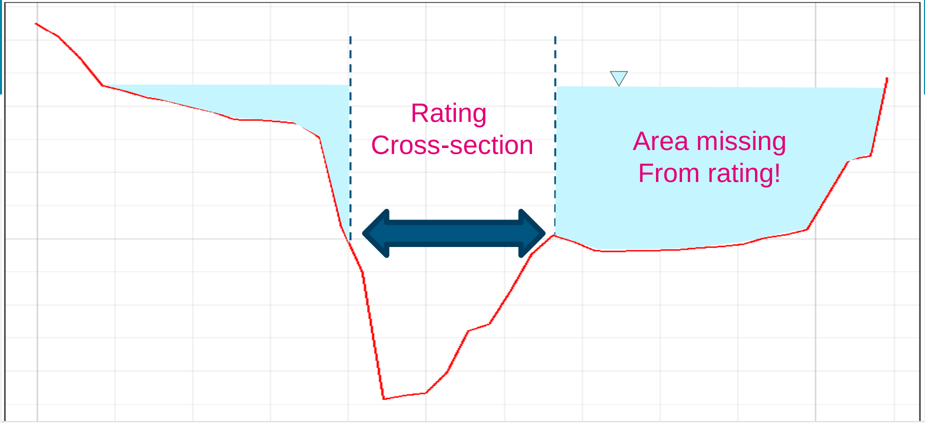
Calibration Data Preparation
Water Level Gauges

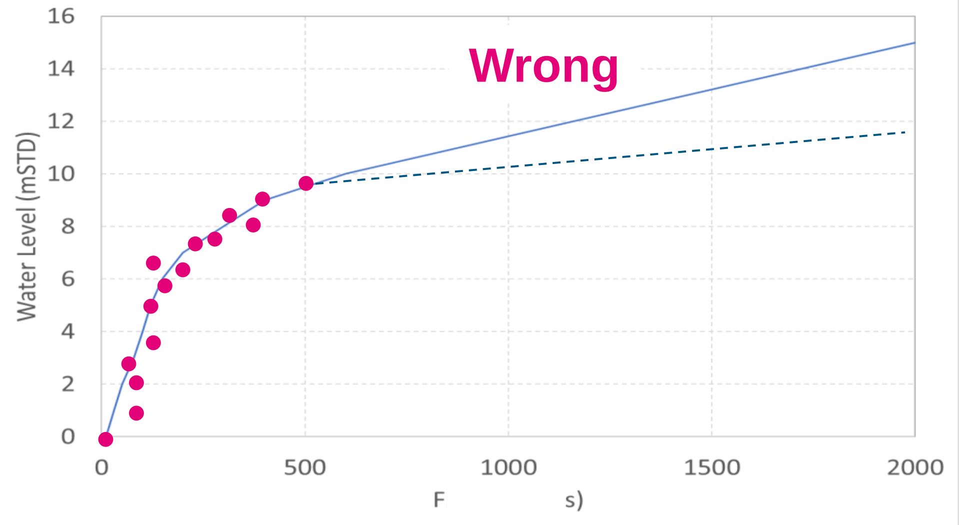
- Confirm gauge datum (not AHD):
  - Inland gauges can use a local datum to offset base elevation
  - Coastal gauges can use Lowest Astronomical Tide (LAT) as datum for navigation purposes
- Check gauge history
  - Location change?
  - Datum change?



Calibration Data Preparation
Velocity Gauging

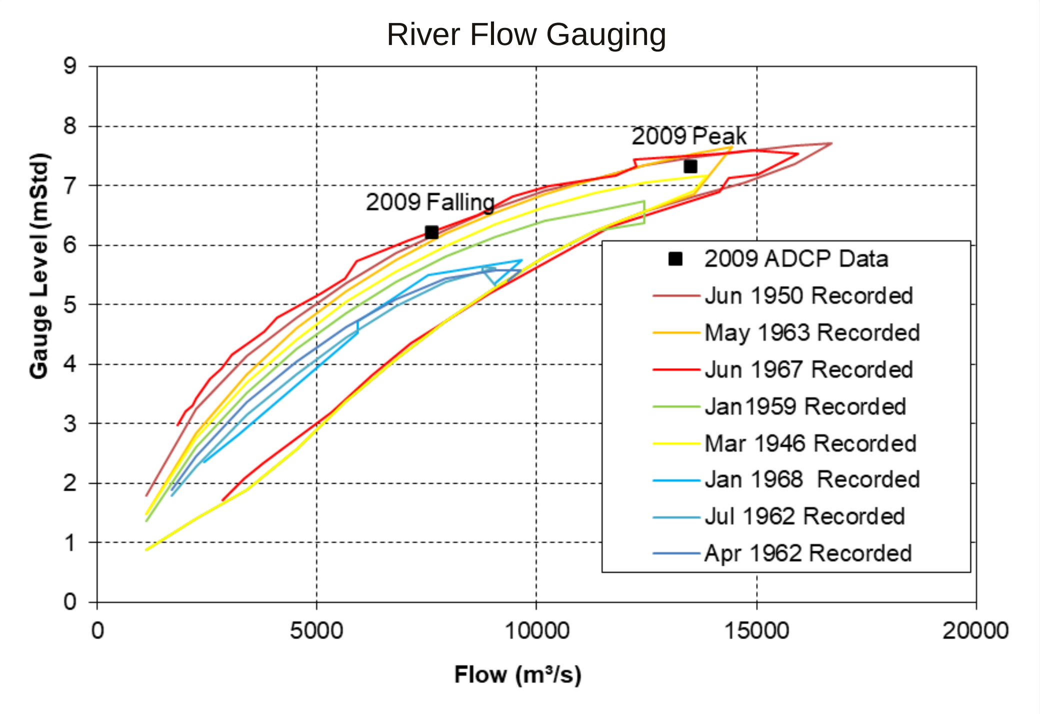
- Useful for derivation of rating curve for initial review of flow estimates from the hydrology model
- Warning: Don't assume the rating curves you're provided are correct. Check metadata
  - Upper limits of rating?
  - Range of uncertainty?





Calibration Data Preparation
Gauge Rating Curve

- Be aware of hysteresis effects
- Multiple velocity gauging / flow calculation at different times during an event are a useful though rare calibration dataset for a hydraulic model



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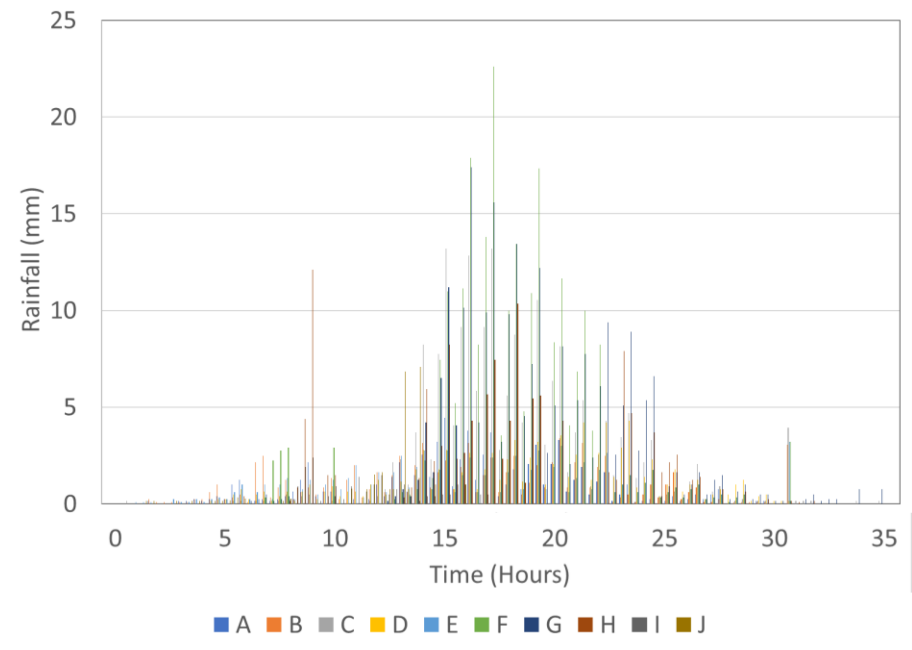
Model Inputs
and
General Model Design Considerations

Model Input Data Preparation
Rainfall Data

- Use real recorded data. DO NOT use design event rainfall as an input for calibration!
- Verify recorded data quality before using
- Were all gauges operational for the whole event?
- Cumulative Rainfall check
- Compare daily / tip bucket totals

Which two gauges failed during this event?



Model Input Data Preparation
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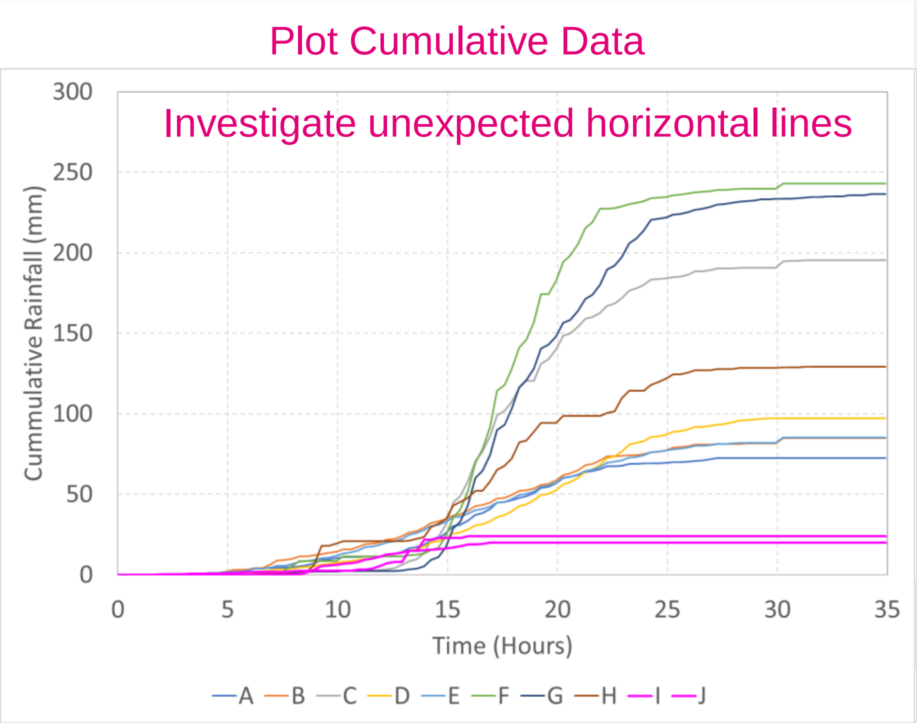
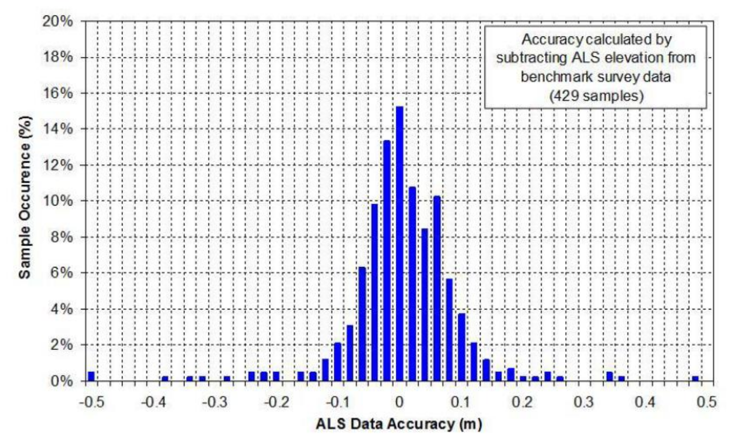
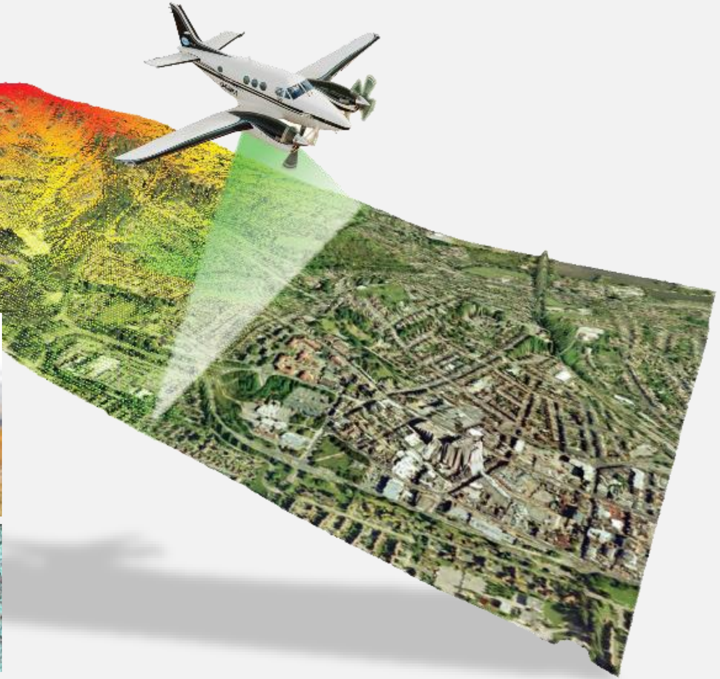


Model Input Data Preparation
Topography Data

Confirm topography data accuracy by validation using secondary datasets

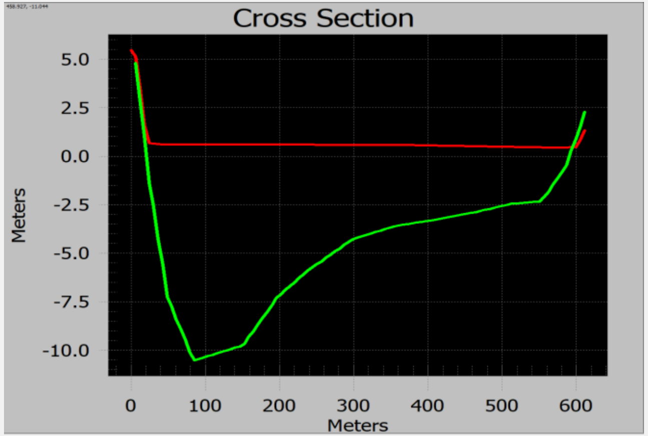


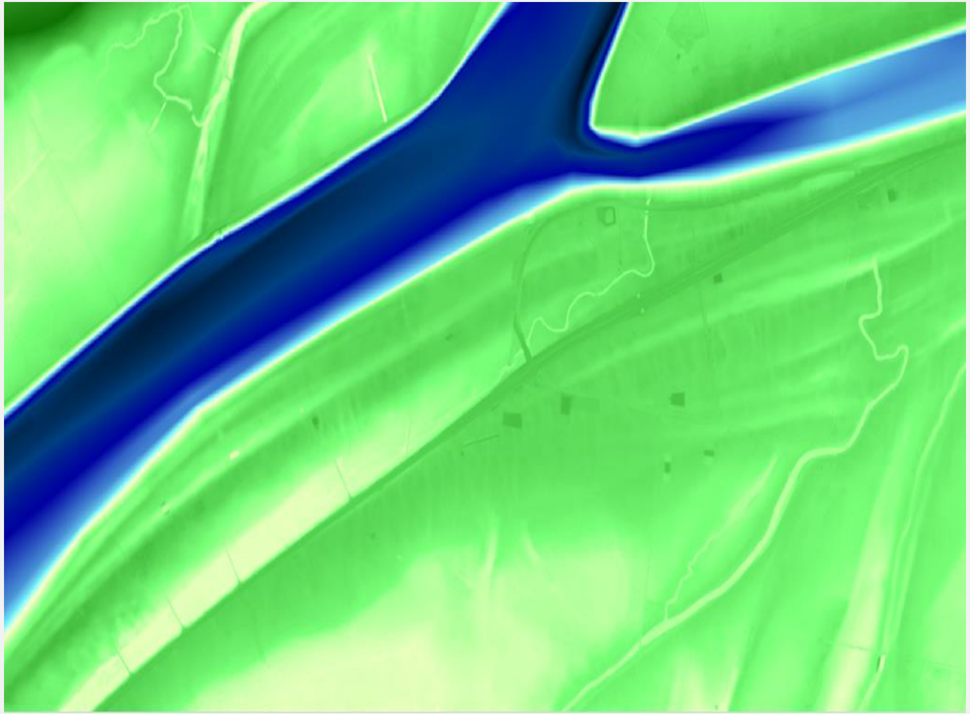


Model Input Data Preparation
Topography Data

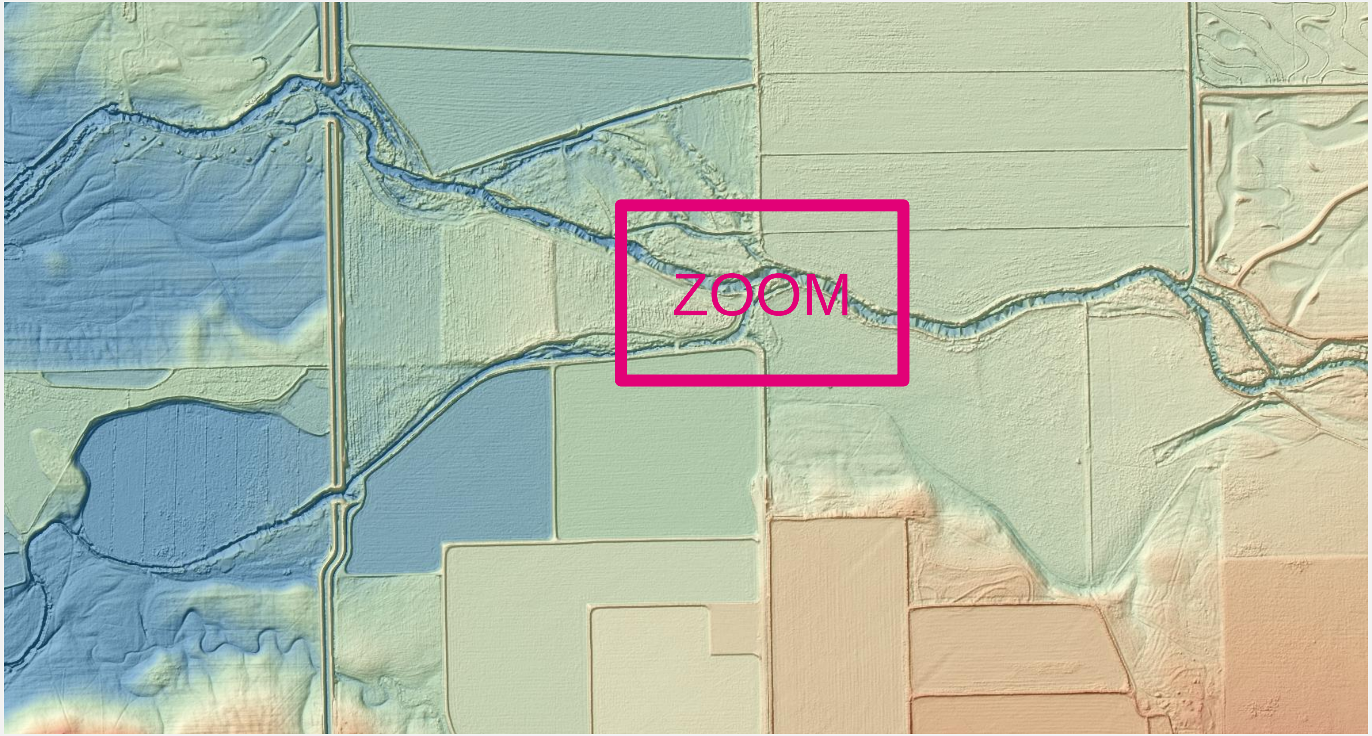
Common Airborne Laser Data (ALS or LIDAR) survey limitations

- Poor ability to penetrate water





Model Input Data Preparation
Topography Data



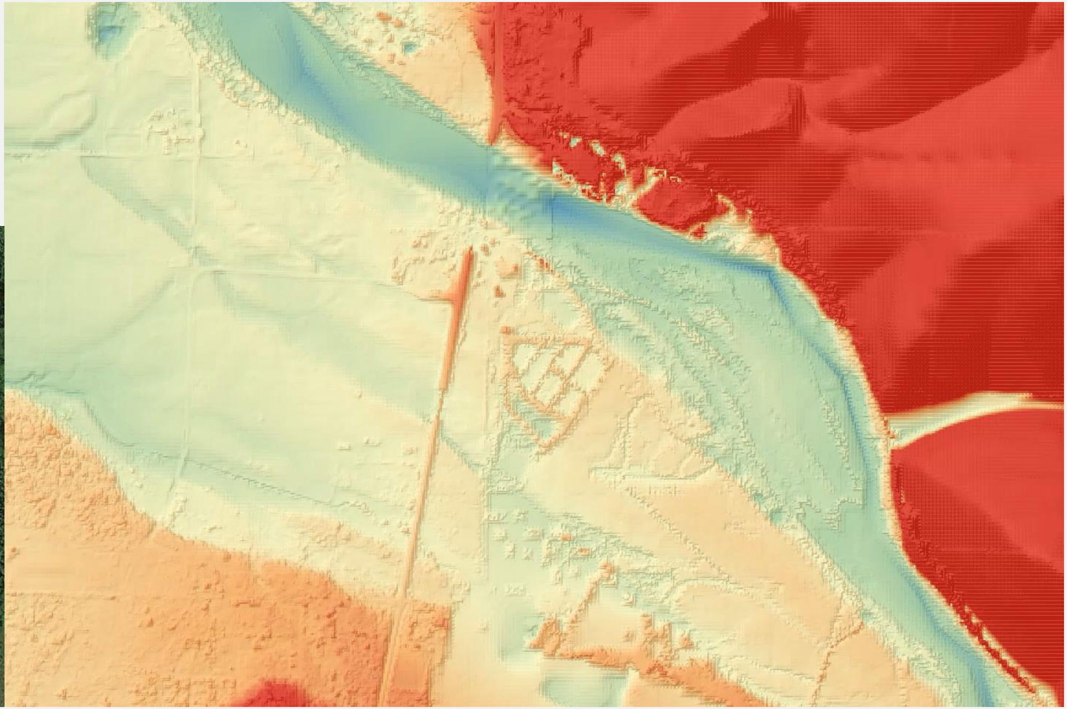
Thoughts on the quality of this data?

