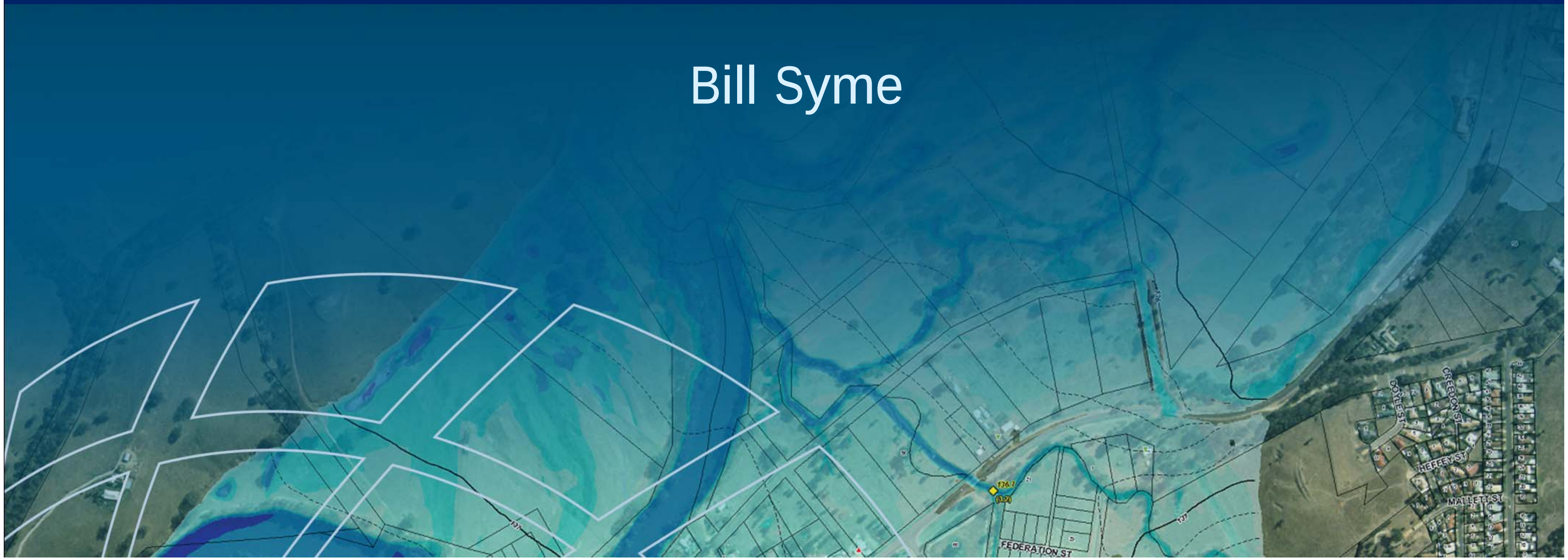
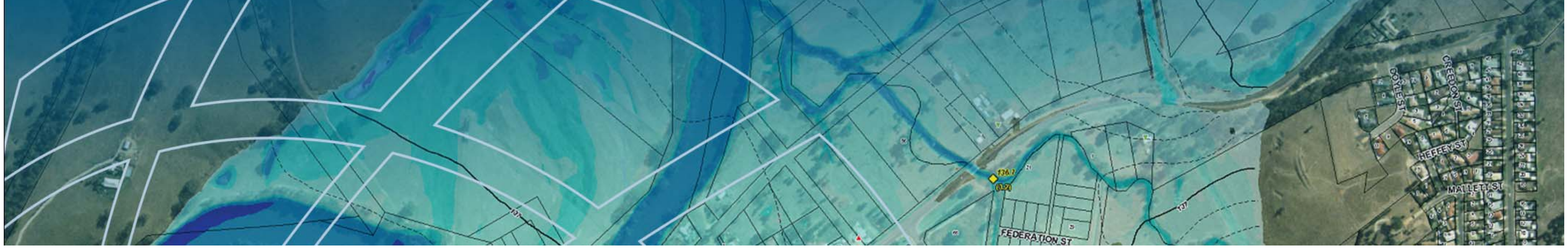
1D and 2D Modelling of Bends and Hydraulic Structures

