1D and 2D Modelling
Bends, Structures and Obstructions

Bill Syme

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1D vs 2D
Understanding the Difference

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Form Losses

- Energy dissipated as heat due to changes in velocity magnitude and direction
- Pronounced at
  - Bends
  - Flow constrictions (structures)
- Form loss coefficient
  - Proportion of dynamic head ($V^2/2g$) lost
  - V = 1m/s; Dynamic Head = 0.05m
  - V = 4m/s; Dynamic Head = 0.82m

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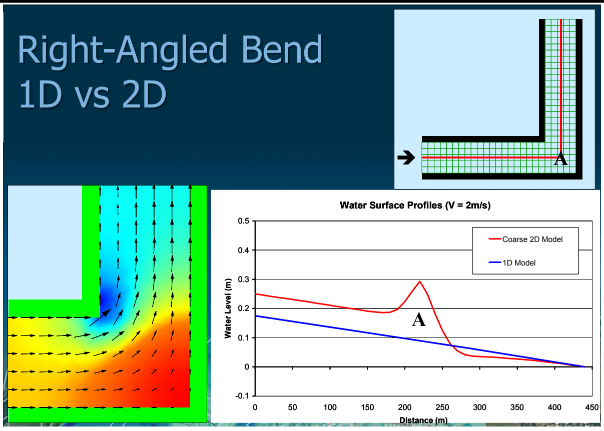
Right-Angled Bend 1D vs 2D



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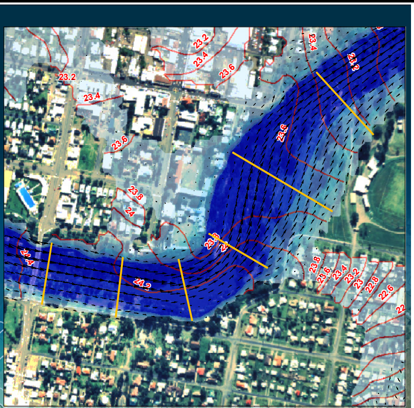
River Bends

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



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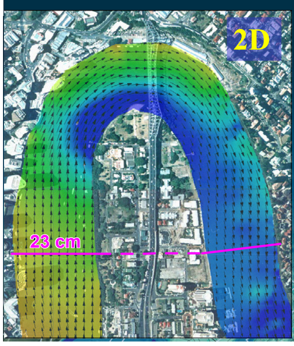
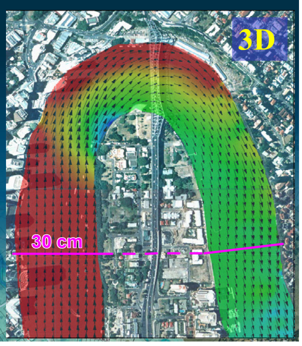
2D vs 3D?





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Bends - Conclusions
1D and 2D Approaches

- 1D
  - Apply extra losses by
    - Form loss coefficient, or
    - Increasing Manning's n
  - Do not model superelevation
- 2D
  - Form losses inherent / Models superelevation
  - However
    - Are model elements too coarse to simulate all losses?
    - Are there losses in the vertical plane? (Helicoidal circulations)
  - Additional form losses may be required

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Hydraulic Structures

- Hydraulic Structures
  - Bridges and Embankments
  - Large Culverts
- Hydraulics is Complex (3D)
  - 1D: Traditional Approach
  - 2D: Looks impressive, but is it accurate?
  - 1D/2D: Best of both?

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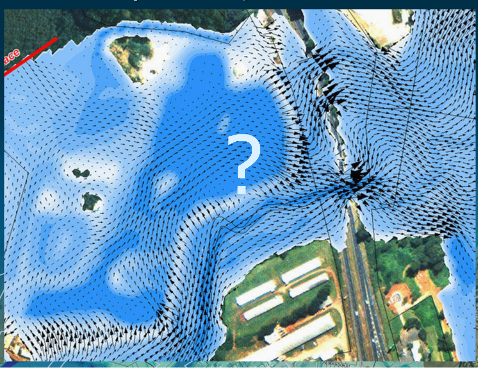
2D: Looks impressive, but is it accurate?



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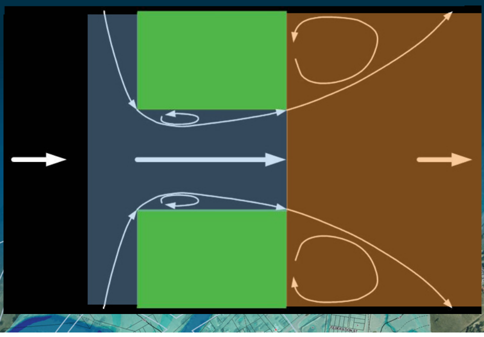
1D: Traditional Approach Uses Contraction/Expansion Losses



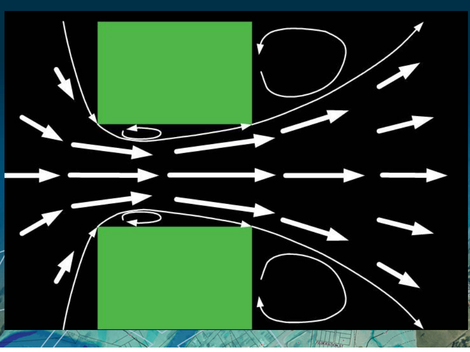
1D Culvert Entrance and Exit Loss Coefficients