Model Input Data Preparation
Topography Data

Hillshade symbology is useful for spotting ALS data errors

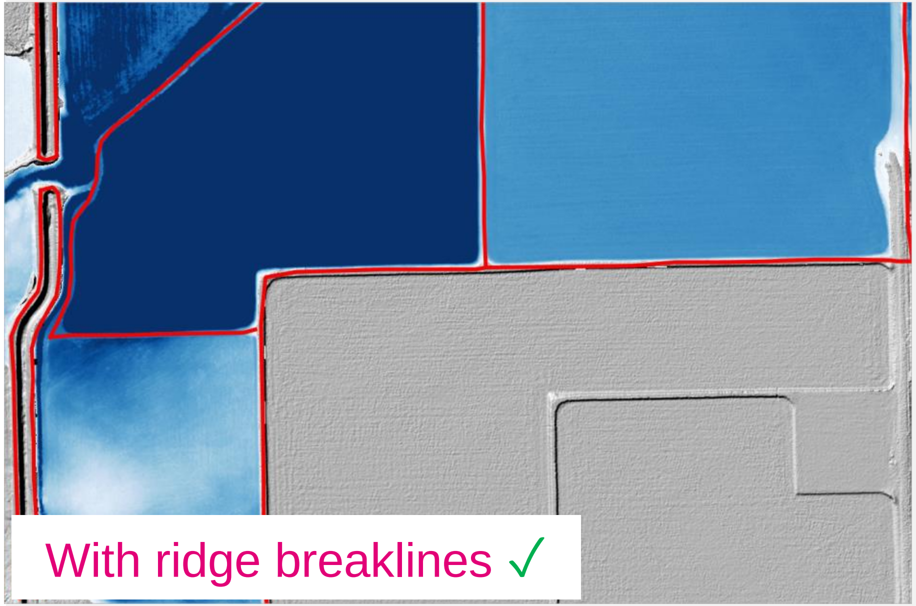
Model Input Data Preparation
Topography Data

Bridge openings sometimes missing or misrepresented in LiDAR



Model Input Data Preparation
Topography Data

Enforce ridge hydraulic controls using breaklines

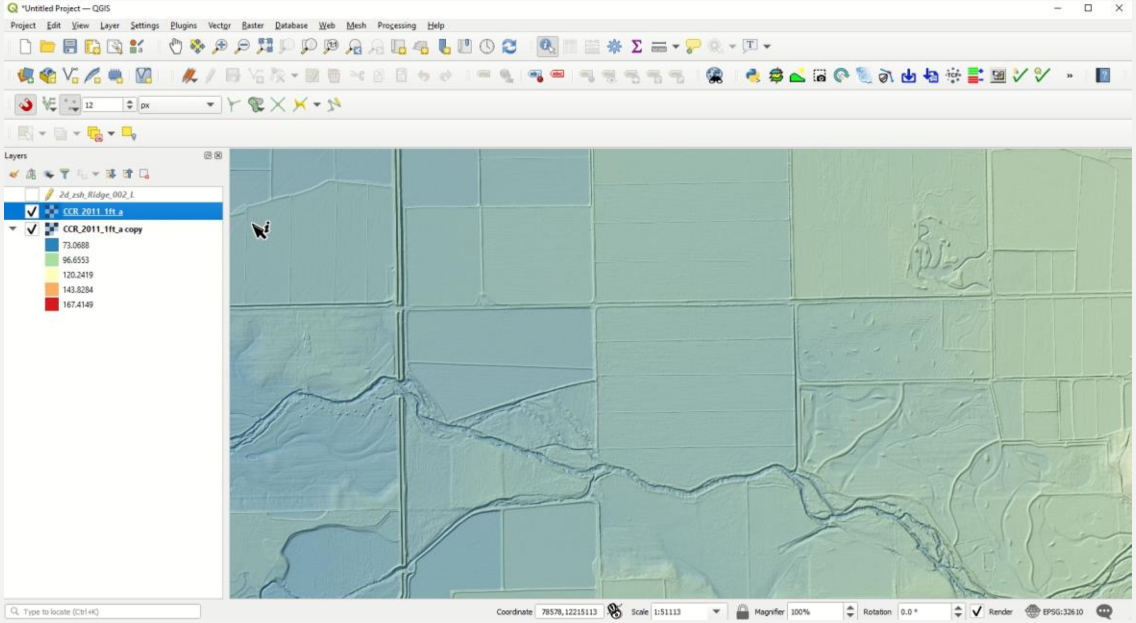


Model Input Data Preparation
Topography Data

Enforce ridge hydraulic controls using breaklines

If no survey data:

1. Draw ridge breaklines manually (*2d_zsh_empty*)
2. Set line parameters:
    1. dz = sample interval
    2. Shape_width = inspection radius
    3. Shape Option = process option



https://wiki.tuflow.com/index.php?title=ASC_to_ASC

Model Input Data Preparation
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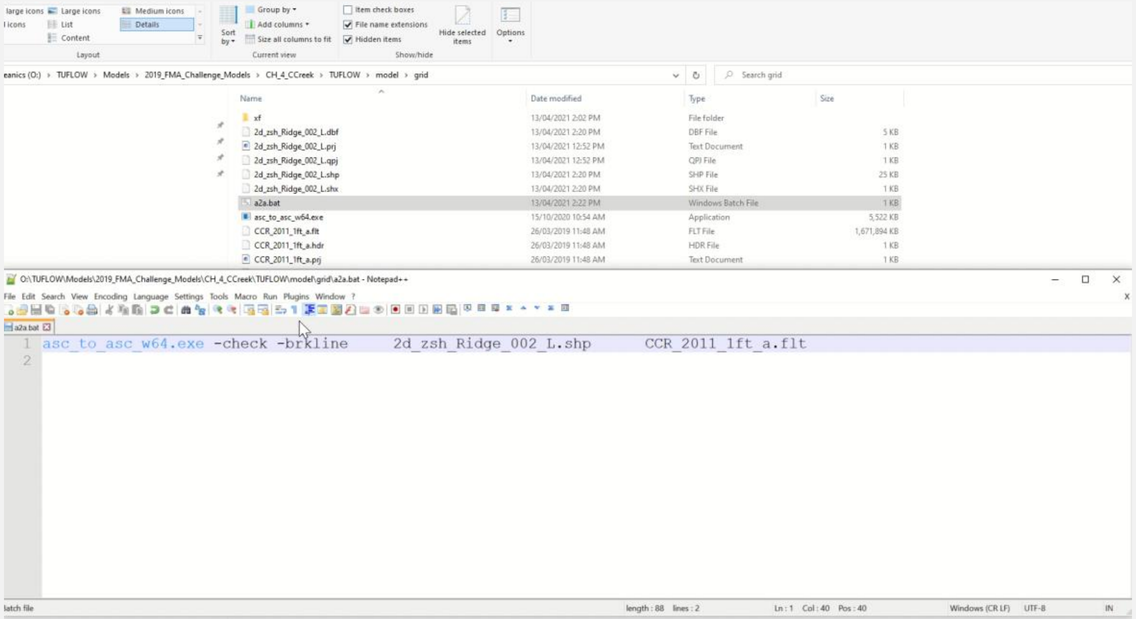
3. Run ASC_to_ASC utility (-*brkline* function)



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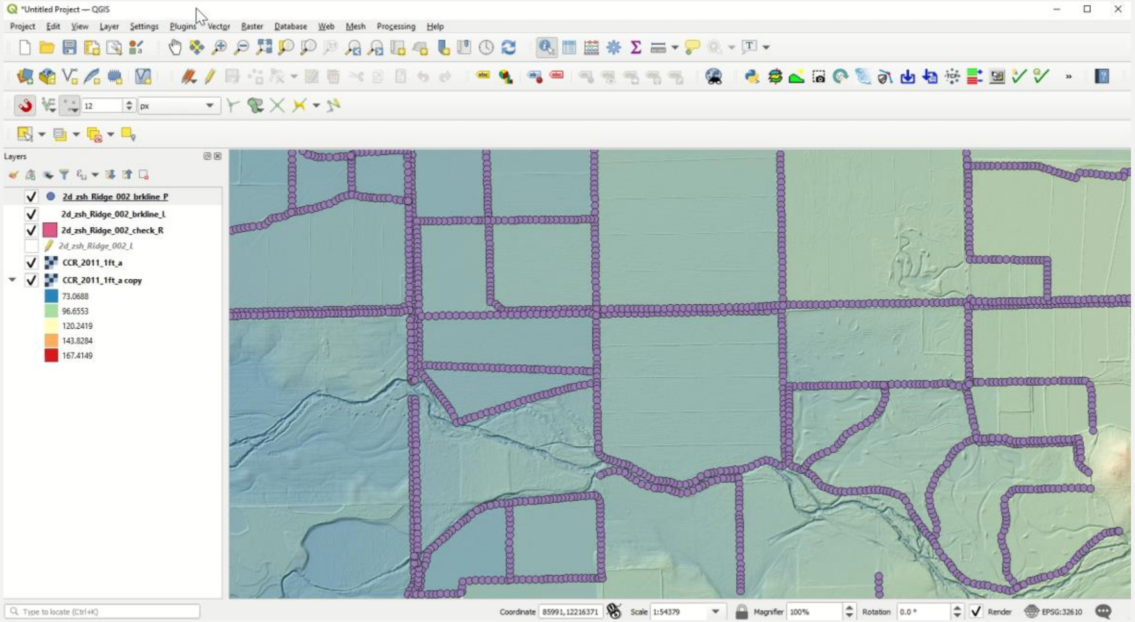

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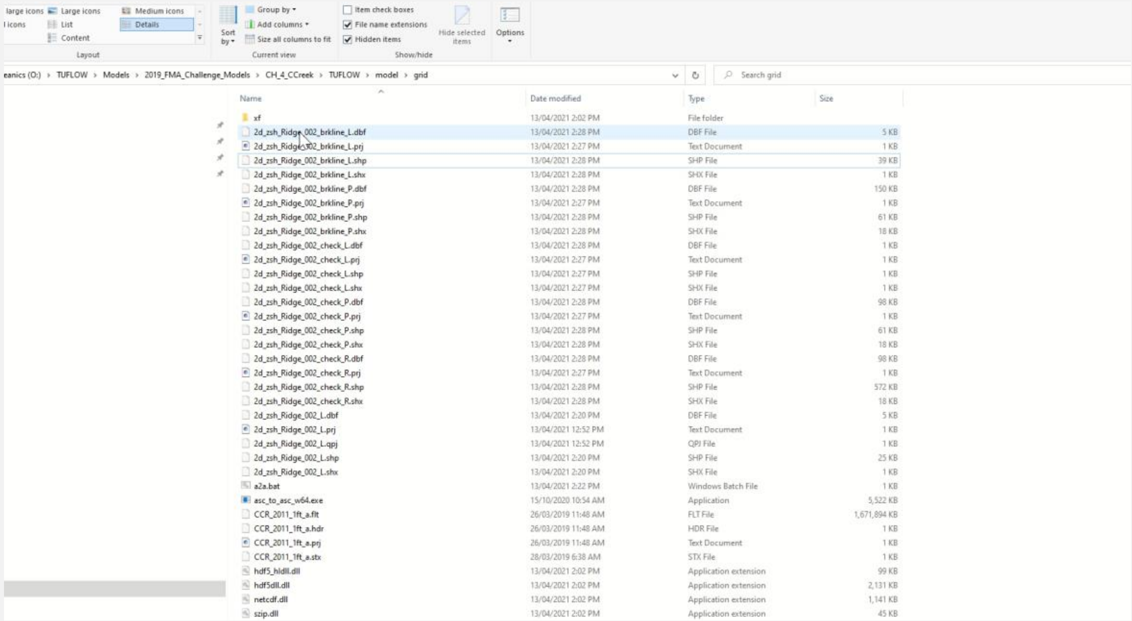
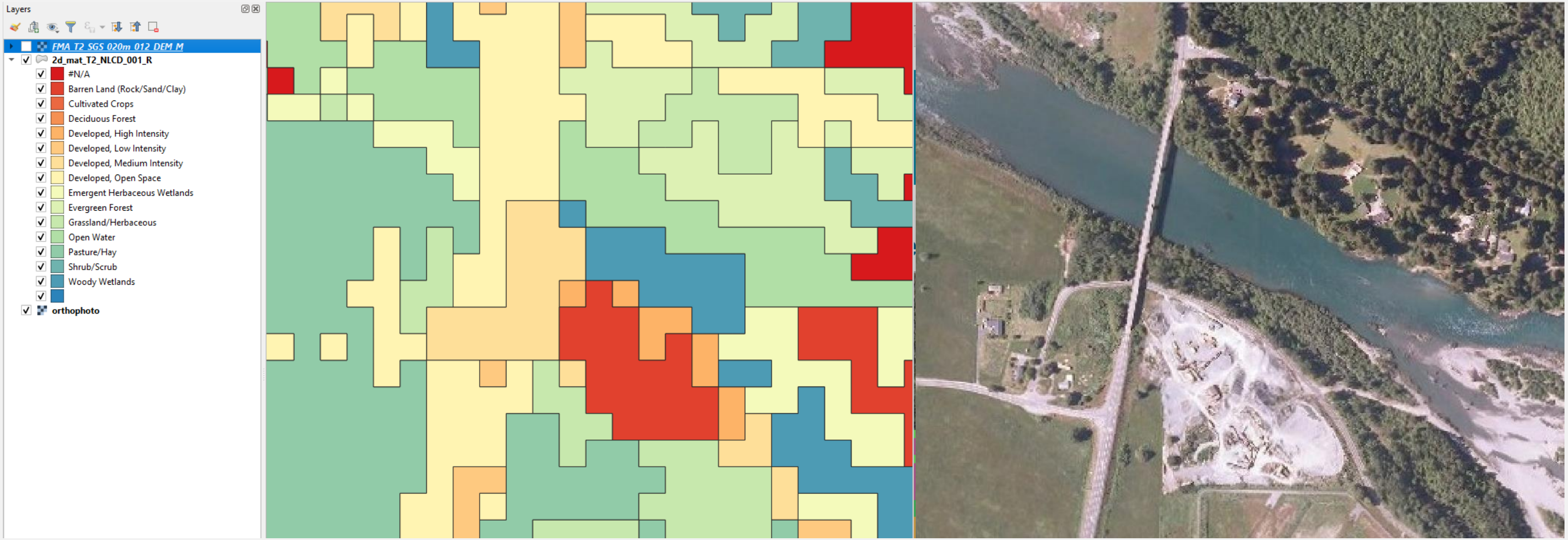
    3. Shape Option = process option
3. Run ASC_to_ASC utility (-*brkline* function)
4. Add new files to TUFLOW model (*Read GIS Z Shape == *)



https://wiki.tuflow.com/index.php?title=ASC_to_ASC

Model Input Data Preparation
Landuse Data

DO NOT trust free online datasets without reviewing them carefully first!



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Model Input Data Preparation
Landuse Data

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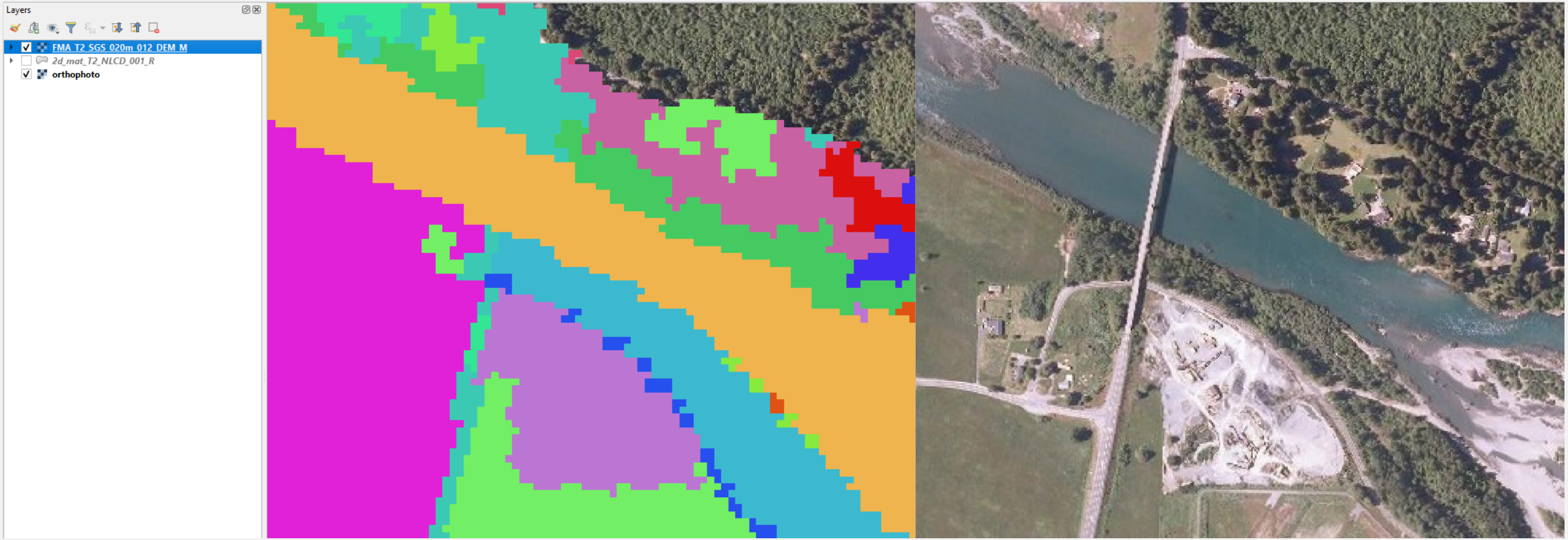
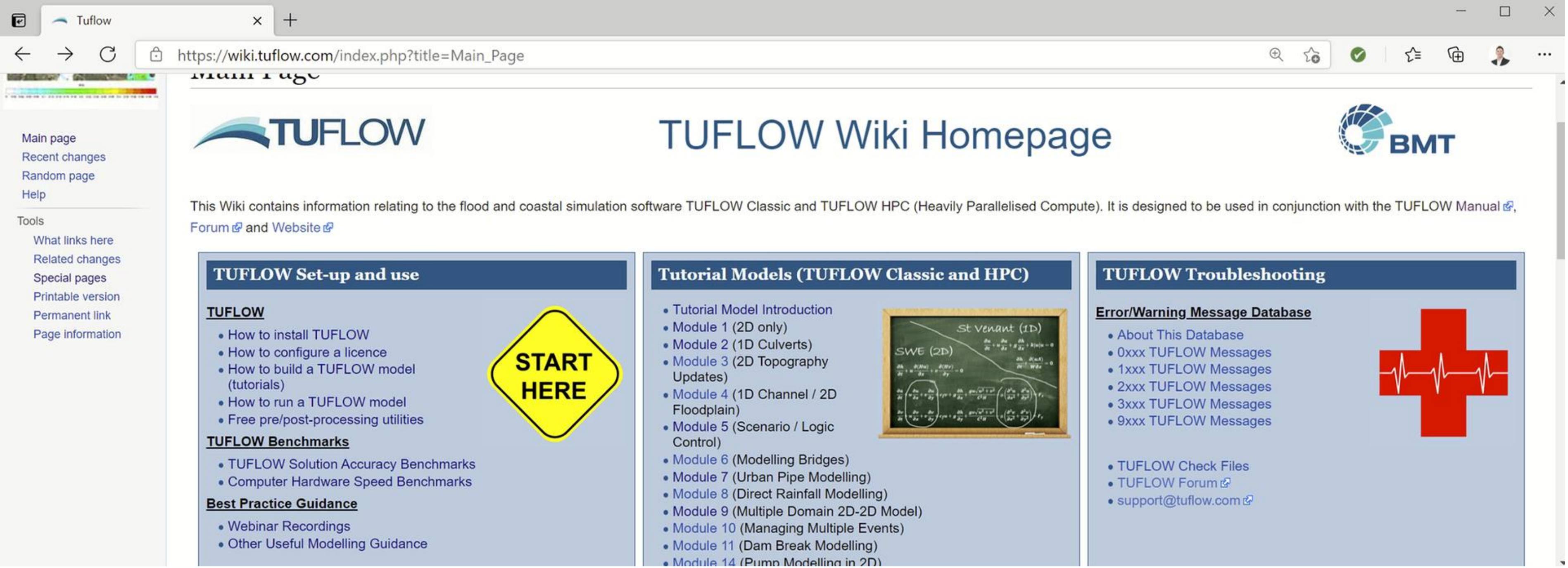


Model Input Data Preparation
Landuse Data

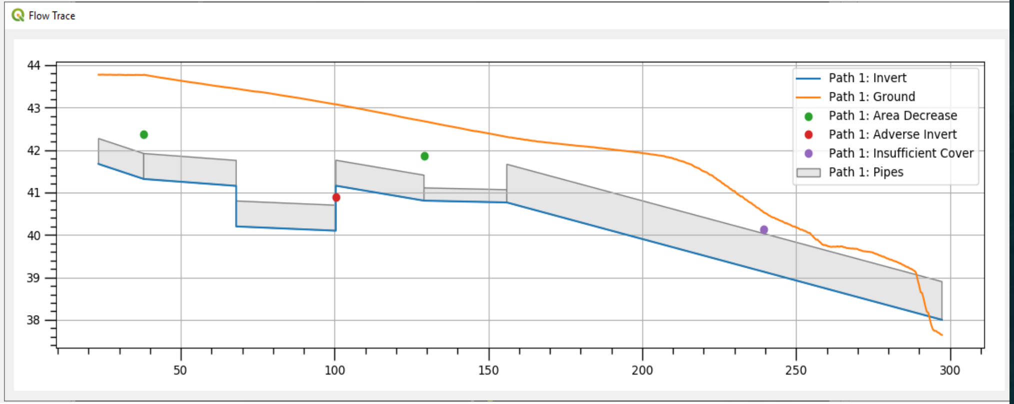
Industry standard values: https://wiki.tuflow.com/index.php?title=Industry_Modelling_Guidelines