Bill Syme

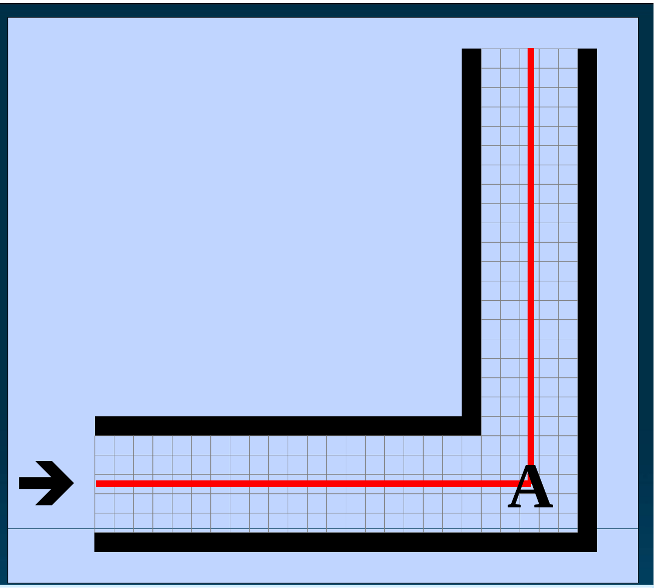


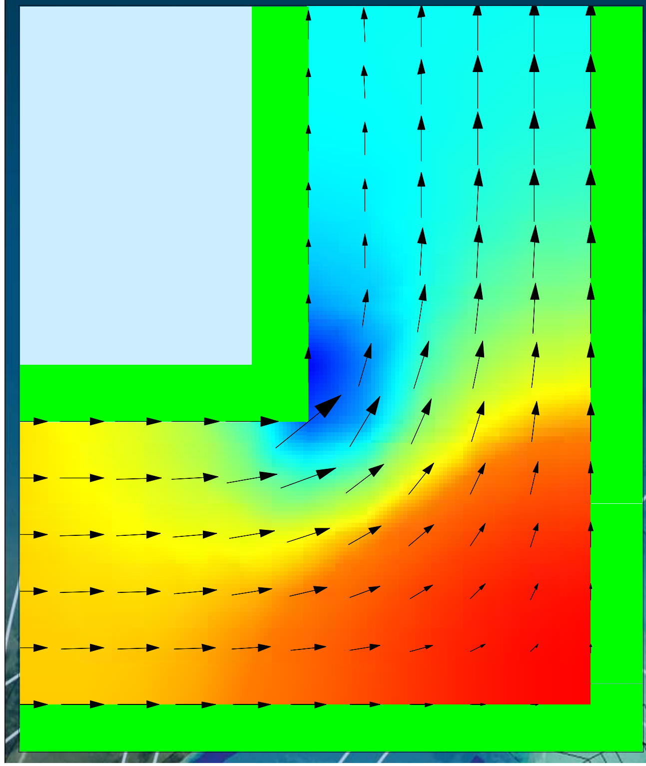
Form Losses

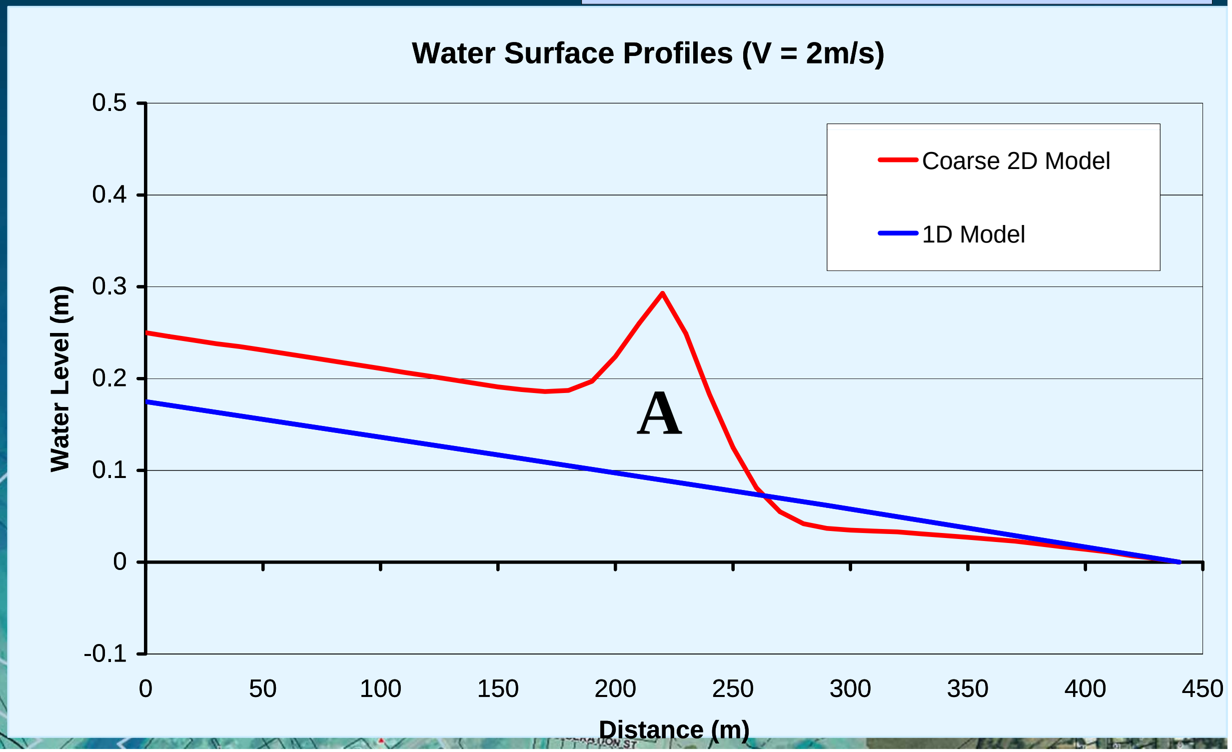
- Energy dissipated as heat due to changes in velocity magnitude and direction
- Pronounced at
  - Bends
  - Flow constrictions (structures)
- Form loss coefficient
  - Proportion of dynamic head ($V^2/2g$) lost
  - V = 1m/s; Dynamic Head = 0.05m
  - V = 4m/s; Dynamic Head = 0.82m



