TUFLOW – An Introduction

FMA Conference, Sacramento, USA, 2012

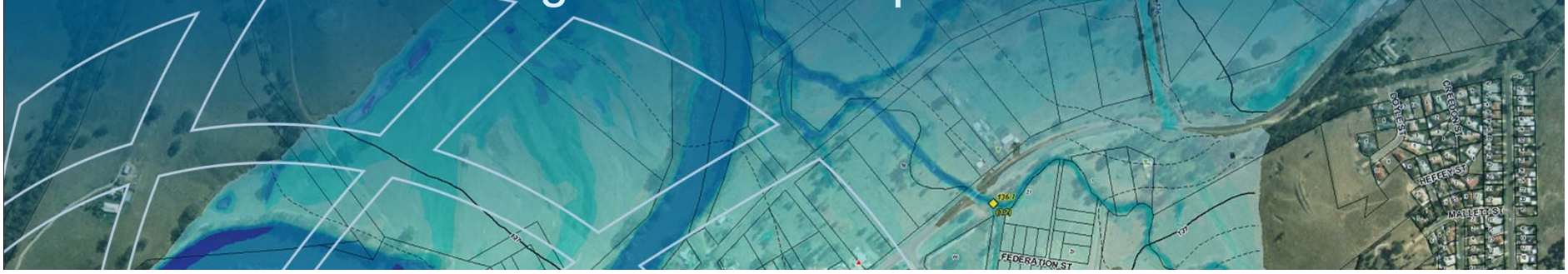
Bill Syme

BMT WBM

TUFLOW
Flood and Tide Simulation Software

TUFLOW Products

- TUFLOW "Classic"
  - Grid based (regular mesh)
  - Advanced 1D/2D Linking
- TUFLOW FV
  - Flexible Mesh (triangles and quadrilaterals)
  - 1D/2D linking under development



TUFLOW (Regular Grid)

- Now predominantly used for flood modeling
  - Major rivers/floodplains
  - Urban inundation
  - Pipe network modeling
- Grid based
- Finite Difference Implicit Solution

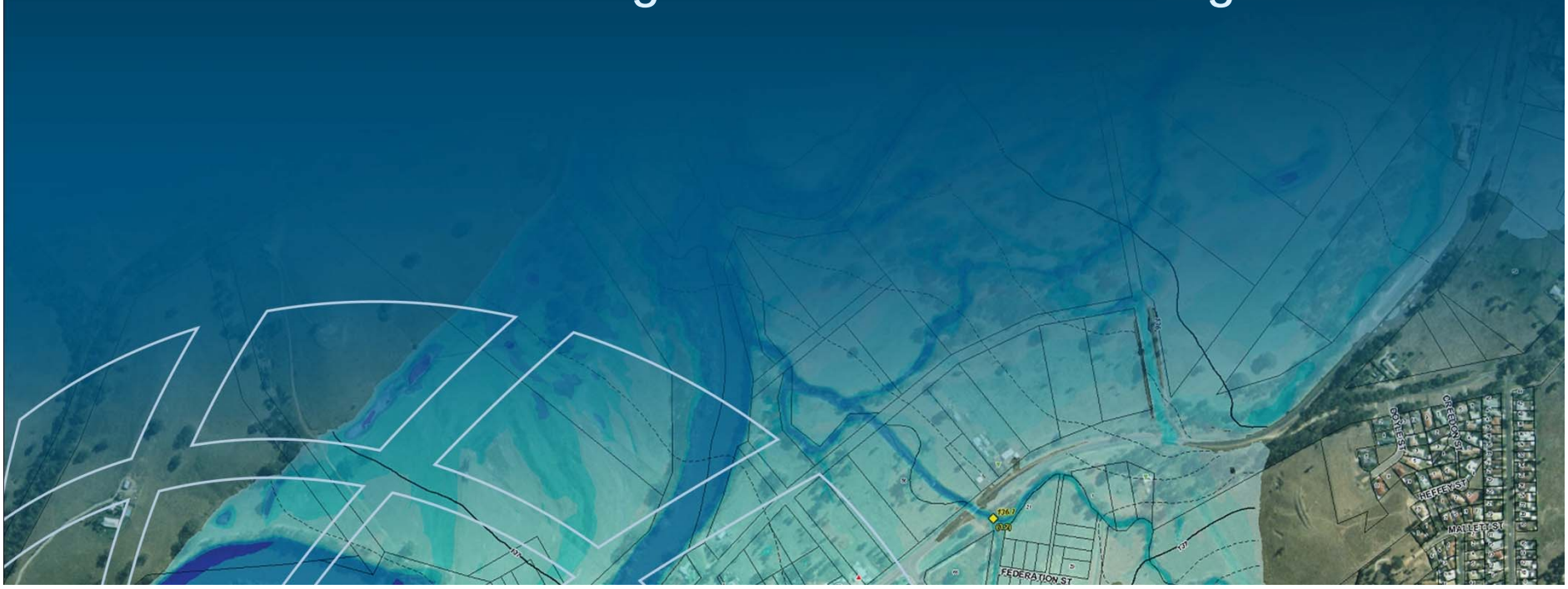
TUFLOW FV (Flexible Mesh)

- Predominantly used for coastal/estuarine modelling
- Finite Volume solution with shock capturing
  (very stable and mass conservative)
- Flooding Applications
  - Excellent alternative to RMA2 and FESWMS
  - Does not have the instability issues Finite Element solvers experience
  - Suitable at all scales (large rivers to flume models)
  - Limited 1D linking at present

Grid or Flexible Mesh?

- Discuss at presentation at 10:30 to 12:00 on Thu

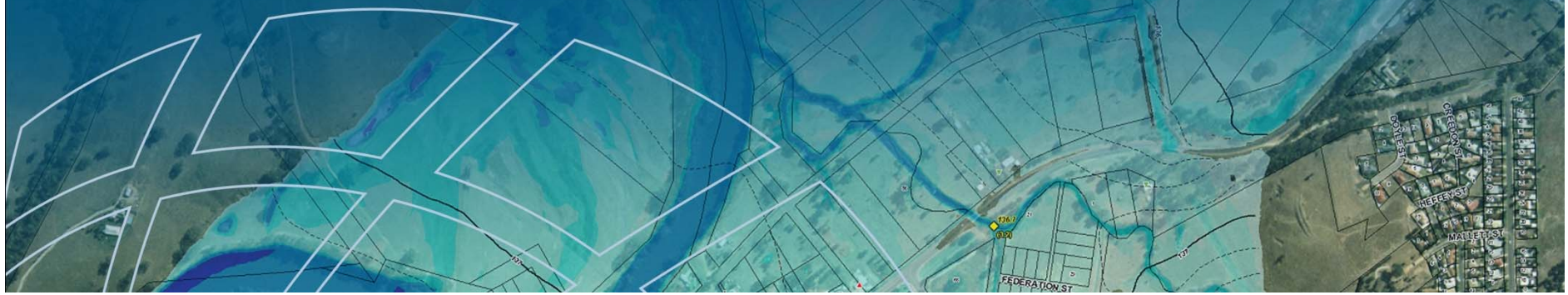
  “Interpreting 2D Models:
  When is a Model Right and When is it Wrong?”



TUFLOW GPU Module

- Up to 100 times faster
  (depends on size of model and graphics card)
- Recently ran a 45 million cell model
- Presentation 10:15 to 11:45 on Friday

  “Rapid and Accurate Flood Modeling using the Full 2D Equations on GPUs”



2D or Not 2D?

Are all “2D” schemes fully 2D?

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TUFLOW
Flood and Tide Simulation Software

TUFLOW Products solve All SWE Physical Processes

How Velocity changes over time

Coriolis Force

Atmospheric Pressure

External Forces (Wind, Waves, ...)

Inertia Term

Gravity

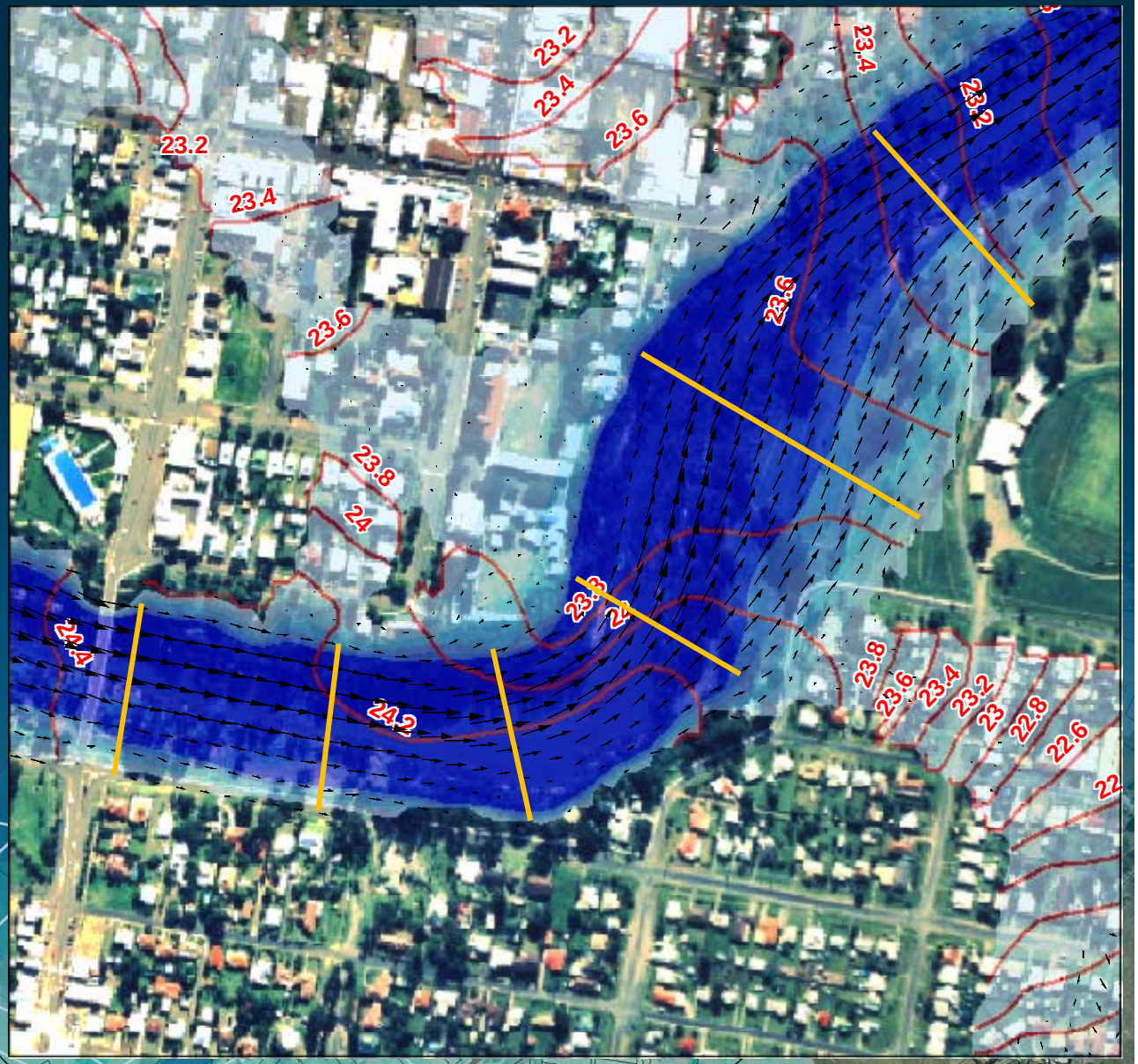
Bed Resistance

Viscosity (Turbulence)

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + c_f u + g\frac{\partial h}{\partial y} + g\,v\frac{\sqrt{u^2+v^2}}{C^2 H} - \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + \frac{1}{\rho}\frac{\partial p}{\partial y} = F_y$$

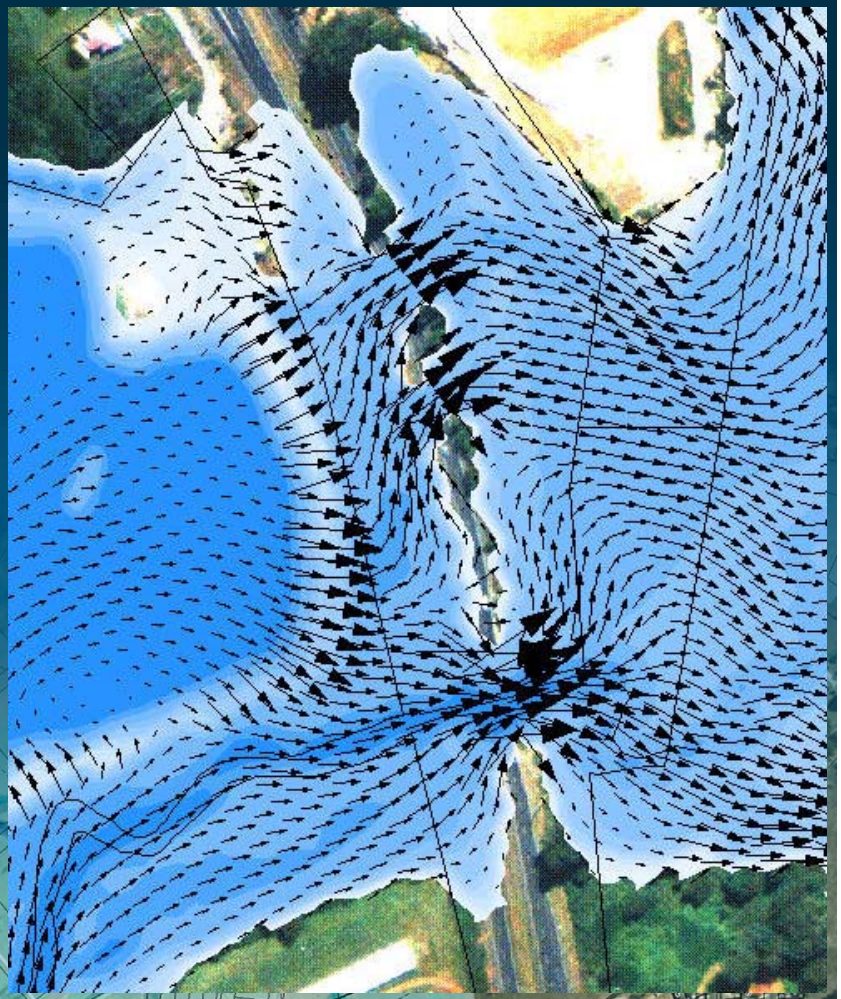
Inertia

- 4 m/s
- 20 m deep
- 0.4m superelevation
- 1D:
  - Need additional losses (eg. higher n)
  - No superelevation



Viscosity
Sub-Grid Scale Turbulence

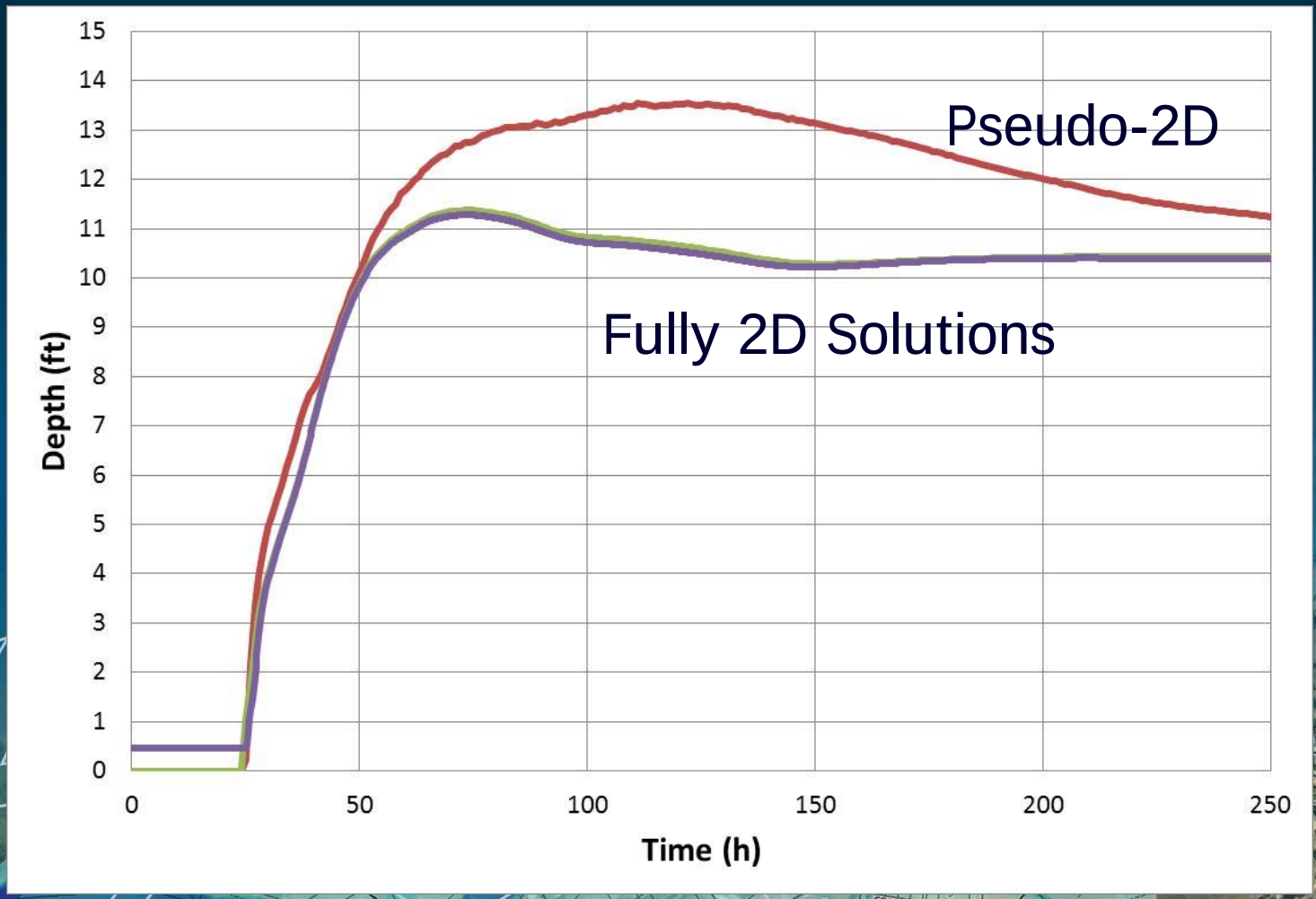
- Important where bed resistance term not dominant and/or
  rapid changes in velocity gradient
  - Low Manning's n values and/or deep water
  - Flow constrictions
- Smagorinsky formula preferred
  (varies coefficient based on velocity gradient)
- Many 2D schemes omit this term
- Never have to artificially increase viscosity for stability



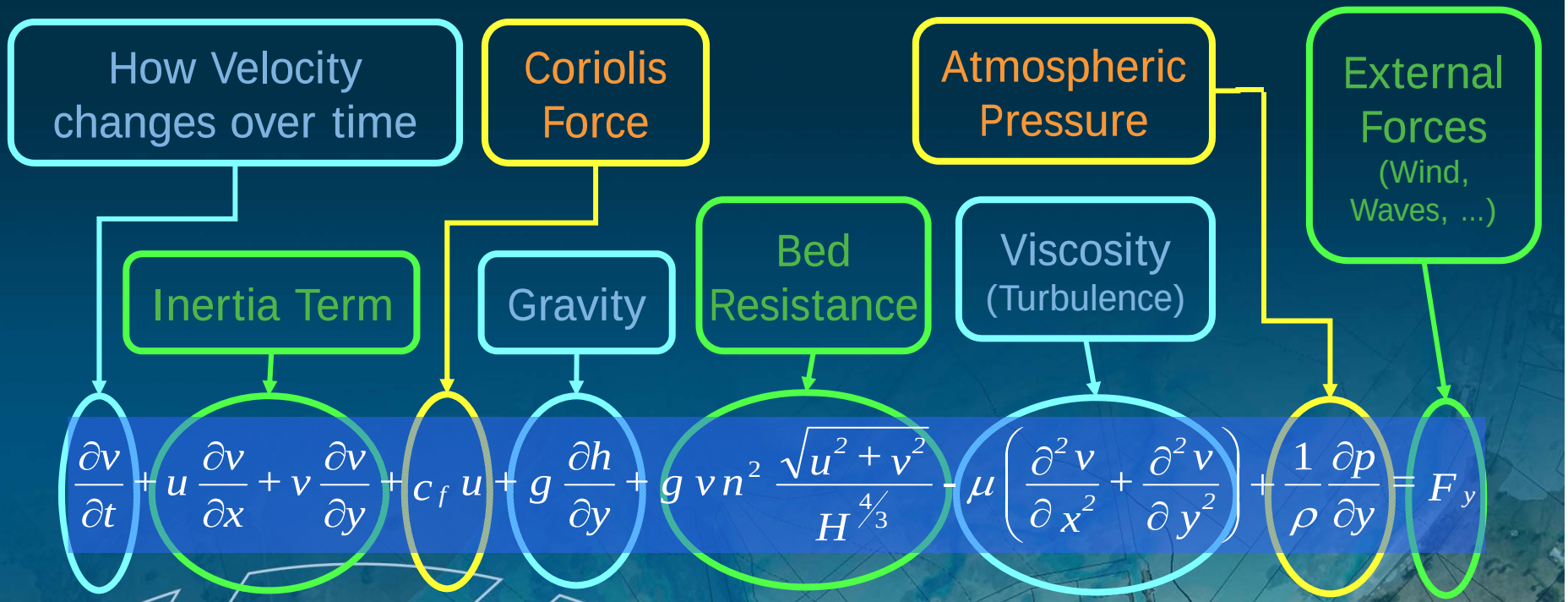
Are All schemes Fully 2D?

- NO
  - Spreading or raster routing models sometimes labelled 2D
- Pseudo-2D schemes solve 1D equations in multiple directions (eg. St Venant with or without momentum, Diffusive Wave)
- Cross-momentum/inertia and eddy viscosity not modelled
- UK EA Benchmarking finding:
  - Pseudo-2D suitable for national, strategic, broad-scale assessments
  - Unsuitable for detailed flood hazard and impact assessments
  - Often no speed gains from using spreading models

Accuracy


Pseudo-2D
Fully 2D Solutions
Depth (ft)
Time (h)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
50
100
150
200
250

Key Physical Processes
(What does your 2D scheme solve?)



What does your 2D scheme **need** to solve?