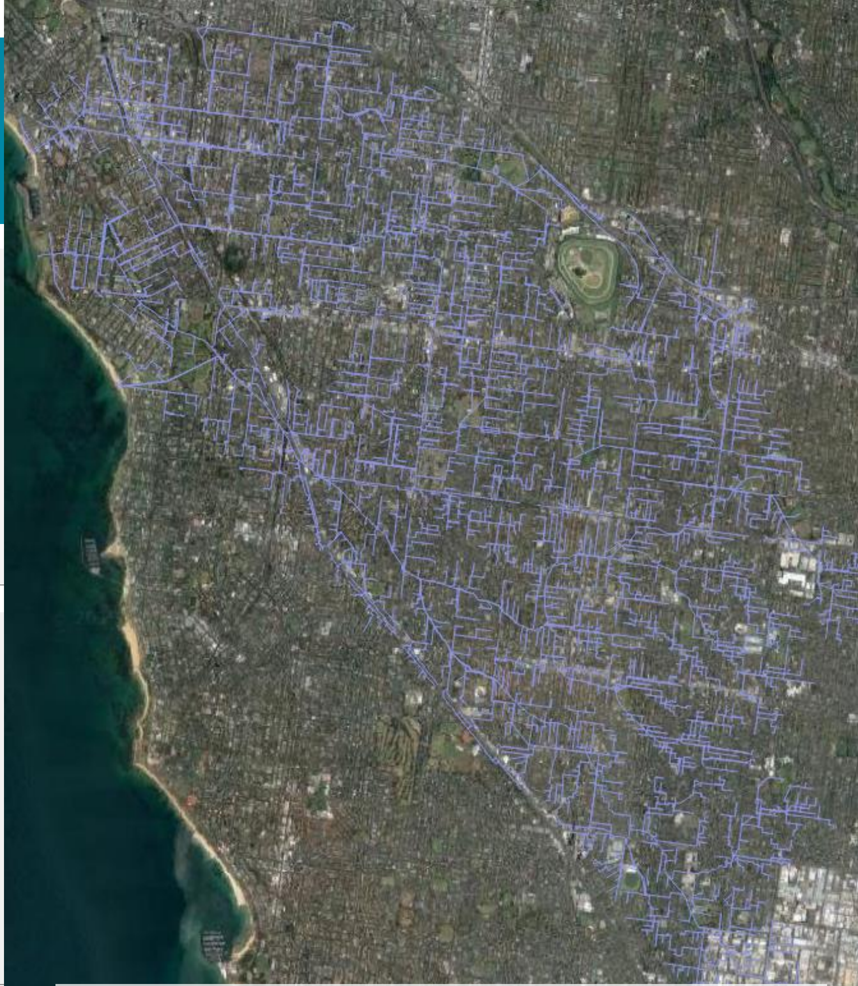


Model Input Data Preparation
Other Major Geometry Inputs

TUFLOW QGIS Plugin - Pipe Integrity Tool

- Snapping check and correction
- Pipe direction
- Continuity





>13,000 pipes = QA Challenge

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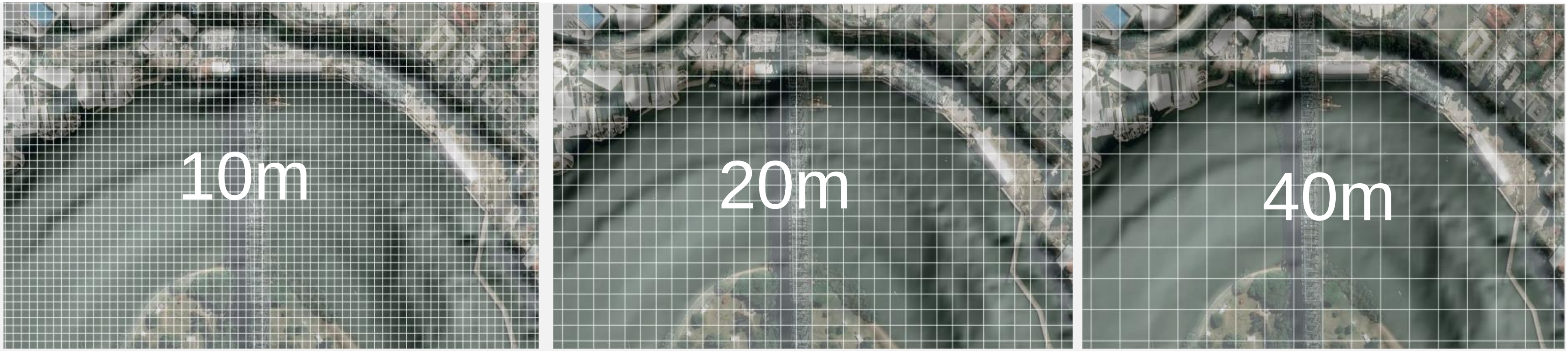
Model Input Data Preparation
Model Cell Size Selection



Result Convergence Testing:

2D Cell Size Selection for Accurate Hydraulic Modelling
www.tuflow.com/library/webinars

Model Input Data Preparation
Site Visit / Meet and talk to the locals

(After) 2020 Flood, Murwillumbah


(After) 2007 Flood, Newcastle

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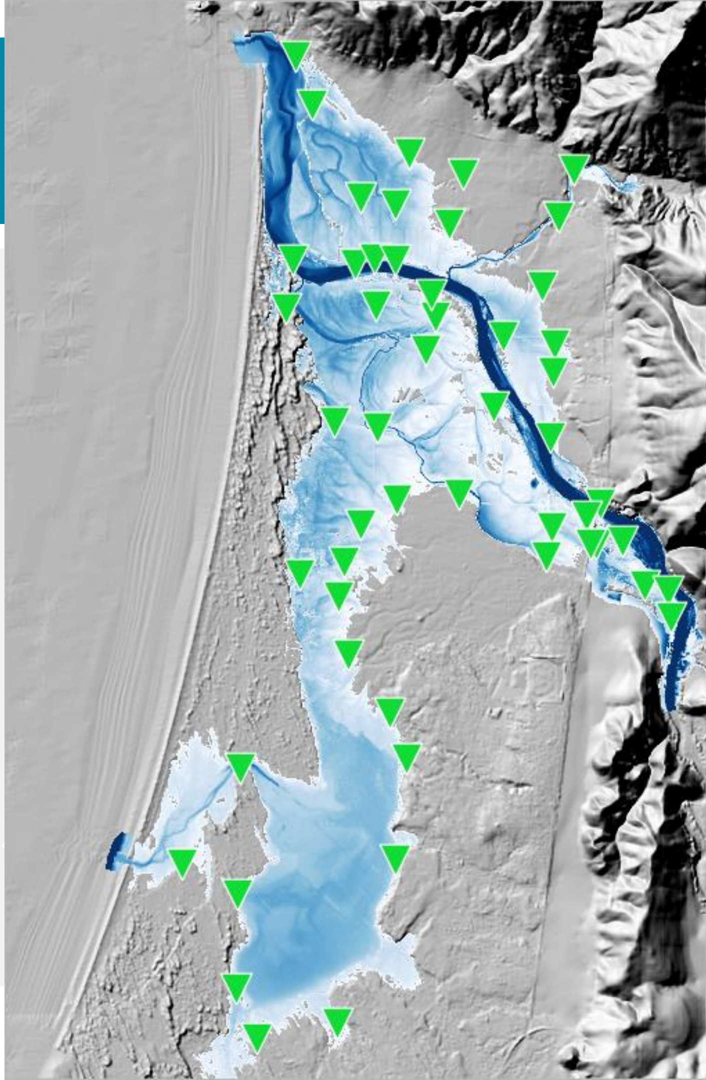
Case Study Demonstration 1

USA Region 9 FMA Challenge 2 Overview

- Flood model calibration
  (1 event only)
- External inflows (provided)
- Landuse data
  - National Land Cover Database (provided)
  - Used data from aerial photography instead
- 5m DEM topography provided
  - Corrected data error at two upstream bridges
  - Added ridge breaklines
- 53 peak flood level marks (provided)



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USA Region 9 FMA Challenge 2
Process Workflow

Calibration Activity	Modelling Task	Simulation Details
Step 1: Define Model Extent	Broadscale model simulation	100m resolution model 1 minute runtime
Step 2: Initial Model Input Corrections	• Land use (Manning's n) • Topography	
Step 3: Result Convergence Test for Cell size Assumptions	10m, 15m, 20m, 30m, 50m, 100m cell resolution simulations	<30m cell resolution is appropriate
Step 4: Calibration Refinement	30m resolution model	3 minute runtime 11 refinement iterations required
Step 5: Final Calibration Simulation	15m resolution model	20 minute runtime

USA Region 9 FMA Challenge 2
Model Correction Example

Impact of correcting bridge opening topography error

USA Region 9 FMA Challenge 2
Model Correction Example

Legend

Modelled Peak Flood Level (m)

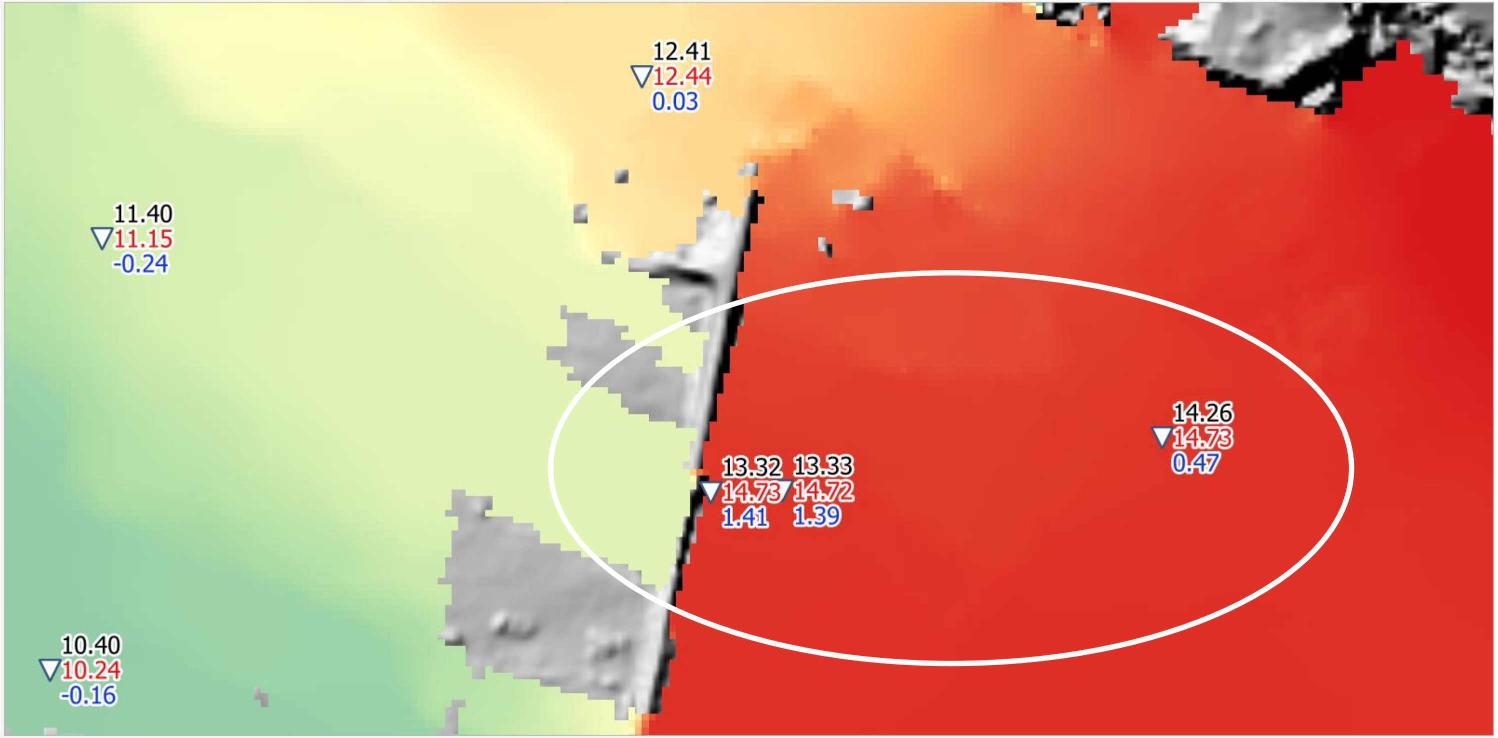
- 9.0000
- 10.5000
- 12.0000
- 13.5000
- 15.0000

▽ Surveyed Flood Mark

0.0 Recorded Peak Level (m)

0.0 Modelled Peak Level (m)

0.0 Difference (m)



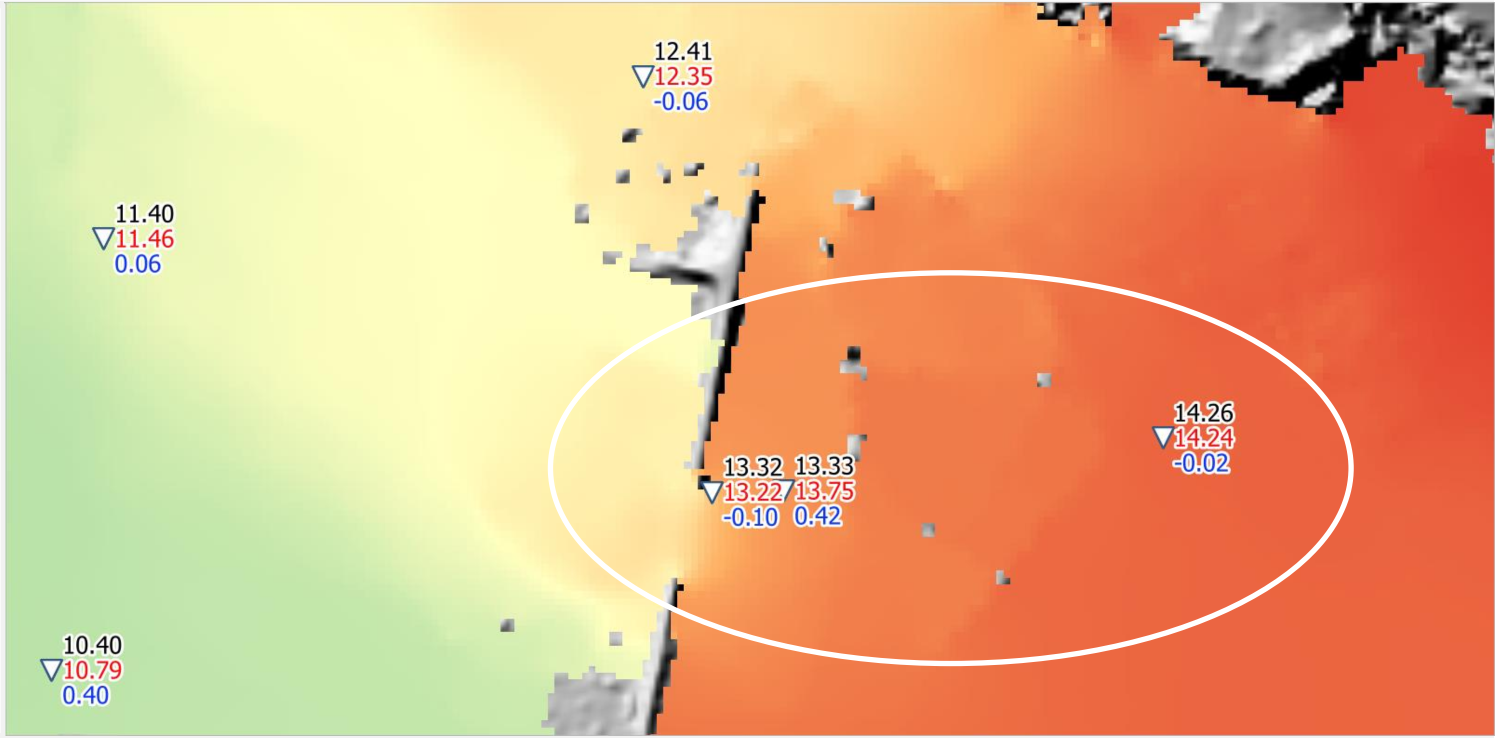
USA Region 9 FMA Challenge 2
Model Correction Example

Legend

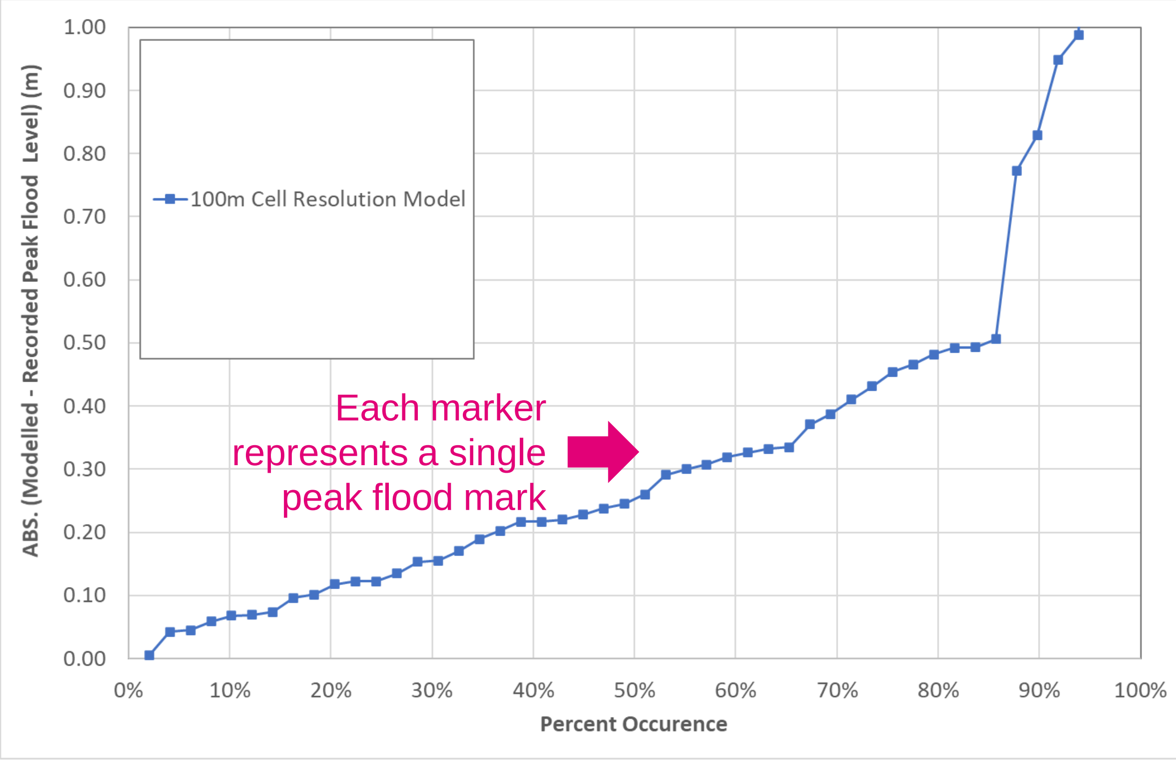
Modelled Peak Flood Level (m)

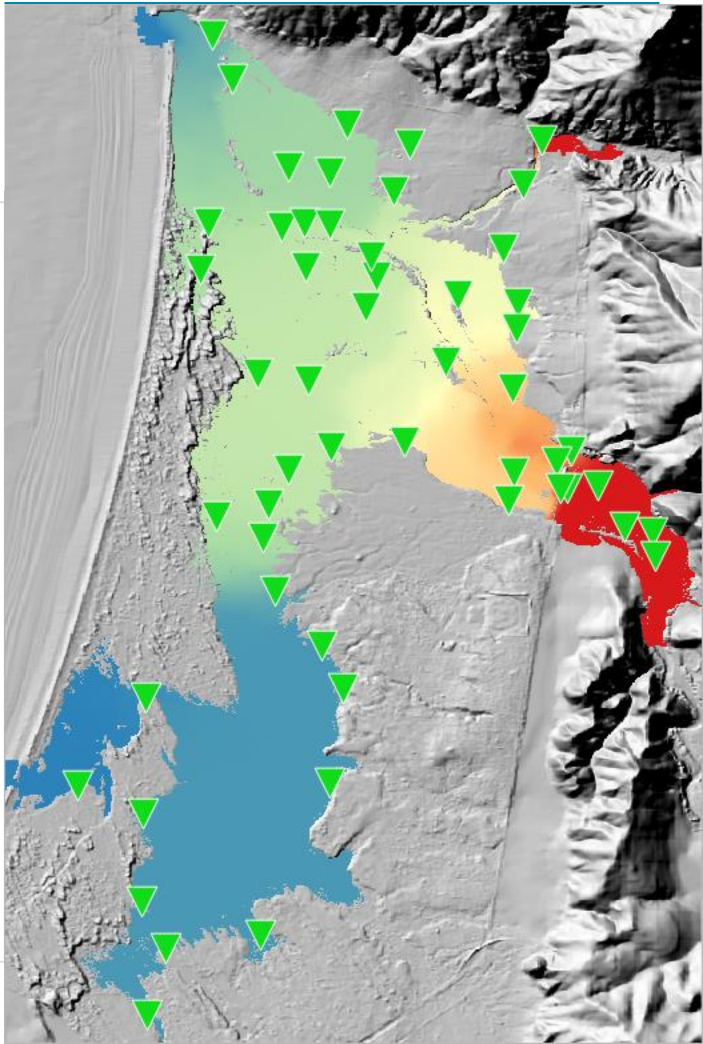
- 9.0000
- 10.5000
- 12.0000
- 13.5000
- 15.0000

▽ Surveyed Flood Mark
0.0 Recorded Peak Level (m)
0.0 Modelled Peak Level (m)
0.0 Difference (m)