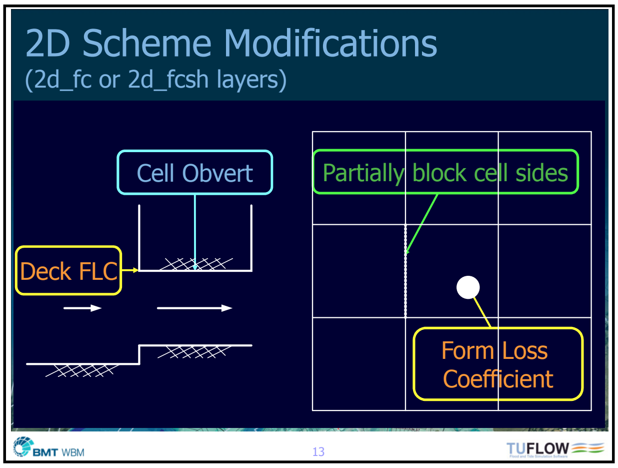
- Coefficients adjusted according to approach and departure velocities in a 1D network (n/a yet when connected to 2D)
- Can fix losses (ie. no adjustment) if desired
- Default unadjusted values typically 0.5 and 1.0
- Energy loss is $C^*V_s^2/2g$

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

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

2D: No Contraction/Expansion Losses?




2D Scheme Modifications
(2d_fc or 2d_fcsh layers)
Cell Obvert
Partially block cell sides
Deck FLC
Form Loss Coefficient
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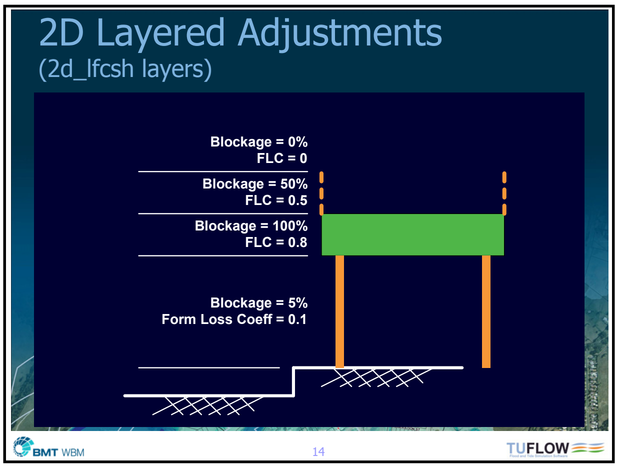
2D Layered Adjustments
(2d_lfcsh layers)
Blockage = 0%
FLC = 0
Blockage = 50%
FLC = 0.5
Blockage = 100%
FLC = 0.8
Blockage = 5%
Form Loss Coeff = 0.1
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14
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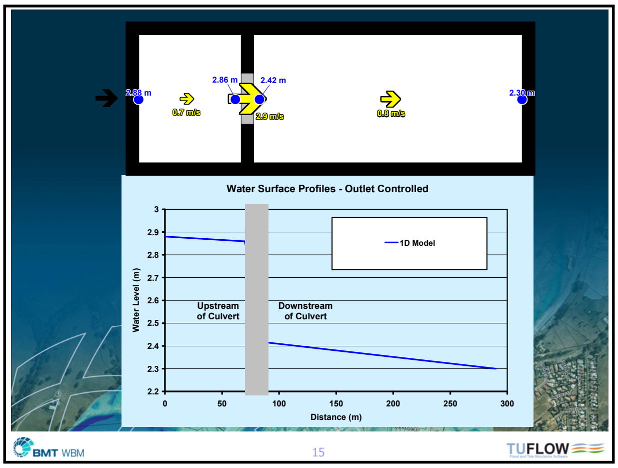
2.88 m
2.86 m
2.42 m
2.30 m
0.7 m/s
2.9 m/s
0.8 m/s
Water Surface Profiles - Outlet Controlled
1D Model
Upstream of Culvert
Downstream of Culvert
Water Level (m)
Distance (m)
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15
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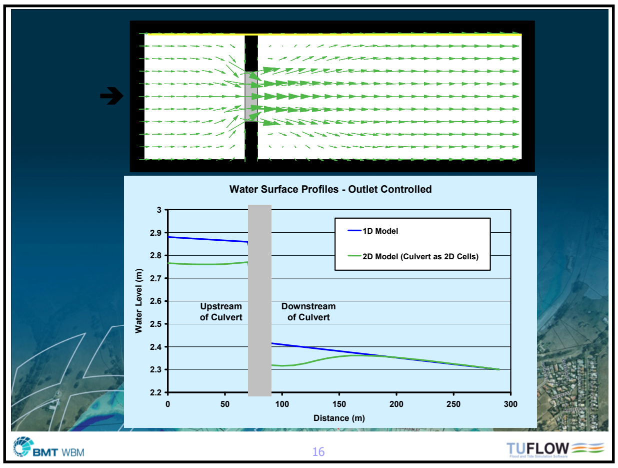


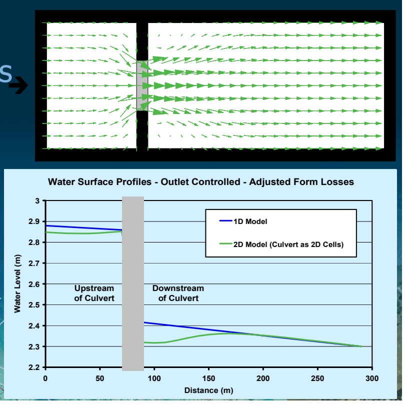
So 2D isn't perfect! What are our options?