Verification / Calibration / Validation

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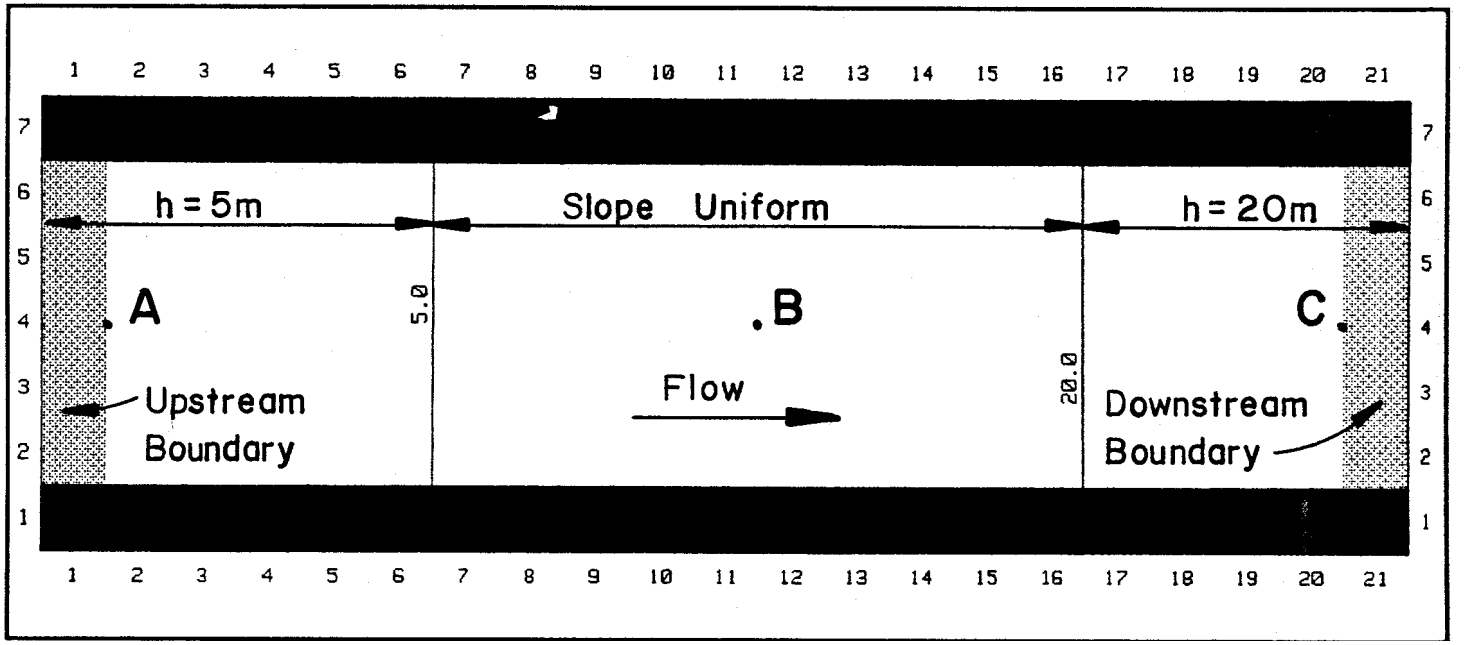
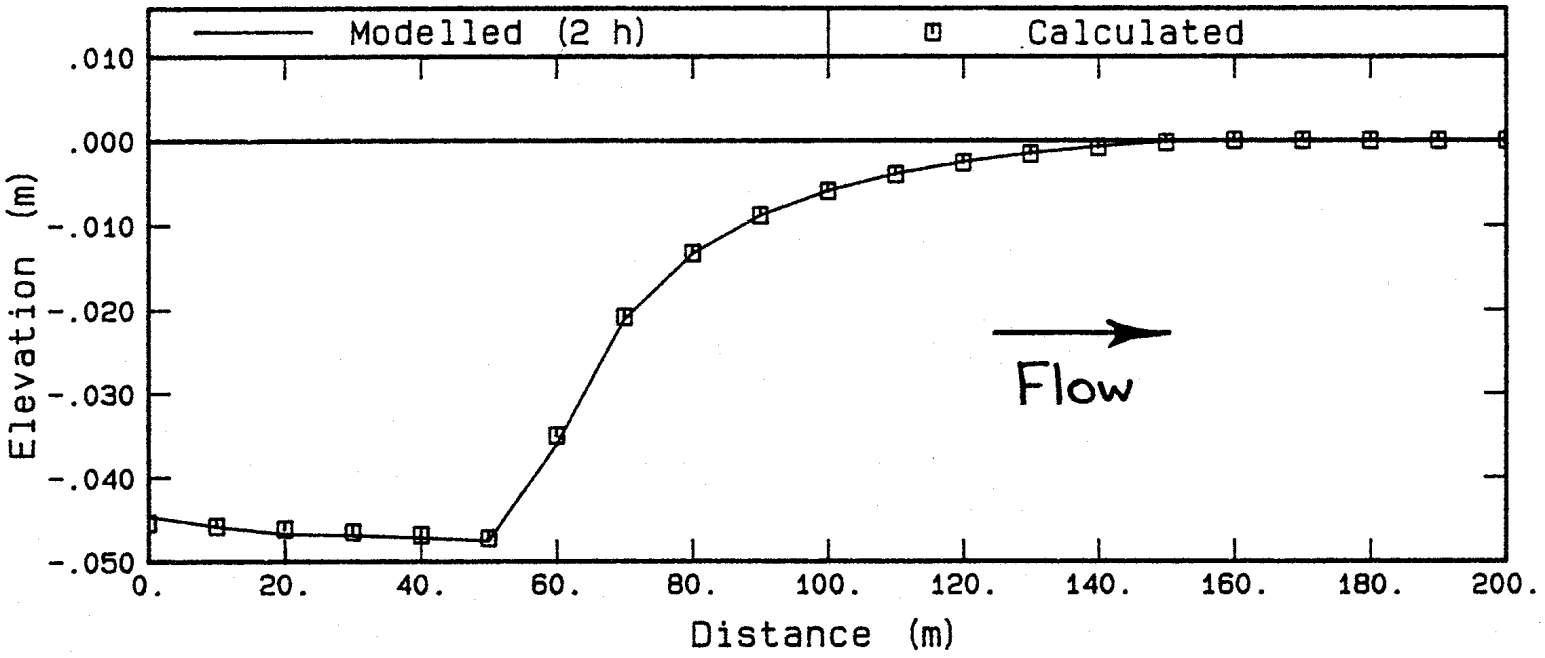
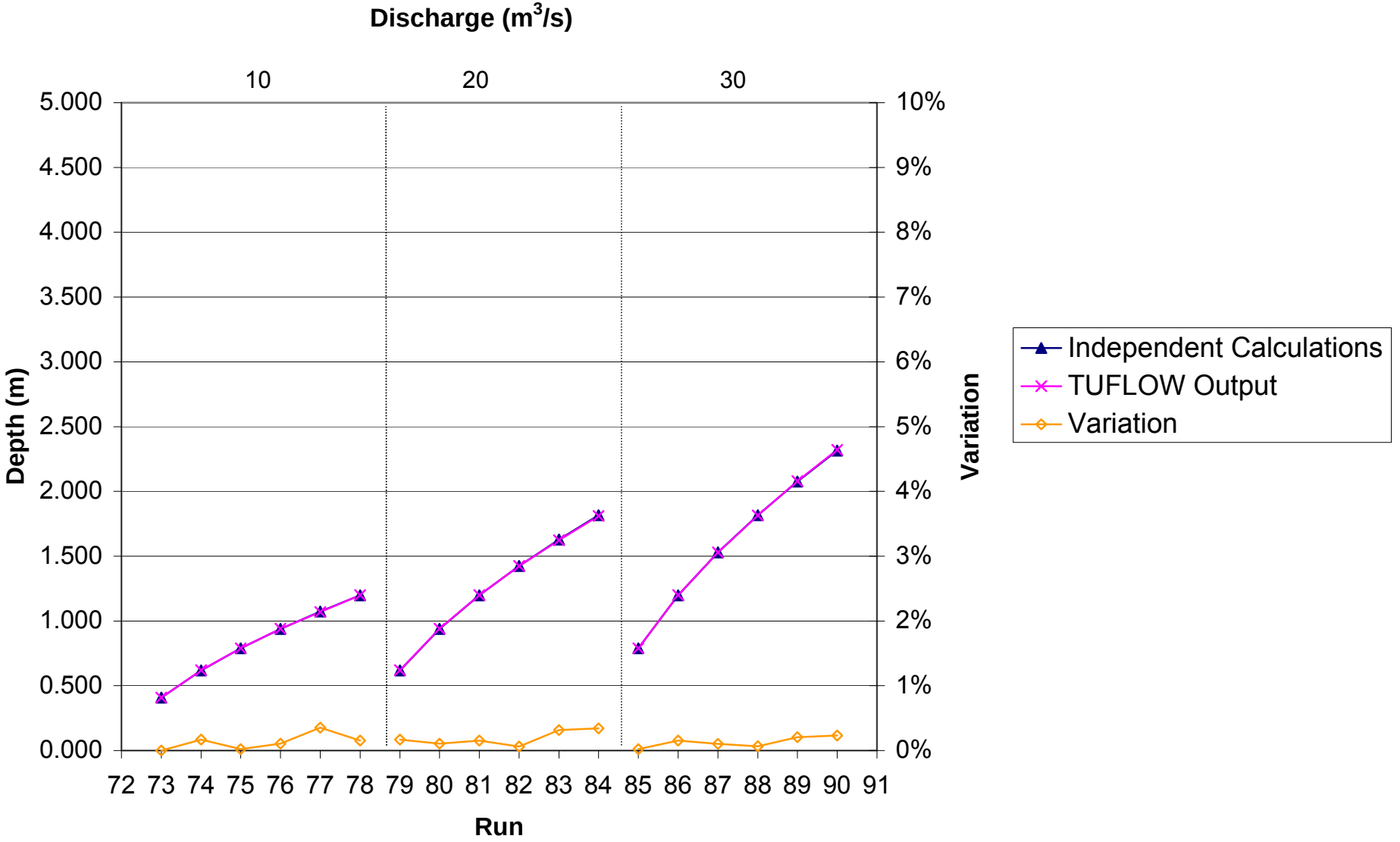
TUFLOW
Flood and Tide Simulation Software



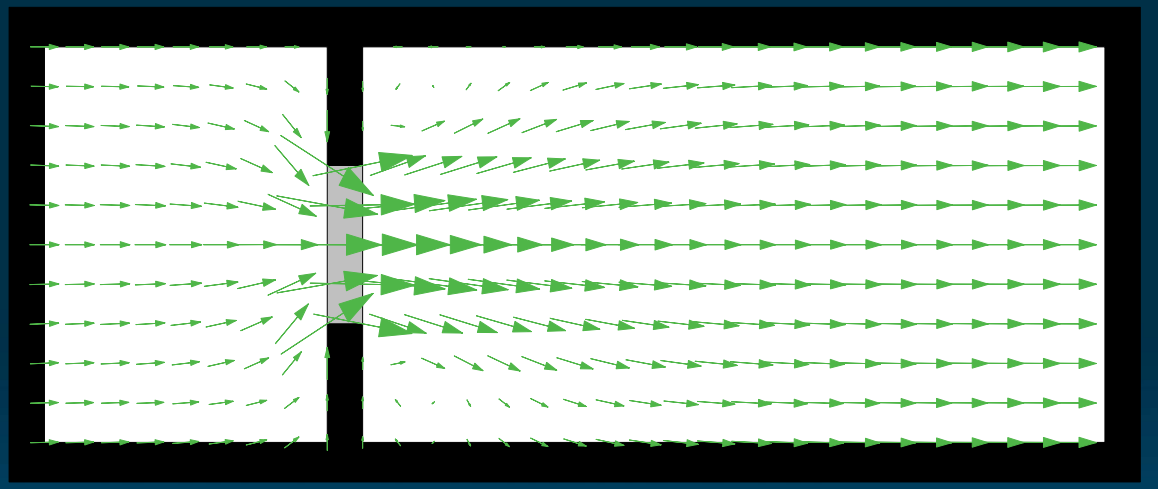


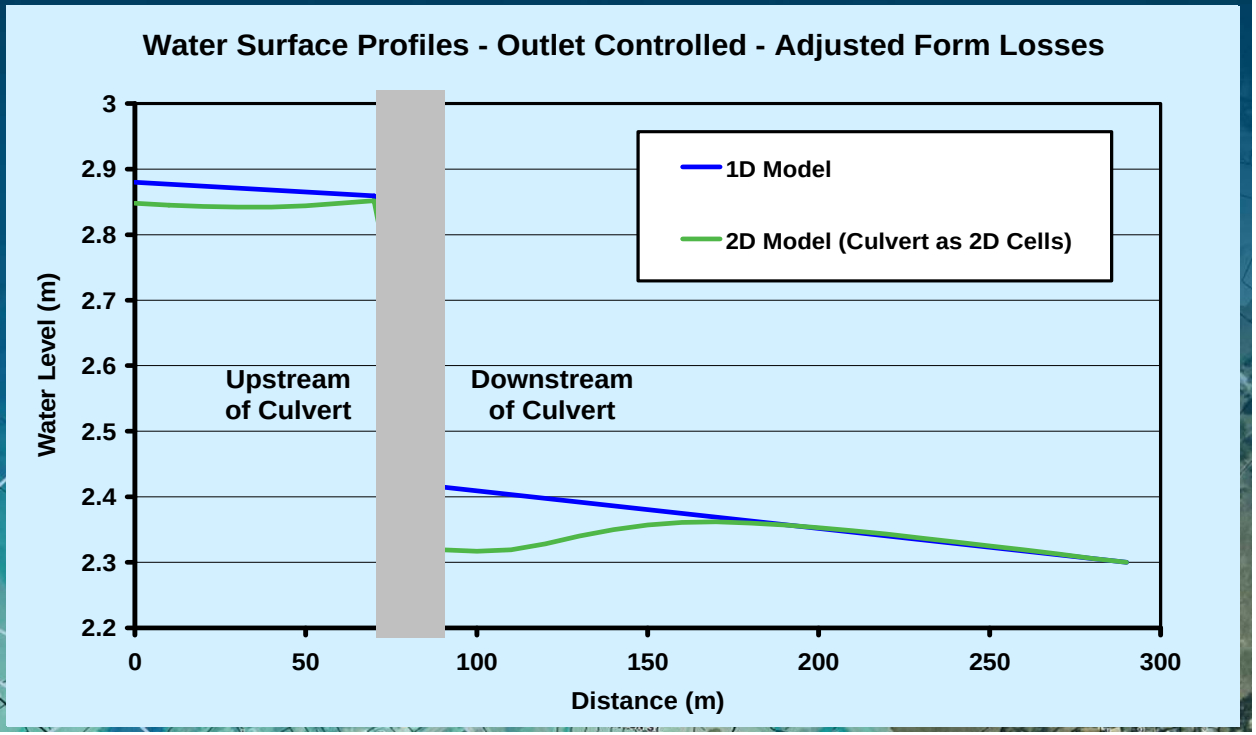
Comparison of Water Level Profiles

Huxley – TUFLOW Validation and Testing

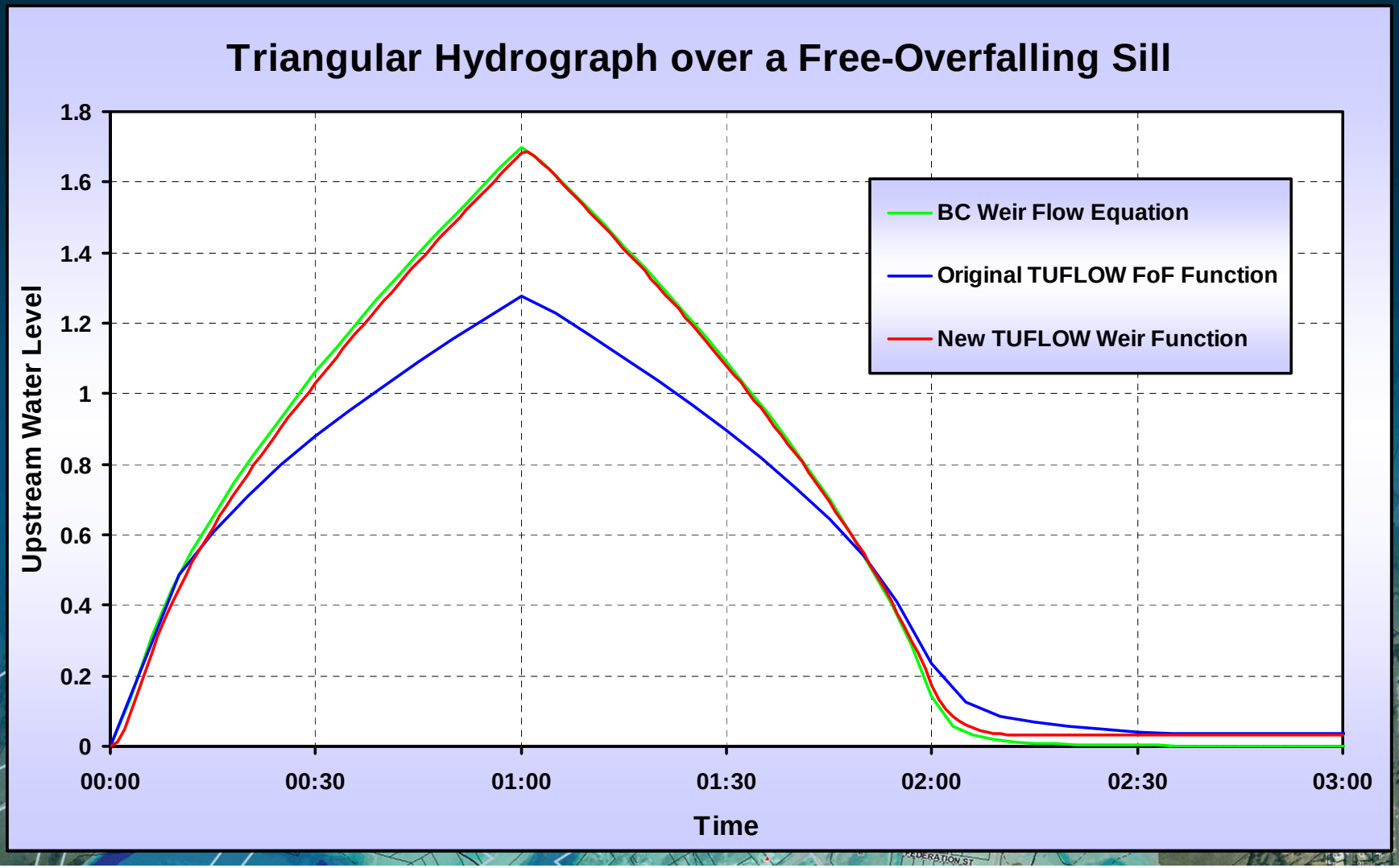


“Calibrating” 2D Structures



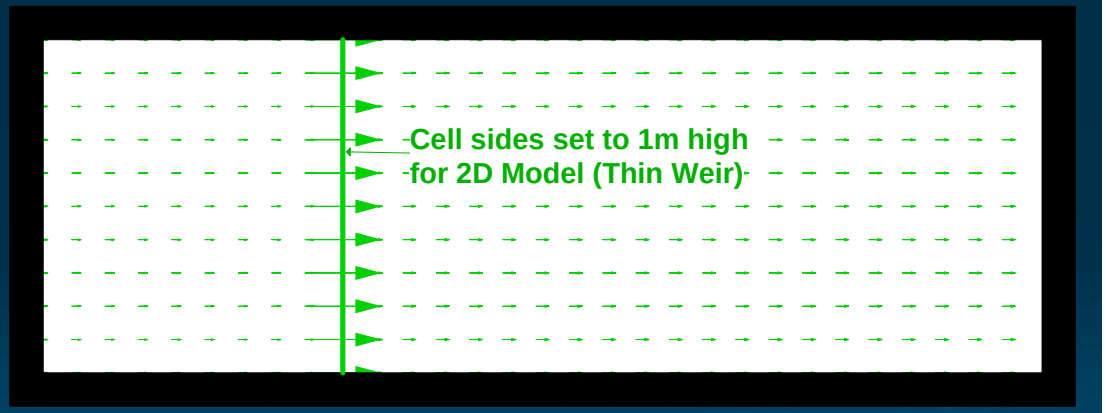


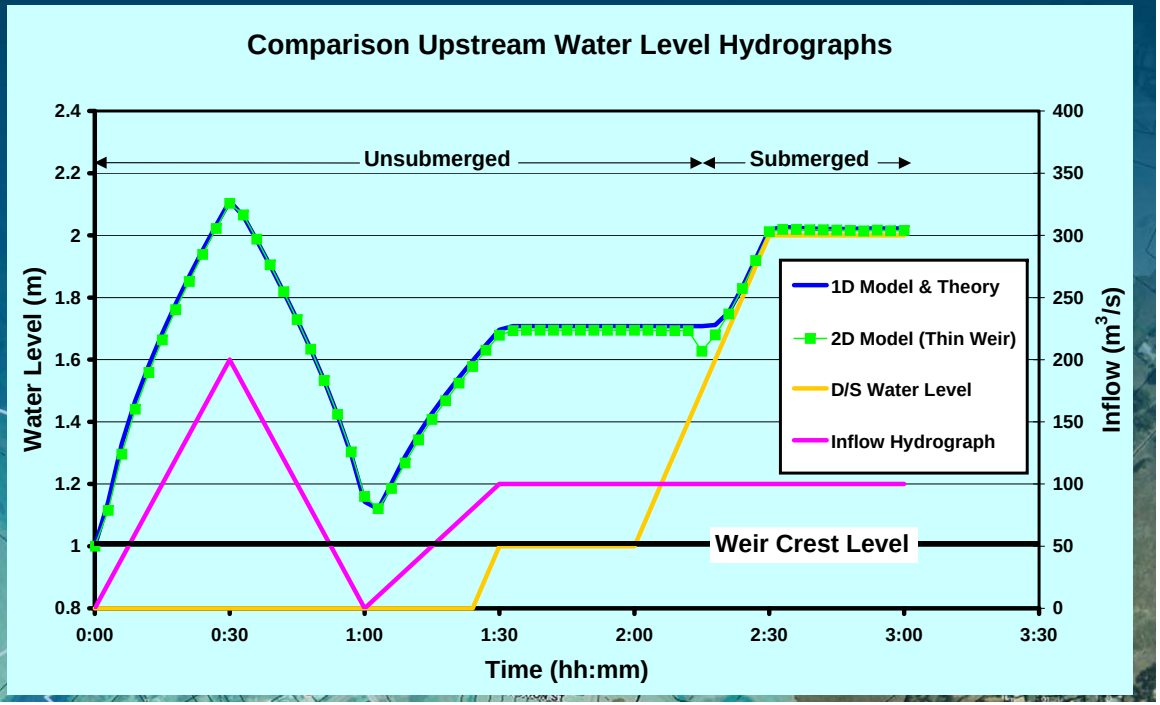
Benchmarking – 2D Weir Flow



Embankments / Levees (Weir Flow)

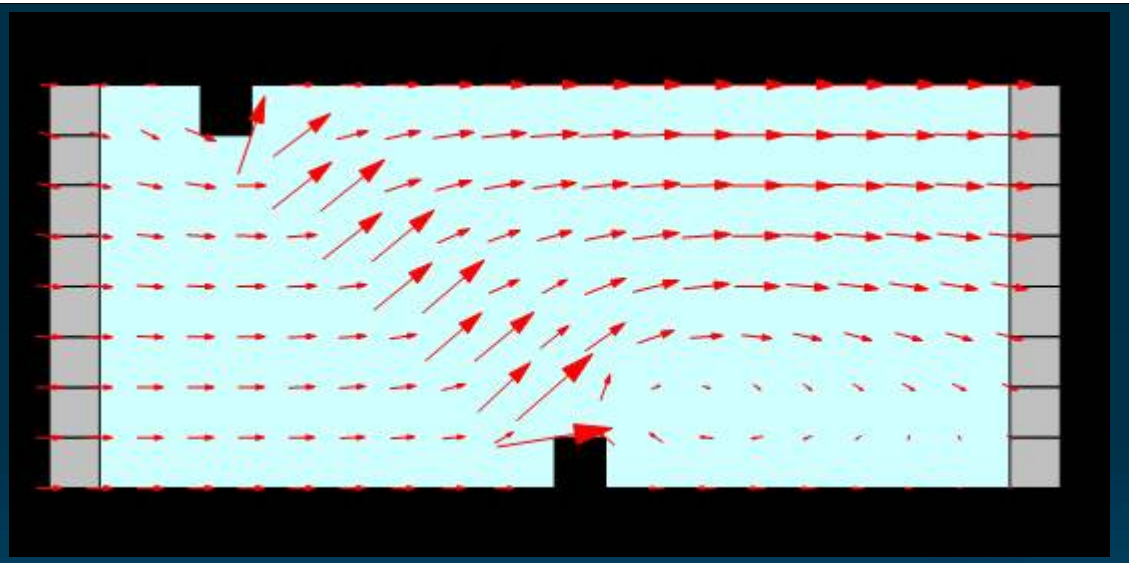
- Approach
  - Test submergence across cell side
  - BC Weir equation if unsubmerged
  - No adjustment if submerged
- Thin Weir Test

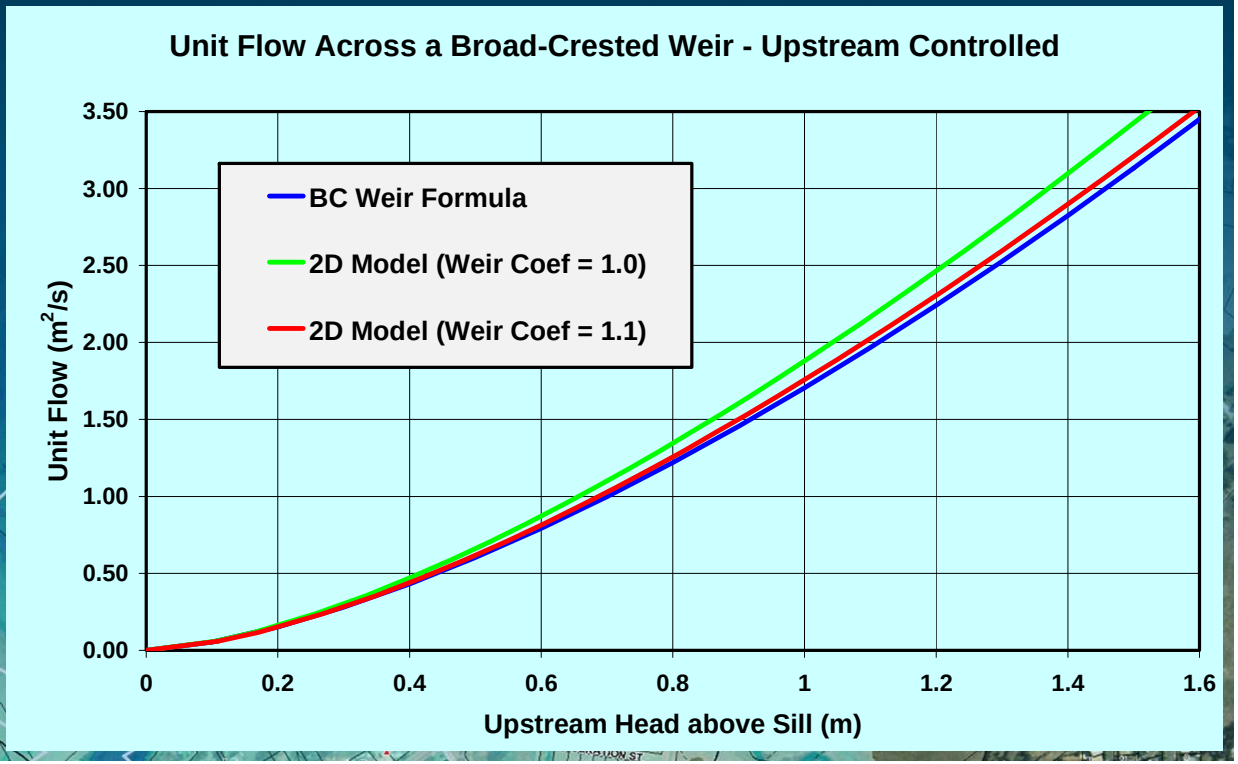




Oblique Weirs

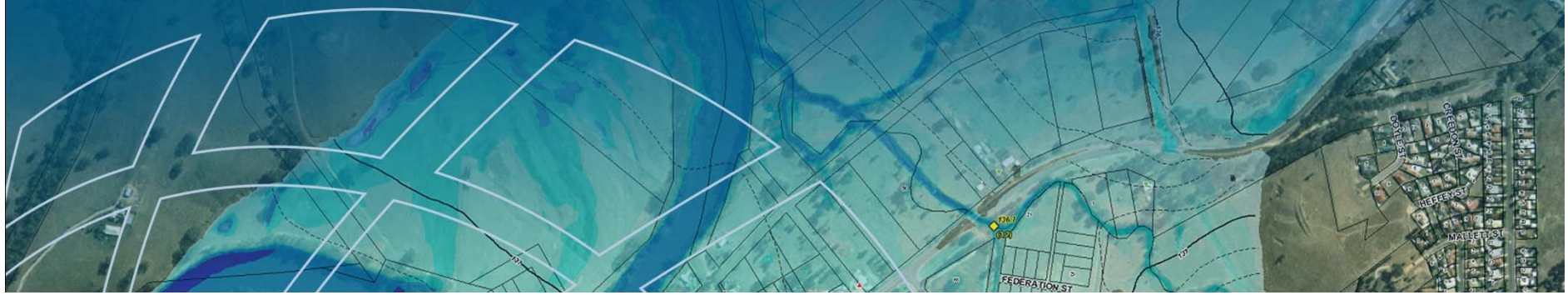
- Flow oblique to grid
- Weir at 45˚ test
- Correct using weir coefficient