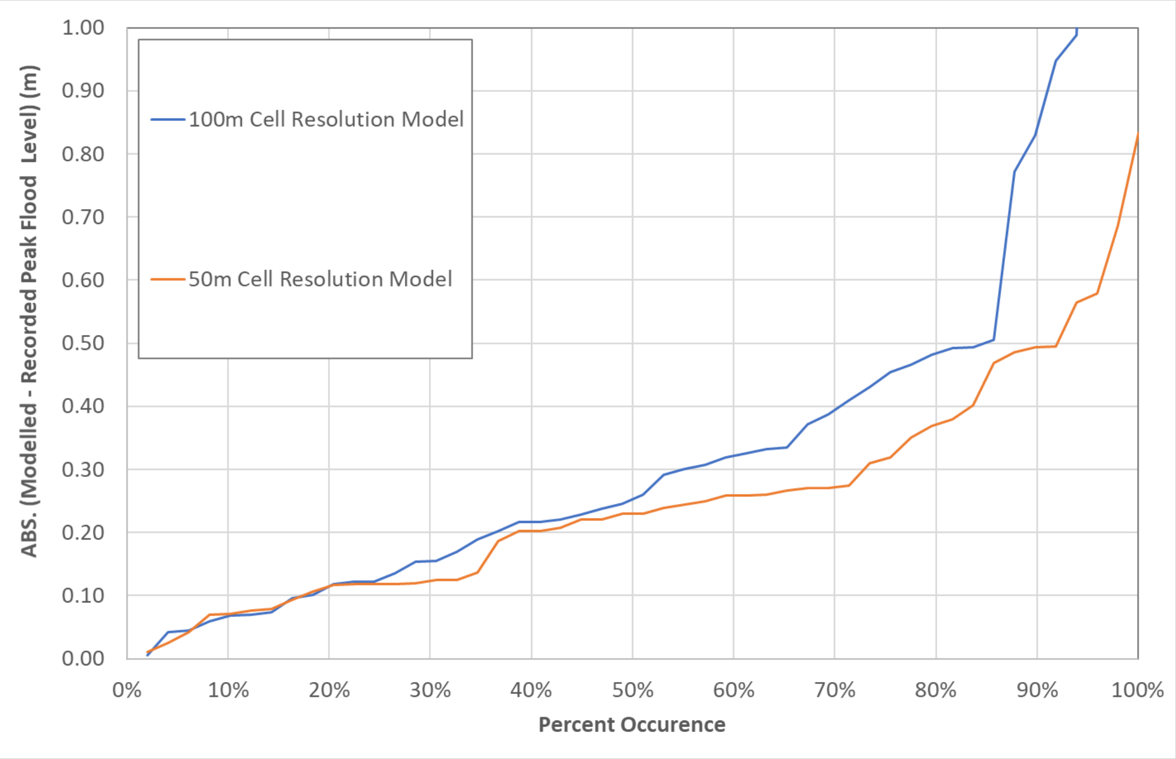


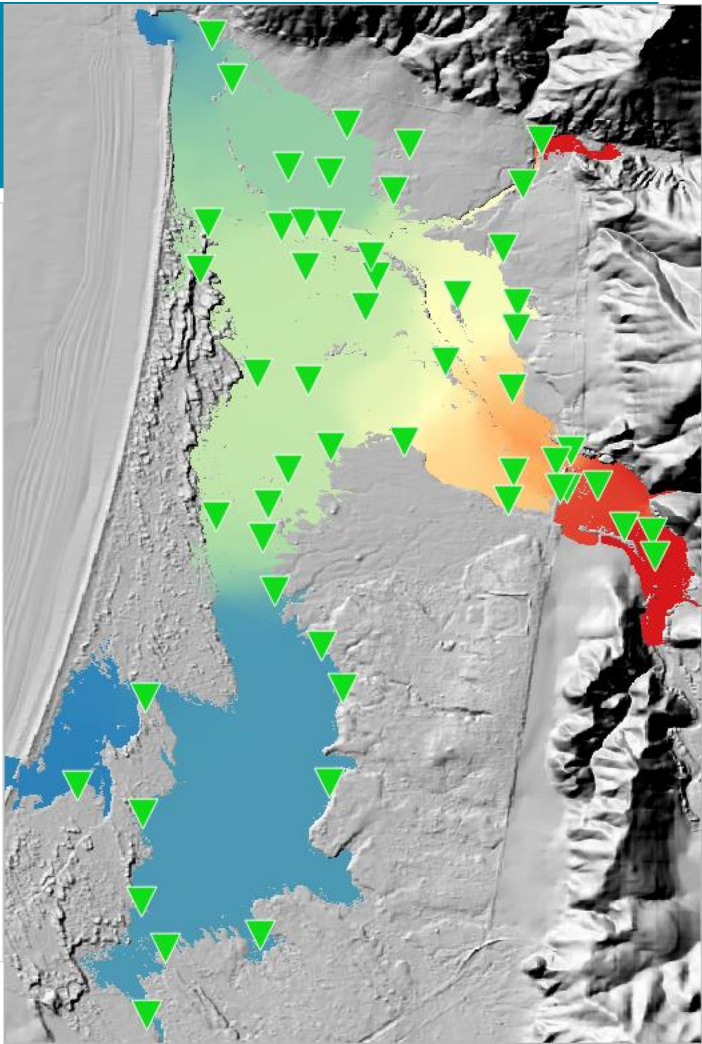
1. ABS (modelled – recorded peak flood level)
2. Sort from smallest to largest
3. Assign % = (data count / max count)*100
4. Plot sorted data vs %



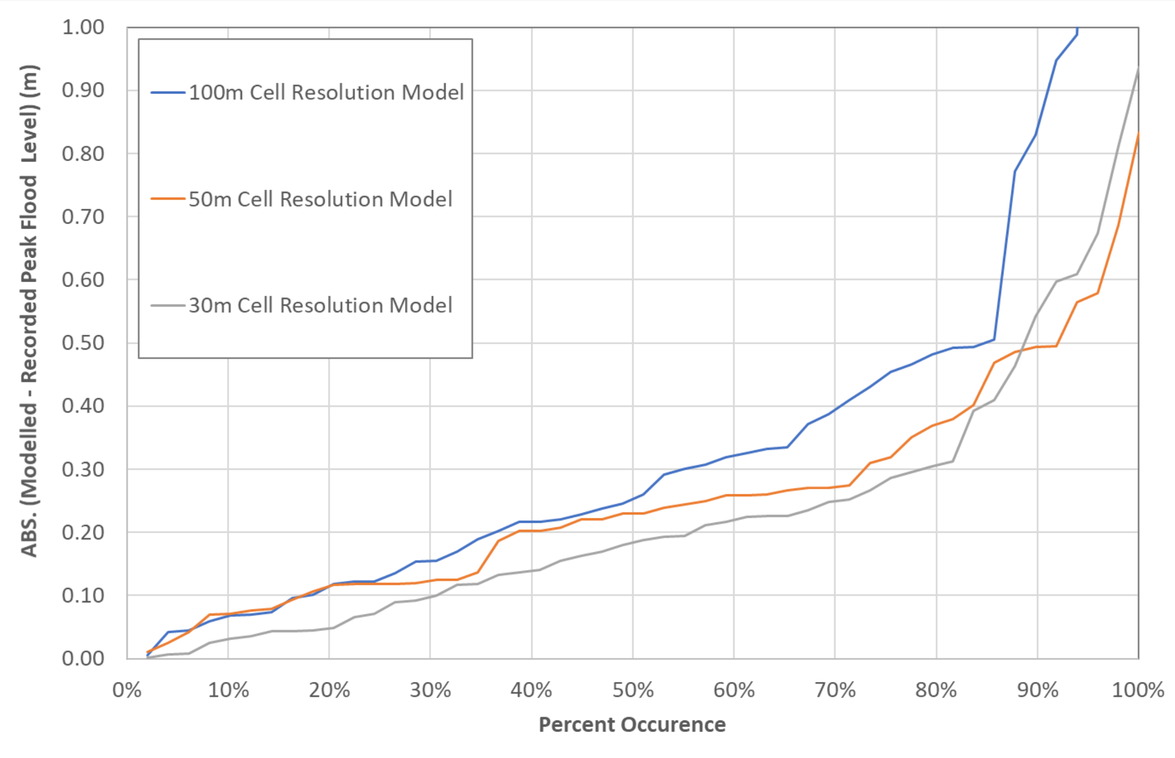


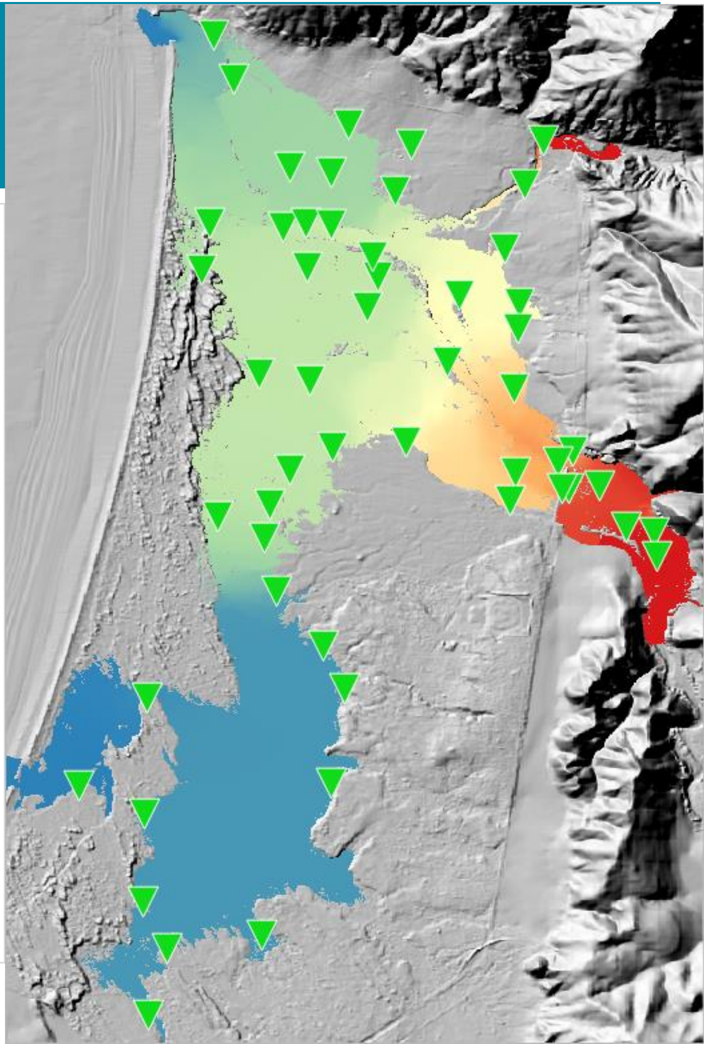
USA Region 9 FMA Challenge 2
Cell Size Selection Test





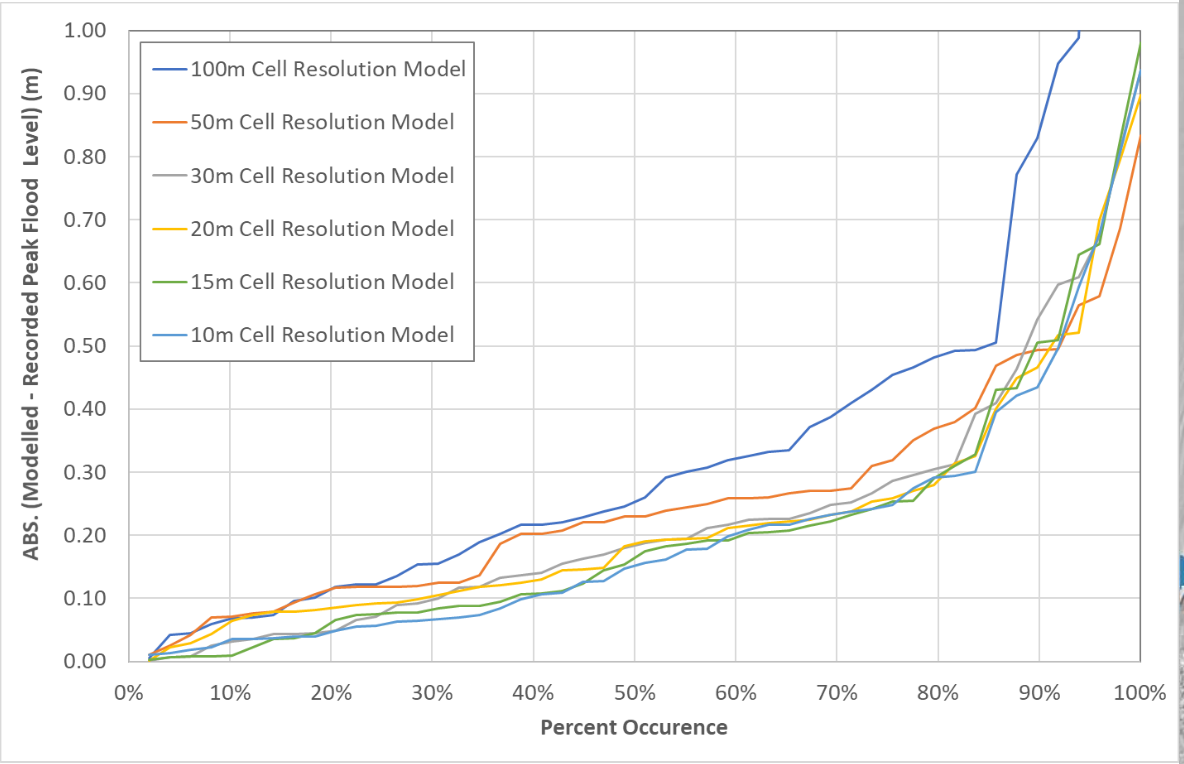
USA Region 9 FMA Challenge 2
Cell Size Selection Test

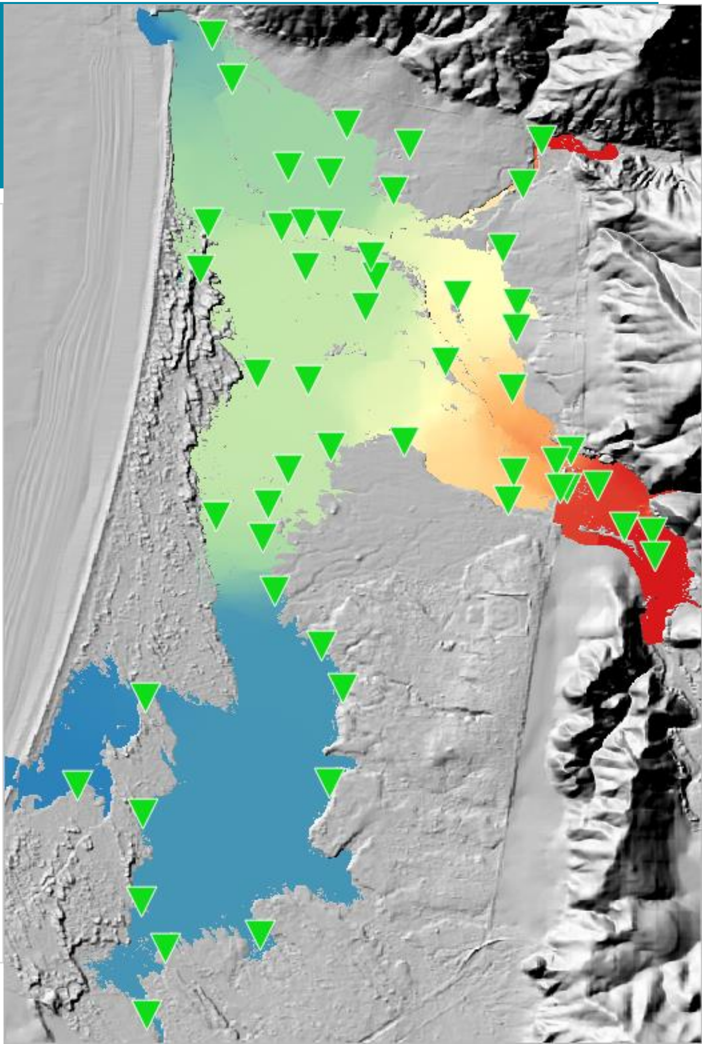




TUFLOW

USA Region 9 FMA Challenge 2
Cell Size Selection Test





TUFLOW

USA Region 9 FMA Challenge 2
Final Result

Legend

Modelled Peak Flood Level (m)

- 3.0000
- 6.0000
- 9.0000
- 12.0000
- 15.0000

▽ Surveyed Flood Mark

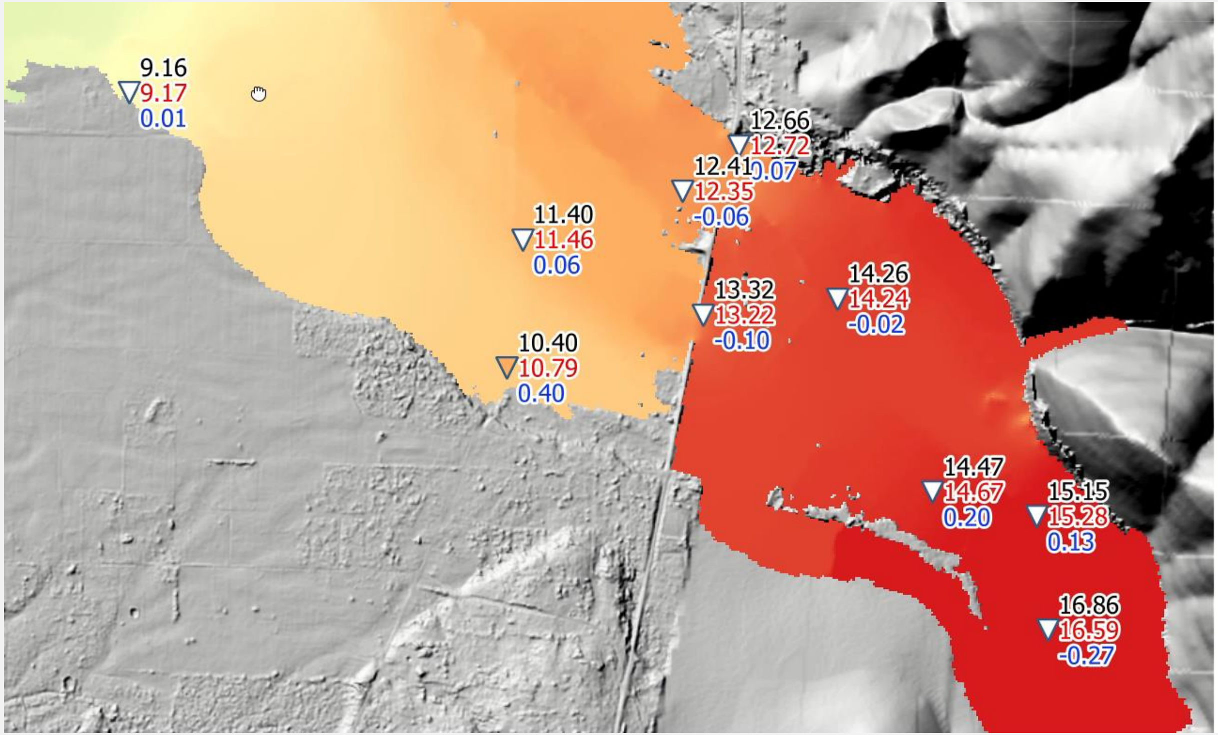
0.0 Recorded Peak Level (m)

0.0 Modelled Peak Level (m)

0.0 Difference (m)

Modelled – Recorded Difference (m)

- -0.6 to -1.0
- -0.3 to -0.6
- -0.3 to 0.3
- 0.3 to 0.6
- 0.6 to 1.0

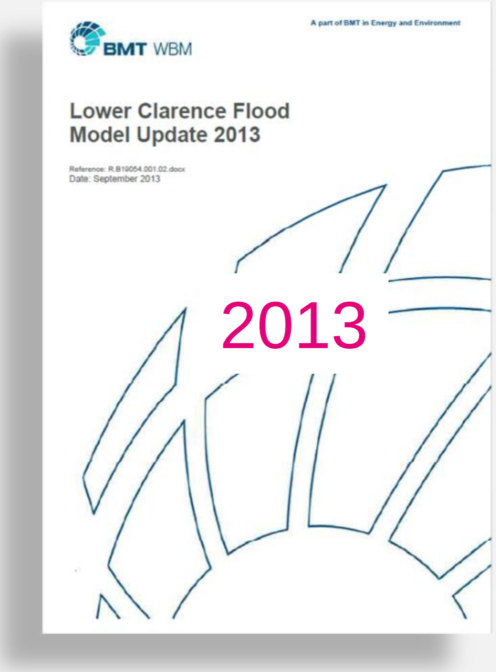


Case Study Demonstration 2

Lower Clarence Valley

- East coast of Australia
- 10,400 km^2 catchment
- Estimated 1% AEP (100 year) event flow of 19,000 m^3/s or 670,000 ft^3/s

Lower Clarence Valley
TUFLOW Historic Event Calibration Modelling


A part of BMT in Energy and Environment

BMT WBM

Lower Clarence Flood Model Update 2013

Reference: R.B19054.001.02.docx
Date: September 2013

2013

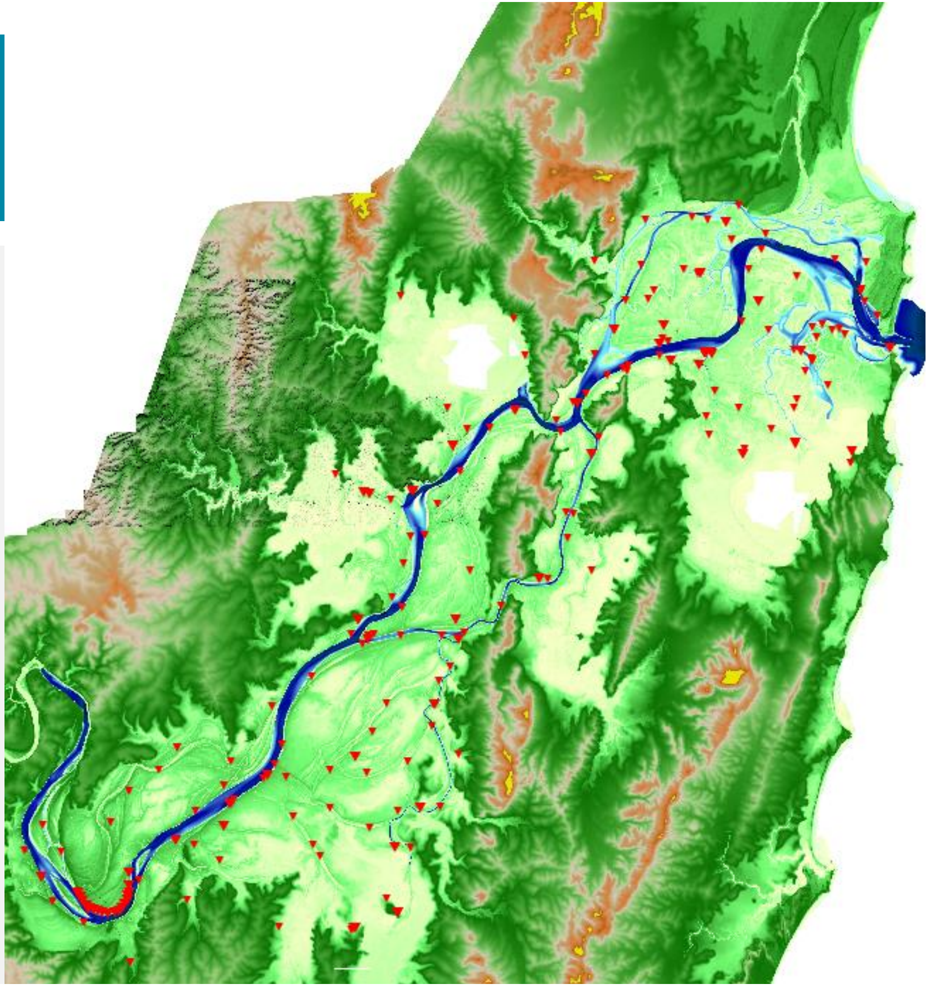
Excellent flood model calibration examples