- Don't use 2D!
- Adapt 2D Solution
- Insert 1D Solution

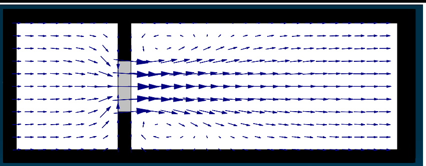
17

"Calibrating" 2D Structures

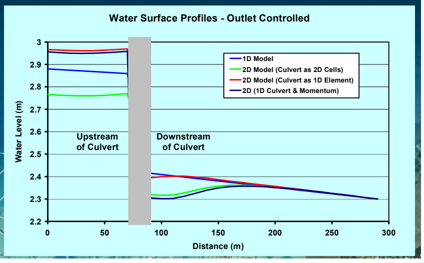
- For example, if we apply a 0.2 FLC, ie. add $0.2*V^2/2g$ energy loss



1D/2D Link Options



- SX Link
- HX Link (Preserves momentum)



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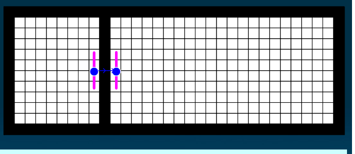
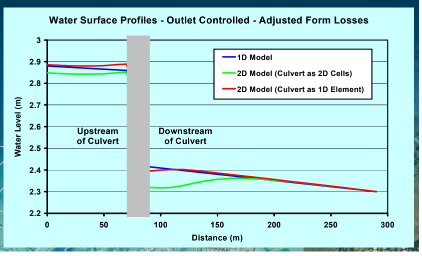
"Calibrating" 1D Culvert linked to 2D



- Culvert as 1D Element
  - Reduce Outlet Loss Coefficient by 0.2



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Modelling Culverts - Conclusions

- Culvert as 2D Cell(s)
  - 2D solution models 70 to 80% of losses
  - Need 20 to 30% additional form losses
- Culvert as 1D Element
  - Over predicts losses by 0 to 70%
  - Small – 0% over prediction
  - Large – up to 70% over prediction
  - Reduce inlet / outlet losses of 1D element(s)

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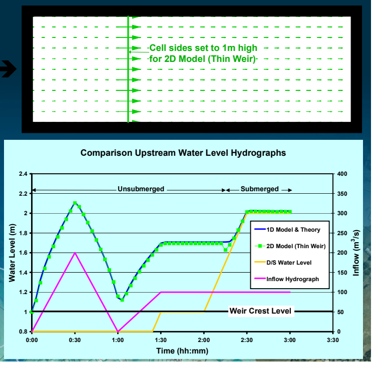
Embankments / Levees (Weir Flow)

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



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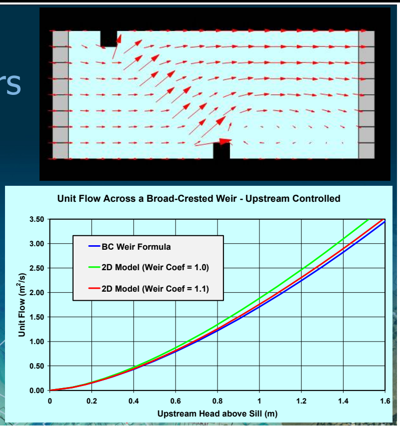
Oblique Weirs

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



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Conclusions

- 2D contracts and expands flow lines
  - Inherently models form losses
- May not model 100% of losses
  - Need ability to add form losses (calibrate)
- Need momentum and viscosity terms
- Linking 1D structures into 2D
  - Useful when the structure is small
  - Large structures (relative to 2D cell size) may over predict losses
    - May need to reduce inlet / outlet losses (calibrate)
- Check and UNDERSTAND your results