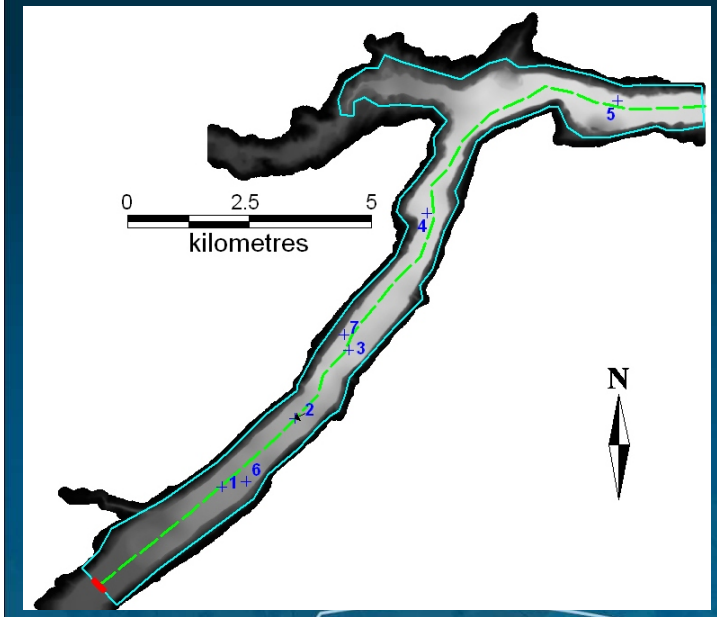


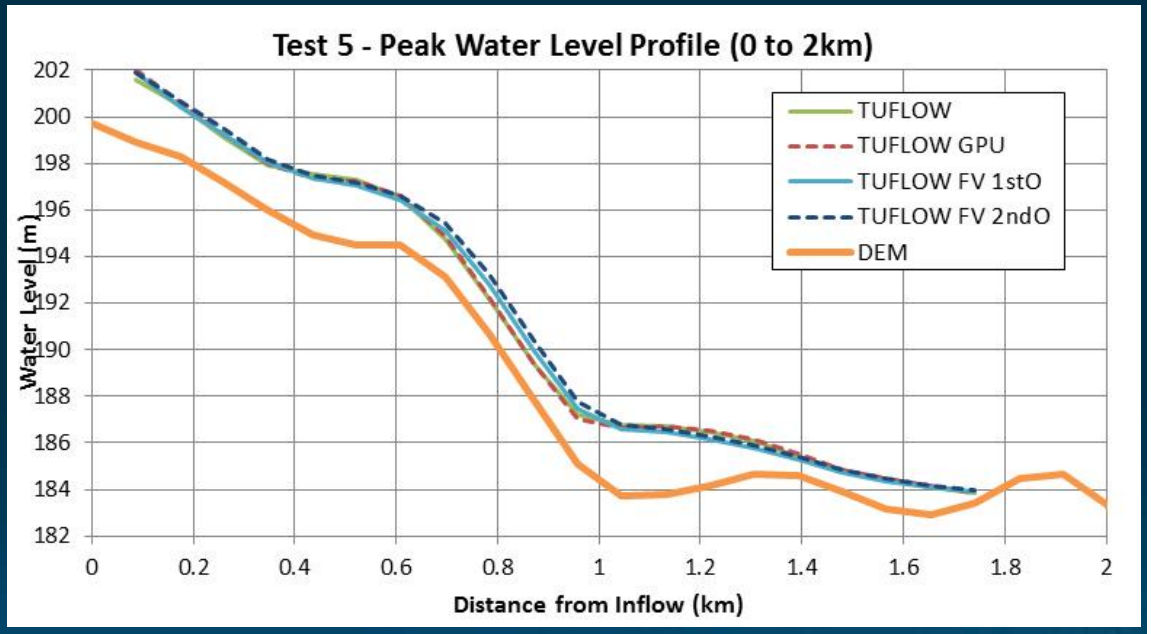
UK EA 2D Benchmarking

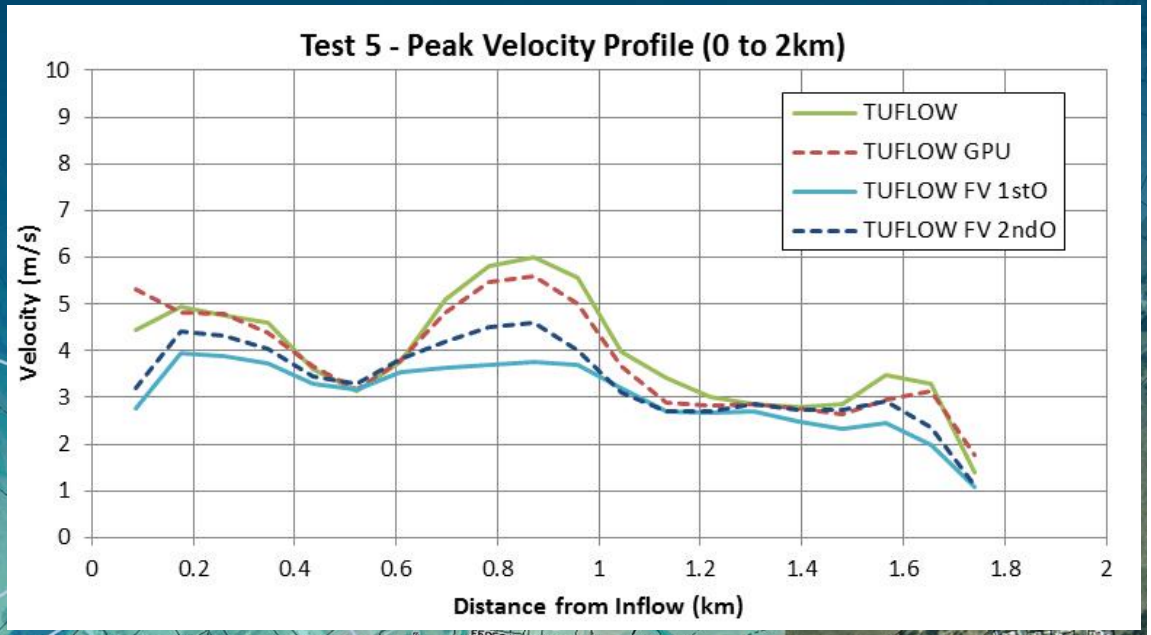
- UK Benchmarking 2010
  - TUFLOW and TUFLOW FV
- UK Benchmarking 2012
  - TUFLOW weak points resolved
  - TUFLOW FV maintained good performance
  - TUFLOW GPU performed well



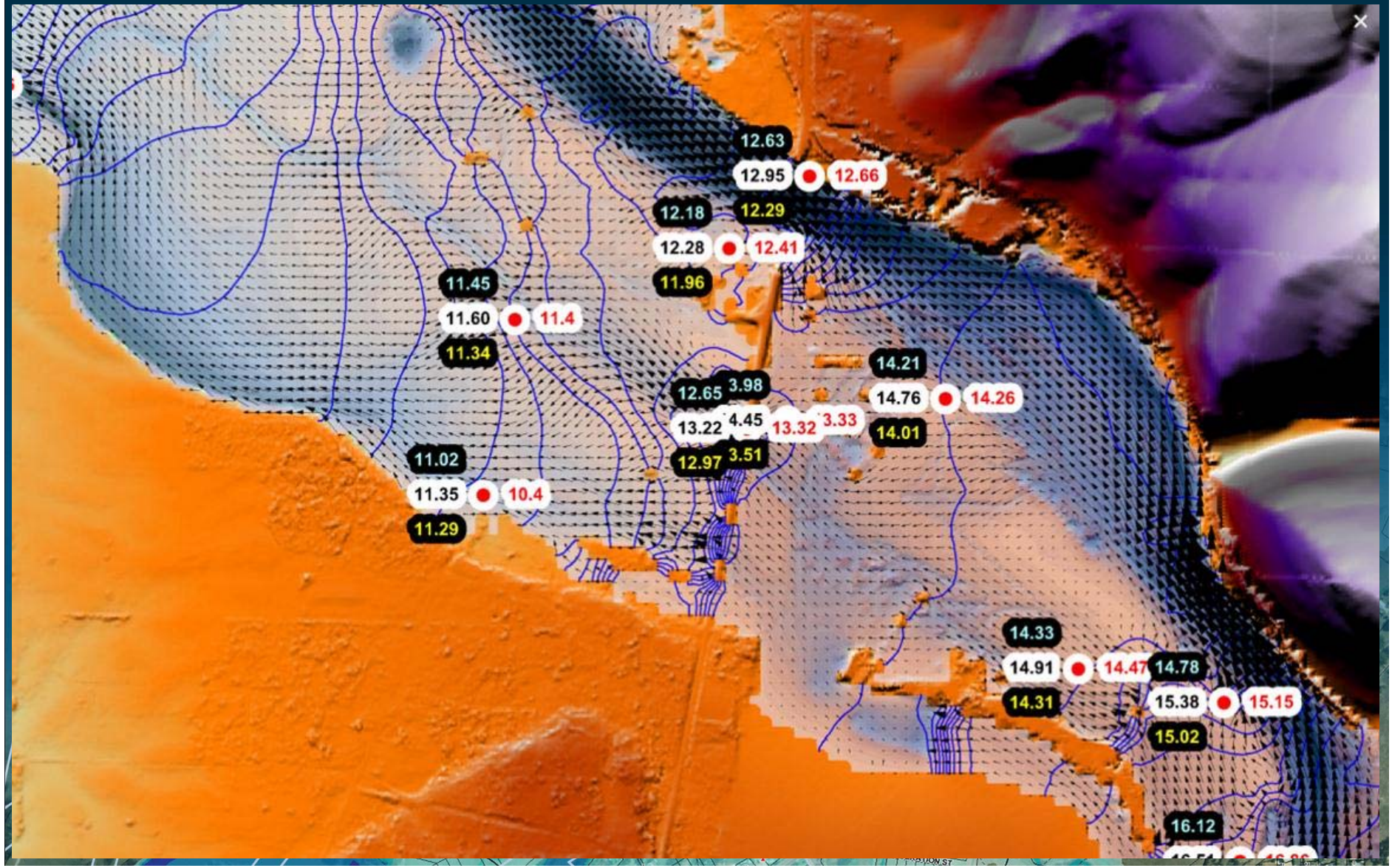
Test 5
UK Benchmarking







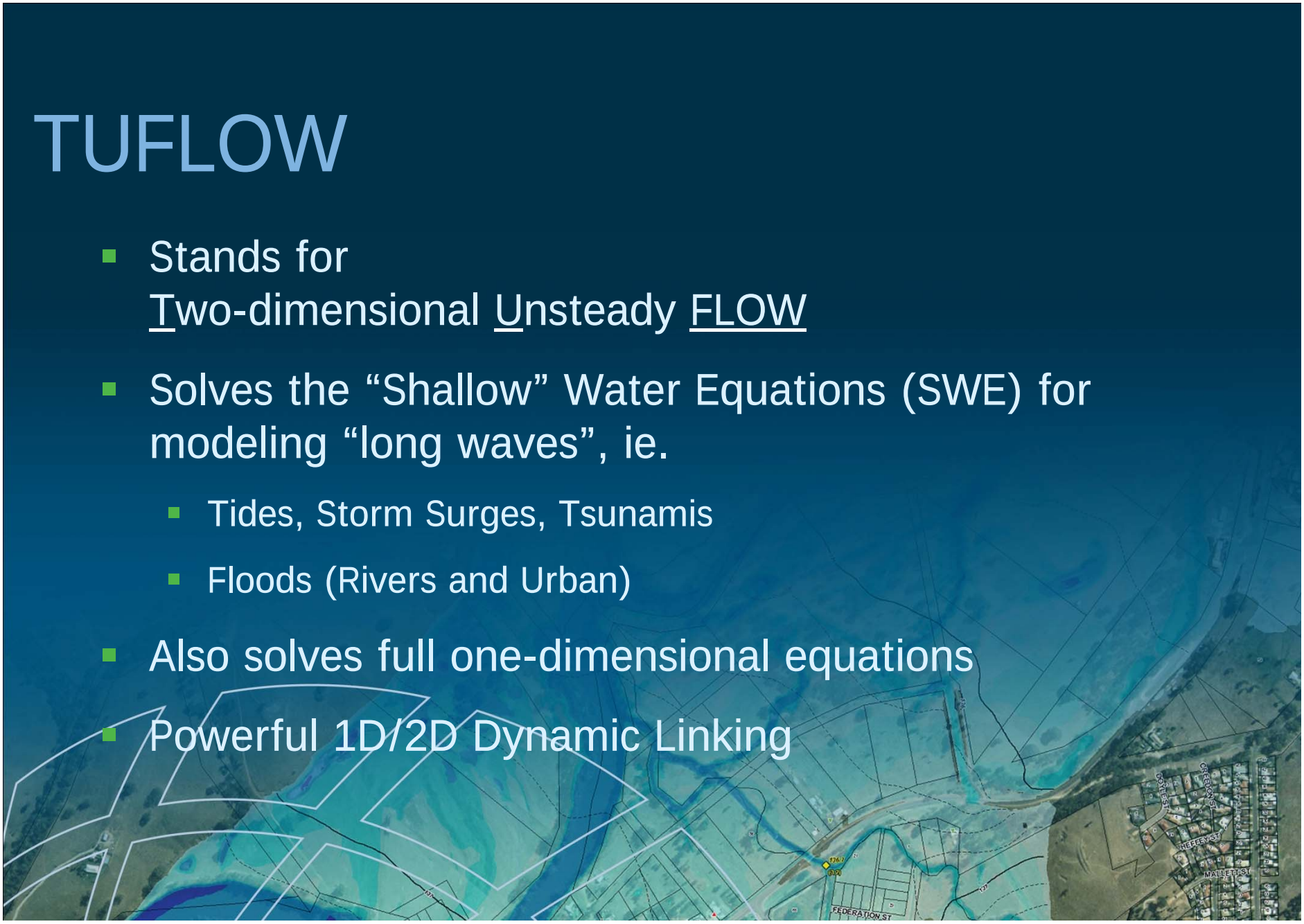
FMA Challenge 2




TUFLOW
Flood and Tide Simulation Software
TUFLOW "Classic"
BMT WBM

TUFLOW

- Stands for
  Two-dimensional Unsteady FLOW
- Solves the “Shallow” Water Equations (SWE) for modeling “long waves”, ie.
  - Tides, Storm Surges, Tsunamis
  - Floods (Rivers and Urban)
- Also solves full one-dimensional equations
- Powerful 1D/2D Dynamic Linking



TUFLOW Milestones

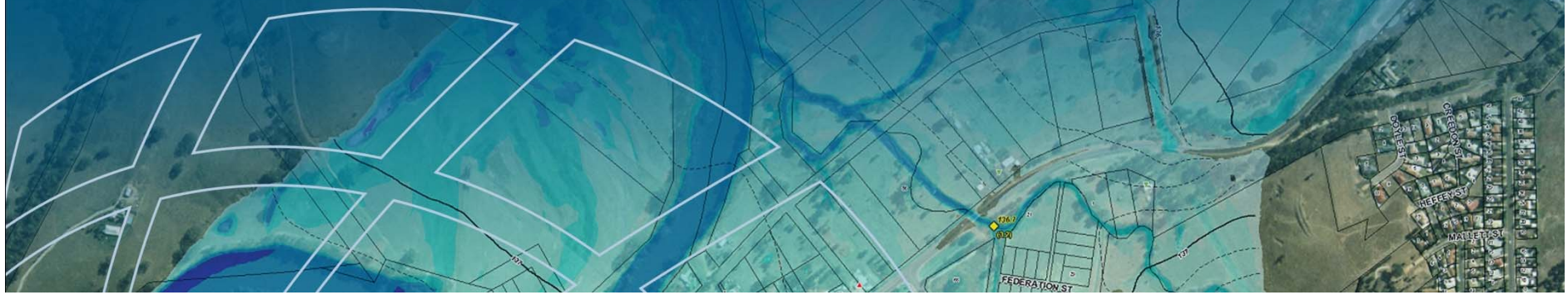
- 1989 TUFLOW 2D developed and dynamically linked to 1D scheme
- 1991–2000 Applied in-house to coastal and flood studies
- 2001 TUFLOW made commercially available
- 2004 Selected for London Storm Surge Inundation Study
- 2004 Dynamically linked to ISIS (UK) and XP-SWMM 1D schemes
- 2006 SMS TUFLOW and XP-2D interfaces released
- 2010 FEMA Region 3 Approval and XP-2D National Approval
- 2010 UK Environment Agency purchases Network 50 License
- 2012 Trialed by USACE Sacramento and Wood Rodgers

The Engine of the Car

- TUFLOW is purely a computational engine
  - No fancy graphics
  - No CFD (Colorful Fluid Dynamics)
- Very powerful, but literally a black box

How Do You Create TUFLOW Models?

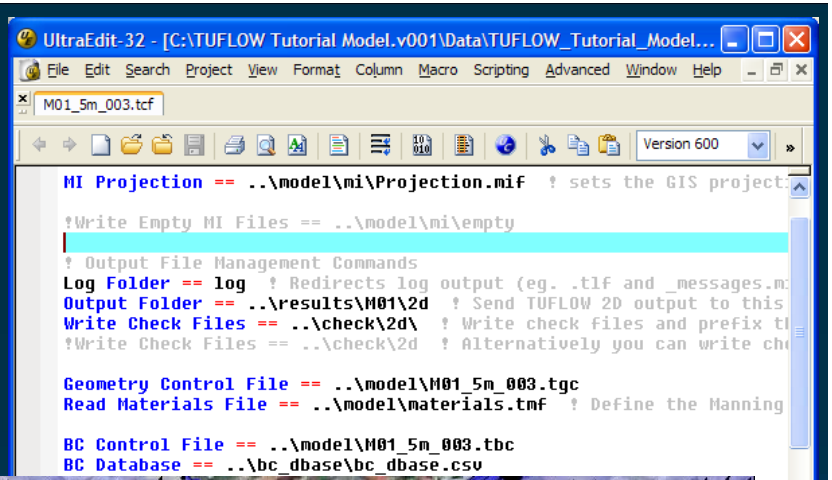
- TUFLOW "Classic" and GPU
  - GIS (ArcGIS, MapInfo, QGIS)
  - SMS TUFLOW Interface
  - XP-Solutions XP-2D Interface (Dynamically linked with XP-SWMM 1D)
  - User customised

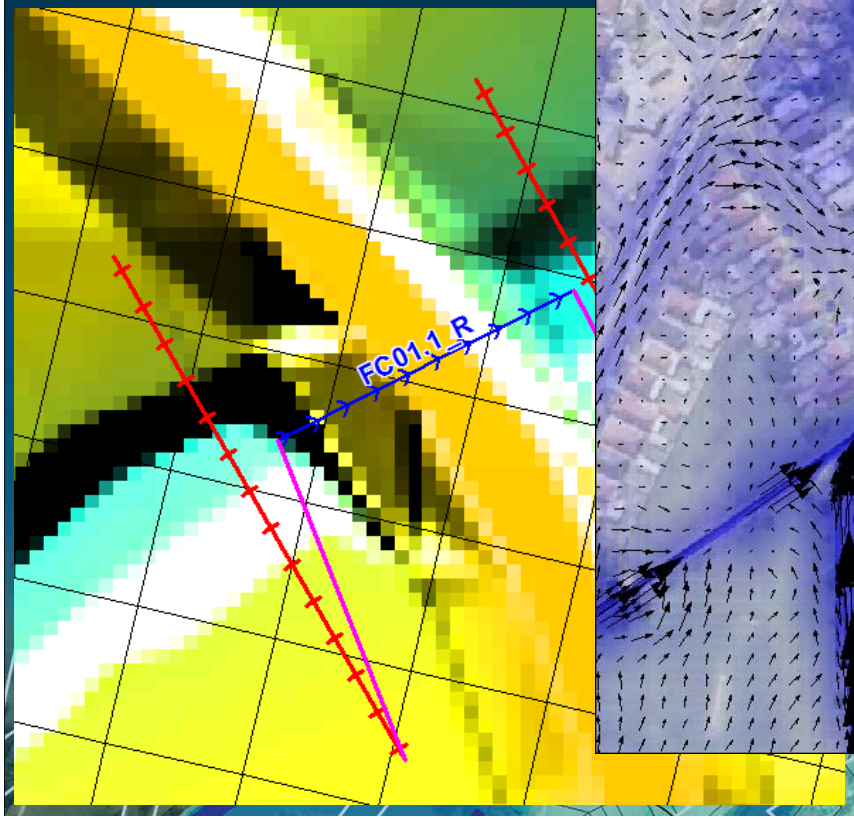


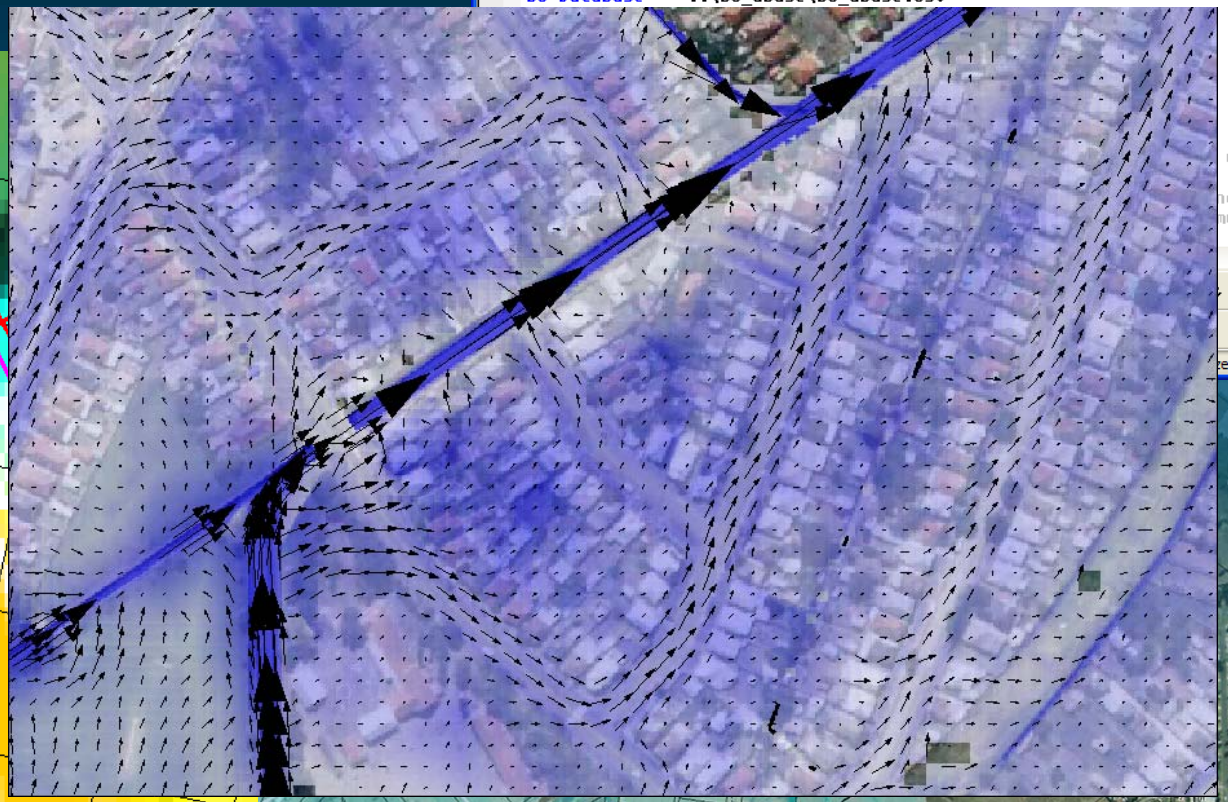
GIS Based

Creating Models: GIS / Text Editor / Excel

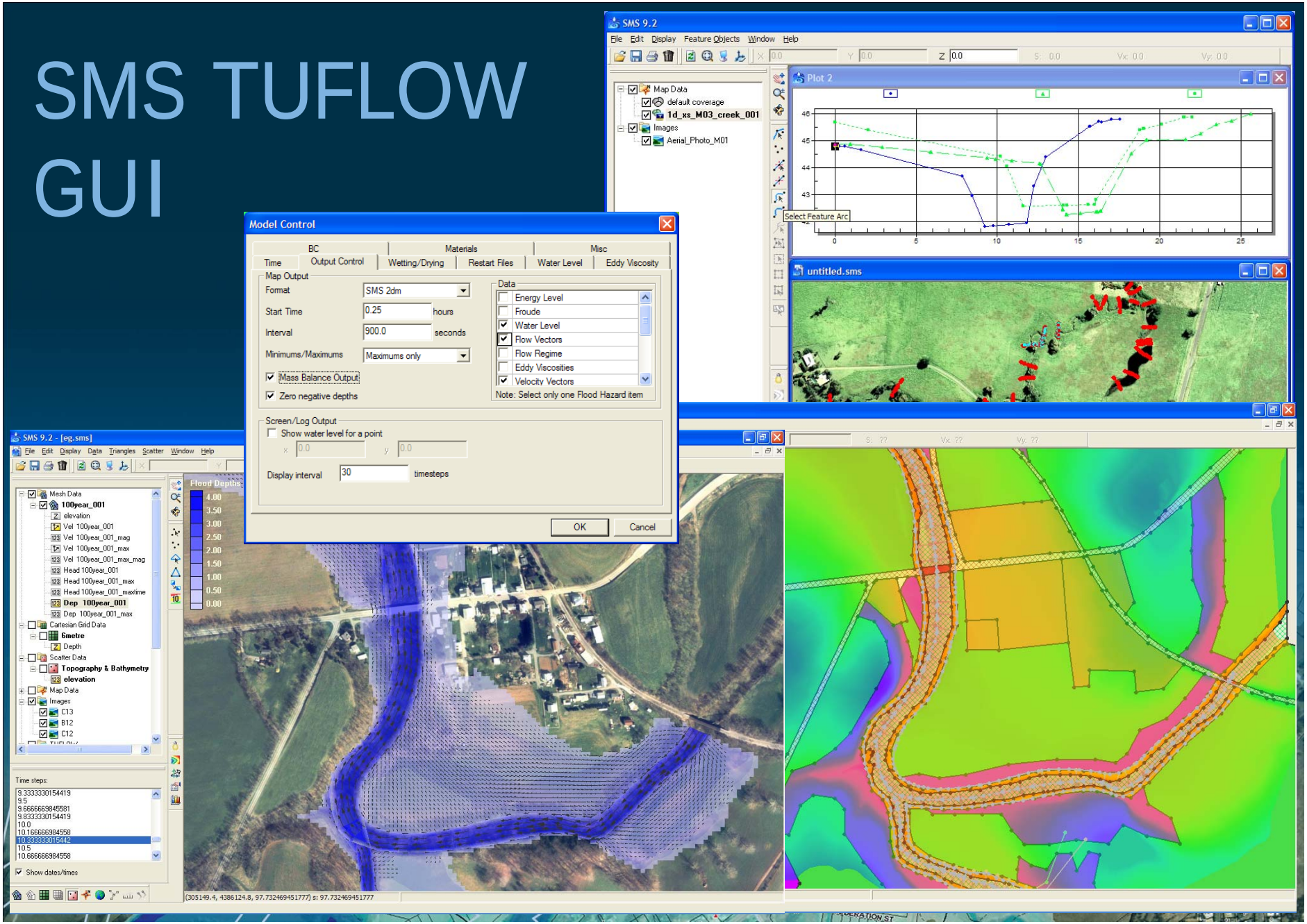
Results: GIS / SMS / WaterRIDE / Excel



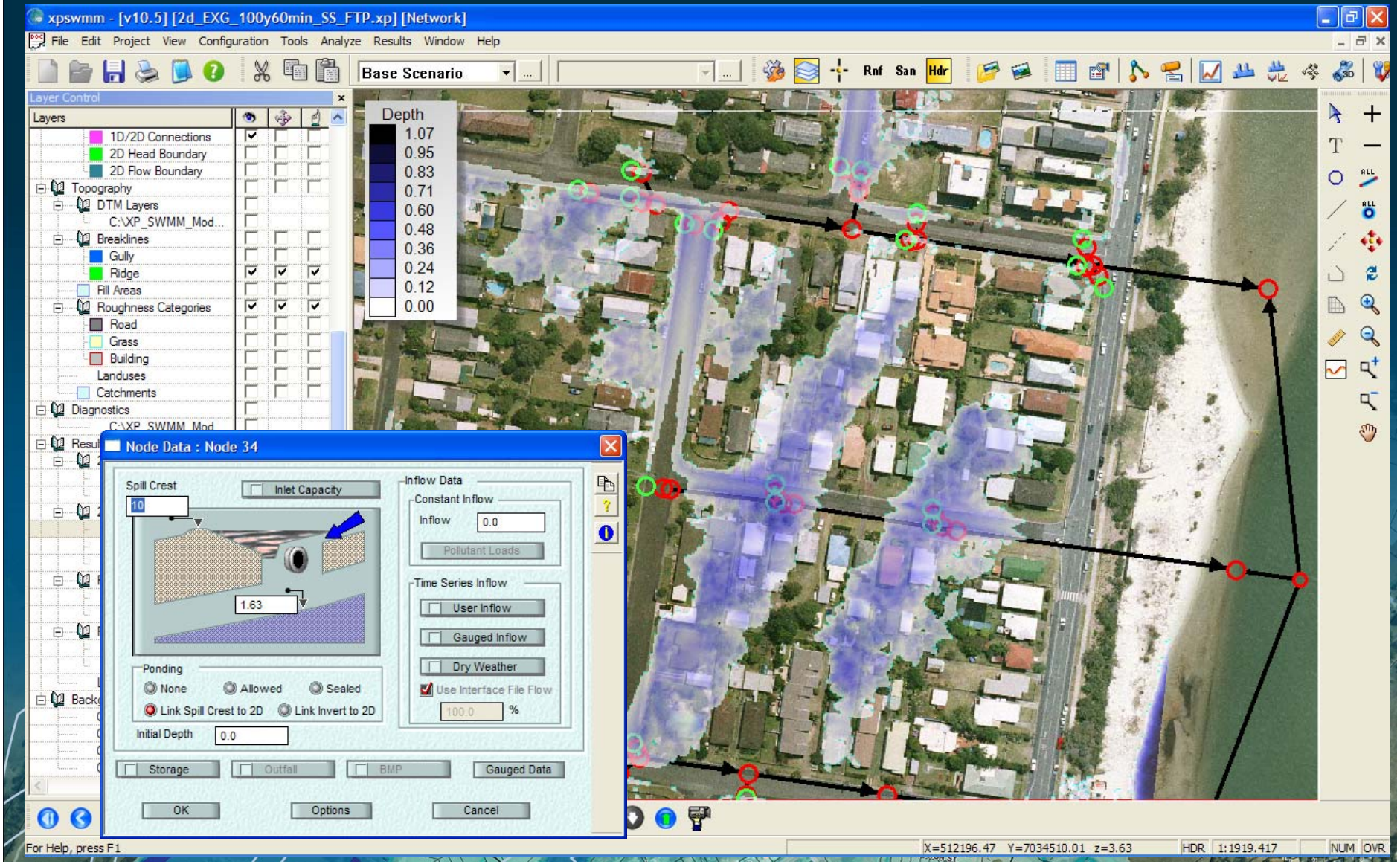




SMS TUFLOW GUI



XP-2D GUI


xpswmm - [v10.5] [2d_EXG_100y60min_SS_FTP.xp] [Network]
File Edit Project View Configuration Tools Analyze Results Window Help
Base Scenario
Rnf San Hdr
Layer Control
Layers
1D/2D Connections
2D Head Boundary
2D Flow Boundary
Topography
DTM Layers
Breaklines
Gully
Ridge
Fill Areas
Roughness Categories
Road
Grass
Building
Landuses
Catchments
Diagnostics
Depth
1.07
0.95
0.83
0.71
0.60
0.48
0.36
0.24
0.12
0.00
Node Data : Node 34
Spill Crest
Inlet Capacity
10
1.63
Inflow Data
Constant Inflow
Inflow
0.0
Pollutant Loads
Time Series Inflow
User Inflow
Gauged Inflow
Dry Weather
Use Interface File Flow
100.0
%
Ponding
None
Allowed
Sealed
Link Spill Crest to 2D
Link Invert to 2D
Initial Depth
0.0
Storage
Outfall
BMP
Gauged Data
OK
Options
Cancel
For Help, press F1
X=512196.47 Y=7034510.01 z=3.63
HDR
1:1919.417
NUM
OVR