Lower Clarence Valley TUFLOW Flood Model

Data courtesy of Clarence Valley Council

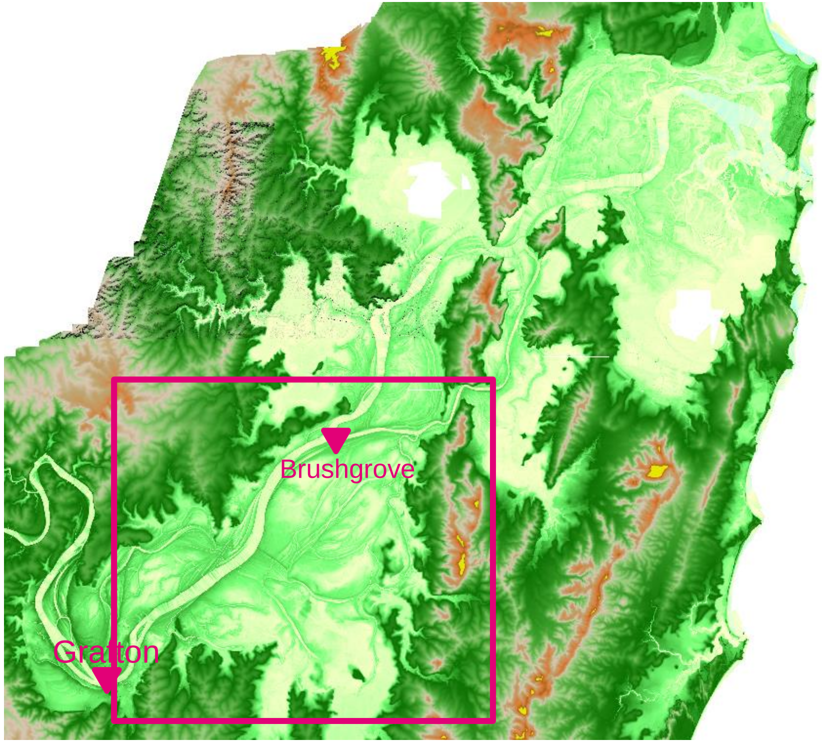
TUFLOW calibration to:

- 25 water level gauge locations in the study area
- 8 major flood events since 1967 (current catchment topography)
- Flood event velocity recordings
- Over 600 surveyed peak flood levels (2001, 2009 and 2013 flood events)



TUFLOW https://flooddata.ses.nsw.gov.au/organization/clarence-valley-council/datasets

Lower Clarence Valley TUFLOW Flood Model

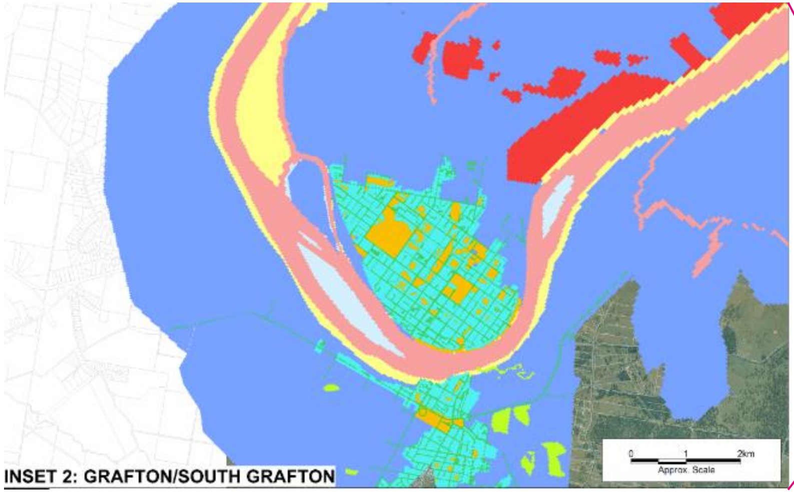


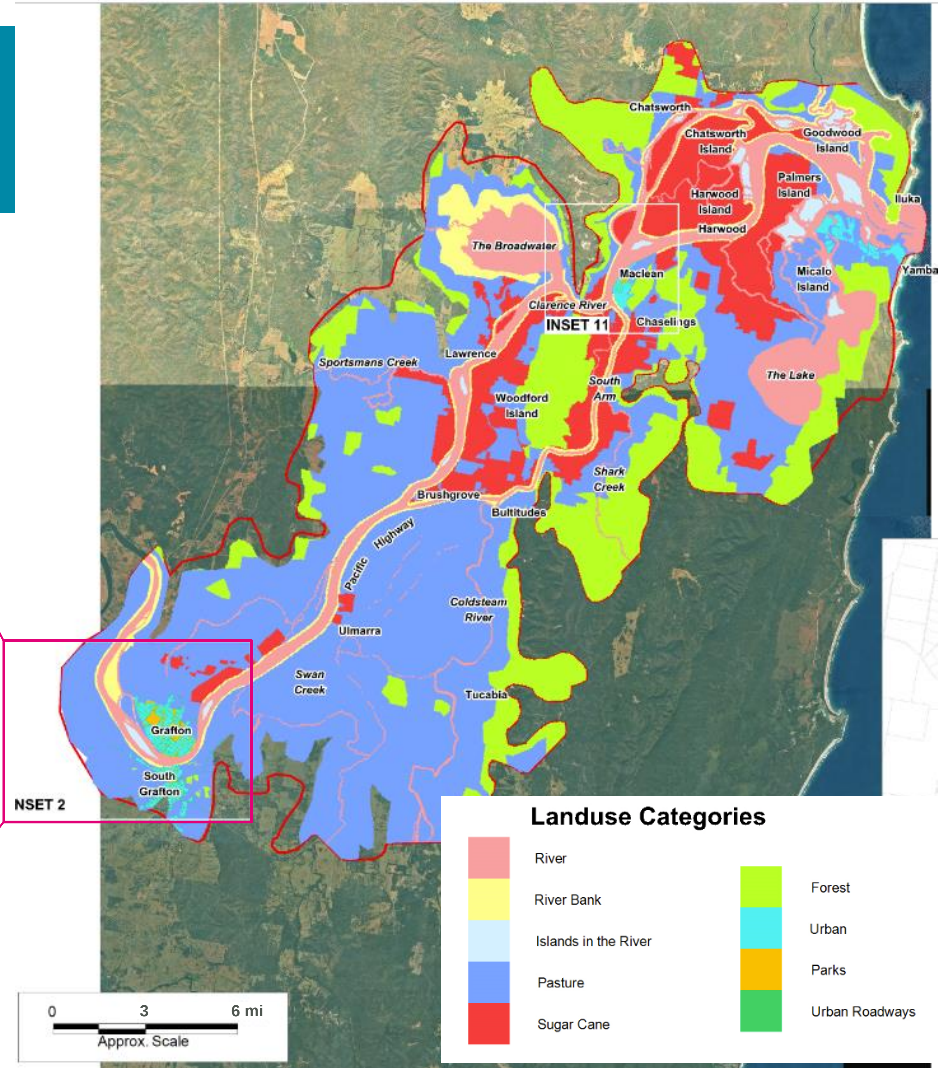
Exercise

Use the 2001 and 2013 events to demonstrate the potential impact of possible model design mistakes / errors

Lower Clarence Valley TUFLOW Flood Model

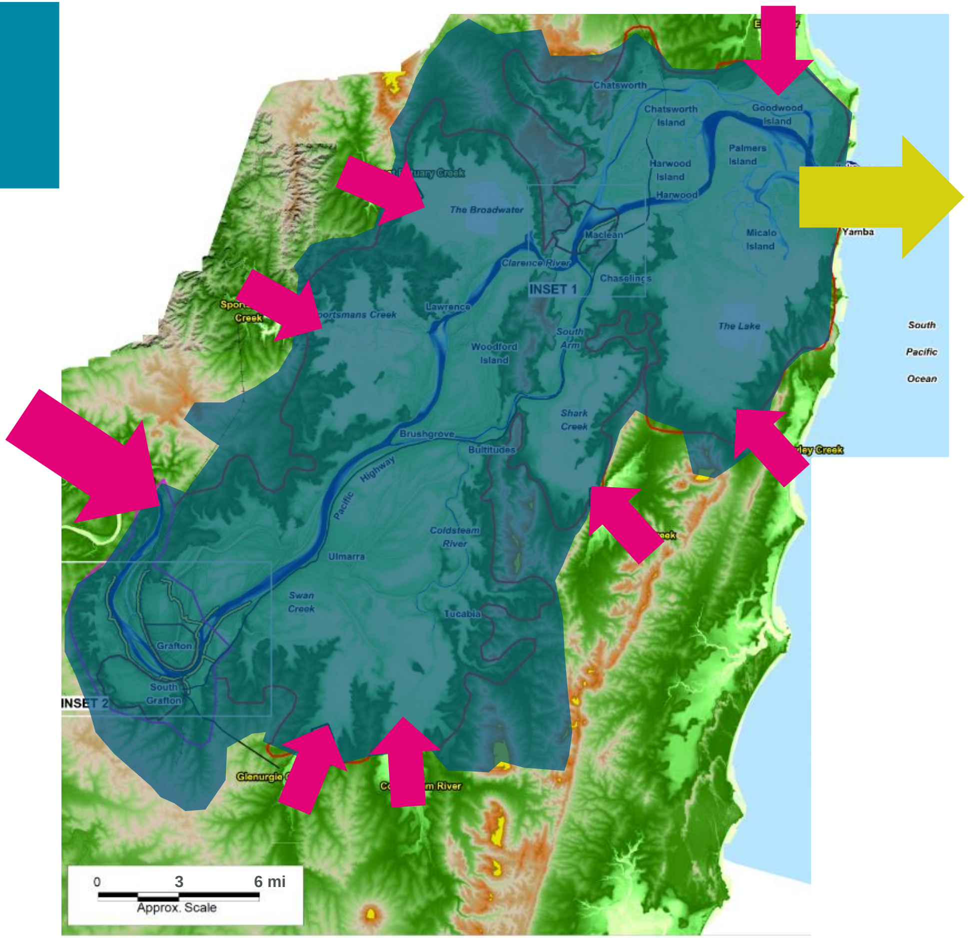
Industry standard Manning's n





Lower Clarence Valley TUFLOW Flood Model

- External Clarence River inflow
- External tributary inflows (7)
- River entrance (tide)
- Internal catchment rainfall



TUFLOW

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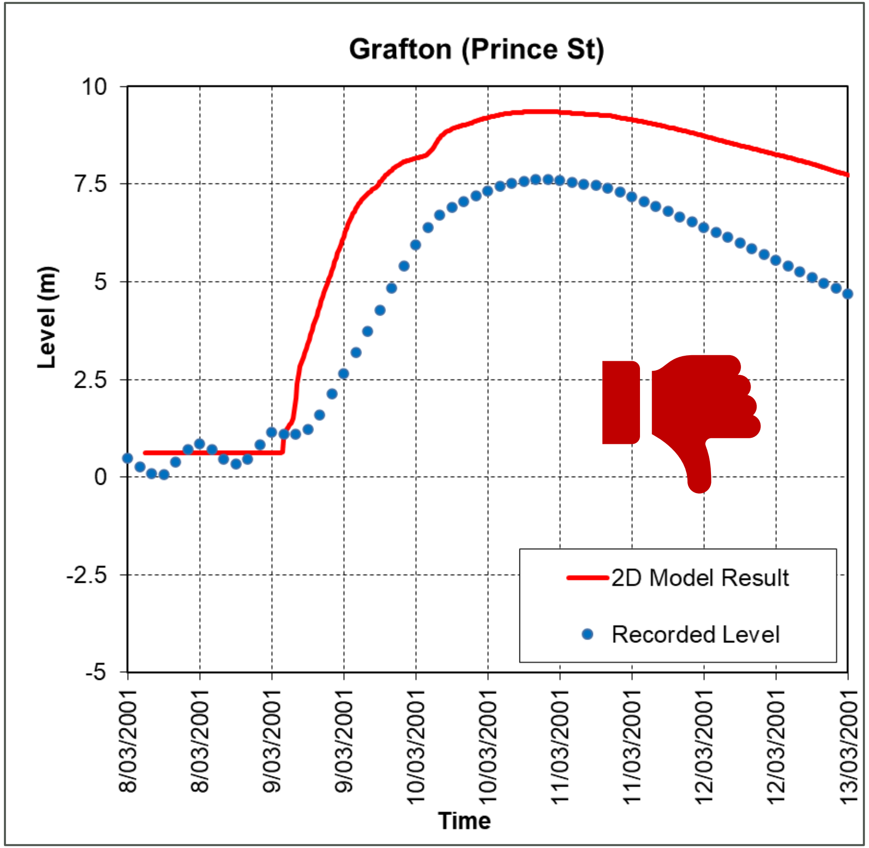
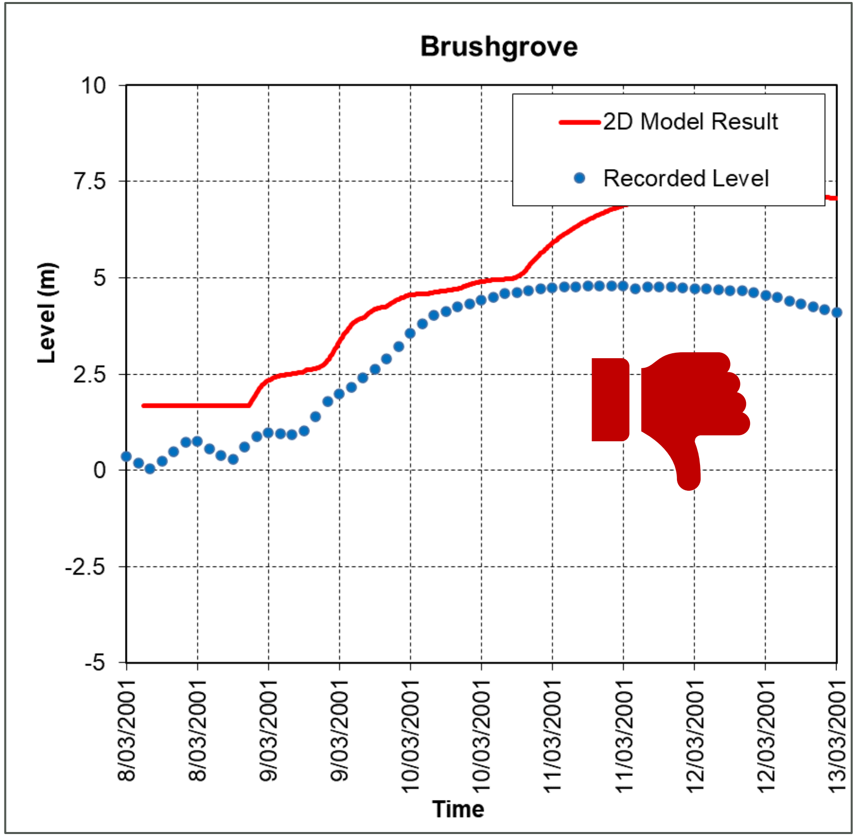
Lower Clarence Valley Result Sensitivity

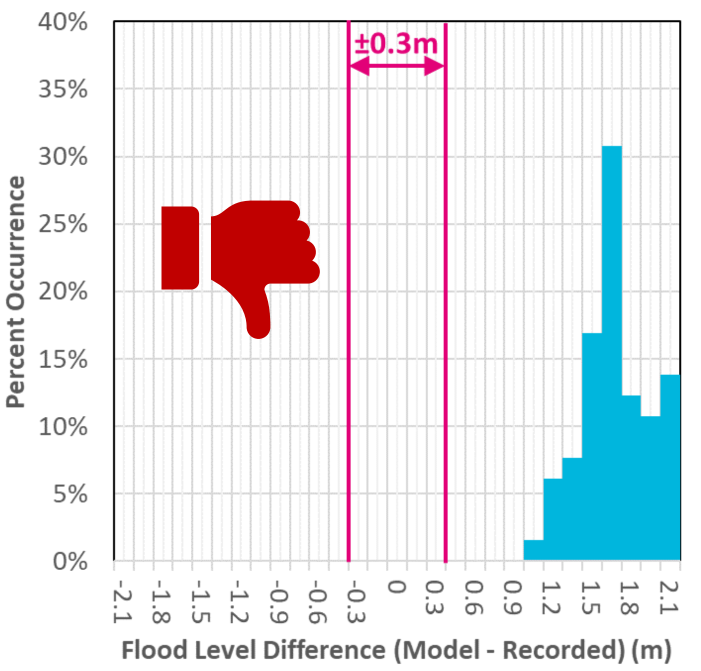
2001 Event

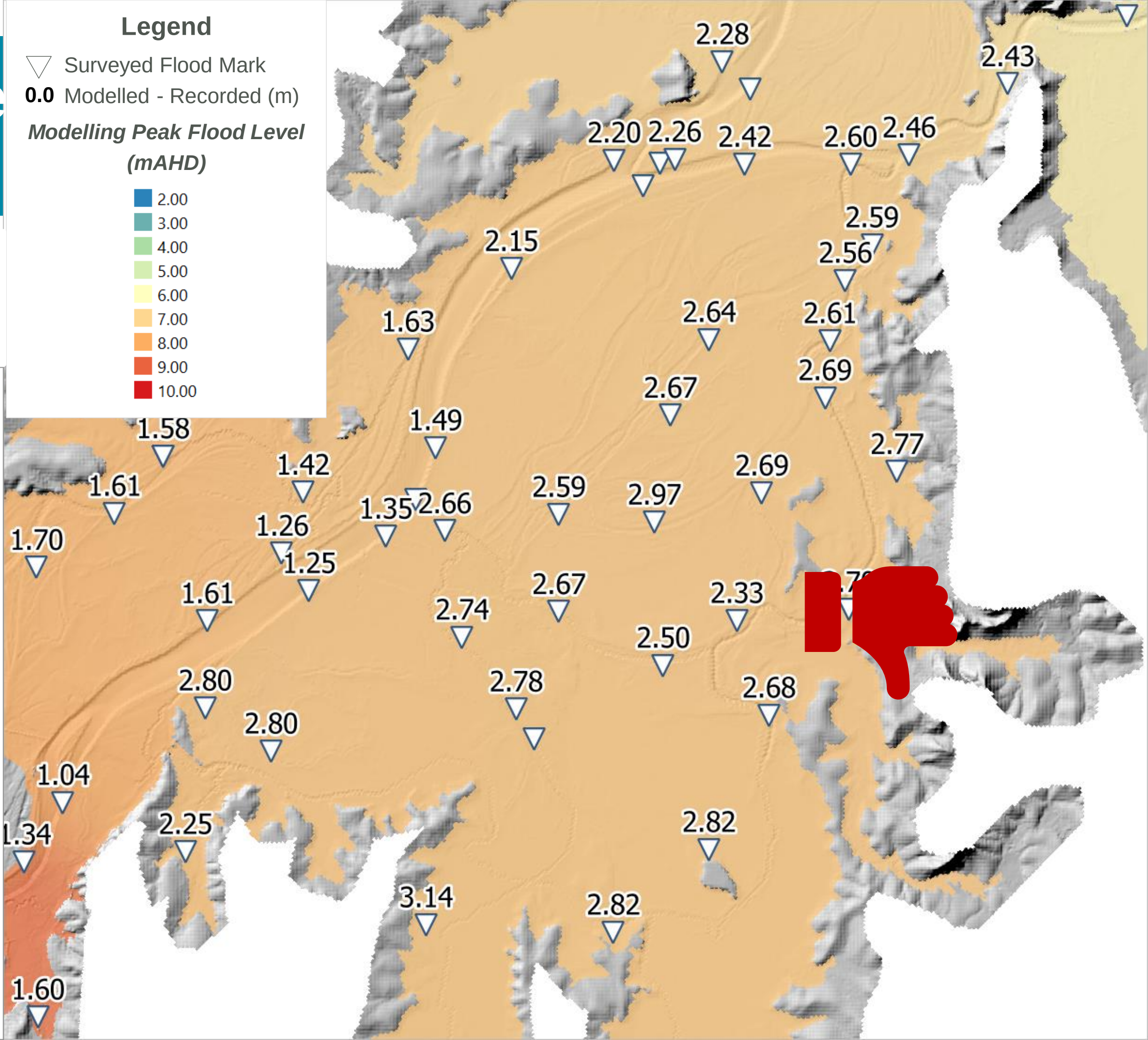




Lower Clarence Valle
Result Sensitivity

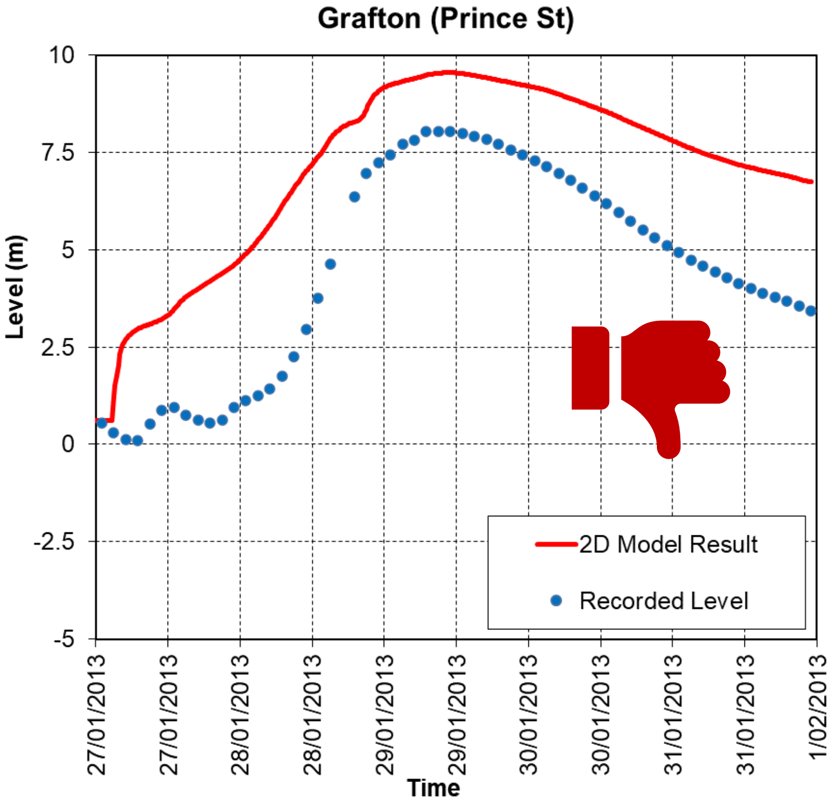
2001 Event
Modelled – Record Peak Flood Level