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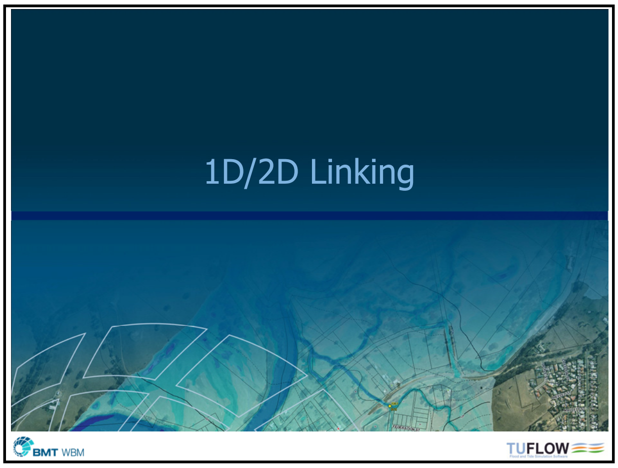
1D/2D Linking
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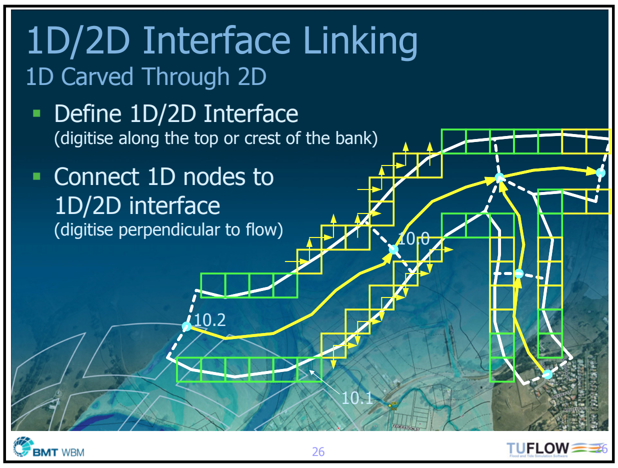
1D/2D Interface Linking
1D Carved Through 2D
Define 1D/2D Interface
(digitise along the top or crest of the bank)
Connect 1D nodes to 1D/2D interface
(digitise perpendicular to flow)
10.0
10.2
10.1
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26
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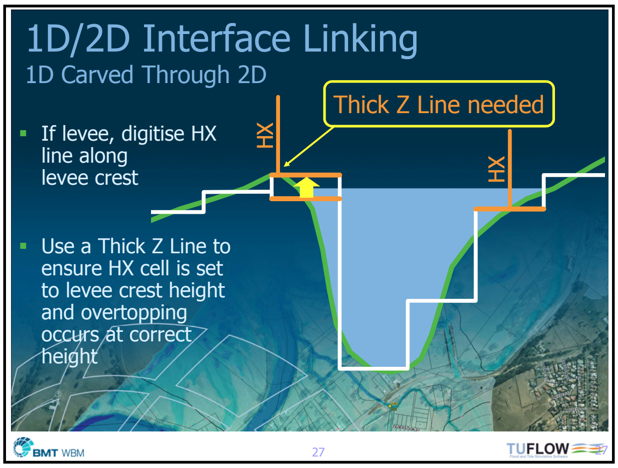
1D/2D Interface Linking
1D Carved Through 2D
If levee, digitise HX line along levee crest
Use a Thick Z Line to ensure HX cell is set to levee crest height and overtopping occurs at correct height
Thick Z Line needed
HX
HX
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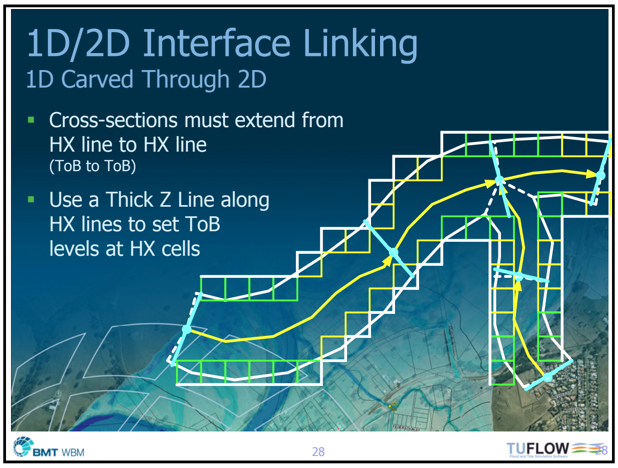
1D/2D Interface Linking
1D Carved Through 2D
Cross-sections must extend from HX line to HX line
(ToB to ToB)
Use a Thick Z Line along HX lines to set ToB levels at HX cells
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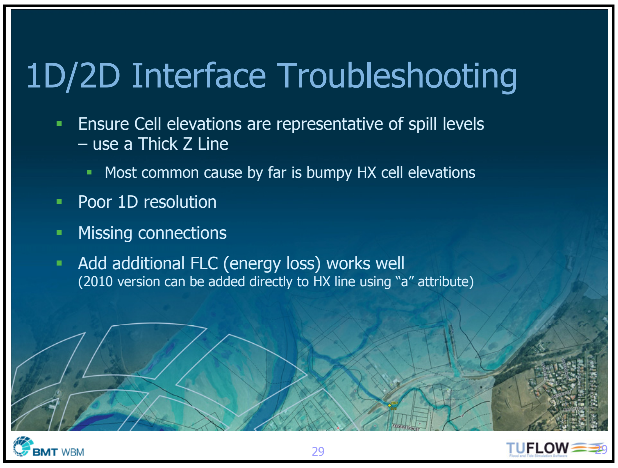
1D/2D Interface Troubleshooting
Ensure Cell elevations are representative of spill levels – use a Thick Z Line
Most common cause by far is bumpy HX cell elevations
Poor 1D resolution
Missing connections
Add additional FLC (energy loss) works well