Behind the Scenes

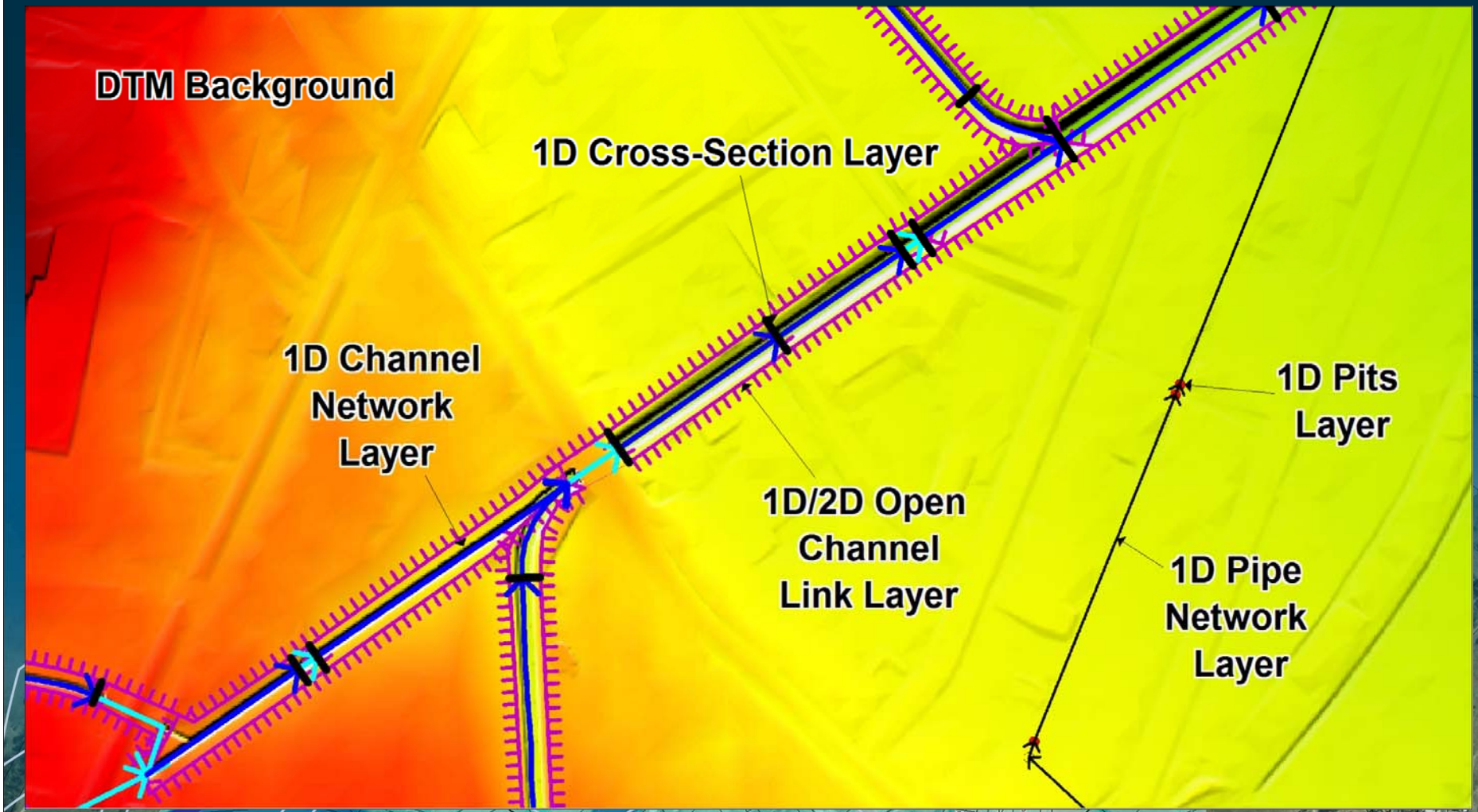
- Macro style control files
- GIS layered data approach

Layered Data Approach

- Feed into TUFLOW any number of GIS data layers
- .shp, .mif and ESRI ASCII grids
- All inputs independent of 2D cell size
- No duplication of data
- Base DEM(s) only exist once
- If a layer is updated, no need to rework inputs
- Challenge 1 Example

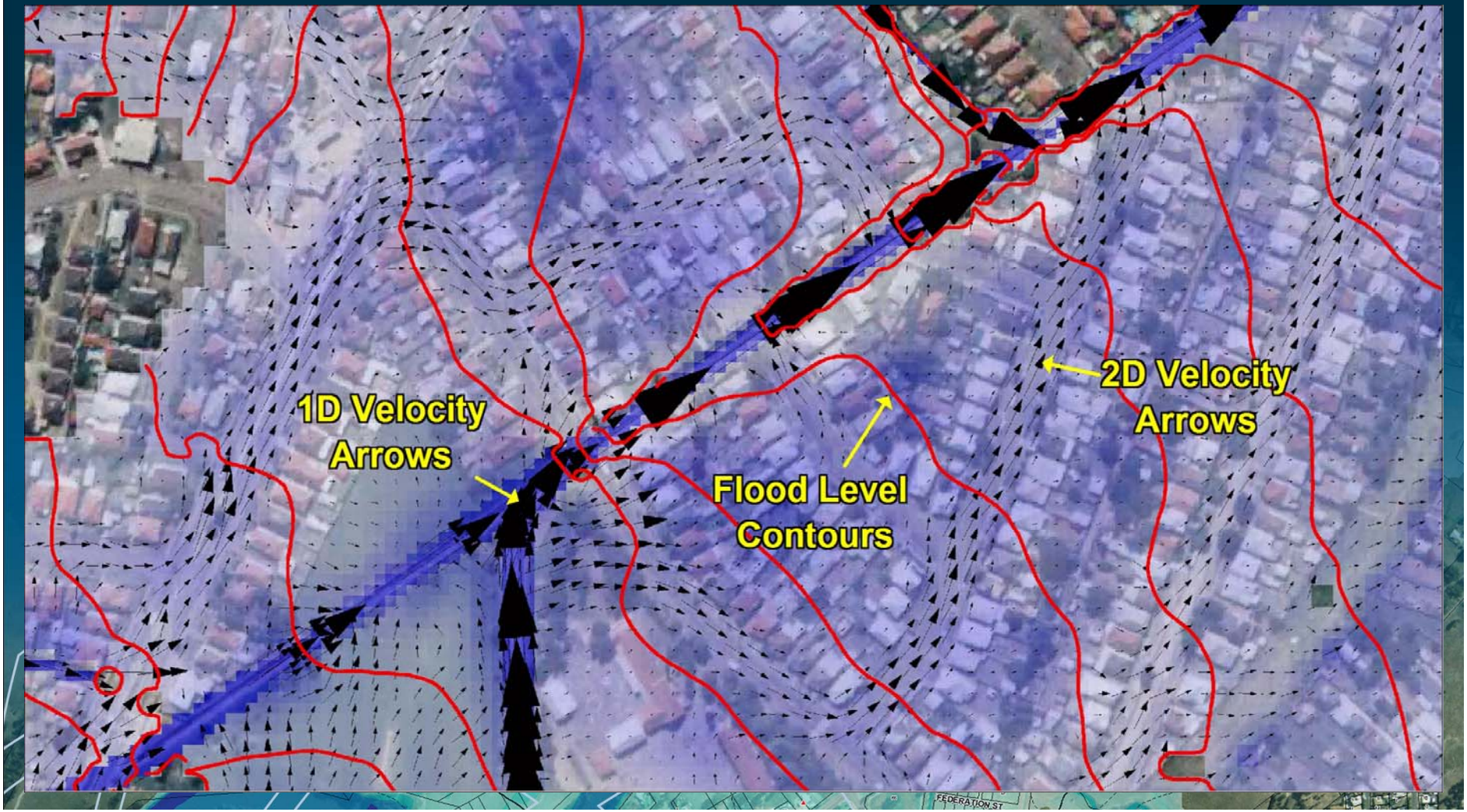
Throsby Creek, NSW, 2006 - 2007

1D/2D Model Development



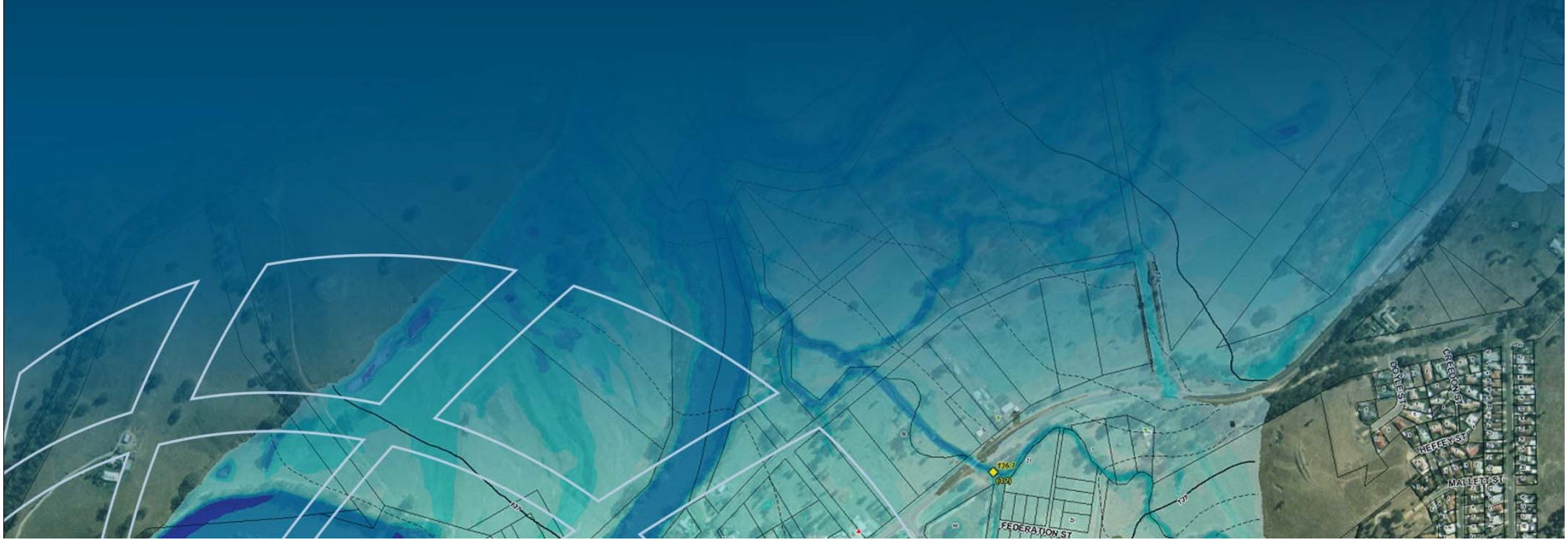
Throsby Creek, NSW, 2006 - 2007

1D/2D Model Results



Modeling Efficiency

- Easy to modify terrain data
- Smart – TUFLOW .xf files
  (Binary dumps of processed inputs)



Topography Example Challenge 2

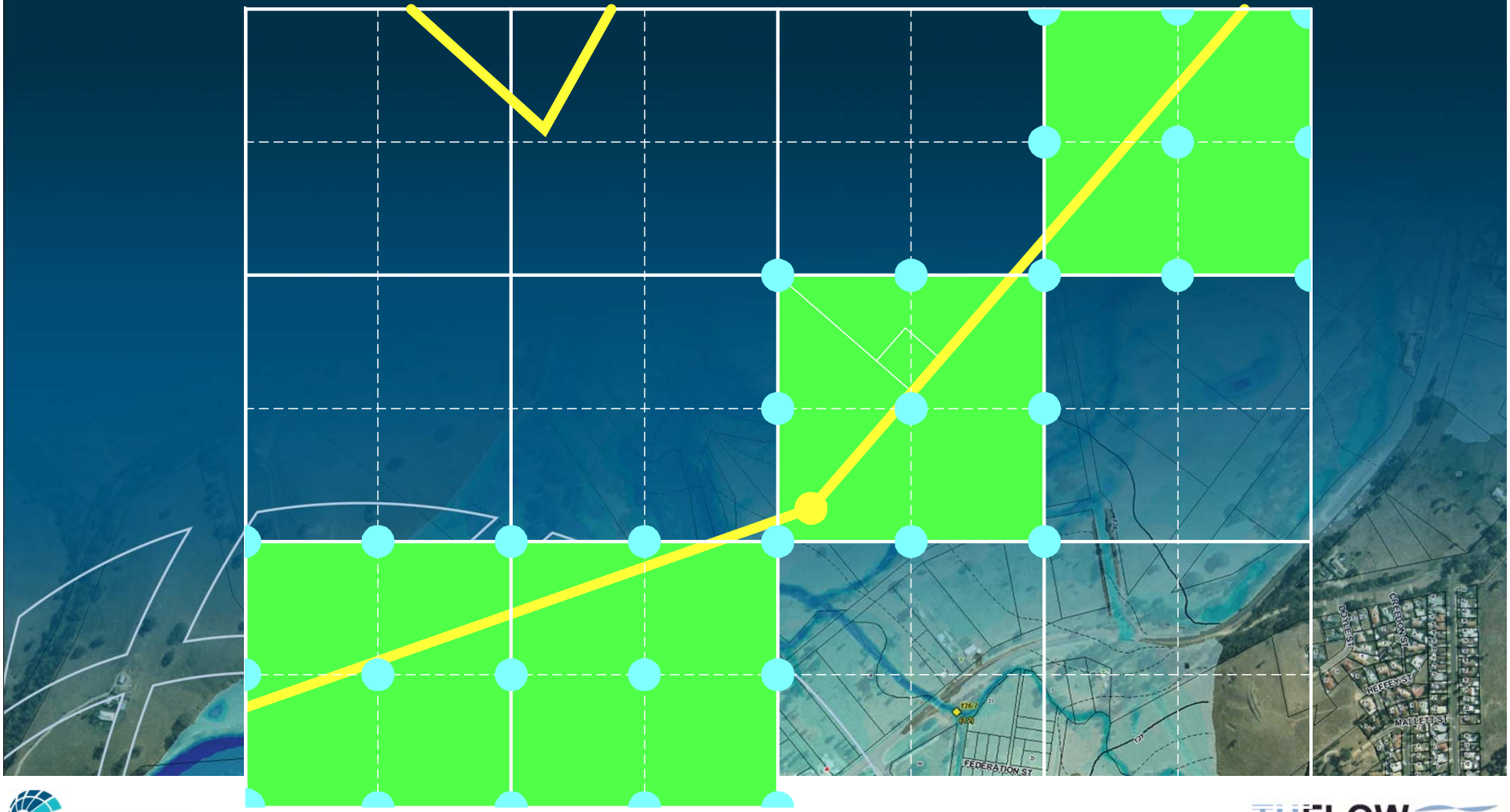
- With Embankments Scenario
  - Ensure embankment crest correctly represented
- Without Embankments Scenario
  - Remove embankments in DEM
- Base DEM not modified in either scenario

3D Breaklines

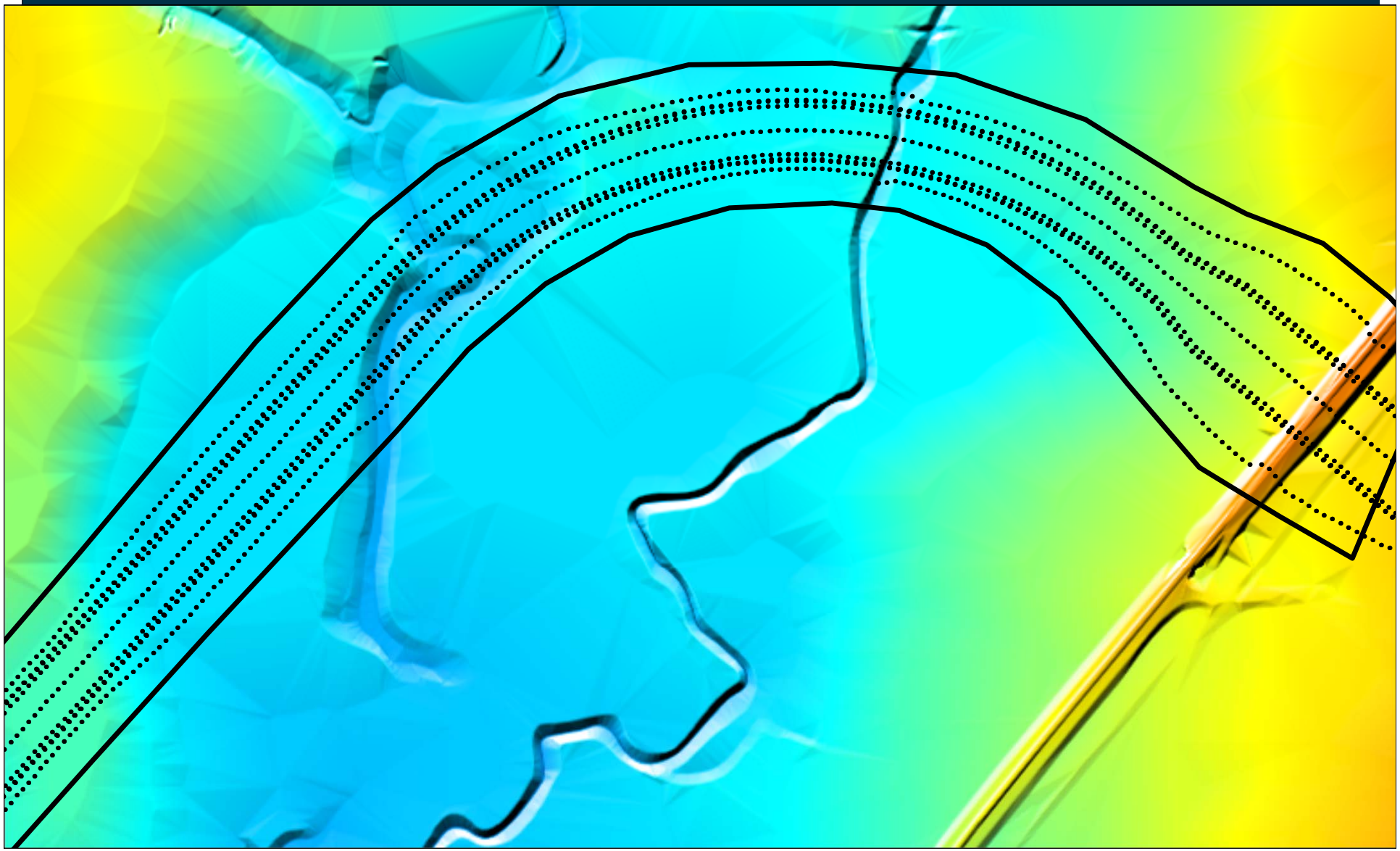
Thin Z Lines (the default)