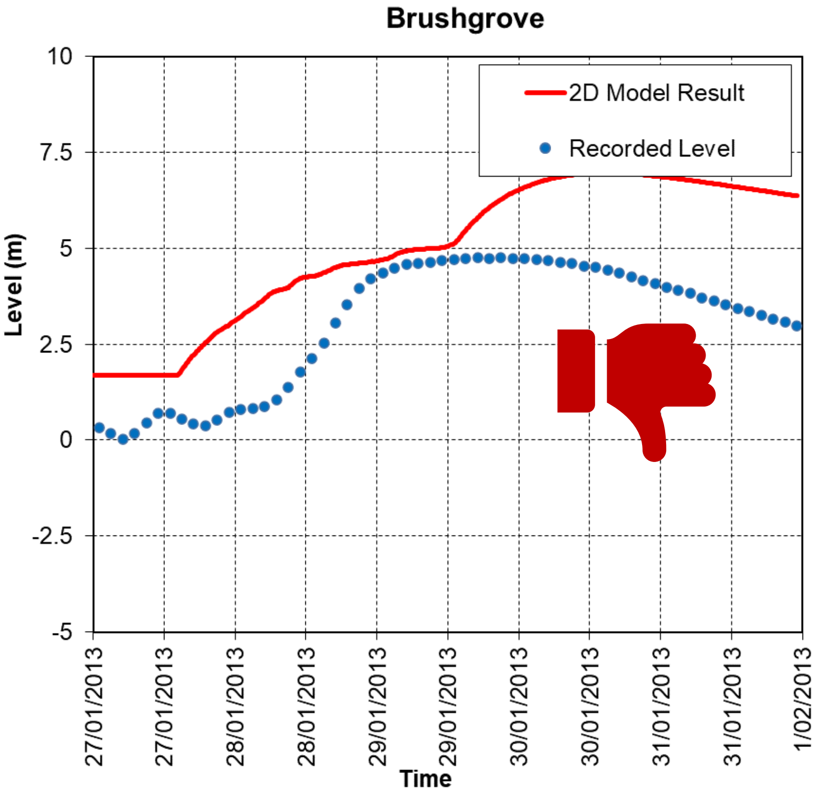




Lower Clarence Valley Result Sensitivity

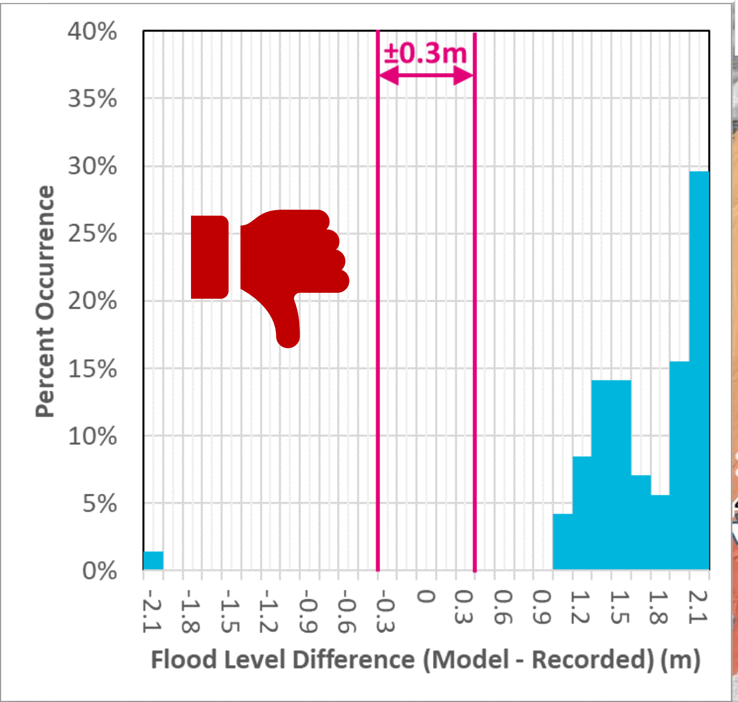
2013 Event

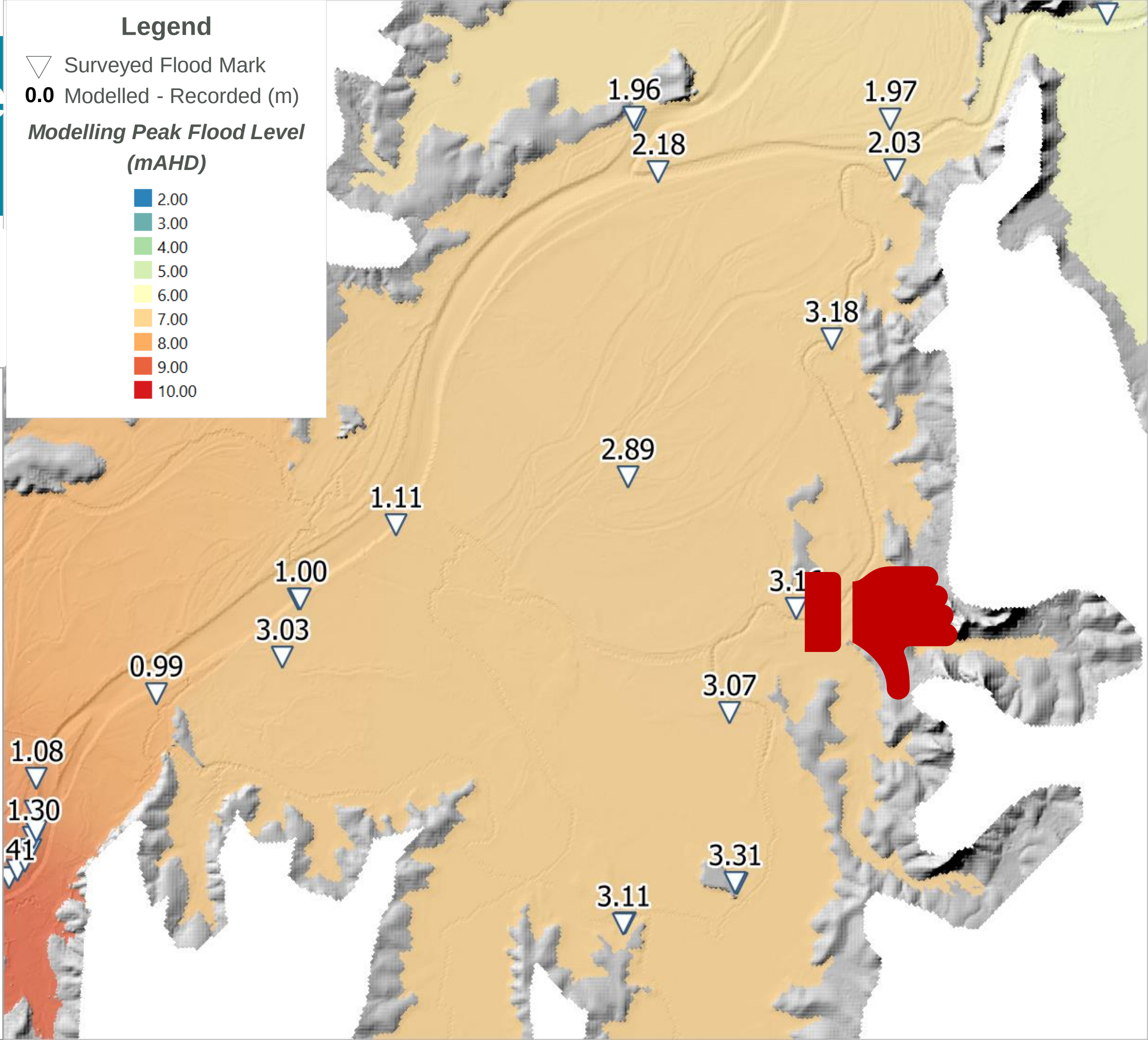




Lower Clarence Valle
Result Sensitivity

2013 Event
Modelled – Record Peak Flood Level

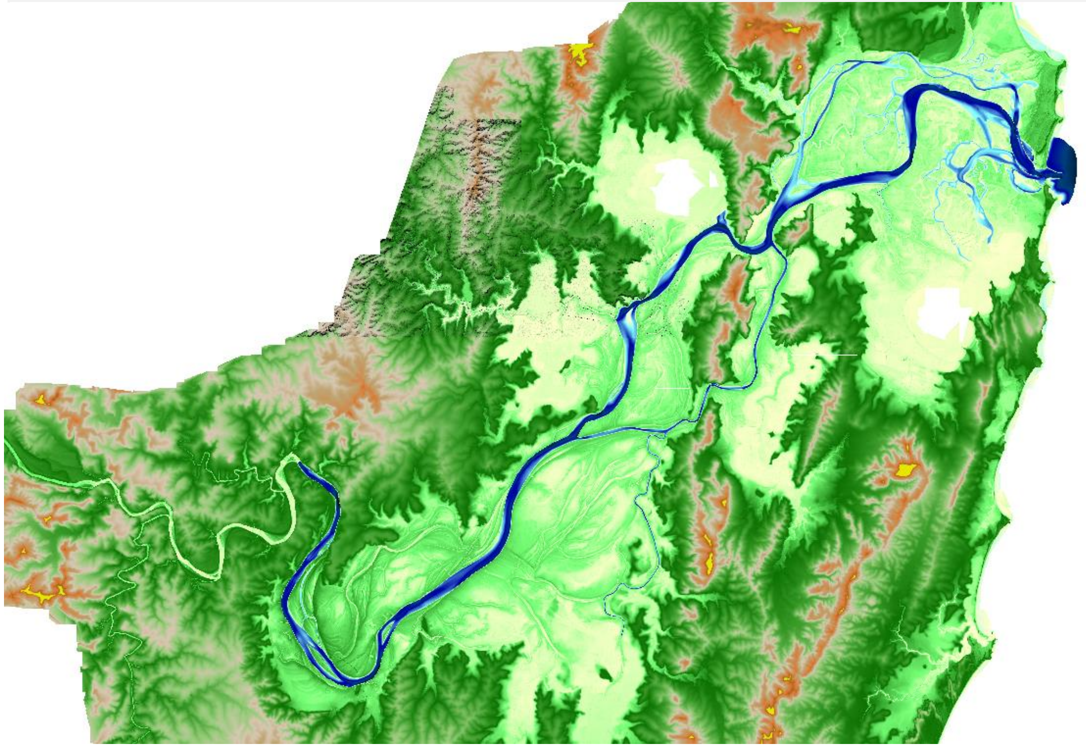




Lower Clarence Valley TUFLOW Flood Model Calibration Tip

- **DO NOT attempt to improve calibration by:**
  - Adjusting Manning's n outside established industry values
  - Using hydrology loss values outside what is physically realistic
- **Ask yourself:**
  - What errors could be in your model?
  - What are the most significant hydraulic features in the project area?

Lower Clarence Valley
LIDAR (ALS) Data + Bathymetry

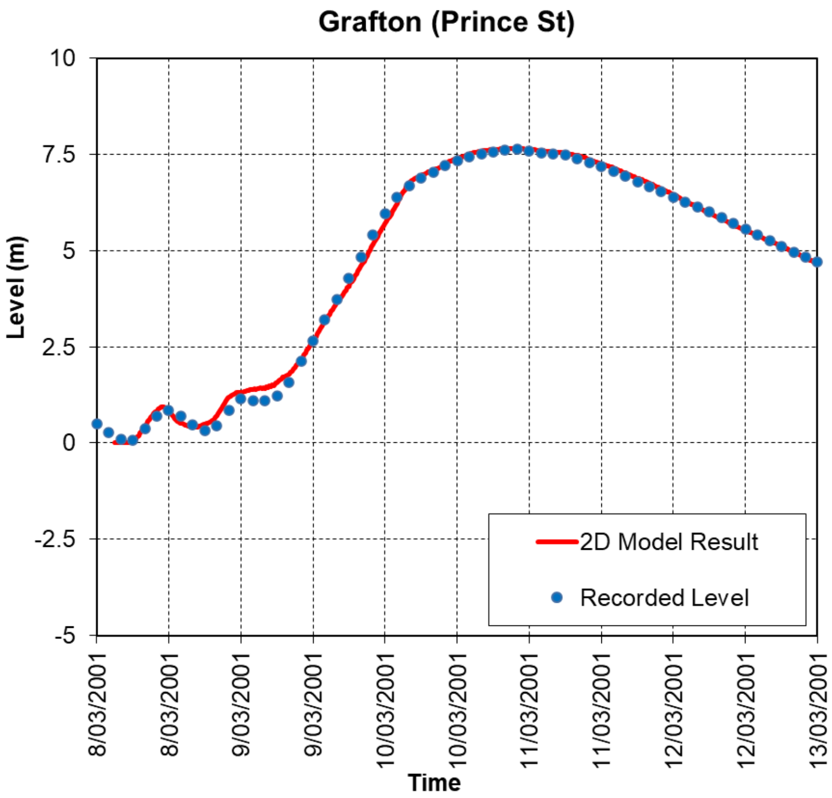


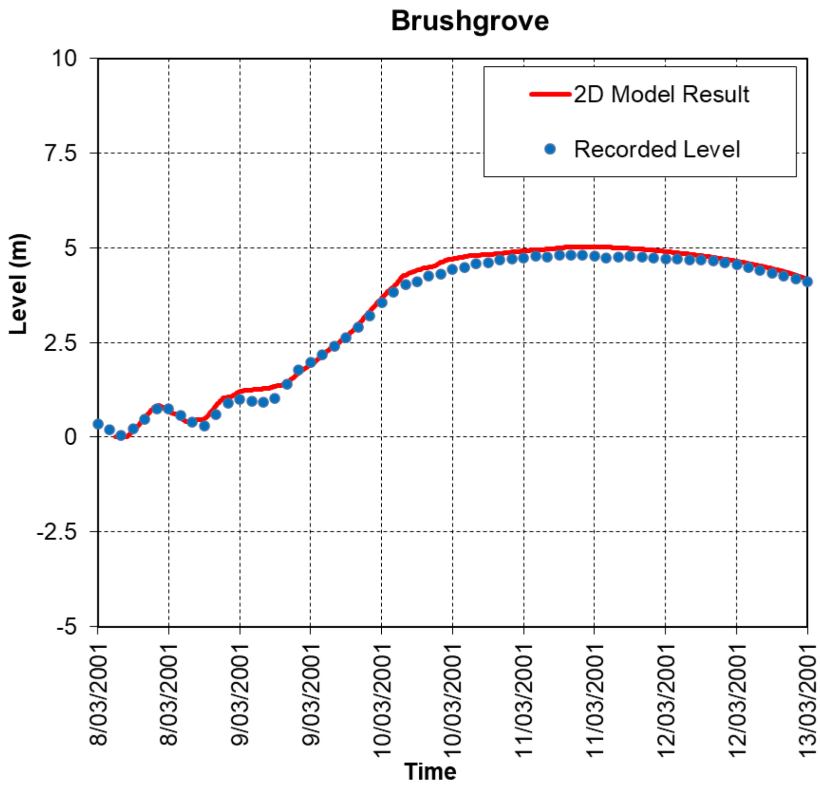
LiDAR data rarely includes bathymetry data:

- Bathymetry added

Lower Clarence Valley Result Sensitivity

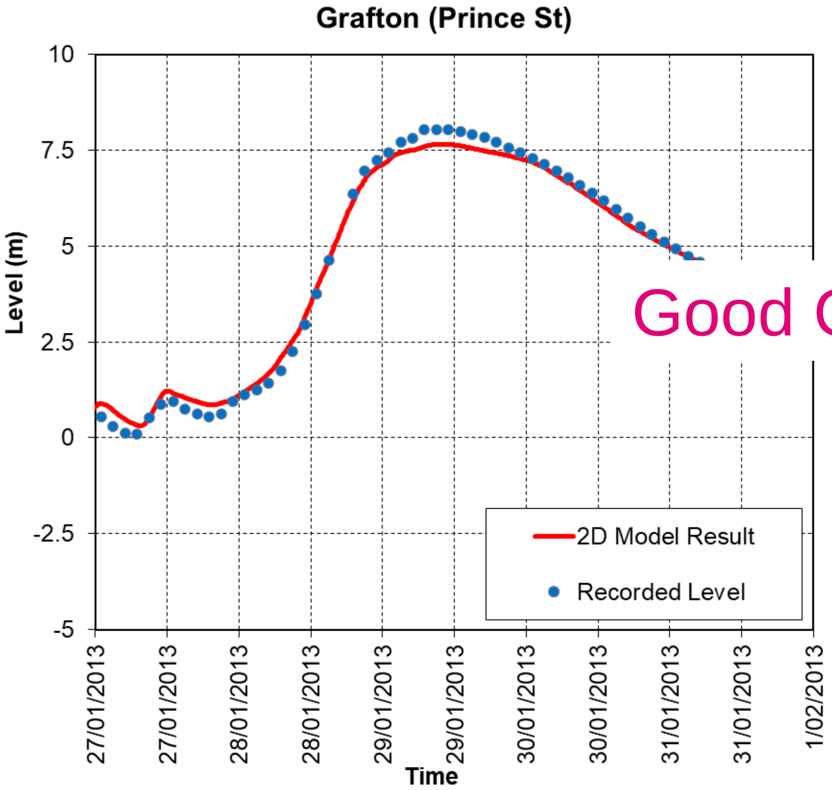
2001 Event

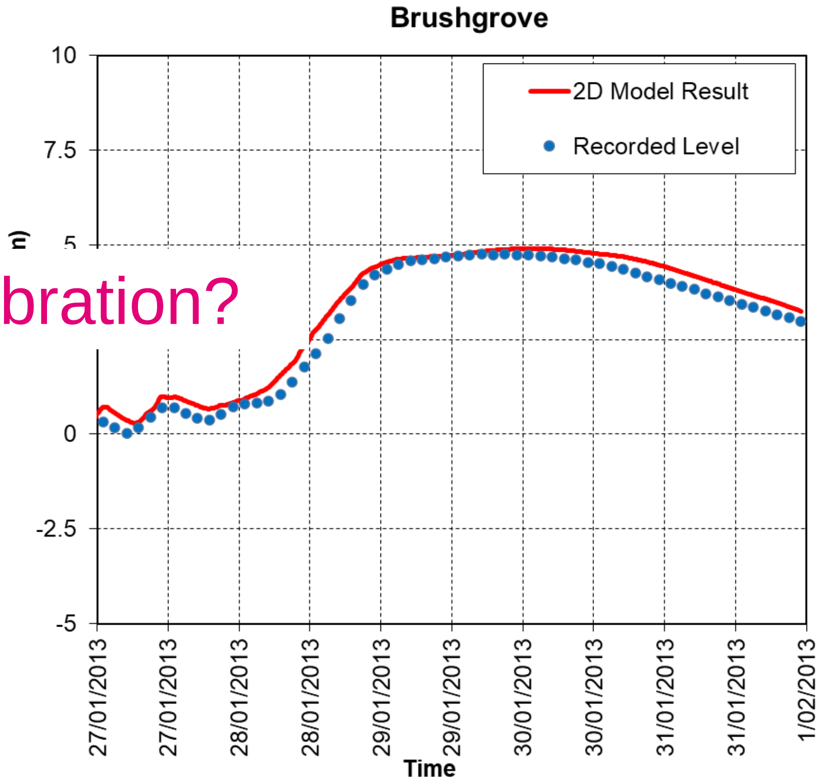




Lower Clarence Valley Result Sensitivity

2013 Event

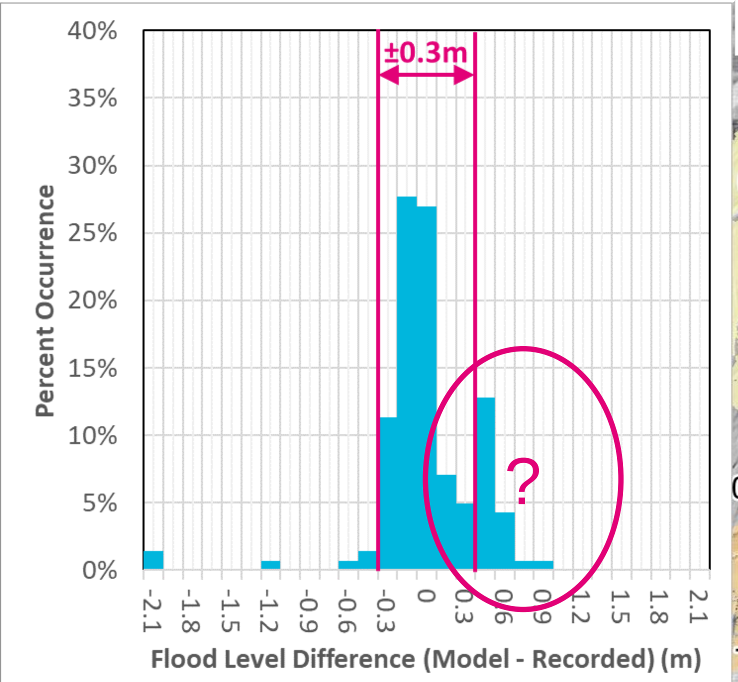


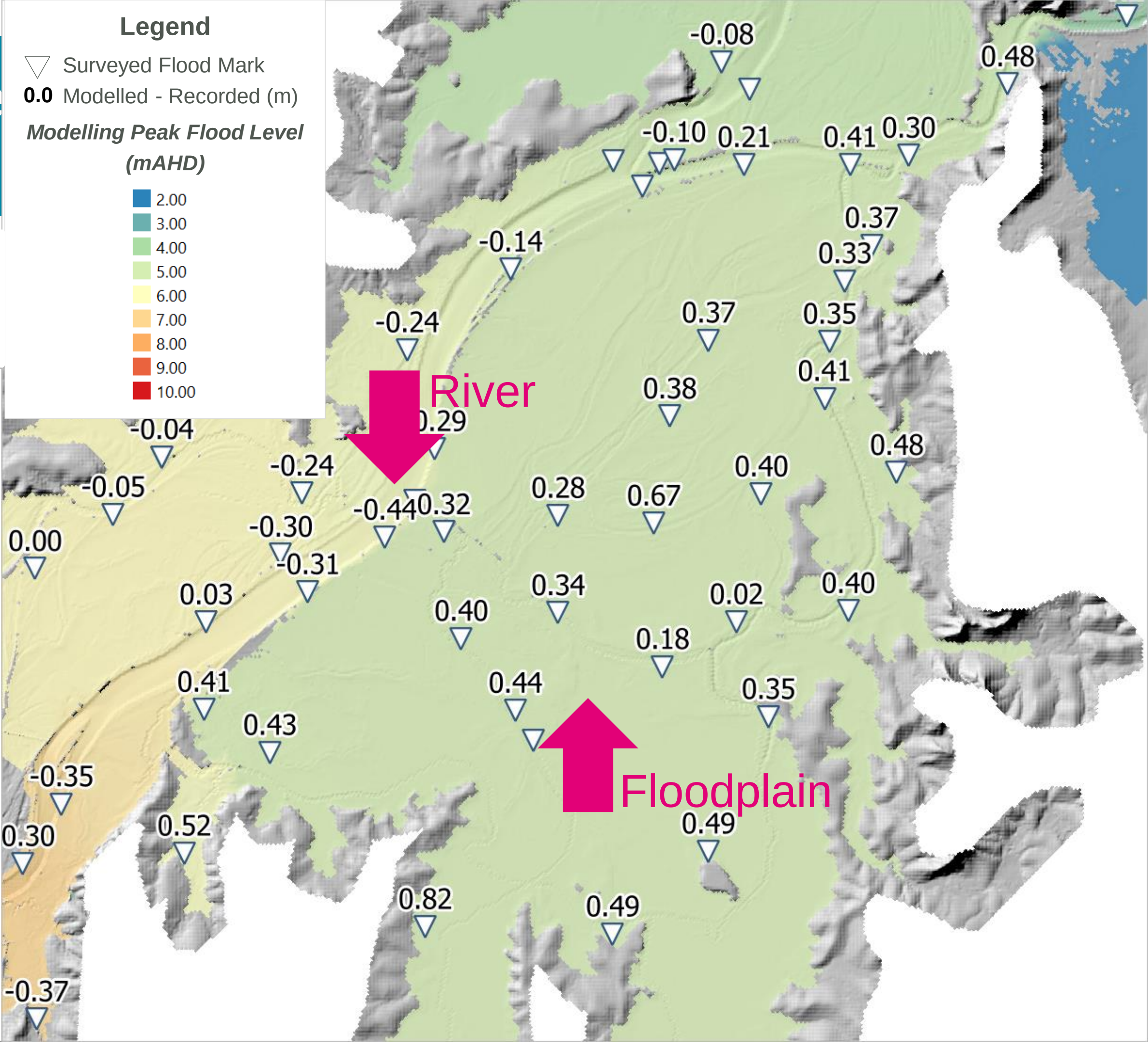


Good Calibration?