(2010 version can be added directly to HX line using "a" attribute)
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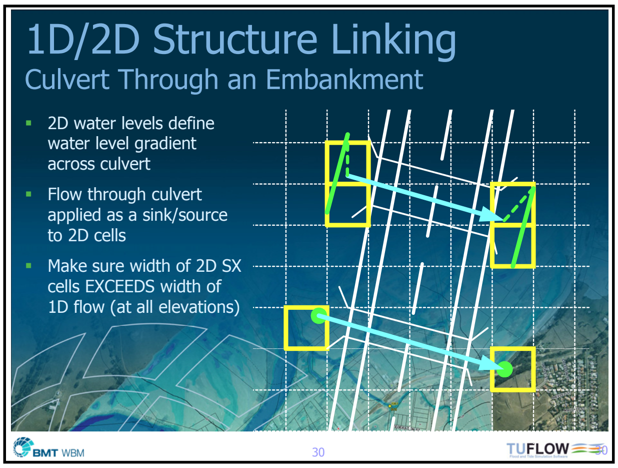
1D/2D Structure Linking
Culvert Through an Embankment
2D water levels define water level gradient across culvert
Flow through culvert applied as a sink/source to 2D cells
Make sure width of 2D SX cells EXCEEDS width of 1D flow (at all elevations)
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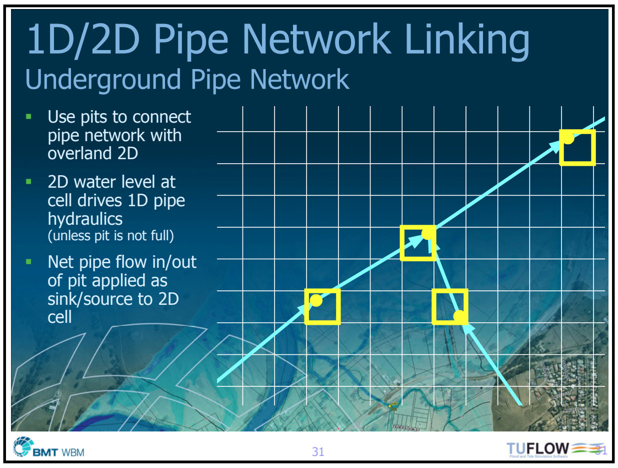
1D/2D Pipe Network Linking
Underground Pipe Network
Use pits to connect pipe network with overland 2D
2D water level at cell drives 1D pipe hydraulics
(unless pit is not full)
Net pipe flow in/out of pit applied as sink/source to 2D cell
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31
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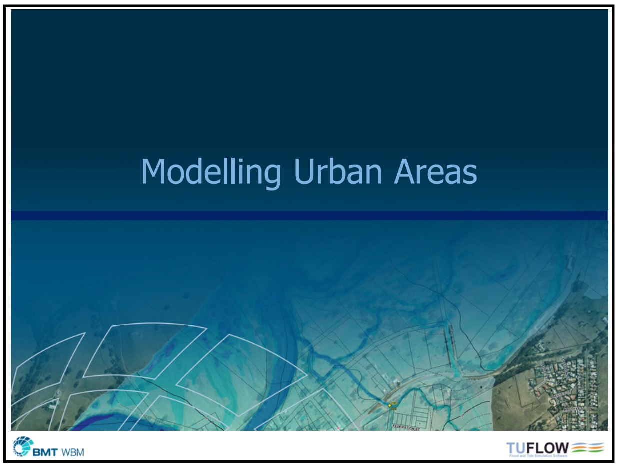
Modelling Urban Areas
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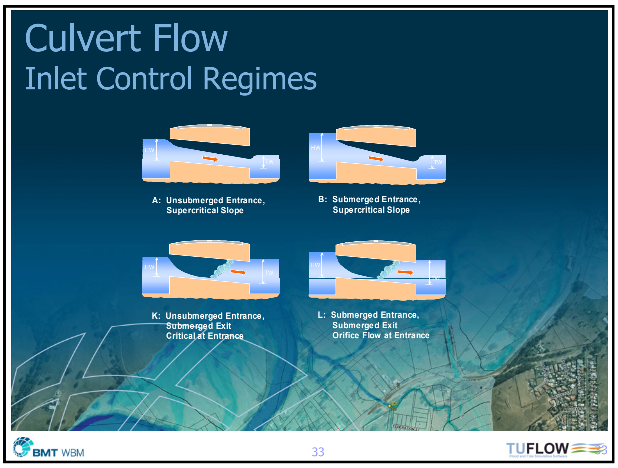
Culvert Flow
Inlet Control Regimes
A: Unsubmerged Entrance, Supercritical Slope
B: Submerged Entrance, Supercritical Slope
K: Unsubmerged Entrance, Submerged Exit Critical at Entrance
L: Submerged Entrance, Submerged Exit Orifice Flow at Entrance
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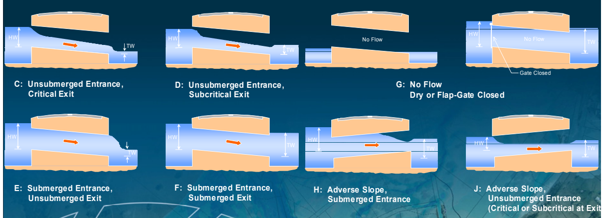
Culvert Flow
Outlet Control Regimes