3D Breaklines

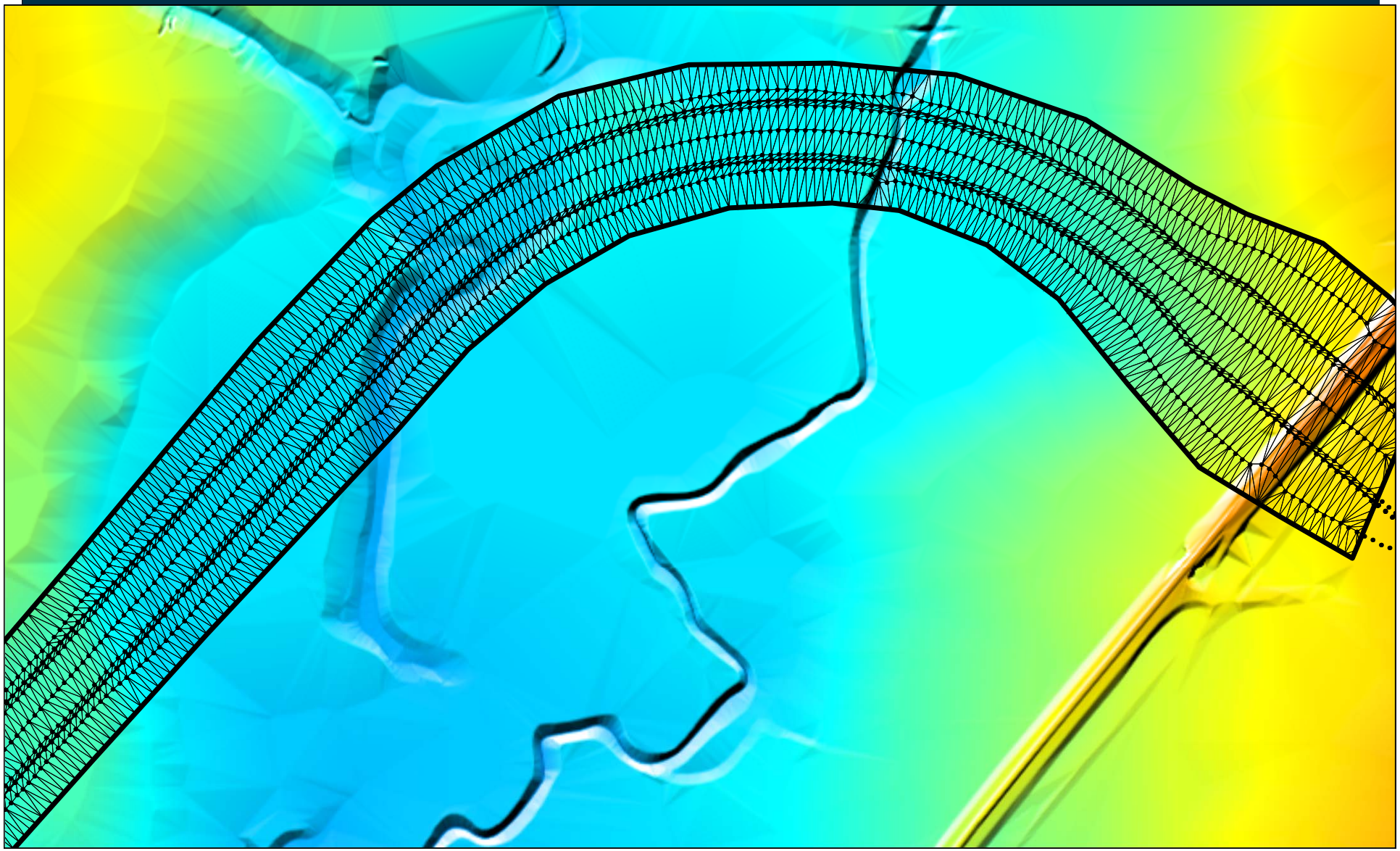
Thick Z Lines



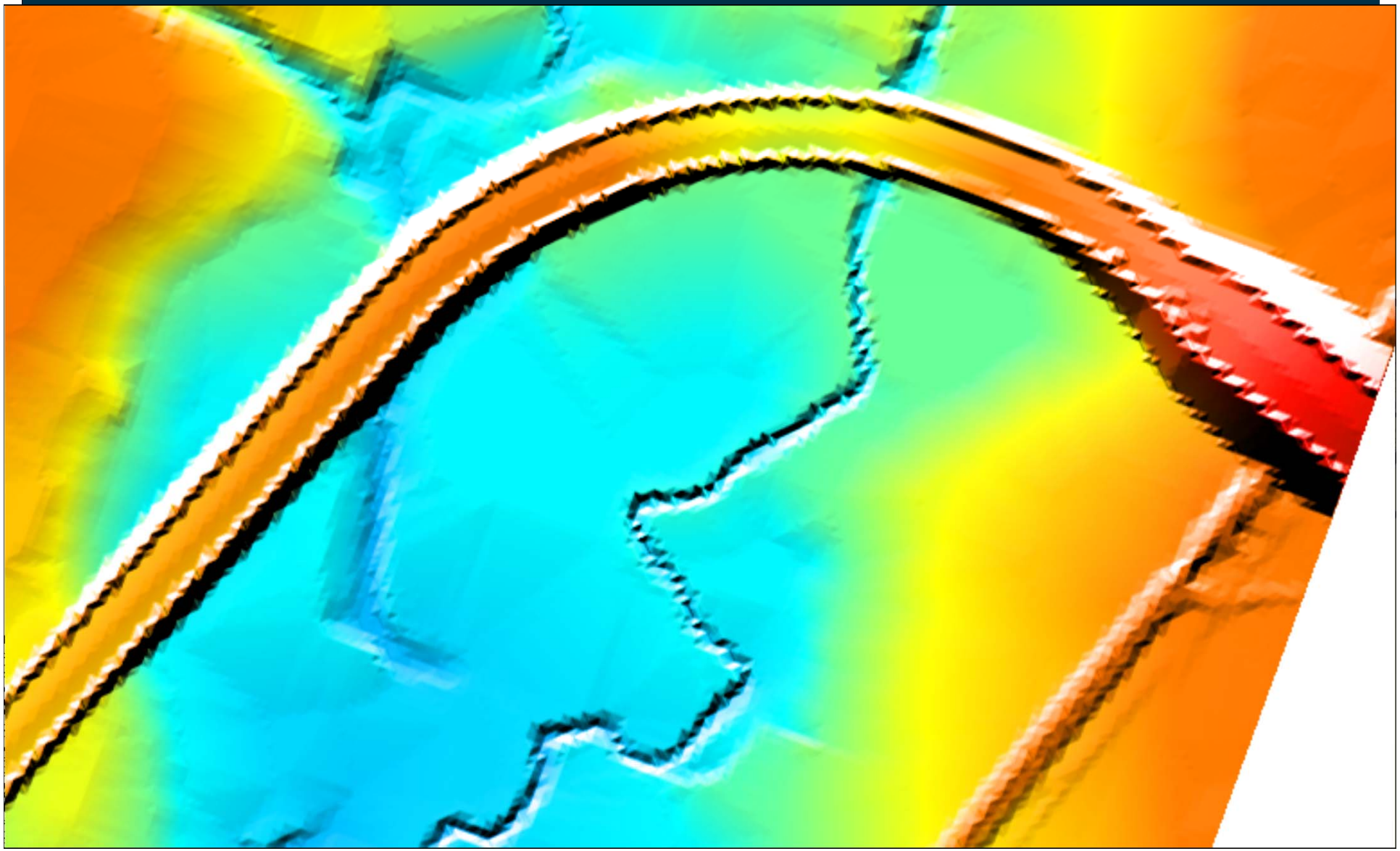
Create TIN Zpts Example

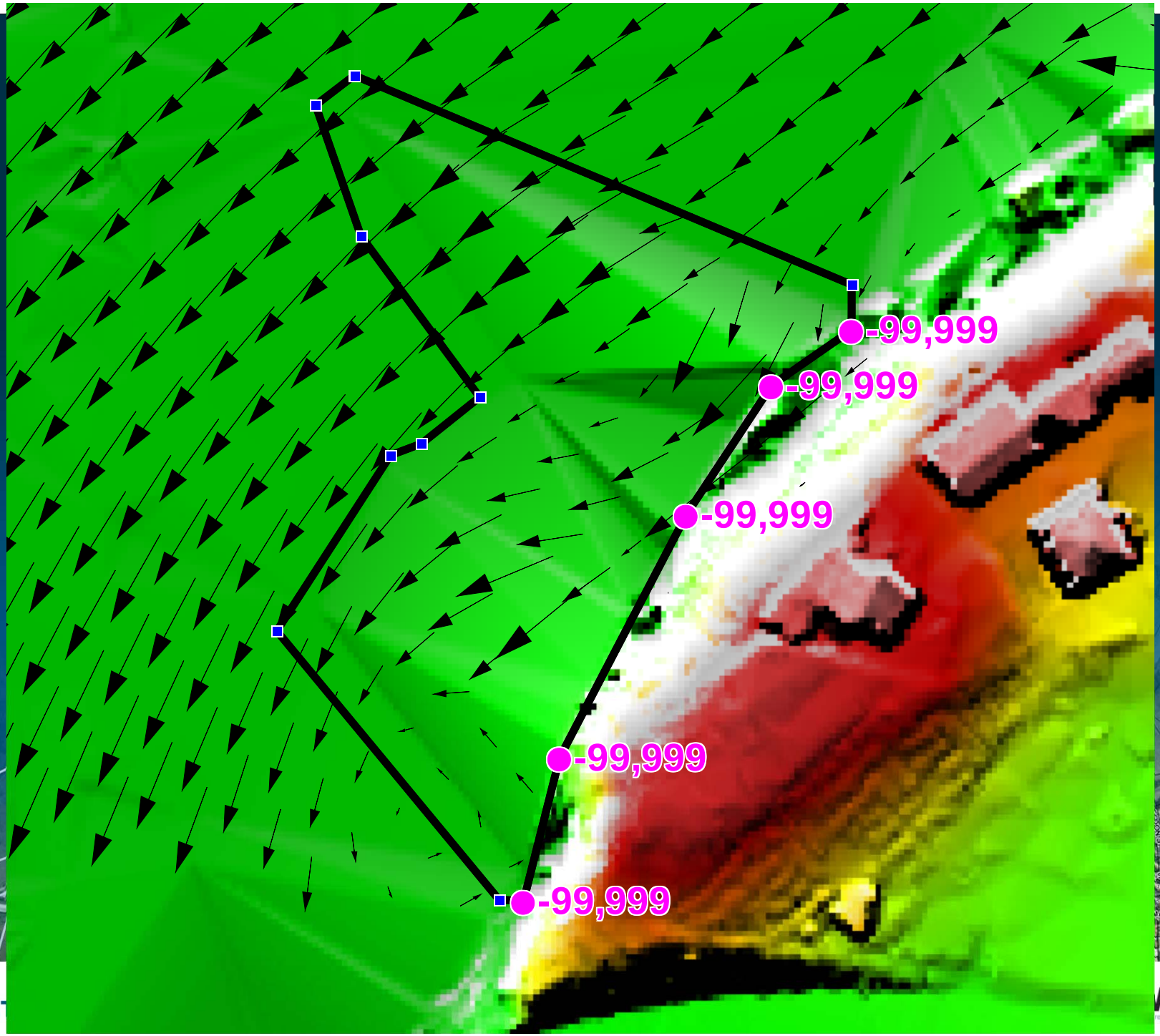


Create TIN Zpts Example



Create TIN Zpts Example




-99,999
-99,999
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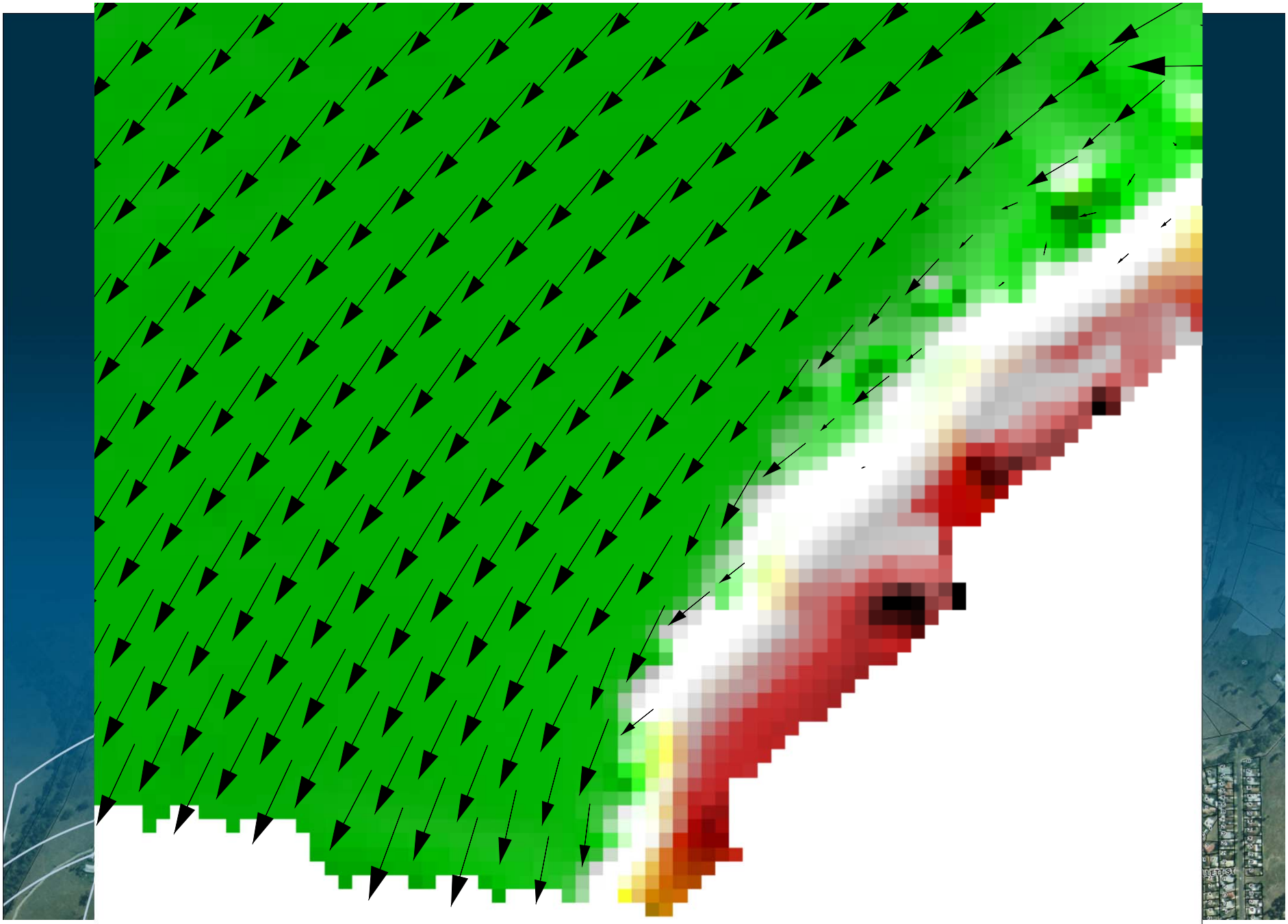
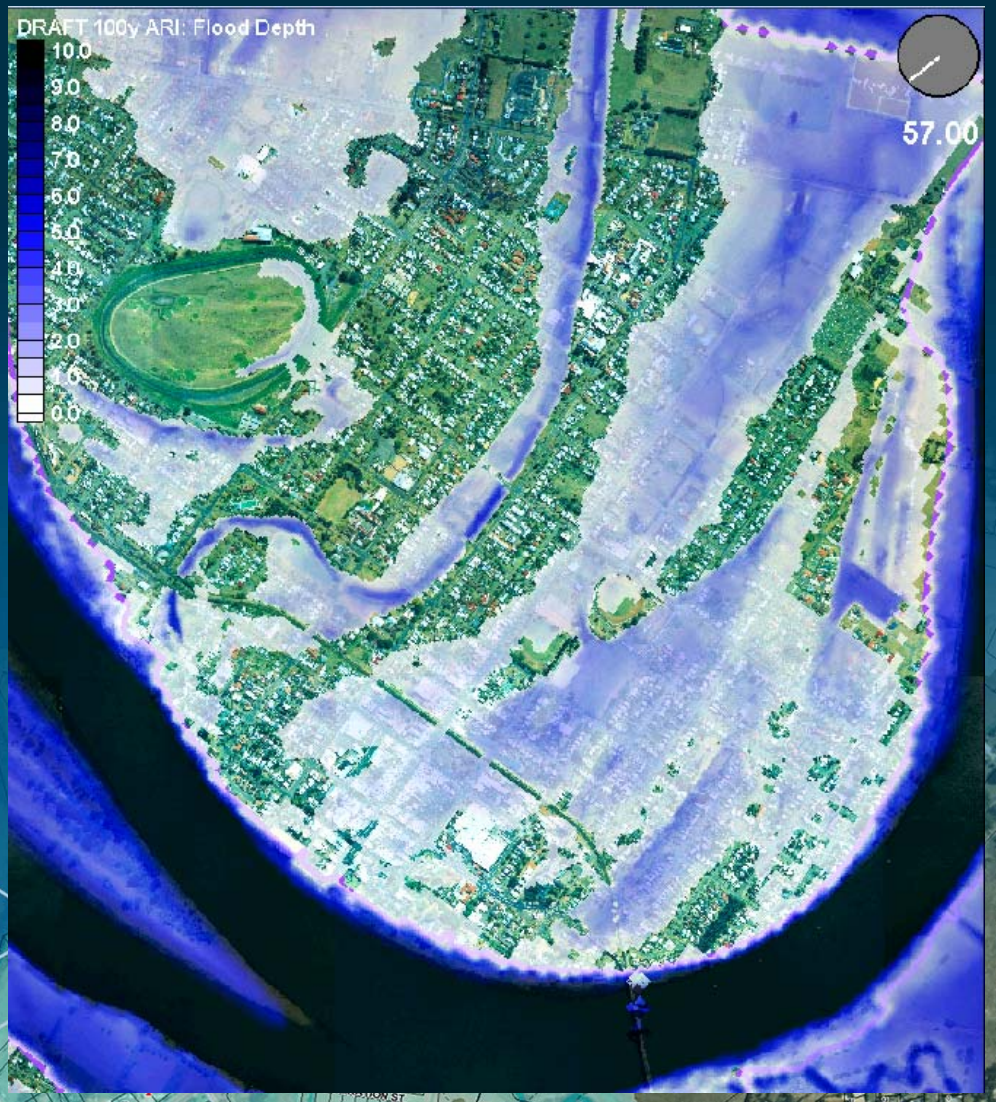


Quality Control

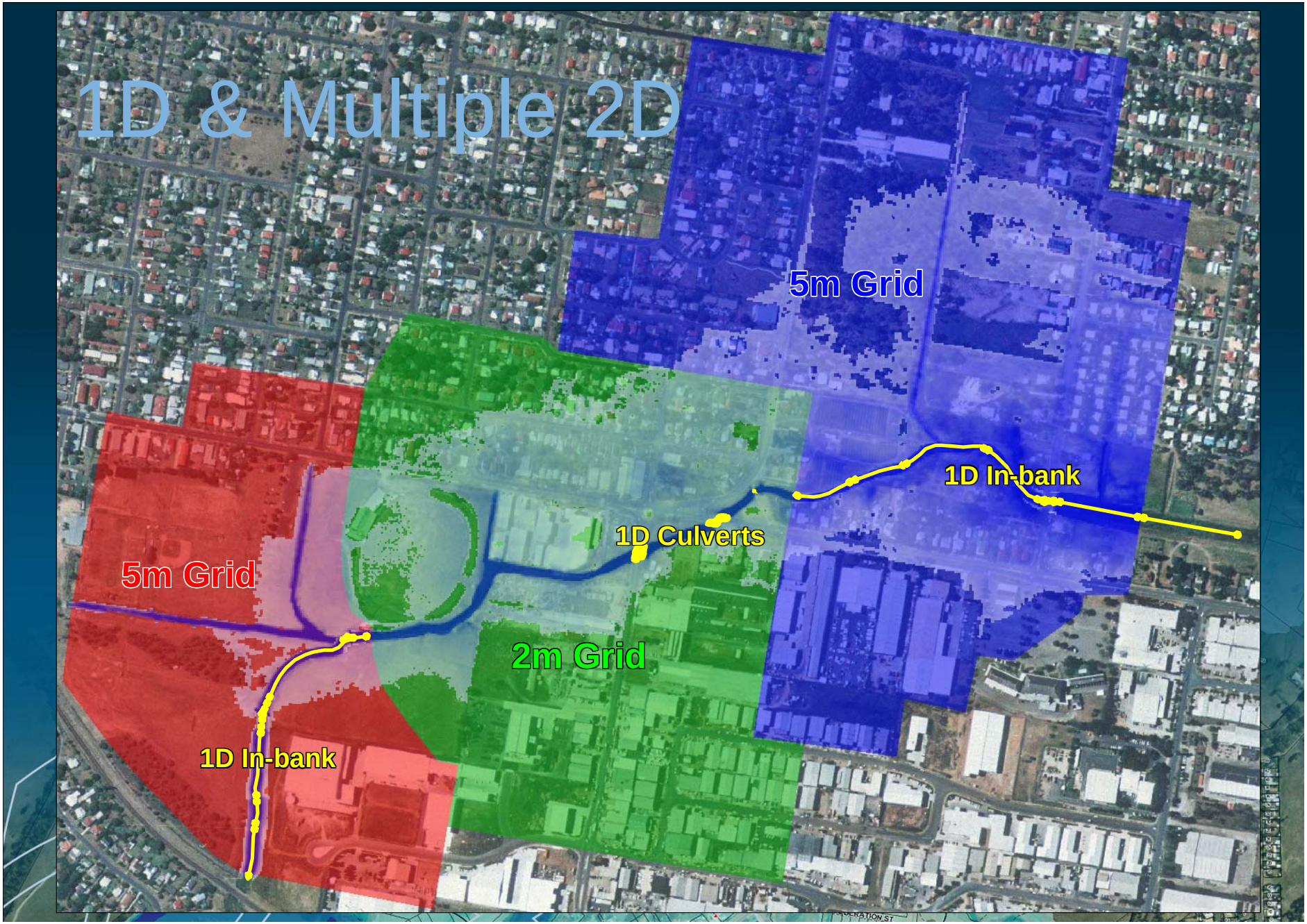
- Numerous check files and GIS layers
- Detailed volume and mass error reporting
- Simulation logging locally and across network
- Challenge 1 examples