Lower Clarence Valle Result Sensitivity

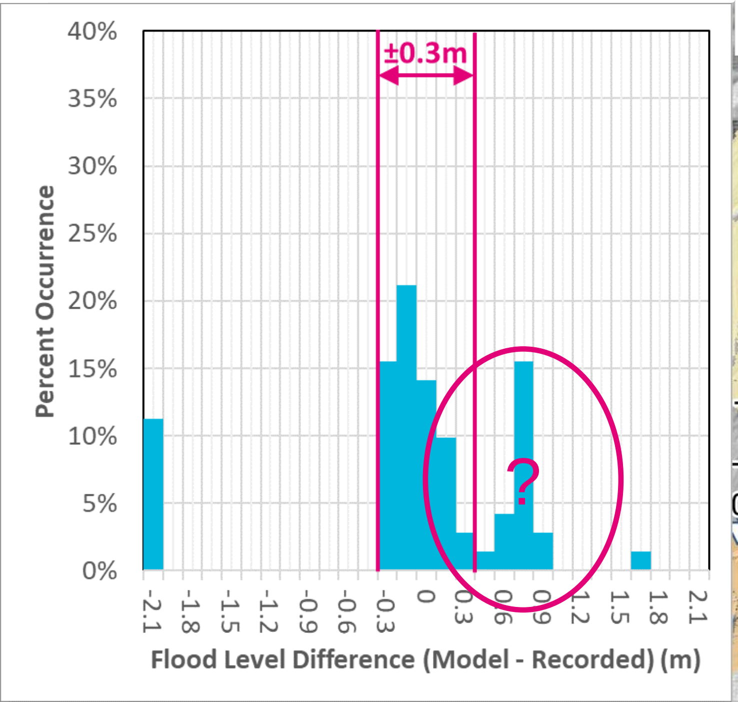
2001 Event
Modelled – Record Peak Flood Level

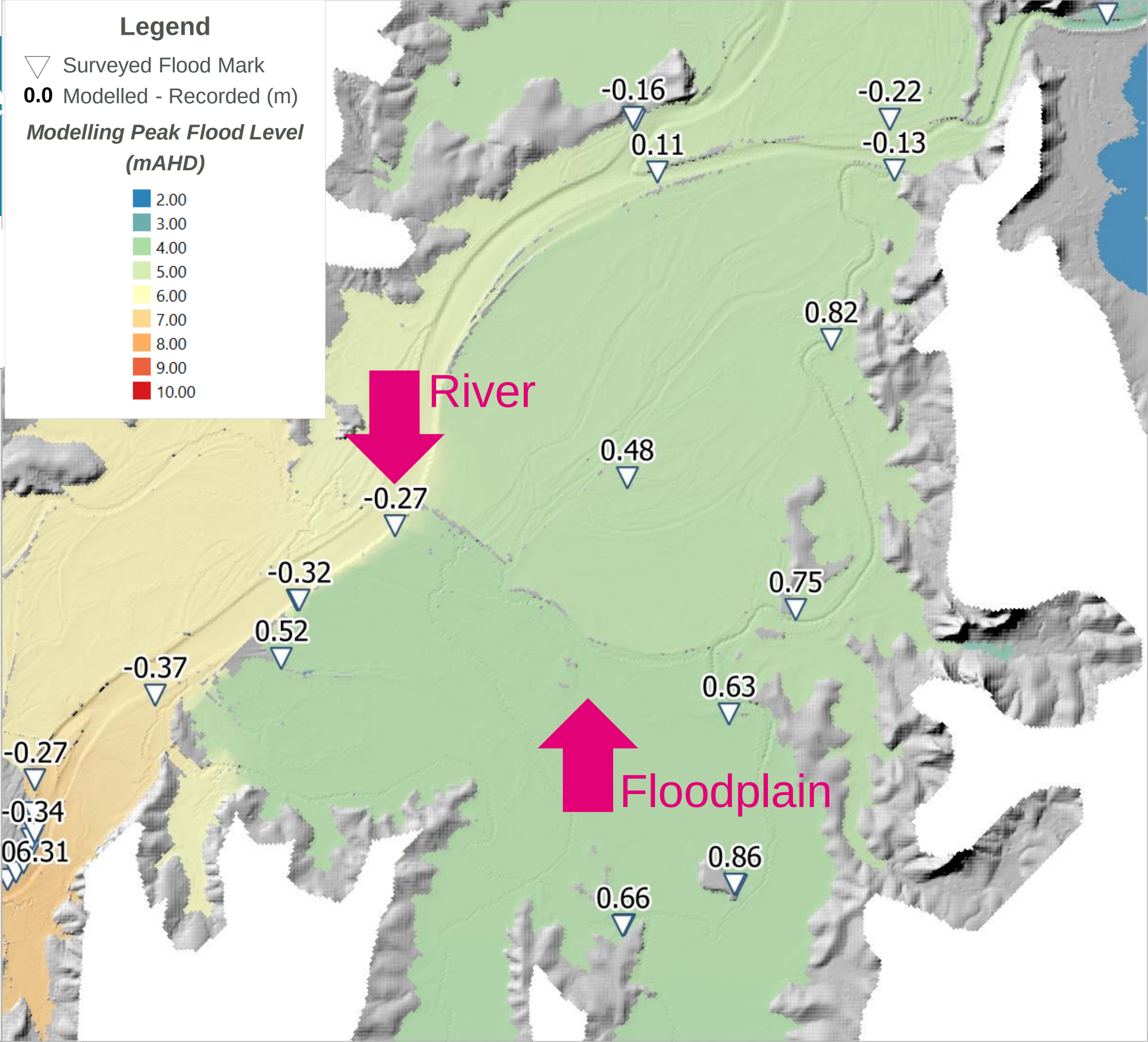




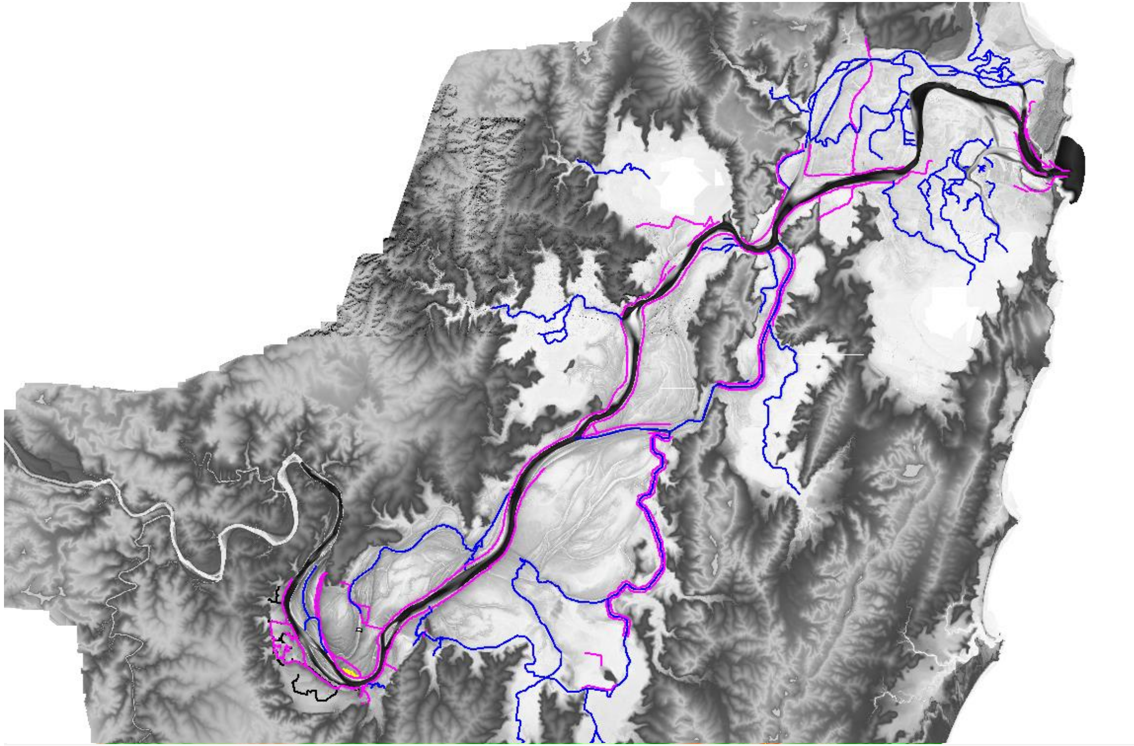
Lower Clarence Valle
Result Sensitivity

2013 Event
Modelled – Record Peak Flood Level





Lower Clarence Valley
LIDAR (ALS) Data + Bathymetry + Breakline Data

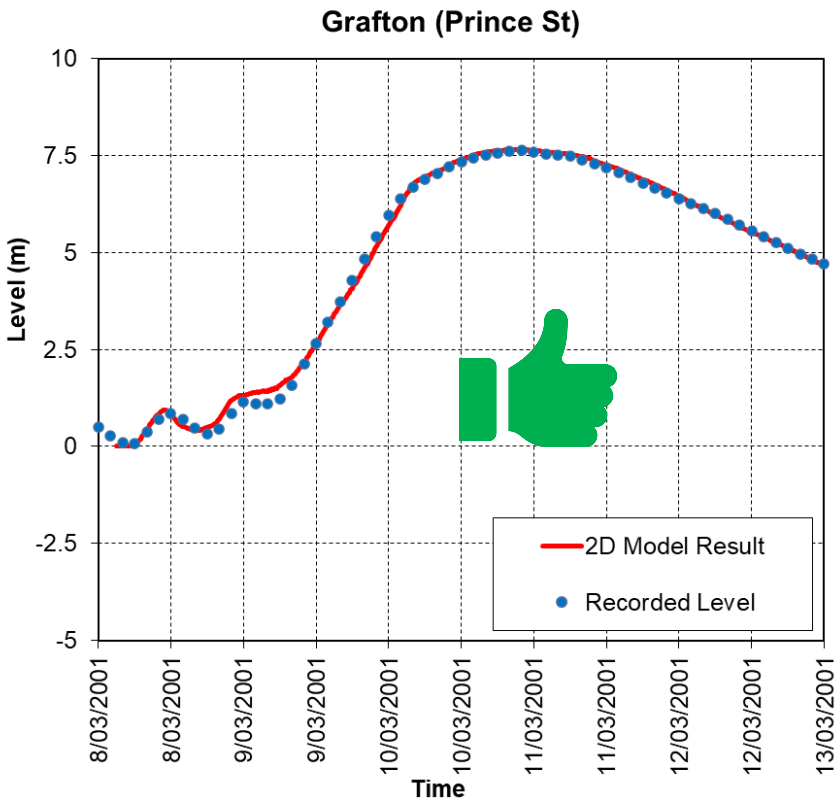


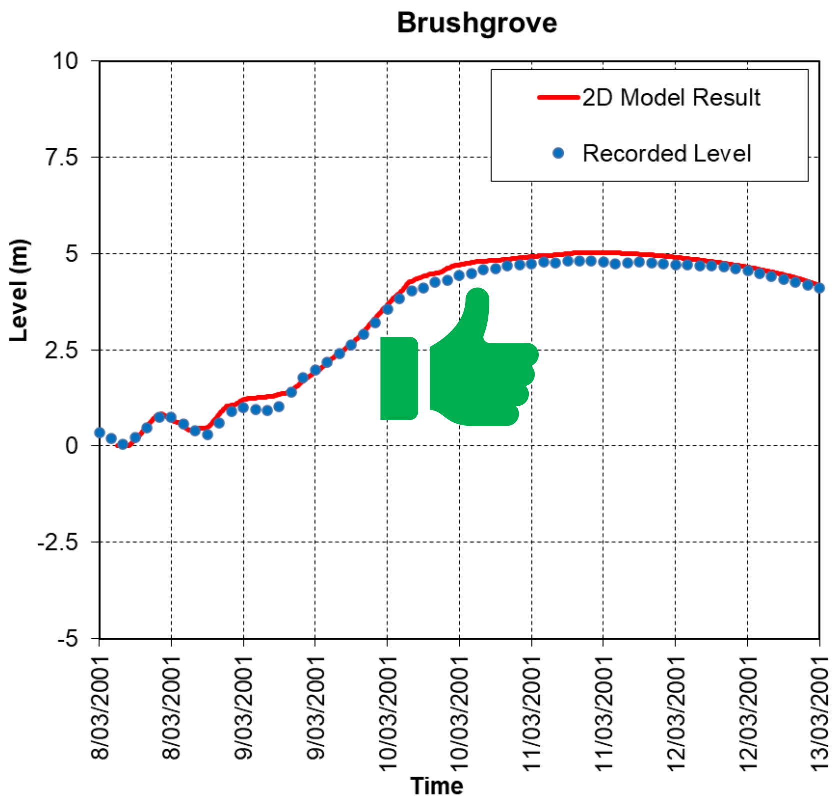
Add breaklines to enforce key topographic hydraulic controls

- Levees
- Raised road embankments
- Raised railway embankments
- Perched riverbanks
- Minor drainage channels
  (if not using SGS)

Lower Clarence Valley Result Sensitivity

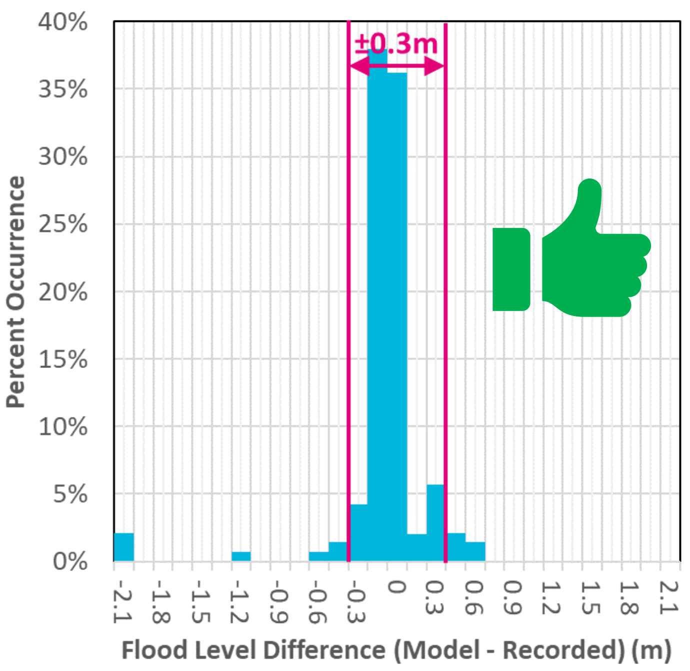
2001 Event

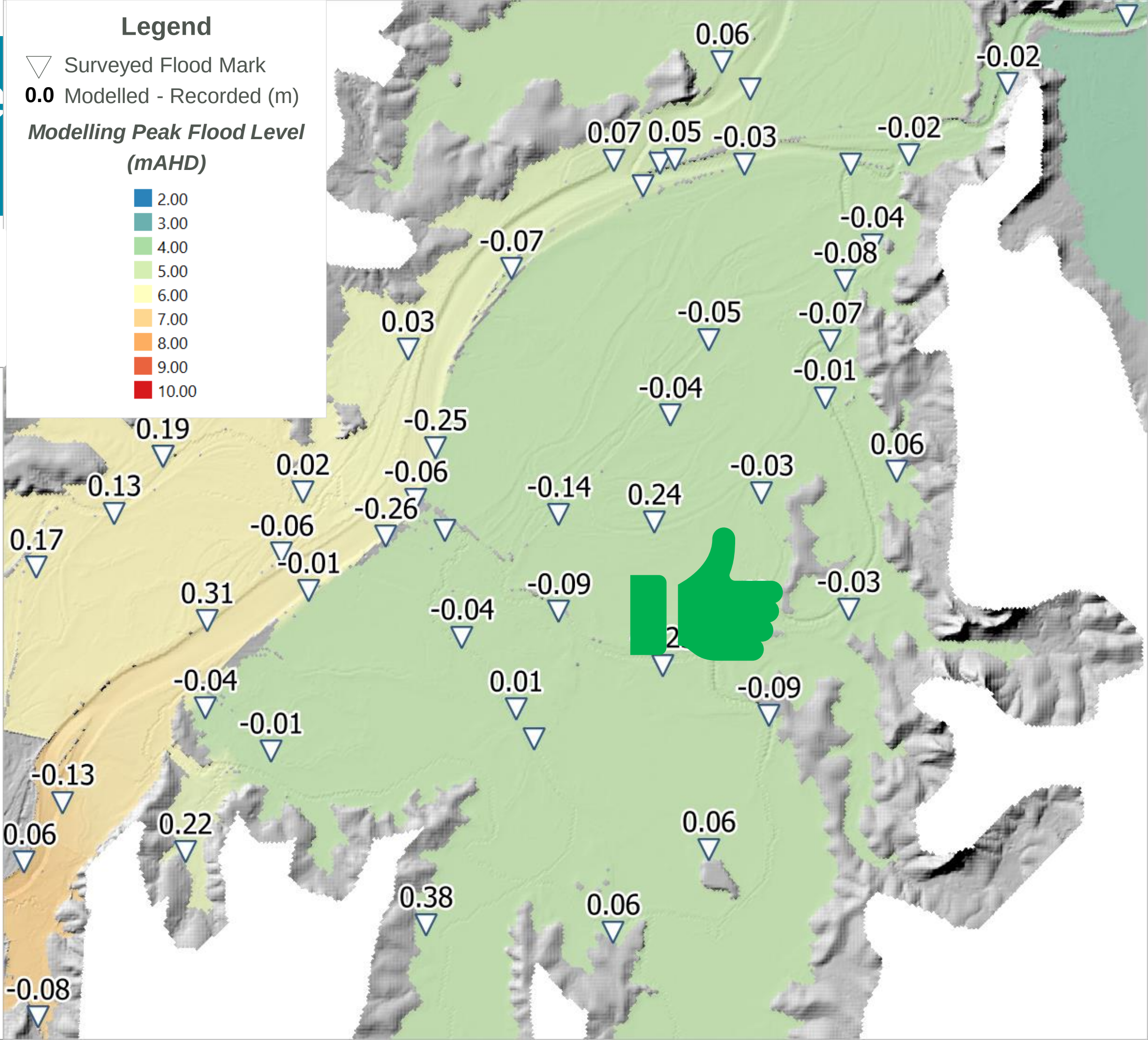




Lower Clarence Valle
Result Sensitivity

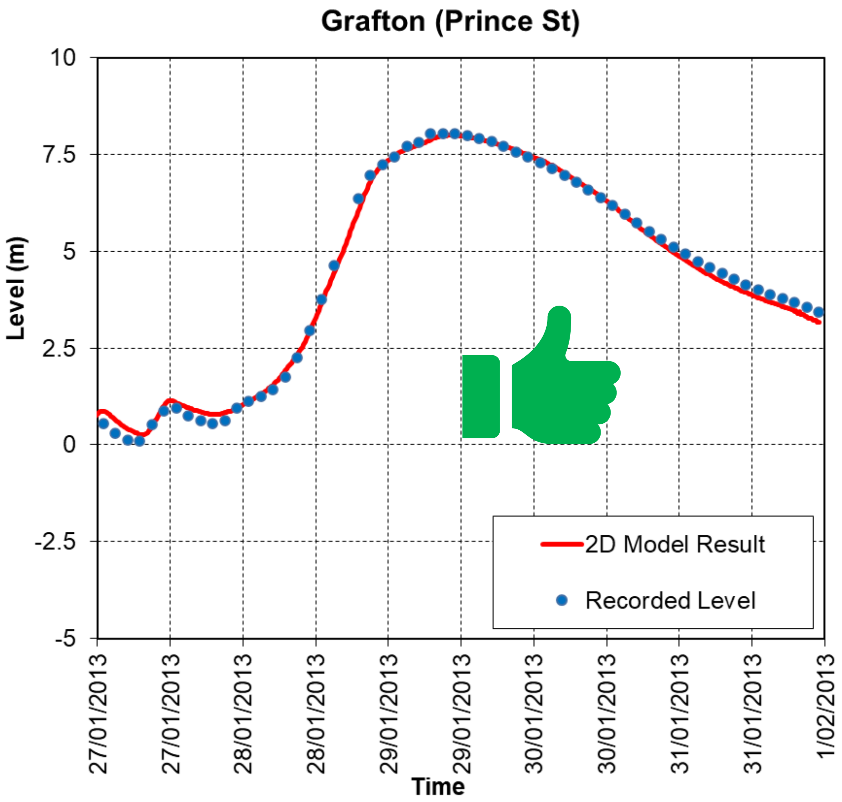
2001 Event
Modelled – Record Peak Flood Level