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Pits
(Drains / Gully Traps)

- Convey the water between above ground and below ground
- Recommendation is to use Q pits and y-Q curves
  - Apply appropriate curves!

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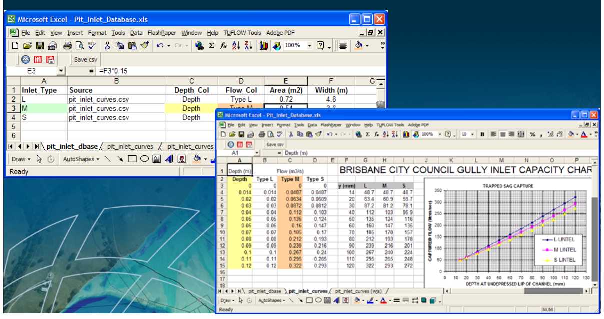
Pit Database

- See Section 4.5.1.2 of 2008 Manual



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Manholes

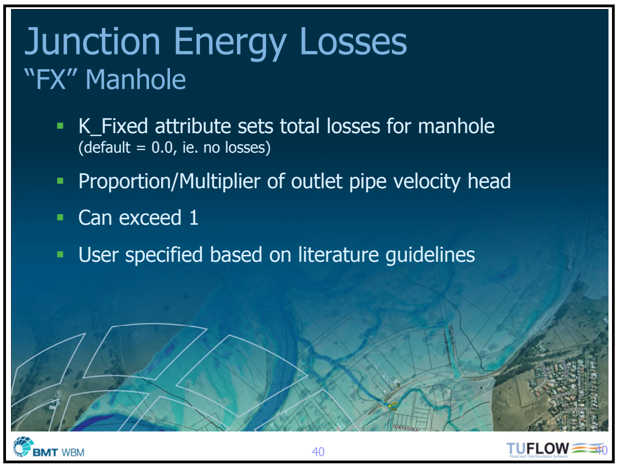
- Represent pipe junctions
- Simulate energy losses at junctions
- Must have at least one pipe in and one pipe out

Junction Energy Losses
Node or "NO" Manhole

- "Structure Losses == ADJUST" (the default) or Channel "A" Flag
  - Inlet/Outlet Losses of pipes/manholes are adjusted based on approach/departure velocities
    (see Section 4.7.4.1 2008 Manual)
  - Adjusted down to zero if velocity unchanged through node
- "Structure Losses == FIX" or Channel "F" Flag
  - Full pipe inlet/outlet losses are applied
  - Can significantly overestimate losses

Junction Energy Losses
"FX" and "EN" Manholes

- For "FX" and "EN" Manholes
  - Exit loss coefficients of all inlet pipes ignored
  - Entrance loss coefficients of all outlet pipes ignored
  - Manhole approach applied instead
  - Any pipe Form_Loss (bend loss) values are applied


Junction Energy Losses
“FX” Manhole
K_Fixed attribute sets total losses for manhole
(default = 0.0, ie. no losses)
Proportion/Multiplier of outlet pipe velocity head
Can exceed 1
User specified based on literature guidelines
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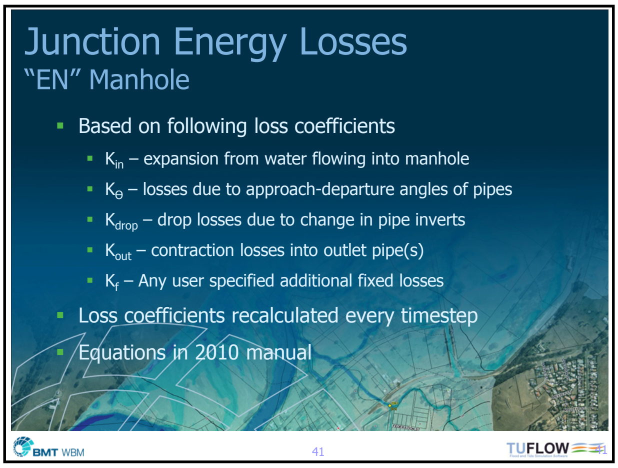
Junction Energy Losses
“EN” Manhole
Based on following loss coefficients
K_{in} – expansion from water flowing into manhole
K_{Θ} – losses due to approach-departure angles of pipes
K_{drop} – drop losses due to change in pipe inverts
K_{out} – contraction losses into outlet pipe(s)
K_f – Any user specified additional fixed losses
Loss coefficients recalculated every timestep
Equations in 2010 manual
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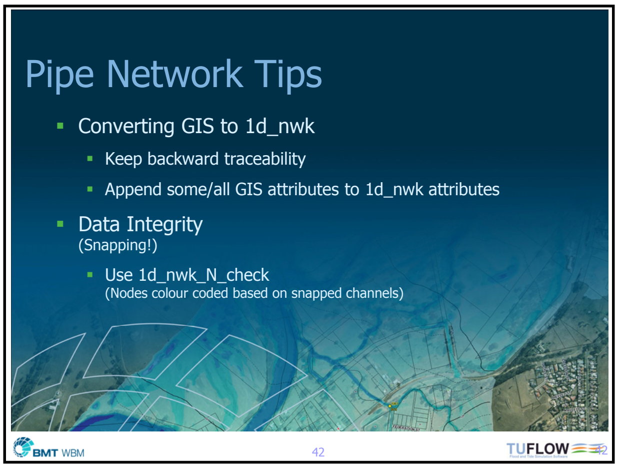
Pipe Network Tips
Converting GIS to 1d_nwk
Keep backward traceability
Append some/all GIS attributes to 1d_nwk attributes
Data Integrity
(Snapping!)
Use 1d_nwk_N_check
(Nodes colour coded based on snapped channels)
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Pipe Network Stability Tips

- 1D timestep for pipe models usually in range from 0.1s to 1.0s
- Beware of very short/steep pipes
- Sometimes additional storage added – sensitivity test!