Example Models

- Large rivers
- Small creeks
- Urban flooding
- Pipe networks
- Coastal/tidal

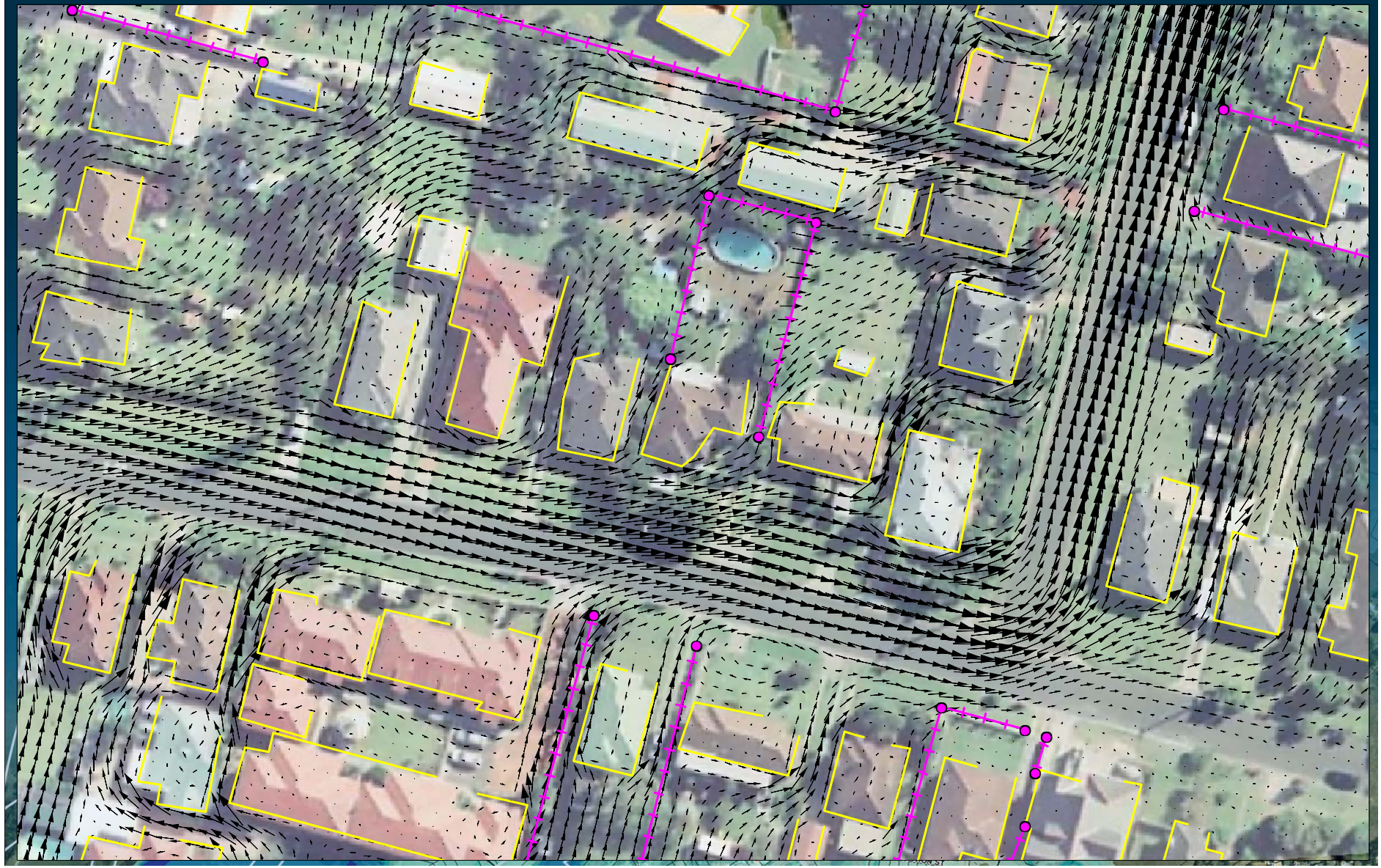


1D & Multiple 2D

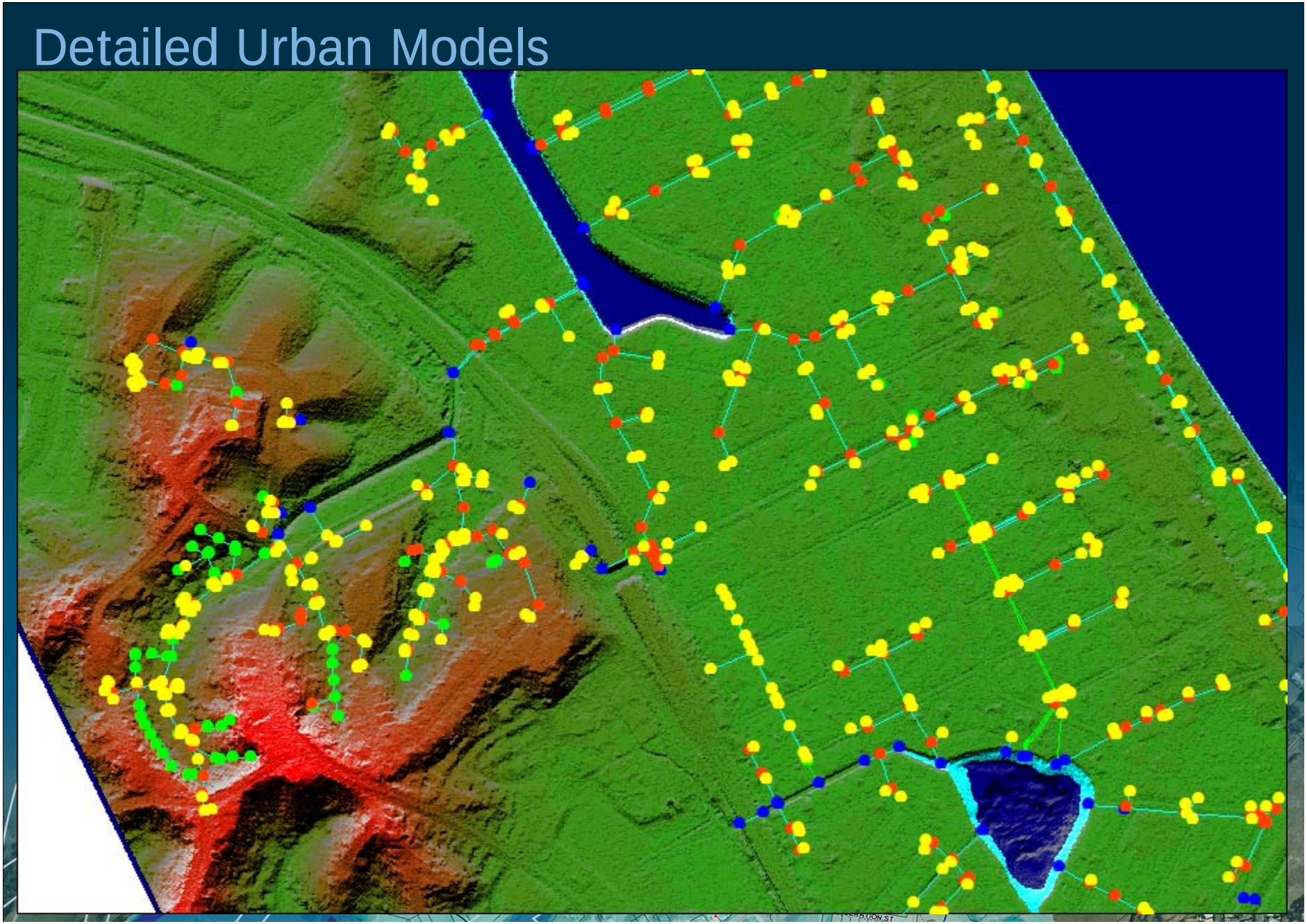


Urban Flood Models

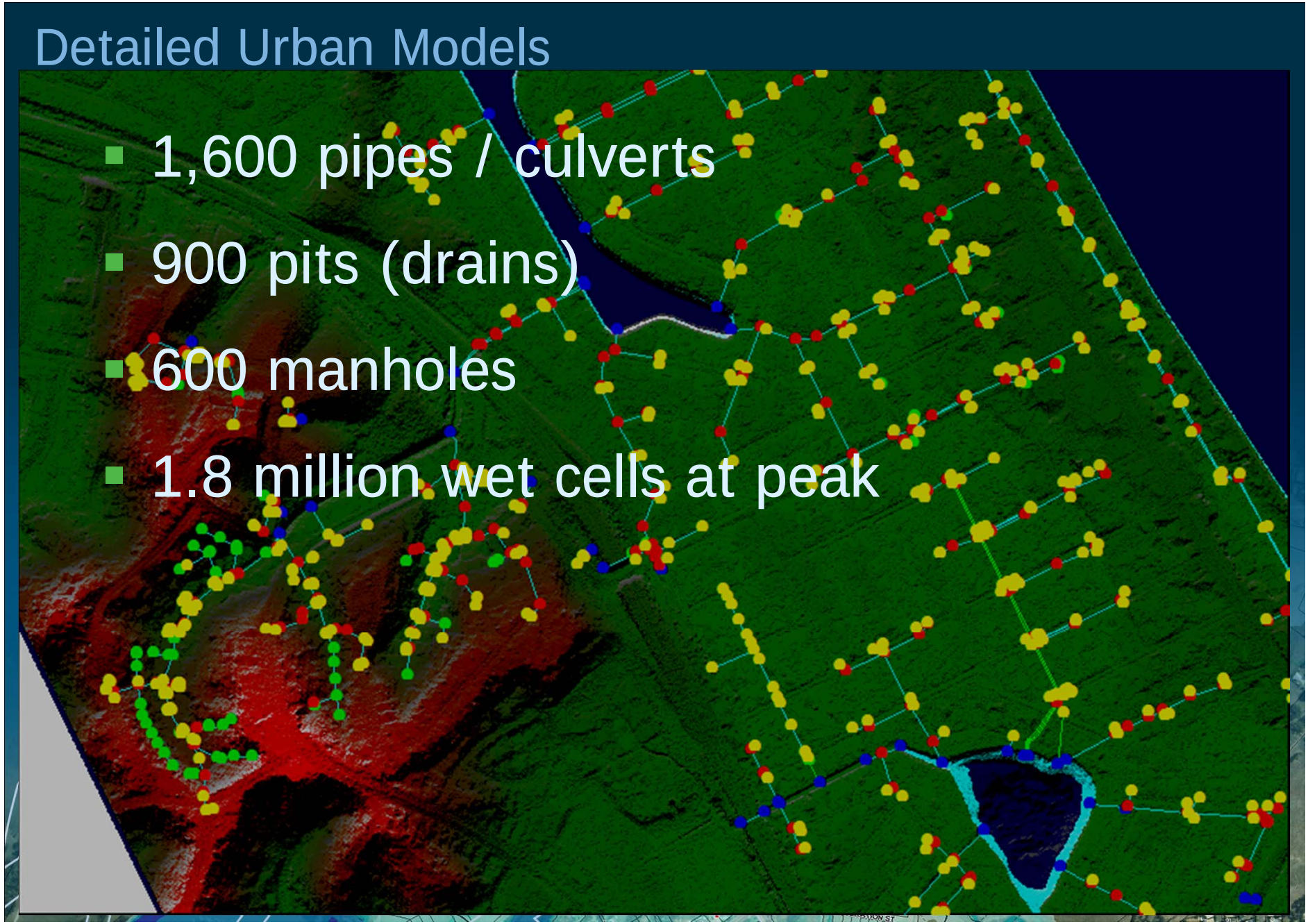
Urban Areas – Buildings and Fences



Detailed Urban Models



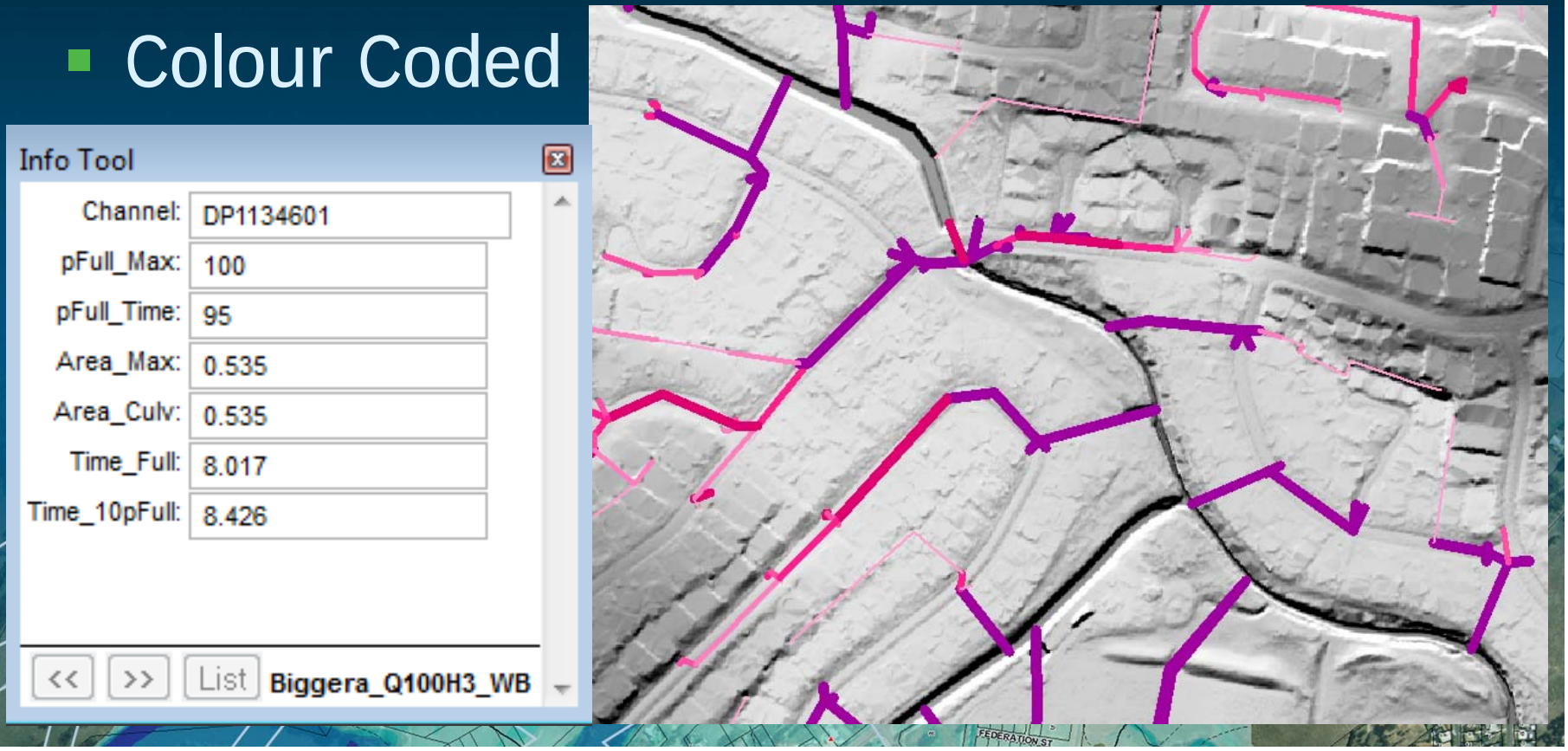
Detailed Urban Models



- 1,600 pipes / culverts
- 900 pits (drains)
- 600 manholes
- 1.8 million wet cells at peak

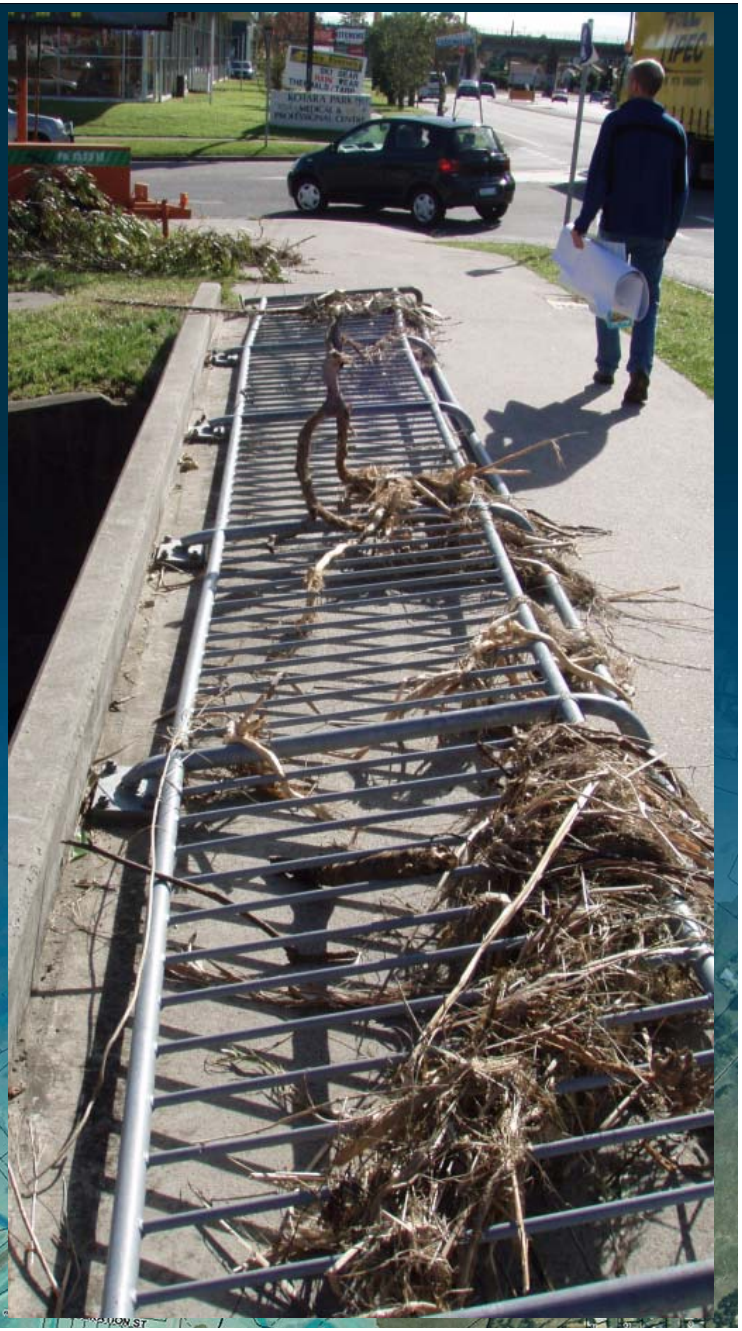
Culvert Capacity and Area

- _ccA.mif (or .shp)
- Colour Coded

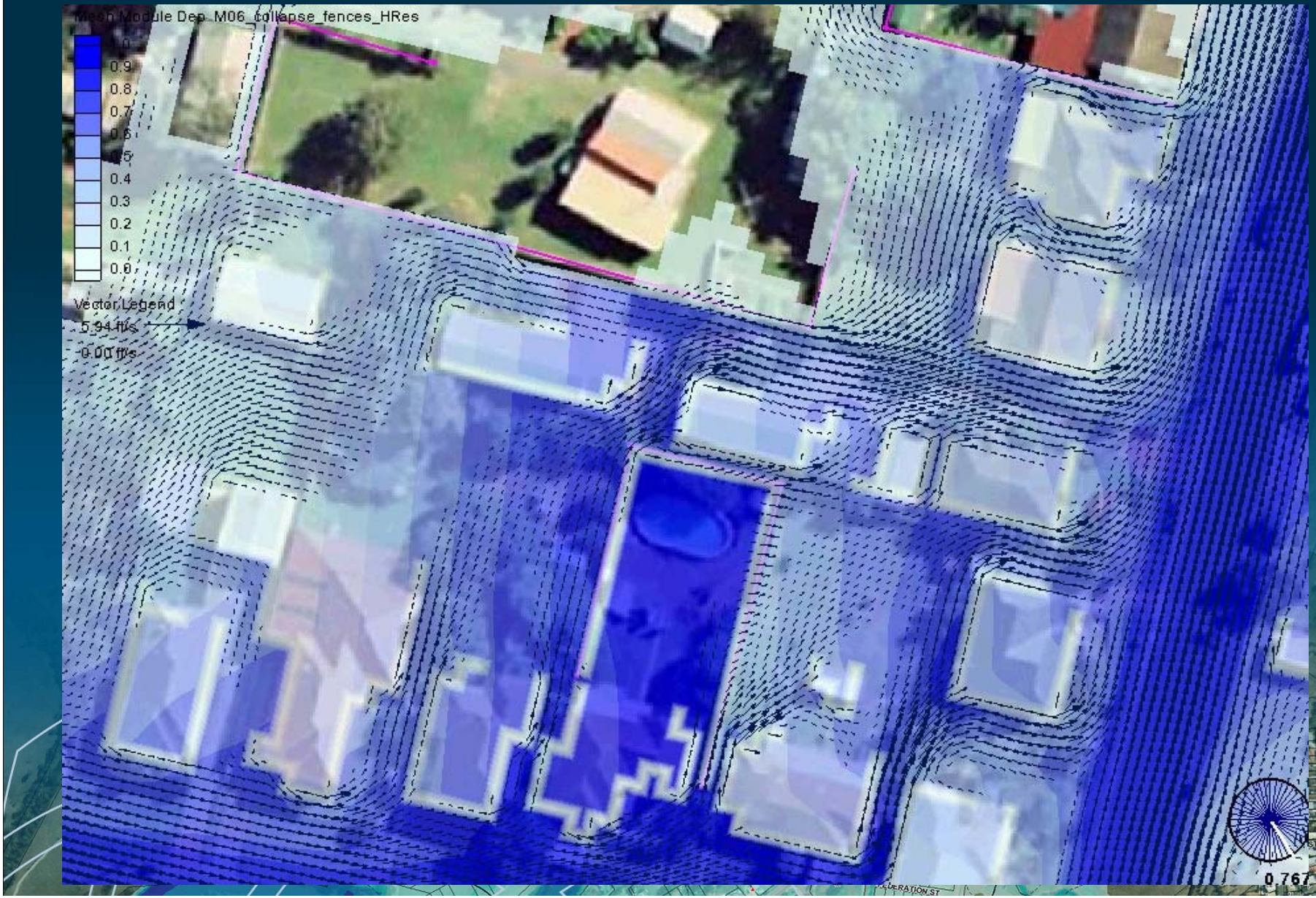


Modelling Fences!

- Able to raise element sides
- Element sides wet and dry
- Layered parameters
  - eg. vary blockage and losses with height
- Collapse element sides
- Switch between u/s and d/s controlled weir flow

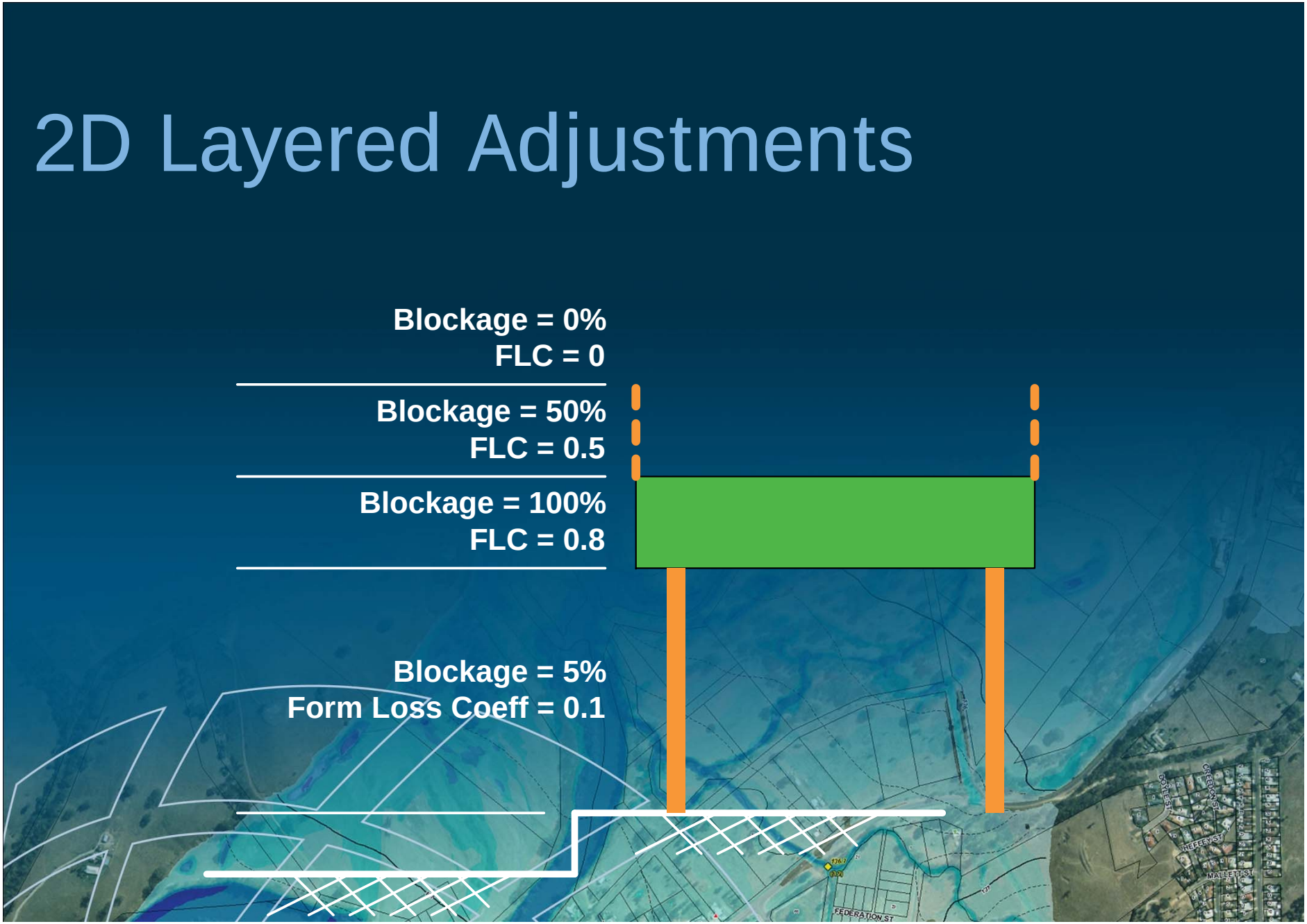


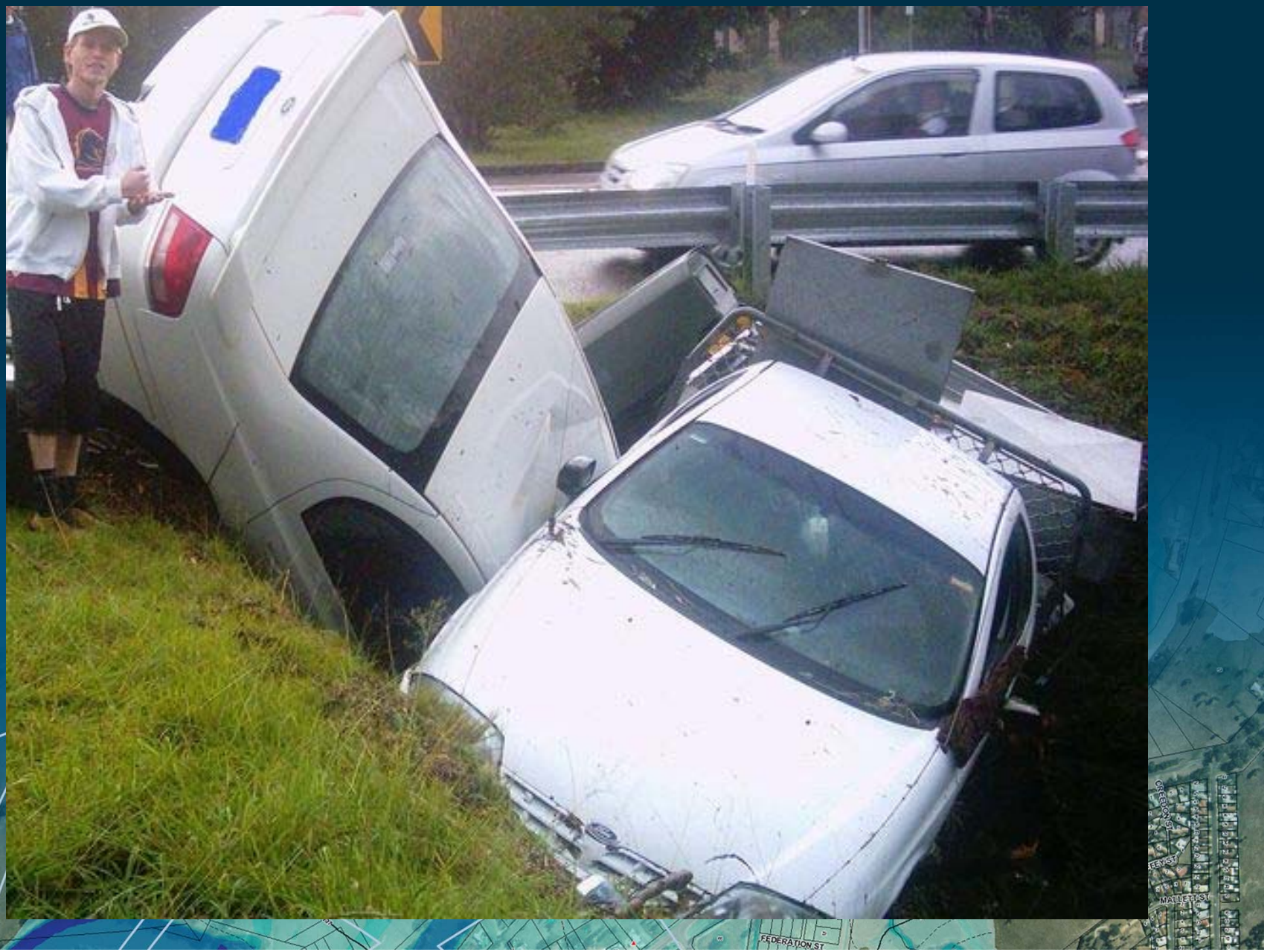
Collapsible Fences Animation



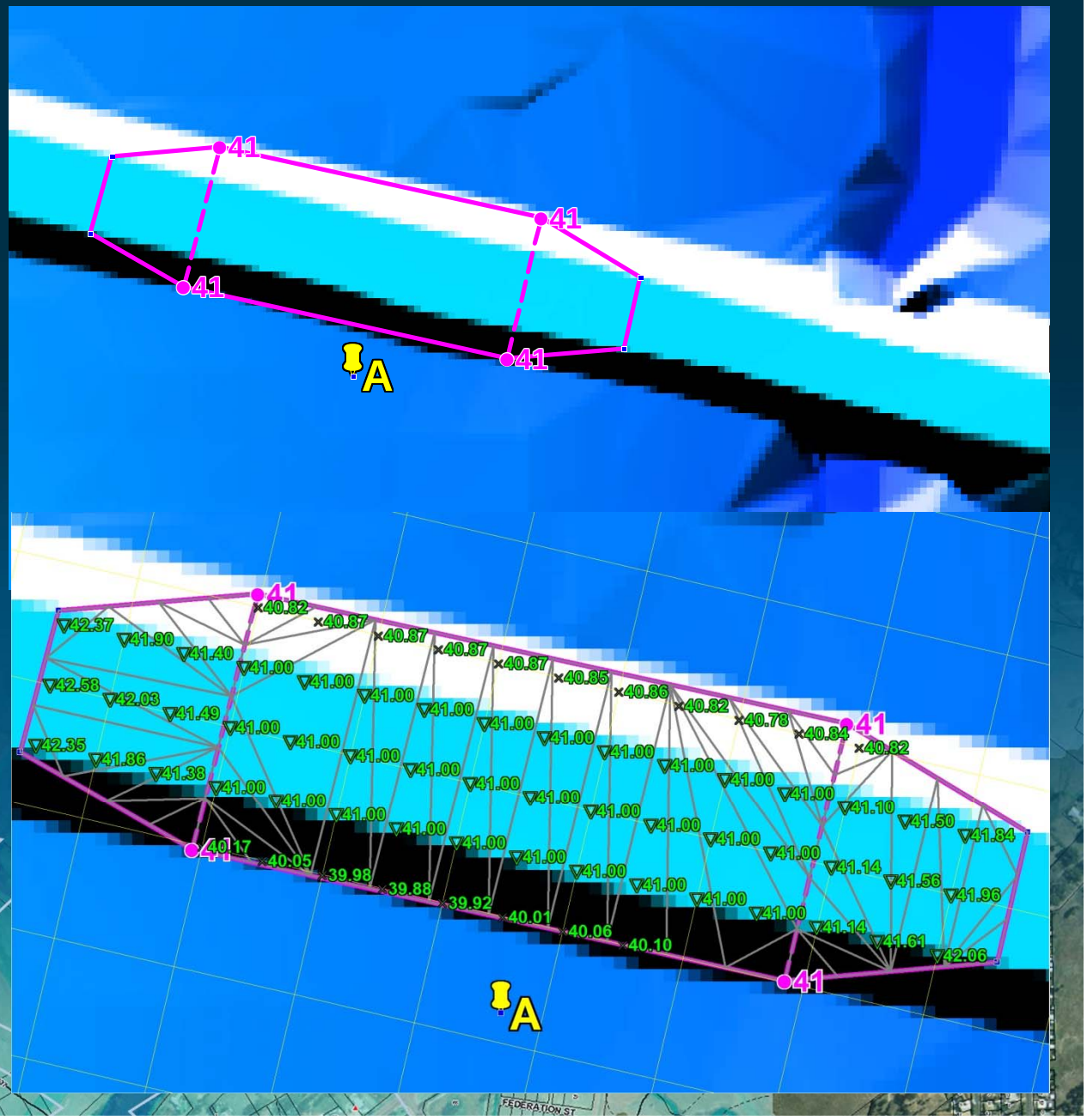
Modelling Blockages!?