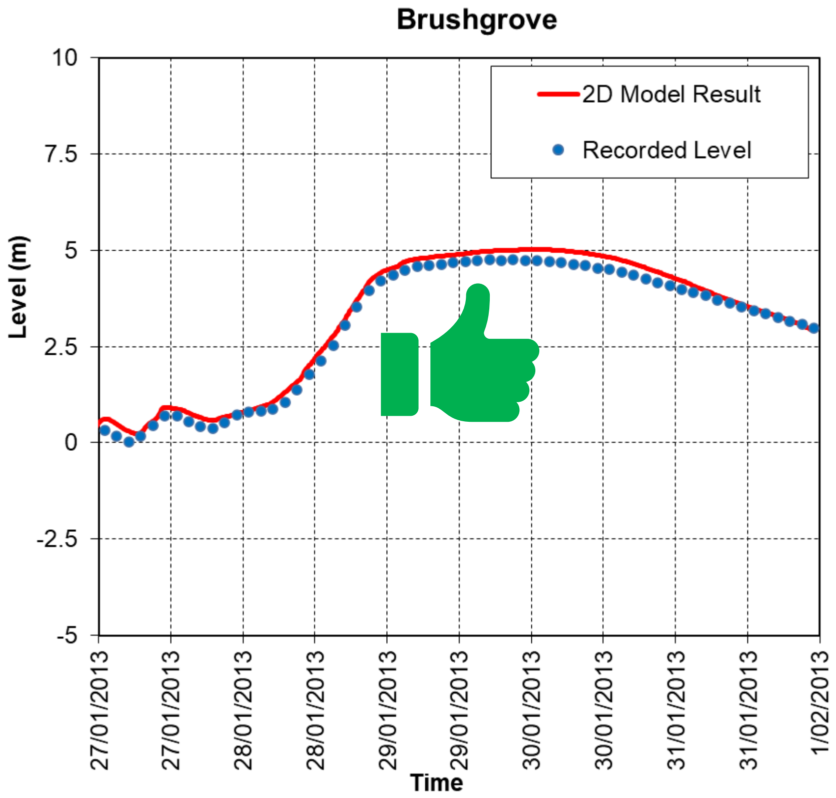




Lower Clarence Valley
Result Sensitivity

2013 Event

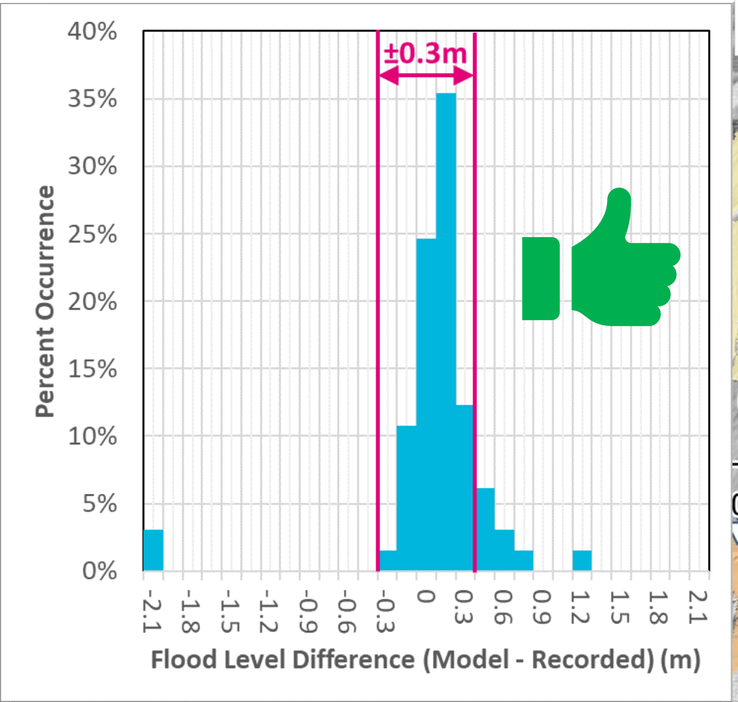


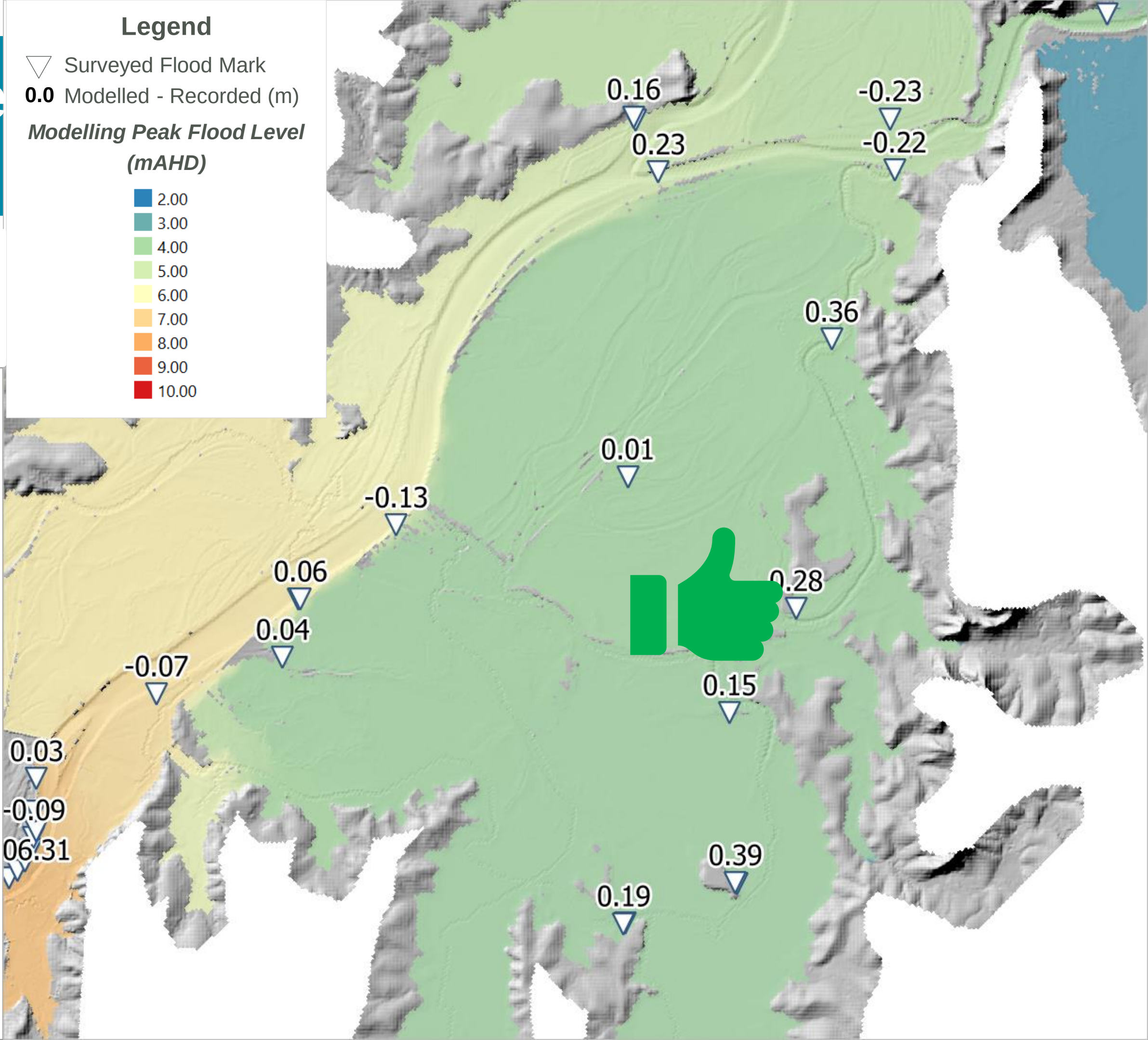


Lower Clarence Valle Result Sensitivity

2013 Event

Modelled – Record Peak Flood Level

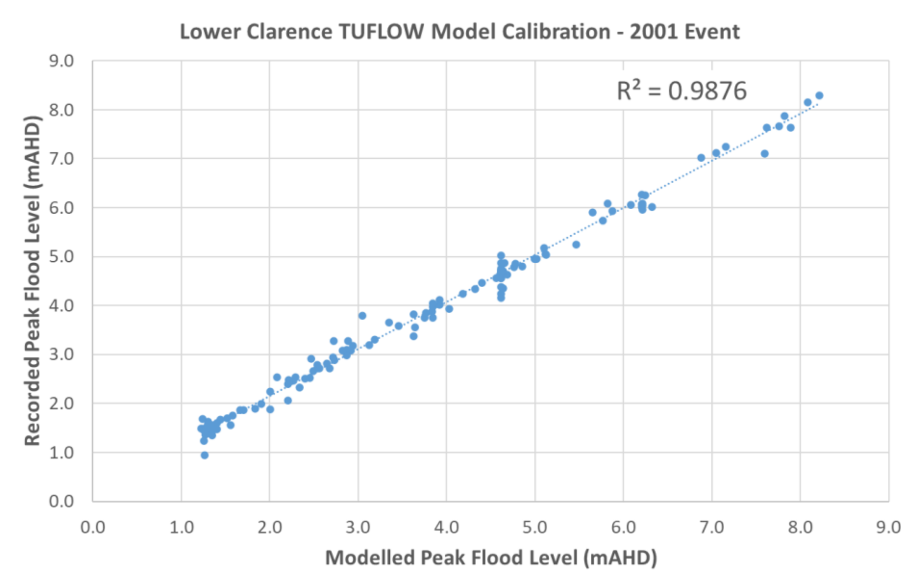




Calibration Reporting

Ccalibration Performance Reporting
Peak Flood Mark Results

- Maps presenting results
- Summary graphs
  - Histogram
  - Recorded vs measured scatter
- Performance reporting statistics
  - Mean, standard deviation and R^2



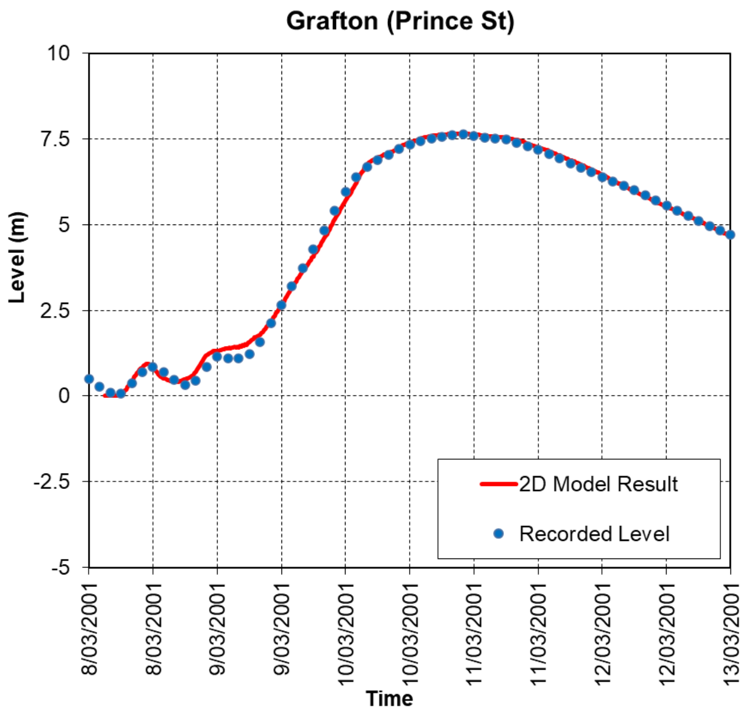
Exhaustive Real-World Example – Hydrology and Hydraulic Model Calibration Reports
https://www.publications.qld.gov.au/dataset/brisbane-river-catchment-flood-study

Calibration Performance Reporting
Water Level Gauge Recording

- Graph reporting - calibration match to peak value and shape (rising and falling limb) are equally important
- Performance reporting statistics

Class	Peak Ratio	Volume Ratio	Nash Sutcliffe
Excellent	< ±10%	< ±15%	≥ ±0.95
Good	< ±15%	< ±25%	≥ ±0.90
Fair			≥ ±0.85
Poor	< ±50%	< ±50%	≥ ±0.50

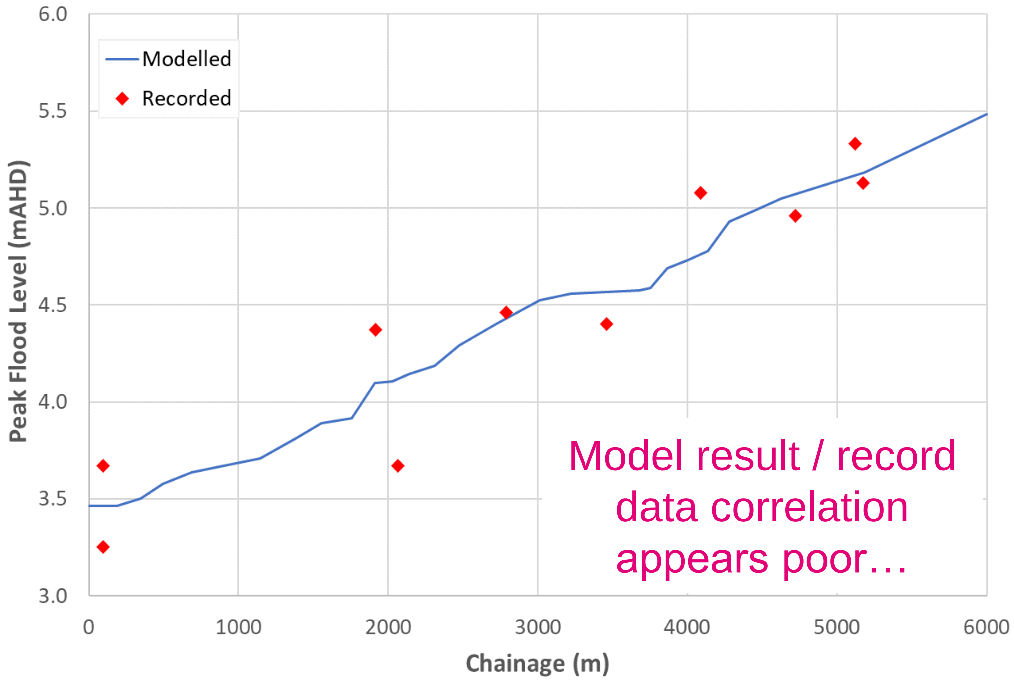
Source: SEQ Water Values reported in the Brisbane River Catchment Flood Study Report



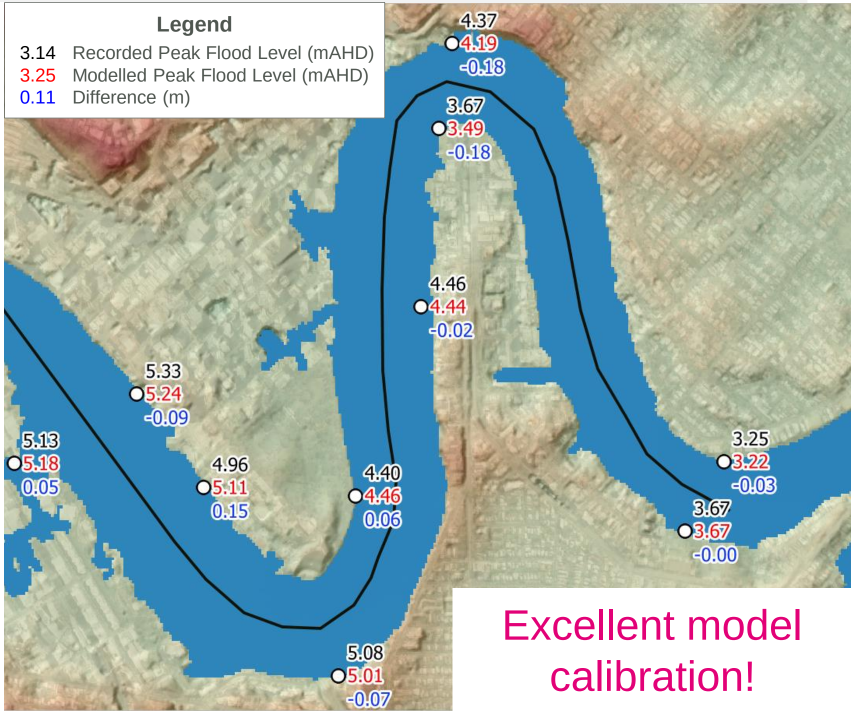
Other ref. https://tonyladson.wordpress.com/2019/08/20/model-performance-based-on-coefficient-of-efficiency/

Calibration Performance Reporting
River Centreline Long-section

- Doesn't accommodate for superelevation around river bends (1D mentality)



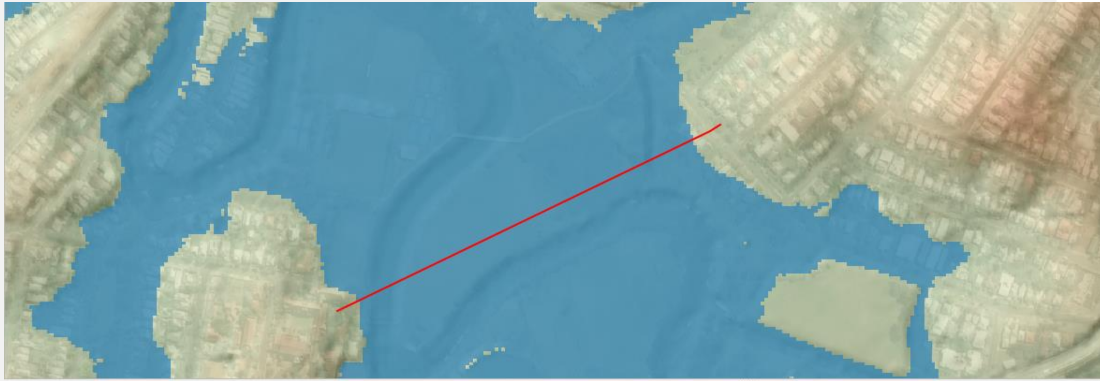
Model result / record data correlation appears poor…

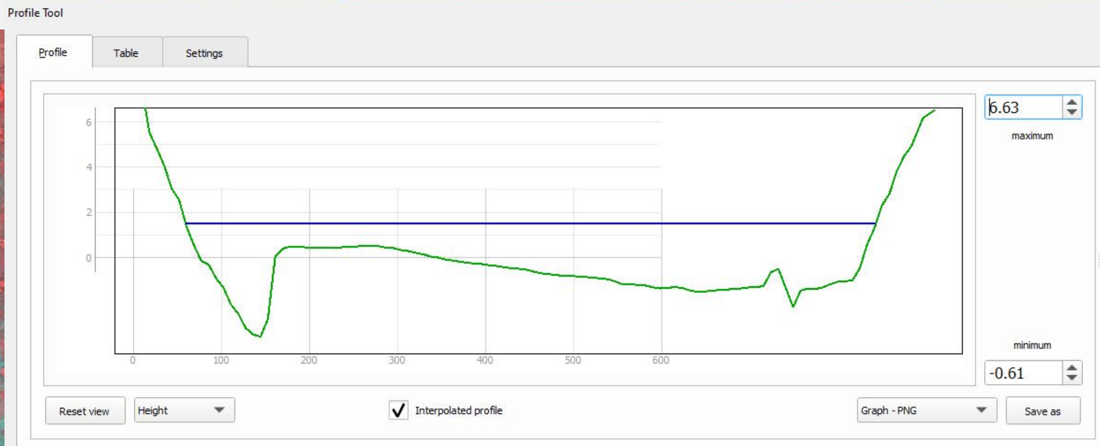


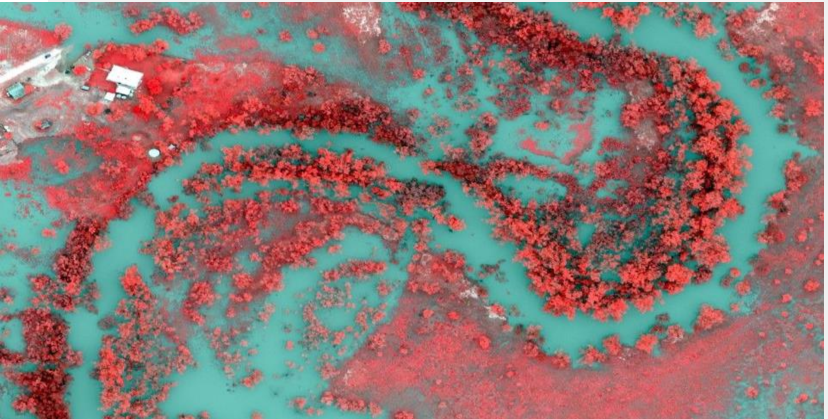
Excellent model calibration!

Calibration Performance Reporting
Aerial Imagery Flood Extent

- Low quality calibration dataset
- Event peak timing challenge
- Often coarse zoom comparison…
- Major flooding often extends to where high gradient topography starts…







Presentation Summary

1. Calibration is necessary to develop fit for purpose flood models
   - Future $$ savings (design costs and reduced unexpected flood damages)
2. Calibrate to multiple events is recommended
   - Consider event magnitude, data availability, event recency
3. Use a common sense approach to achieve a quality calibration result
   - Quality check data quality prior to use
   - Employ best practice model design/build principles
   - Use software that's suitable for the flood behaviour being modelled
4. Calibration Reporting
   - Necessary so future model users are aware of uncertainty

Modelling When Calibration Data is Scarce?

Webinar: Modelling when calibration data is scarce

What parameters and quality control tests should be adopted for uncalibrated hydraulic modelling?

What parameters and quality control tests should be used for an uncalibrated hydraulic model and understanding the model's uncertainty?

Date: Wednesday, 16 June 2021

Time: 1:00pm (Australia/Sydney; find your local time)

TUFLOW Webinars

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

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Questions?