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Modifying Networks

- Can upgrade or modify existing pipe(s) by simply overriding with repeat pipe(s) in separate 1d_nwk layer
  - Select and save pipe(s) to be modified
  - Save as new 1d_nwk layer
  - Modify pipe(s)
  - Add in new "Read MI Network" line
- Cross-check using 1d_nwk_check layer and/or viewing .eof file

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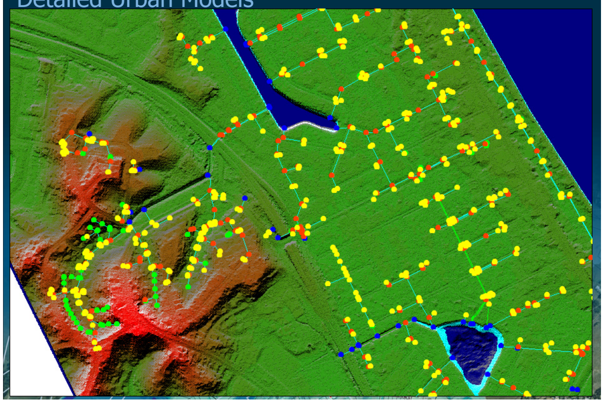
Detailed Urban Models



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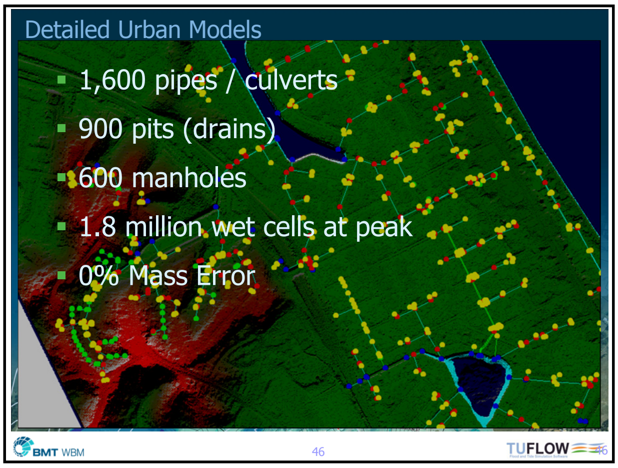
Detailed Urban Models
1,600 pipes / culverts
900 pits (drains)
600 manholes
1.8 million wet cells at peak
0% Mass Error
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Modelling Buildings?
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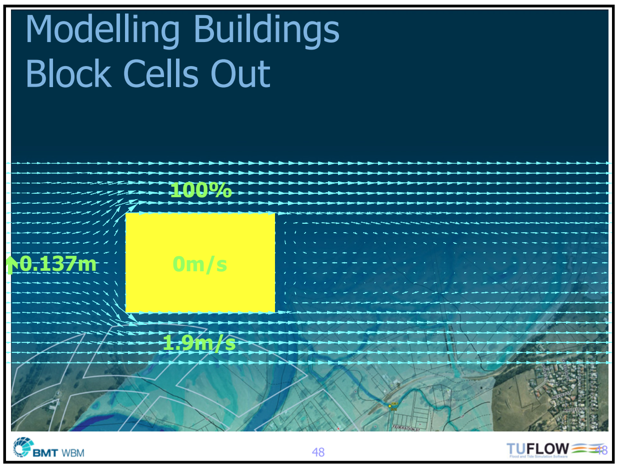
Modelling Buildings
Block Cells Out
100%
0.137m
0m/s
1.9m/s
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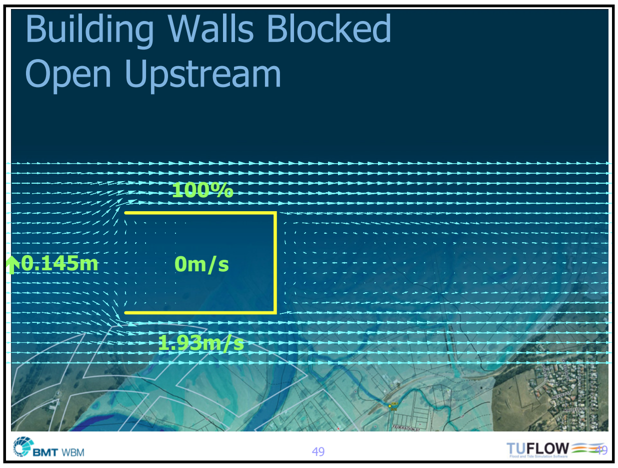
Building Walls Blocked
Open Upstream
100%
0.145m
0m/s
1.93m/s
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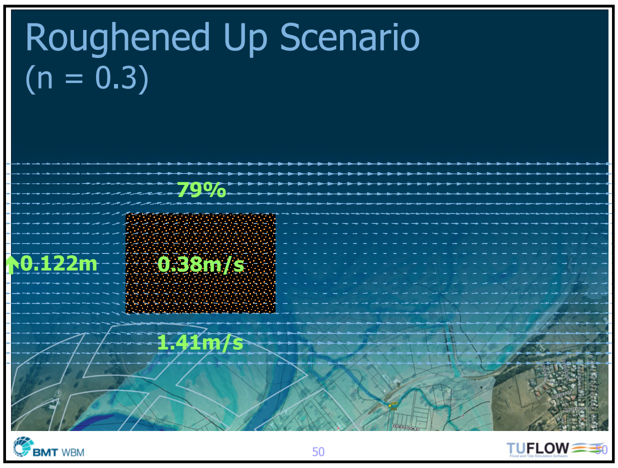
Roughened Up Scenario
(n = 0.3)
79%
0.122m
0.38m/s
1.41m/s
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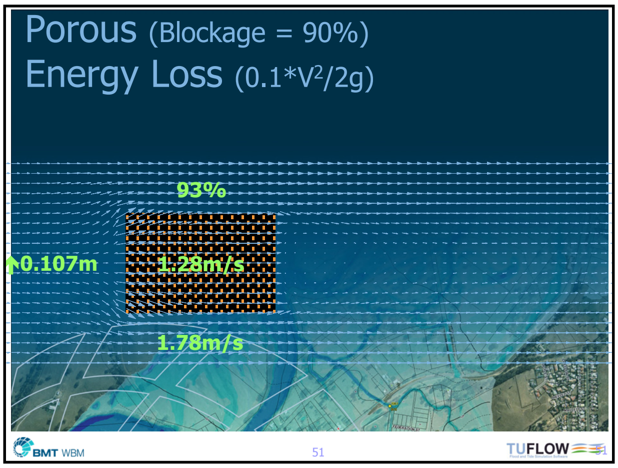
Porous (Blockage = 90%)
Energy Loss (0.1*V²/2g)
93%
0.107m
1.28m/s
1.78m/s
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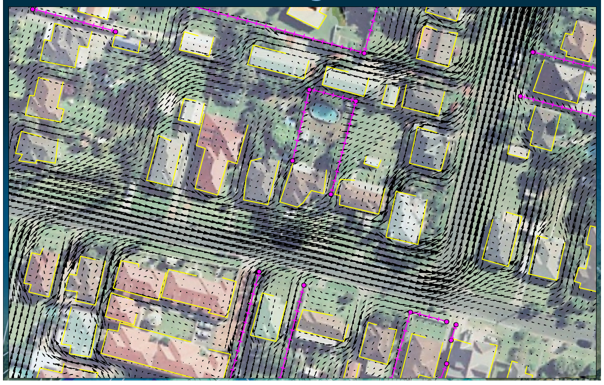
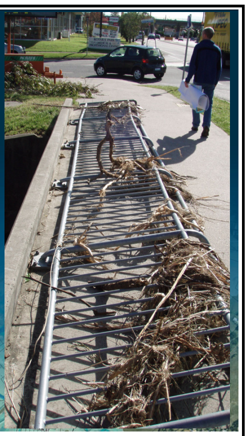
Modelling Fences!