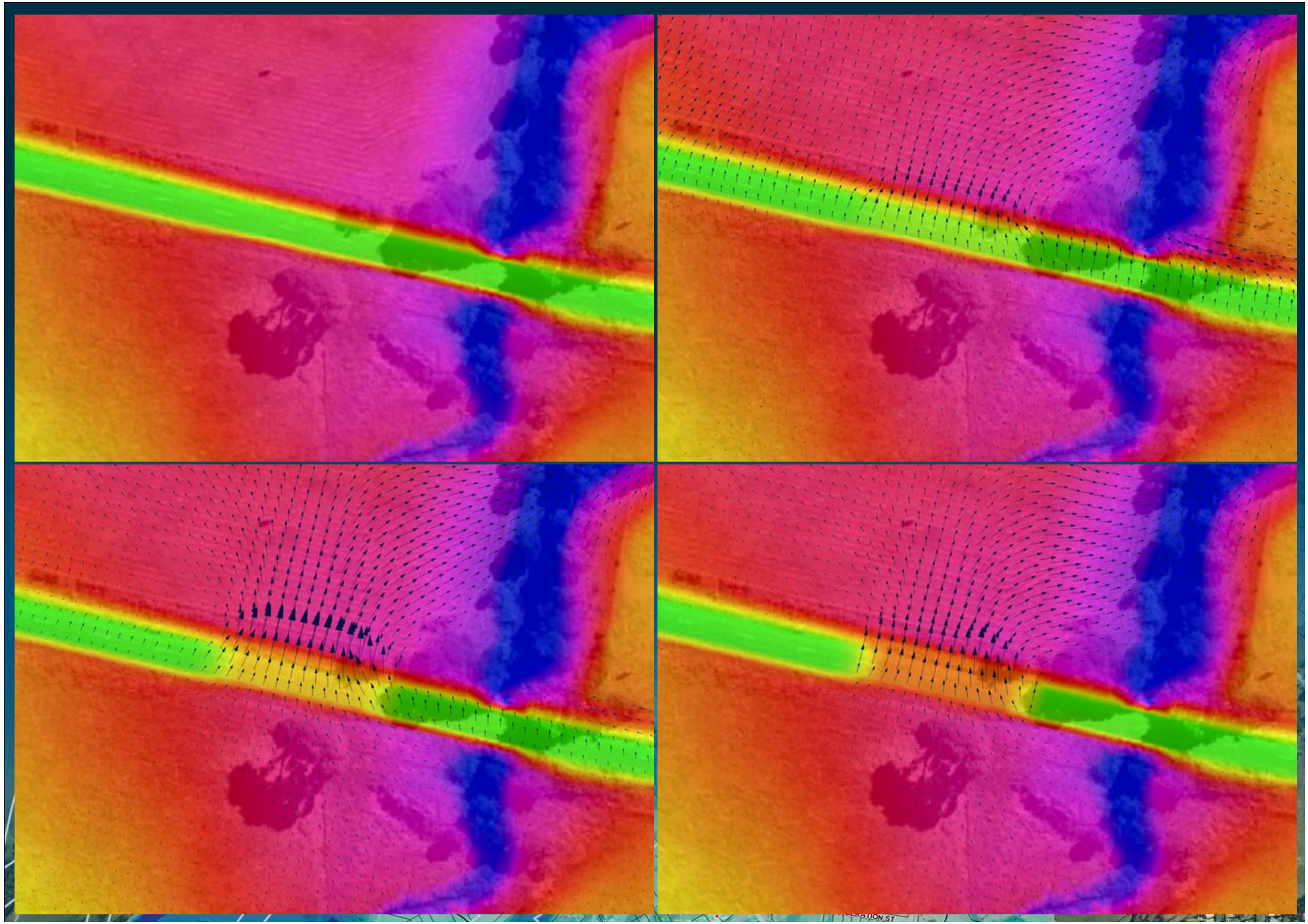
2D Layered Adjustments




FEDERATION ST
MALLETT ST

Embankment Failure

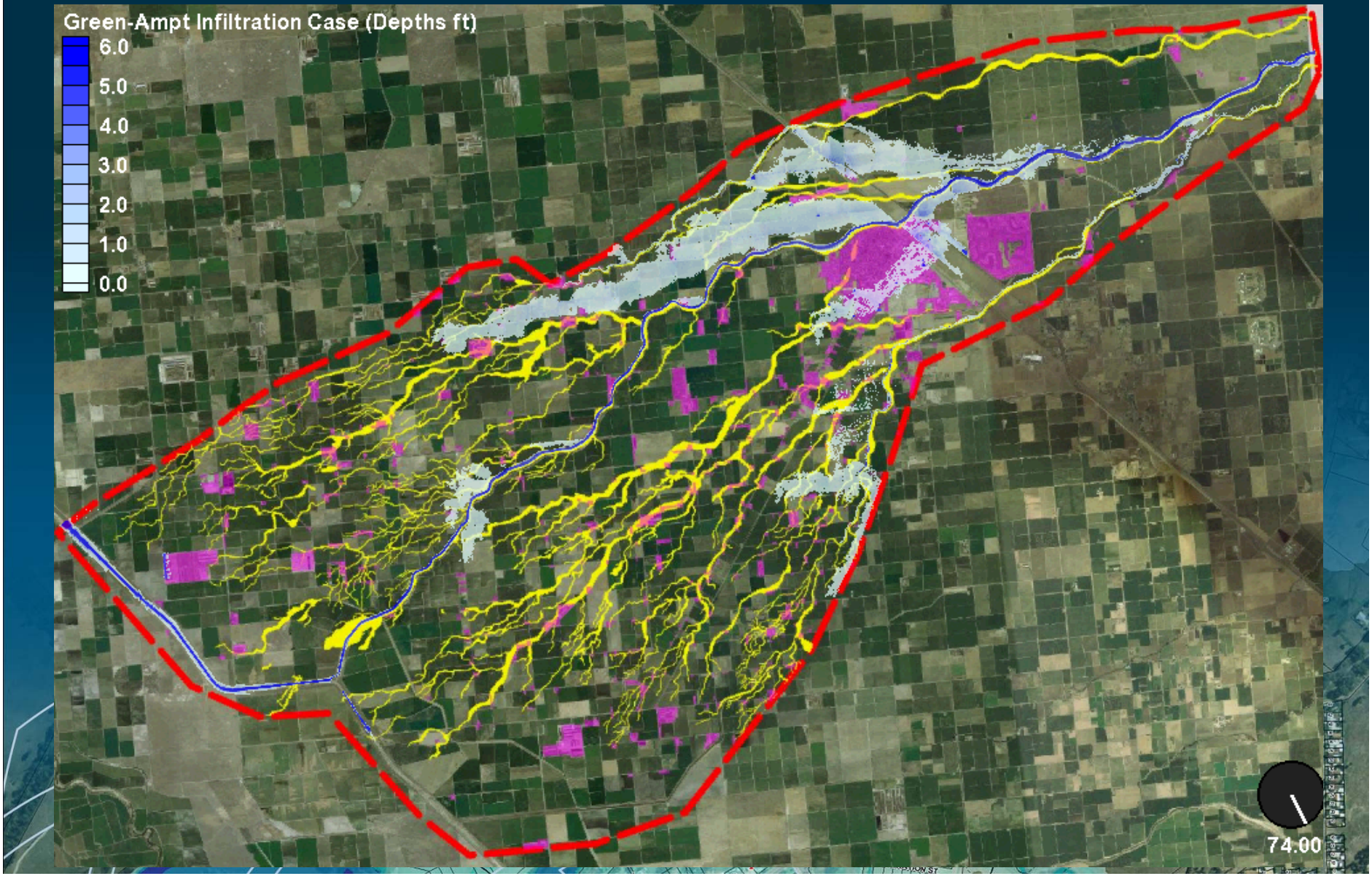




Infiltration

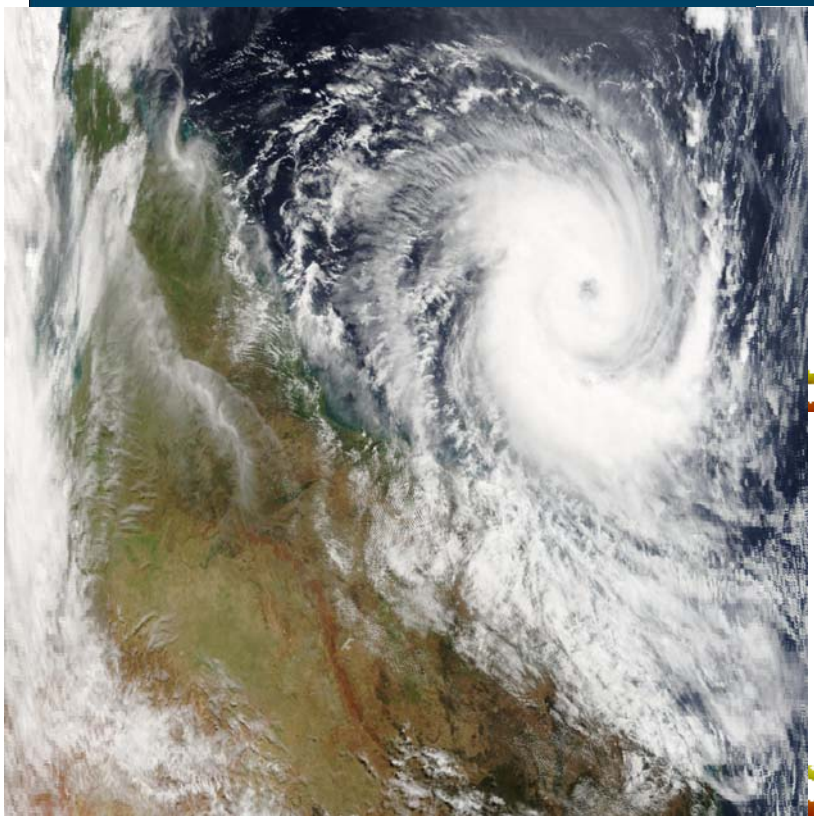
- Ponded water can be infiltrated into the ground based on
  - Soil properties
  - Imperviousness of the surface
- Can specify saturation depth (eg. to groundwater level)
- Two infiltration methods at present
  - Green-Ampt Method
  - Initial Loss / Continuing Loss
- Surface imperviousness
- Soil characteristics
  (Suction, Hydraulic Conductivity, Porosity, Initial Moisture)

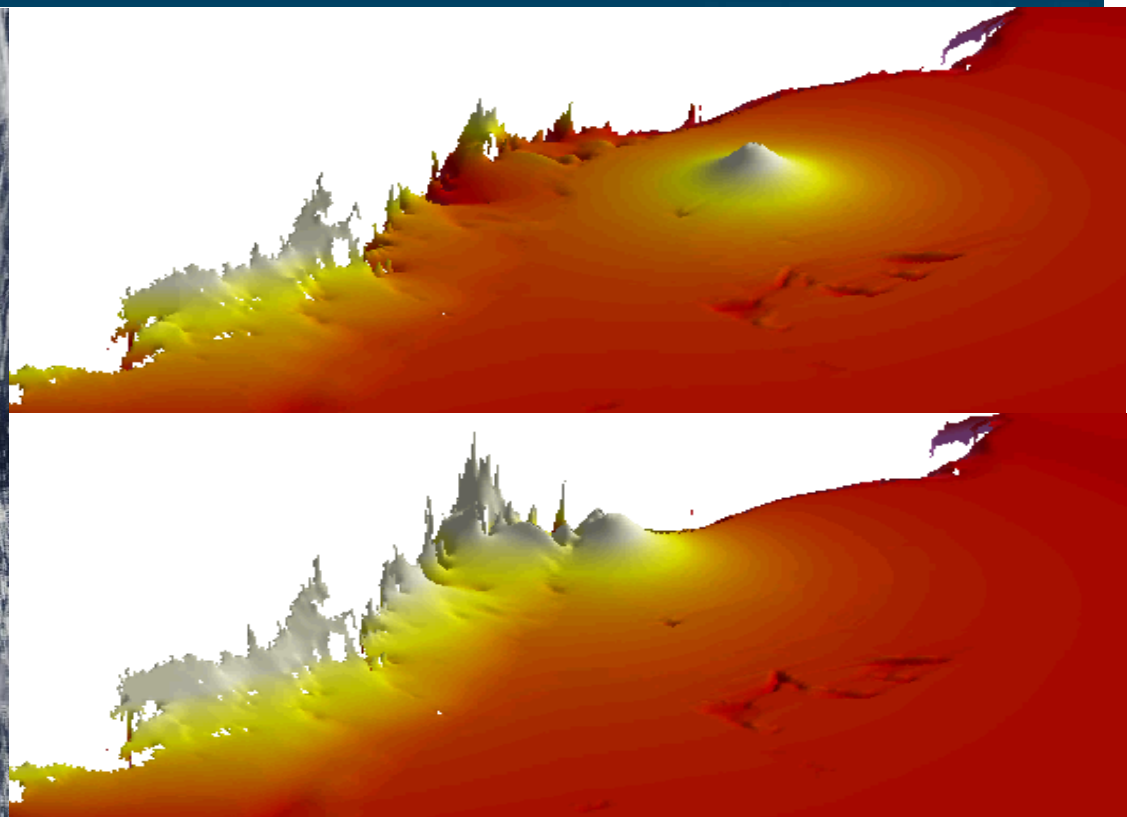
Challenge 3 Green-Ampt Example



Cyclone/Hurricane Modelling

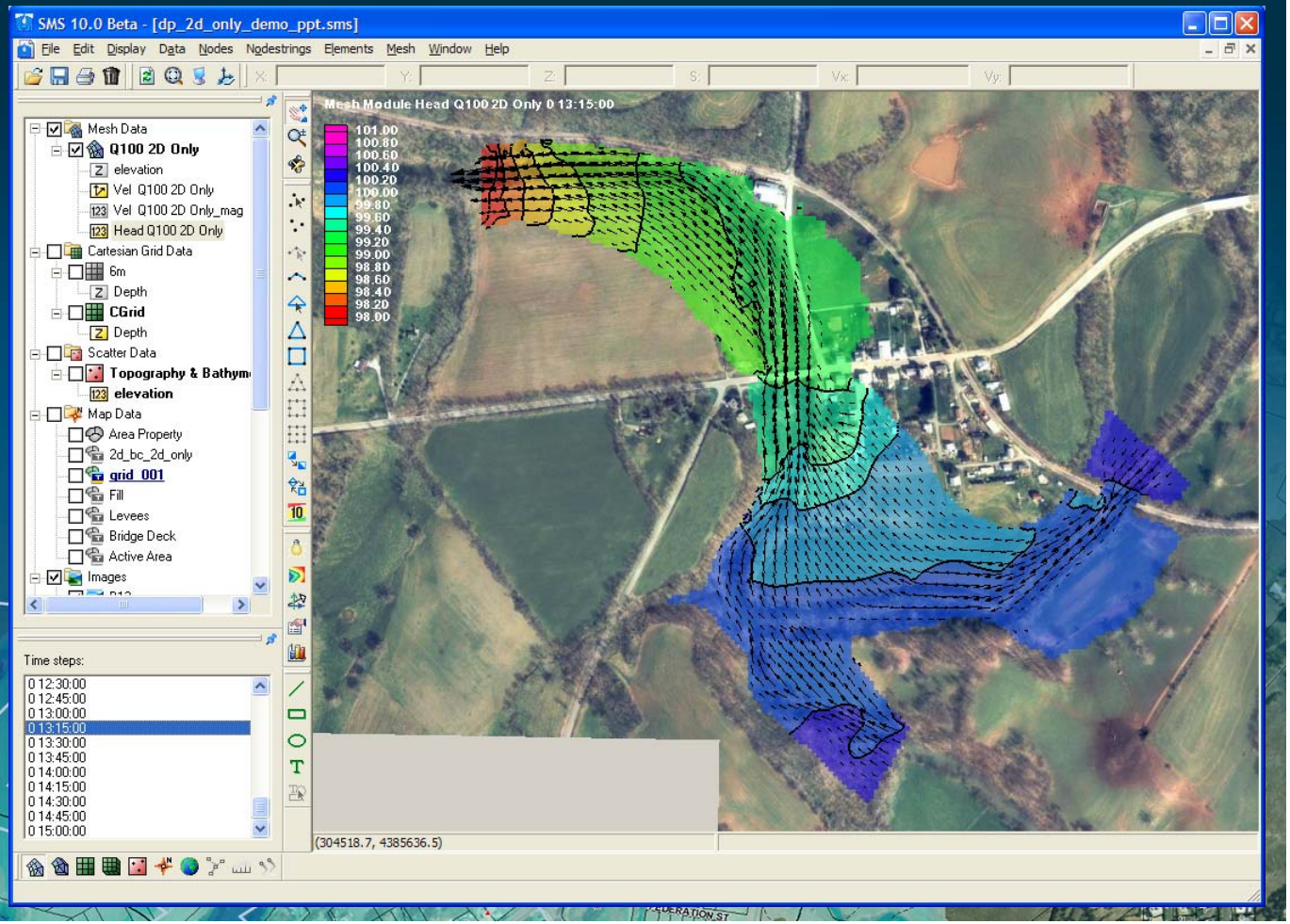
- Calibrated to Category 5 Cyclone Larry
- Storm Surge Studies

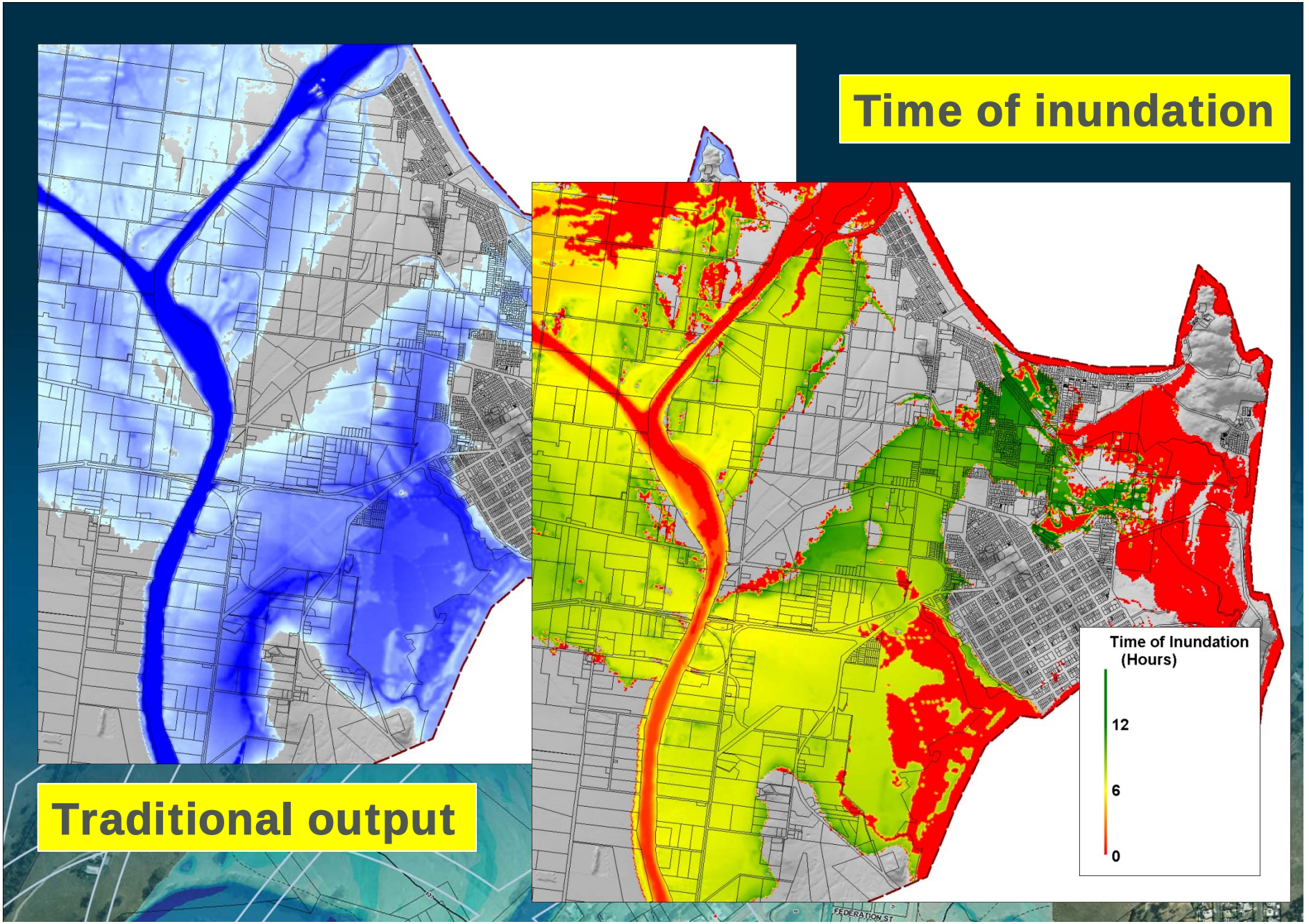




2D Data Output Types

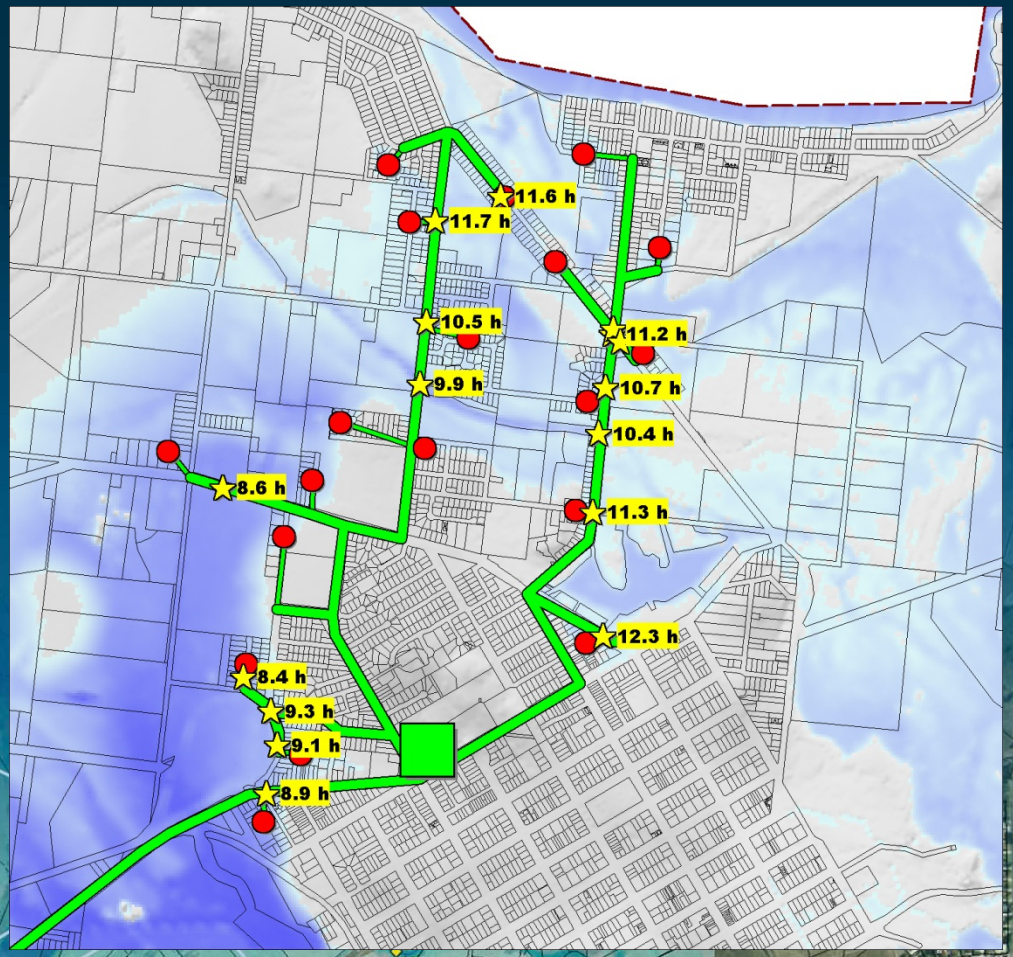
- Water Levels (h)
- Velocities (V)
- Depths (d)
- Unit Flow (q)
- >10 Hazard Categories (Zx)
- Energy (E)
- Froude No. (F)
- Flow Regime (R)
- Mass Error (MB1)
- and more…



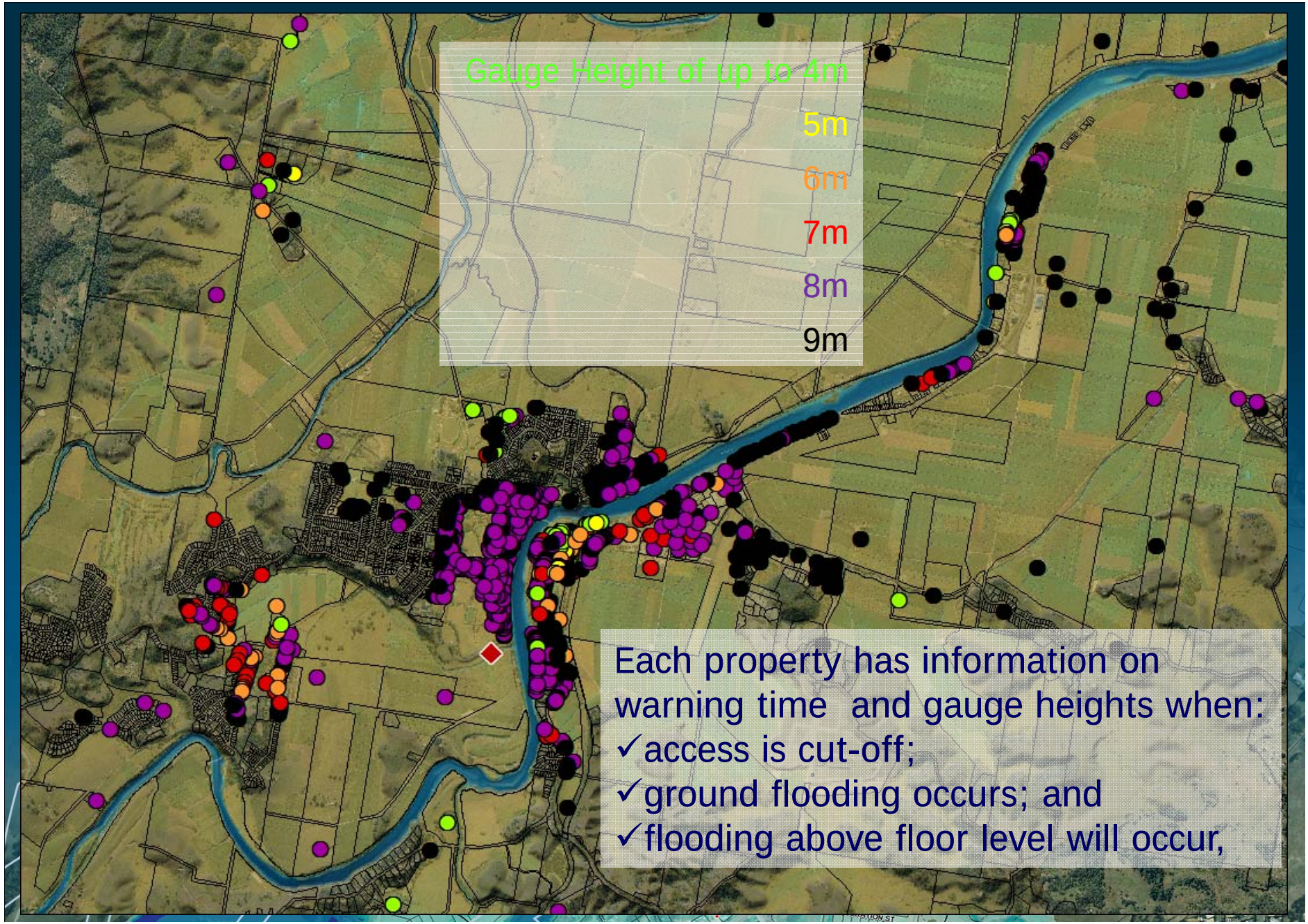

Time of inundation
Traditional output
Time of Inundation
(Hours)
12
6
0
FEDERATION ST

Flood model → Evac model

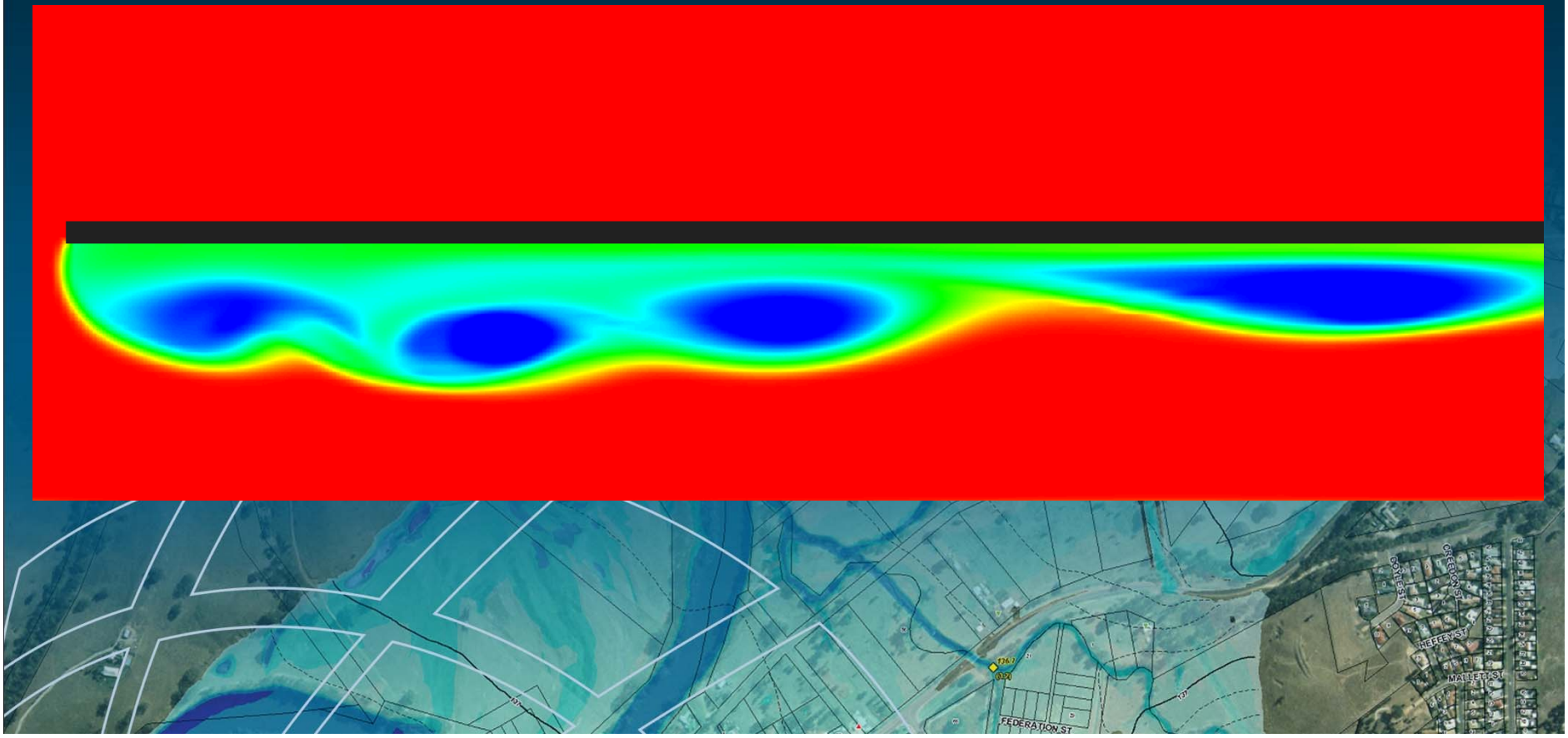
- Spatial
  - Inundation
    - Properties
    - Vulnerable
    - Evac centres
- Timing
  - Flood warning
  - Route closure



Route closure


Gauge Height of up to 4m
5m
6m
7m
8m
9m
Each property has information on warning time and gauge heights when:
✓access is cut-off;
✓ground flooding occurs; and
✓flooding above floor level will occur,

TUFLOW AD Module

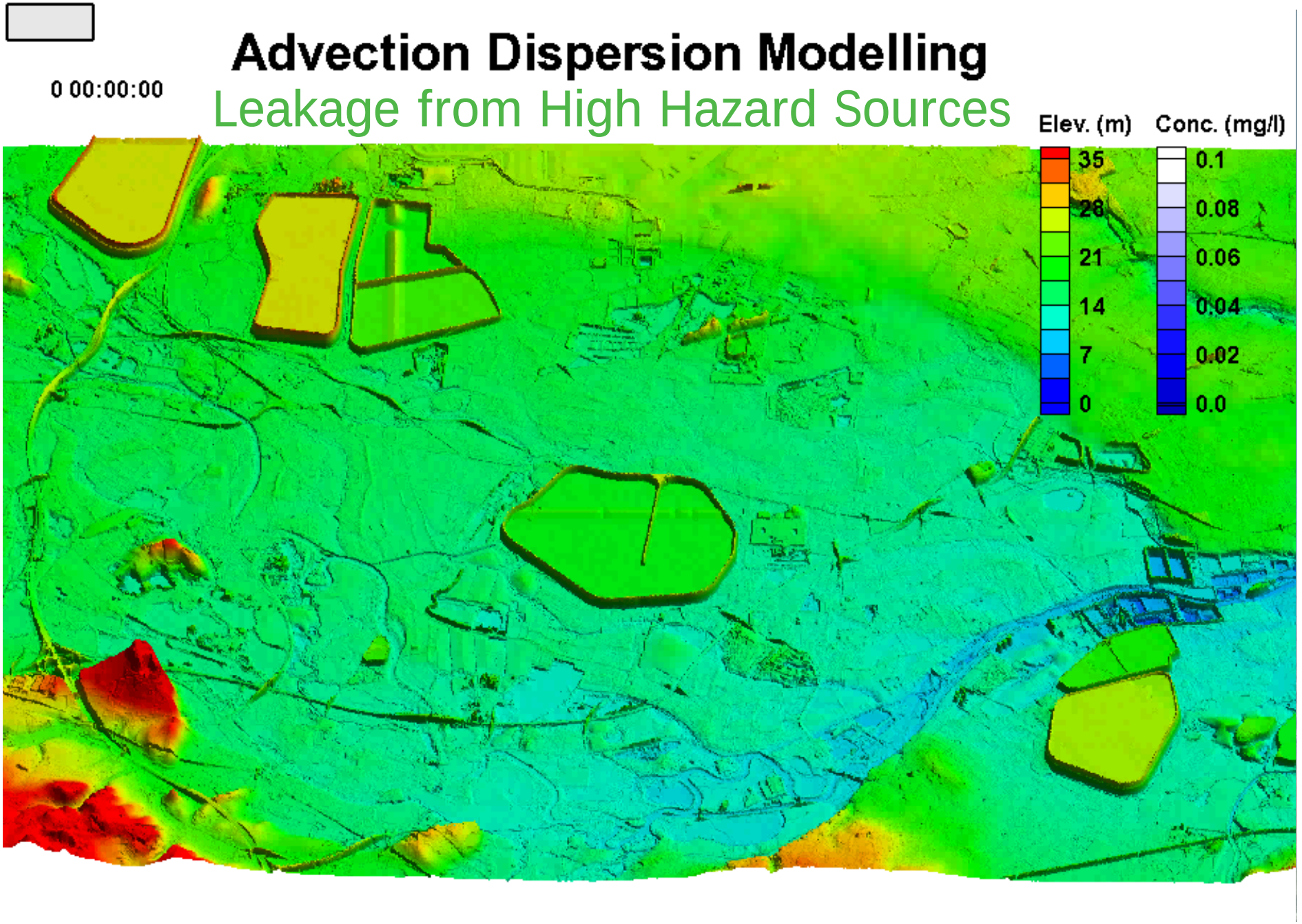


TUFLOW AD

- Simulates fate and transport of dissolved and particulate constituents
- Point source pollution
  - Sewage discharges / Industrial outfalls
  - Concentrated (piped) stormwater flows
  - Leakage from high hazard sources
- Diffuse source pollution (eg. from catchment runoff)
- Estuarine dynamics
  - Post flood salt recovery
  - Pollutant transport under the action of tides

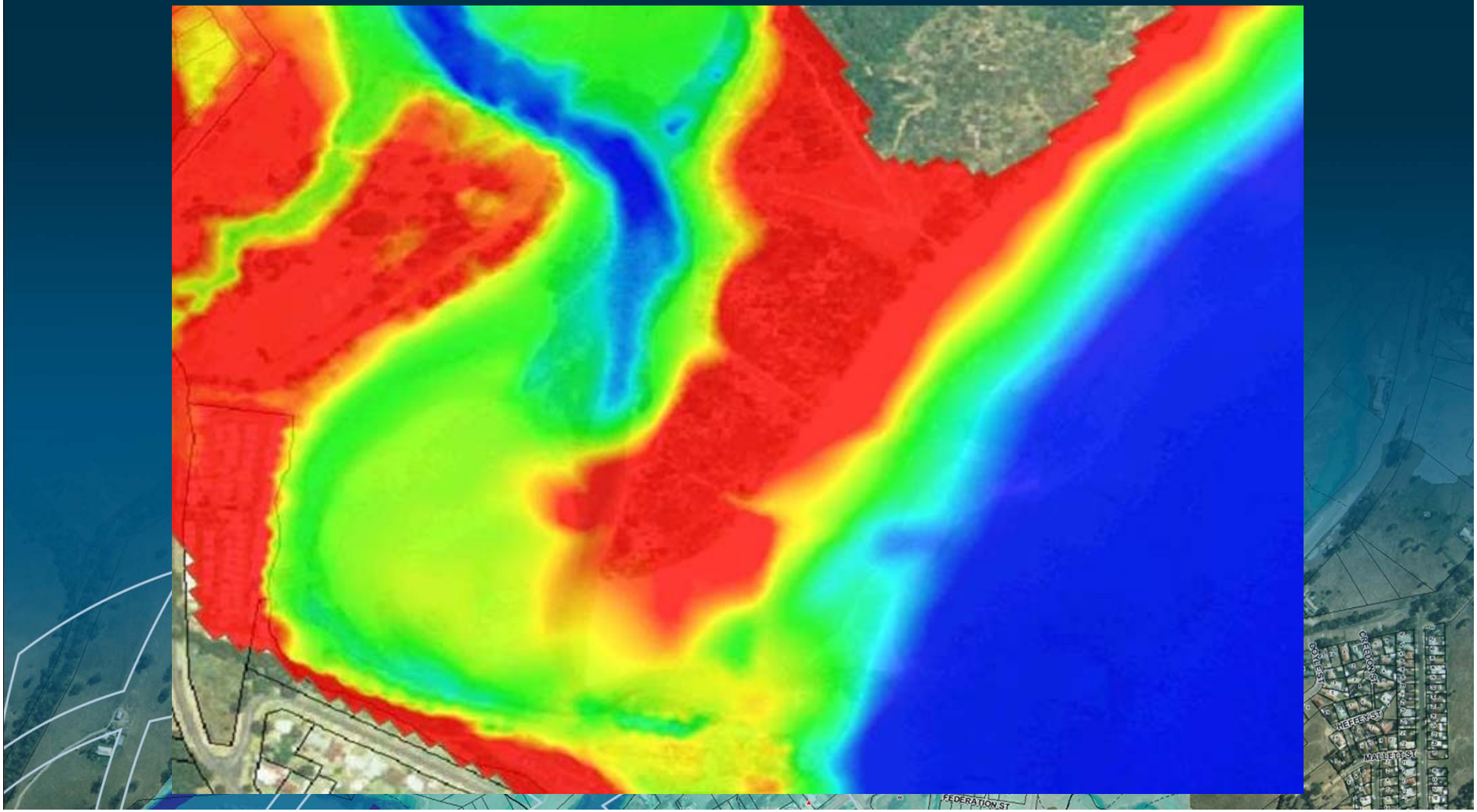
Advection Dispersion Modelling

Leakage from High Hazard Sources



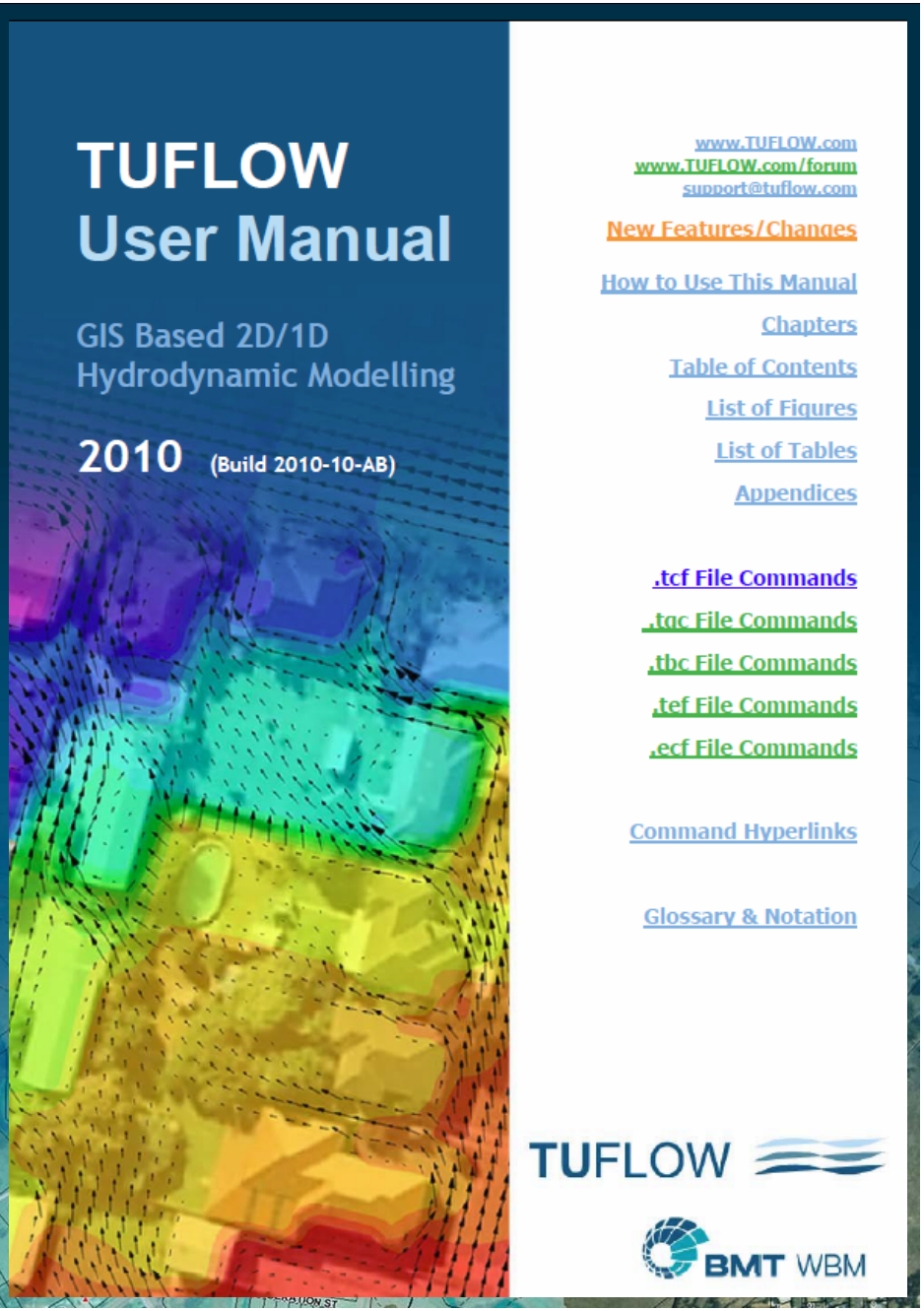
Courtesy CAPITA-SYMONDS, UK

TUFLOW MOR Module



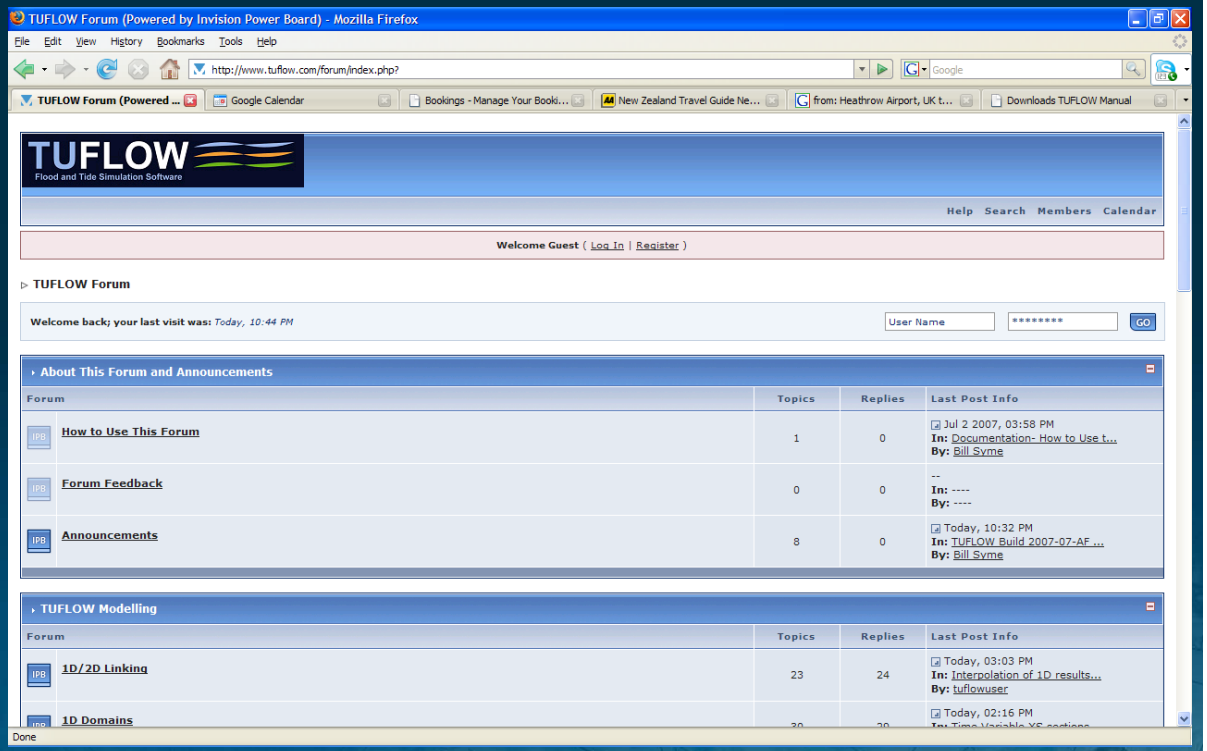
TUFLOW Manual

- 550 pages
- Hyperlinked
  - Easy to navigate
- Very detailed
- Messages and Tutorial Wikis



TUFLOW Forum

- Post and reply to topics
- Receive emails of TUFLOW updates and announcements
- ~1,000 members
- www.tuflow.com\forum

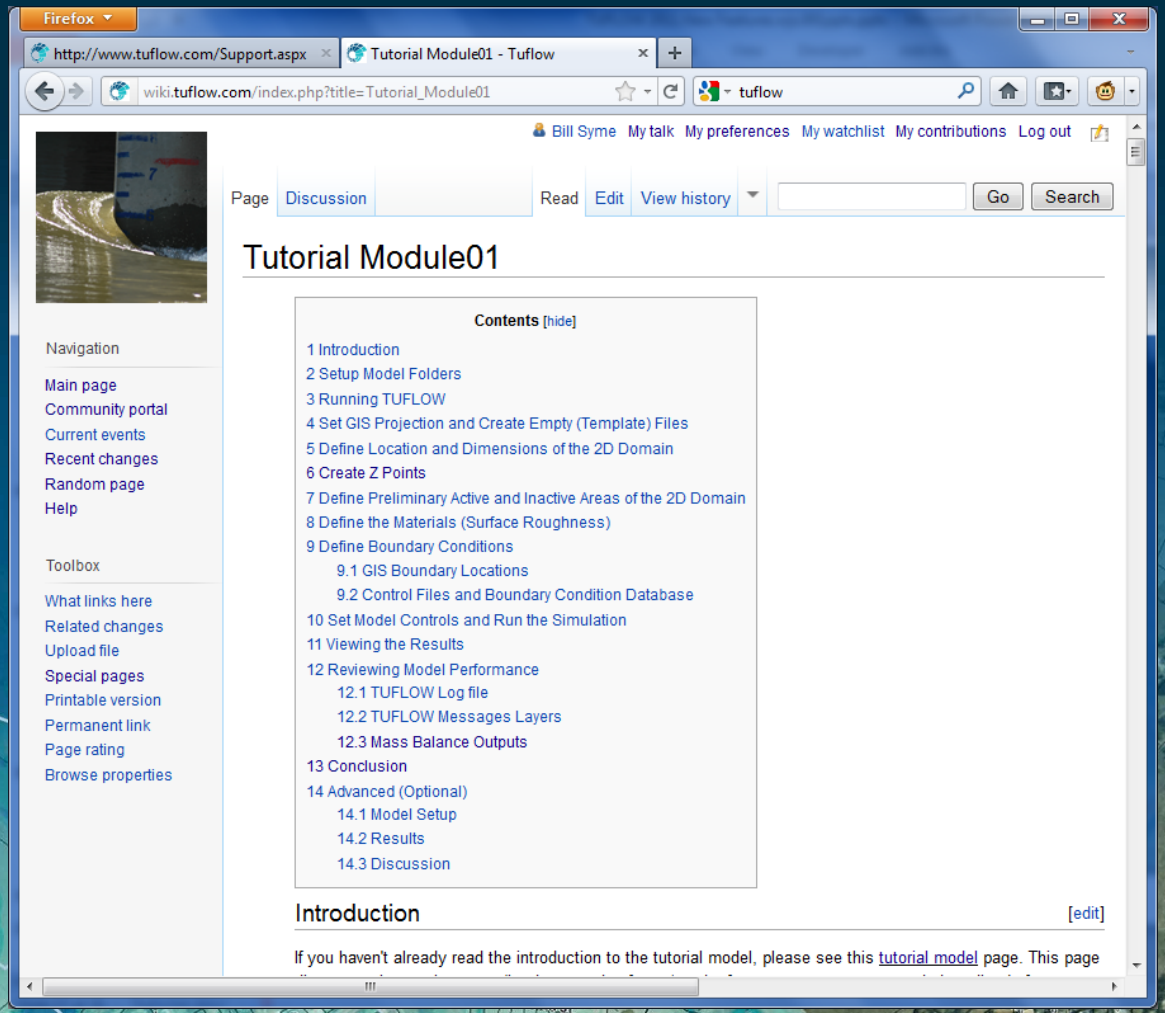


TUFLOW Wiki

- Covers
  - Messages Database
  - Tutorial Models
  - Tips and Tricks
- Continuously under development
- Need to register
  (to keep spammers away!)
- Add comments, suggestions

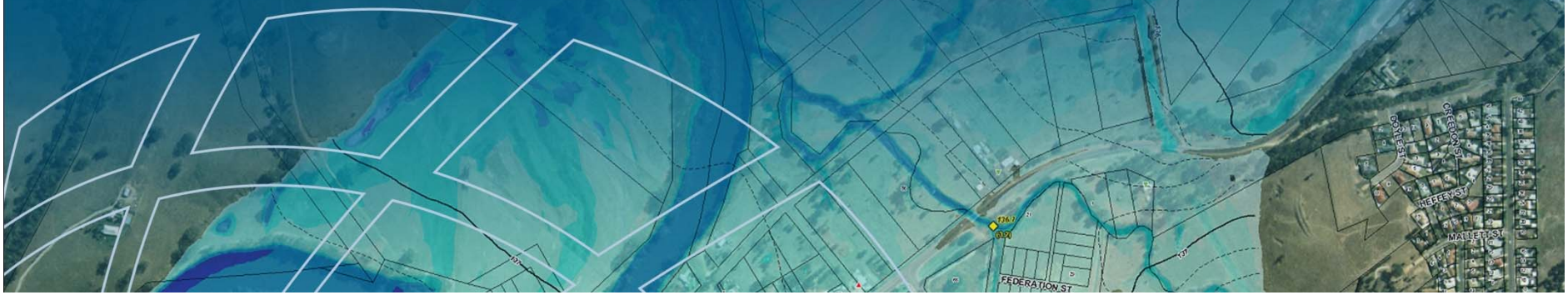
TUFLOW Wiki Tutorial Models

- All modules from 2007 tutorial models being updated and incorporated
- Aiming for a new module per month over next year
- Will have around 12 modules all up to cover majority of TUFLOW's features



Wiki Tutorial Model

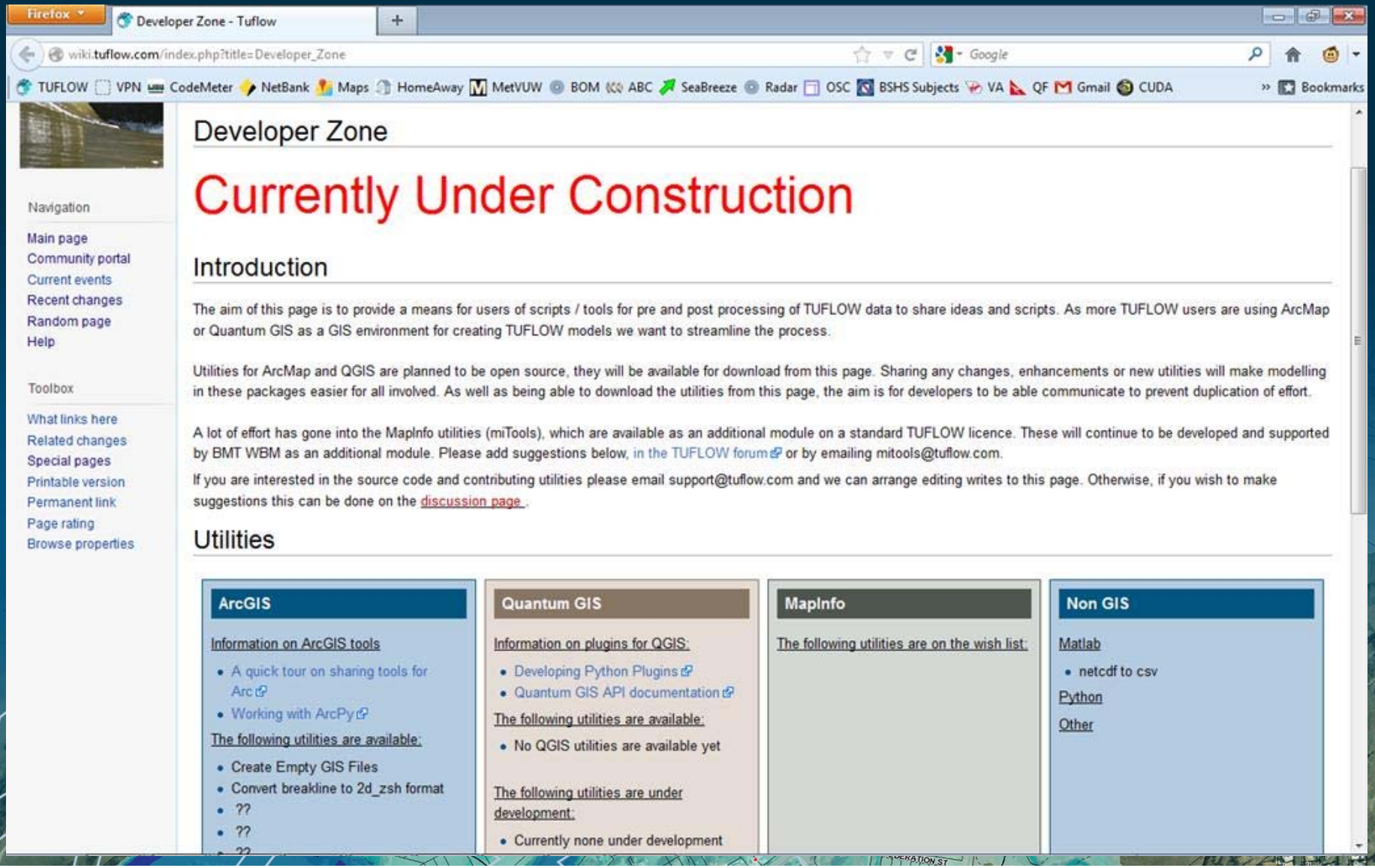
- Very useful for in-house training
- Designed for
  - MapInfo with Vertical Mapper
  - MapInfo with Discover 3D
  - ArcGIS with Spatial Analyst
  - QGIS (free open source GIS)
- Can simulate models without a TUFLOW licence
- Download files/models from Downloads page on www.tuflow.com



TUFLOW Wiki Tips and Tricks

- Tips and Tricks from Chapter 12 of the manual being added
- New ones added and will continuously be added
- Use Discussion page or email support@tuflow.com to comment or make suggestions

TUFLOW Wiki Developer's Zone



Summary

- TUFLOW successfully applied to:
  - Rivers, Creeks and Floodplains (2D or 1D/2D)
  - Urban Flooding (Overland 2D; Channels, Pipes, Manholes and Pits 1D)
  - Hydrologic Modeling (Direct rainfall application)
  - Estuaries / Coastal Waters / Storm Surges
- GIS Based – Cost Effective
- Create and view models via GIS, or SMS and XP-2D Interfaces
- Used around the world by more than 400 organizations
- Most used 1D/2D Flood Modeling Software in Australia and the UK

TUFLOW Advantages

- Verified, Calibrated (many times), Benchmarked
- Highly Efficient and Cost Effective
- Large Range of Features
- Layered Data Approach / No Duplication of Input Data
- All Inputs Independent of 2D Grid
- Fast and Accurate (Solves Full 2D SWE)
- Detailed Manual / Active Online User Forum and Wiki
- Support comes from the developers
- Proven Track Record / Defendable

thank you