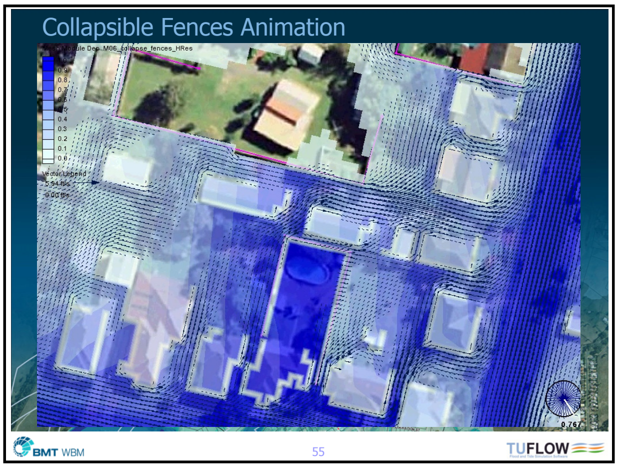
Urban Areas – Buildings and Fences



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
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Modelling Blockages!?
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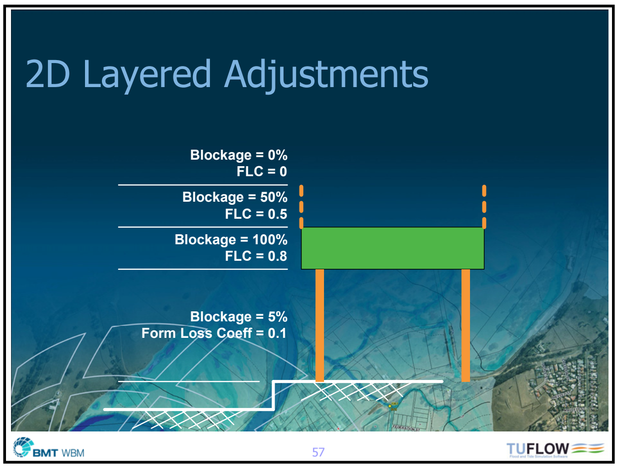
2D Layered Adjustments
Blockage = 0%
FLC = 0
Blockage = 50%
FLC = 0.5
Blockage = 100%
FLC = 0.8
Blockage = 5%
Form Loss Coeff = 0.1
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57
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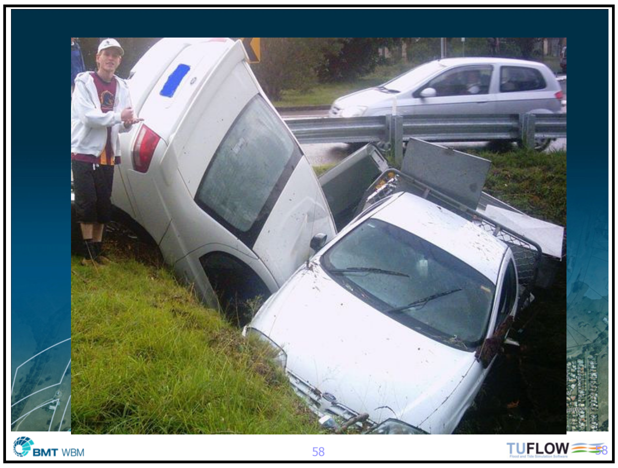
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58
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