Right-Angled Bend
1D vs 2D

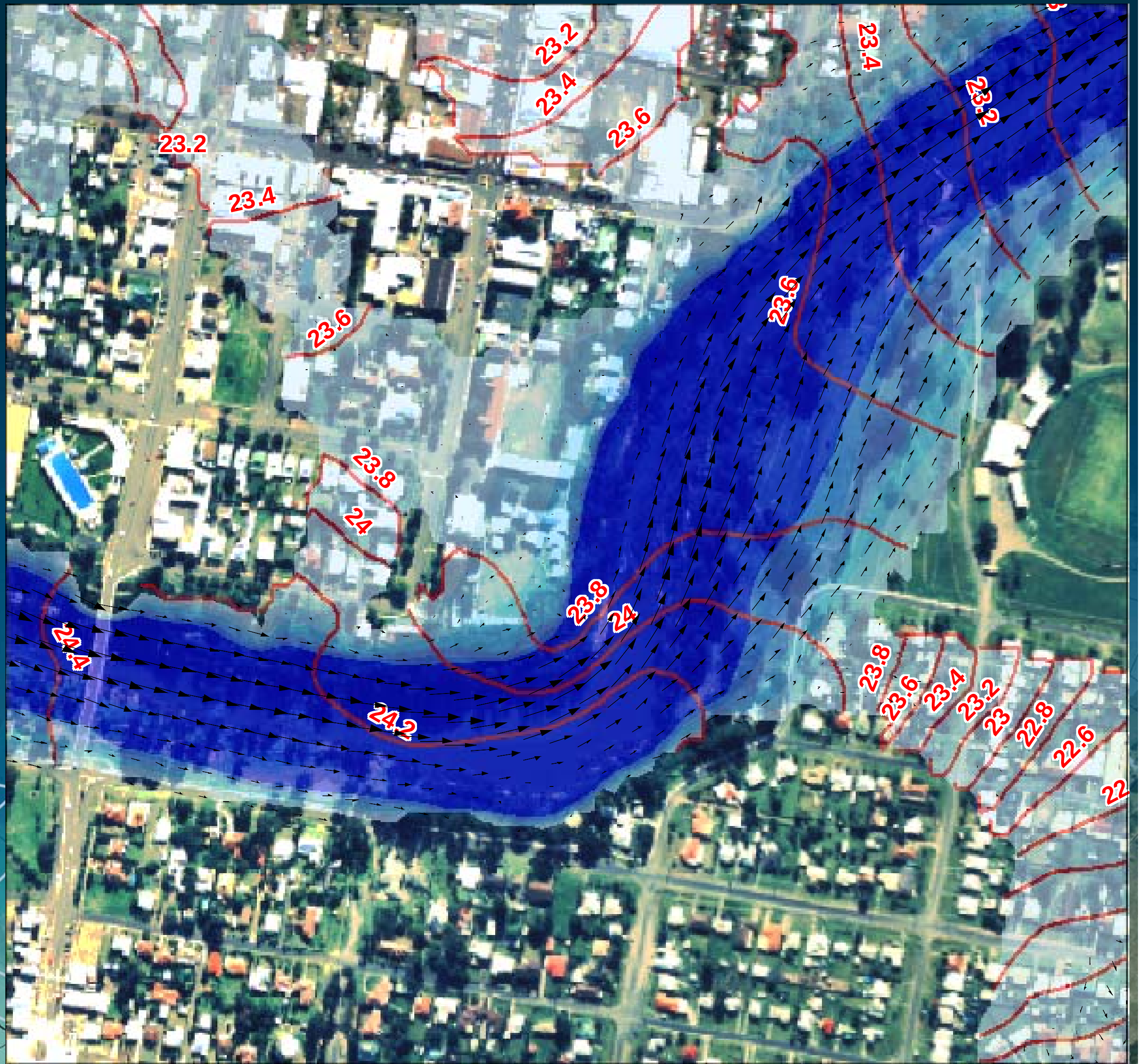




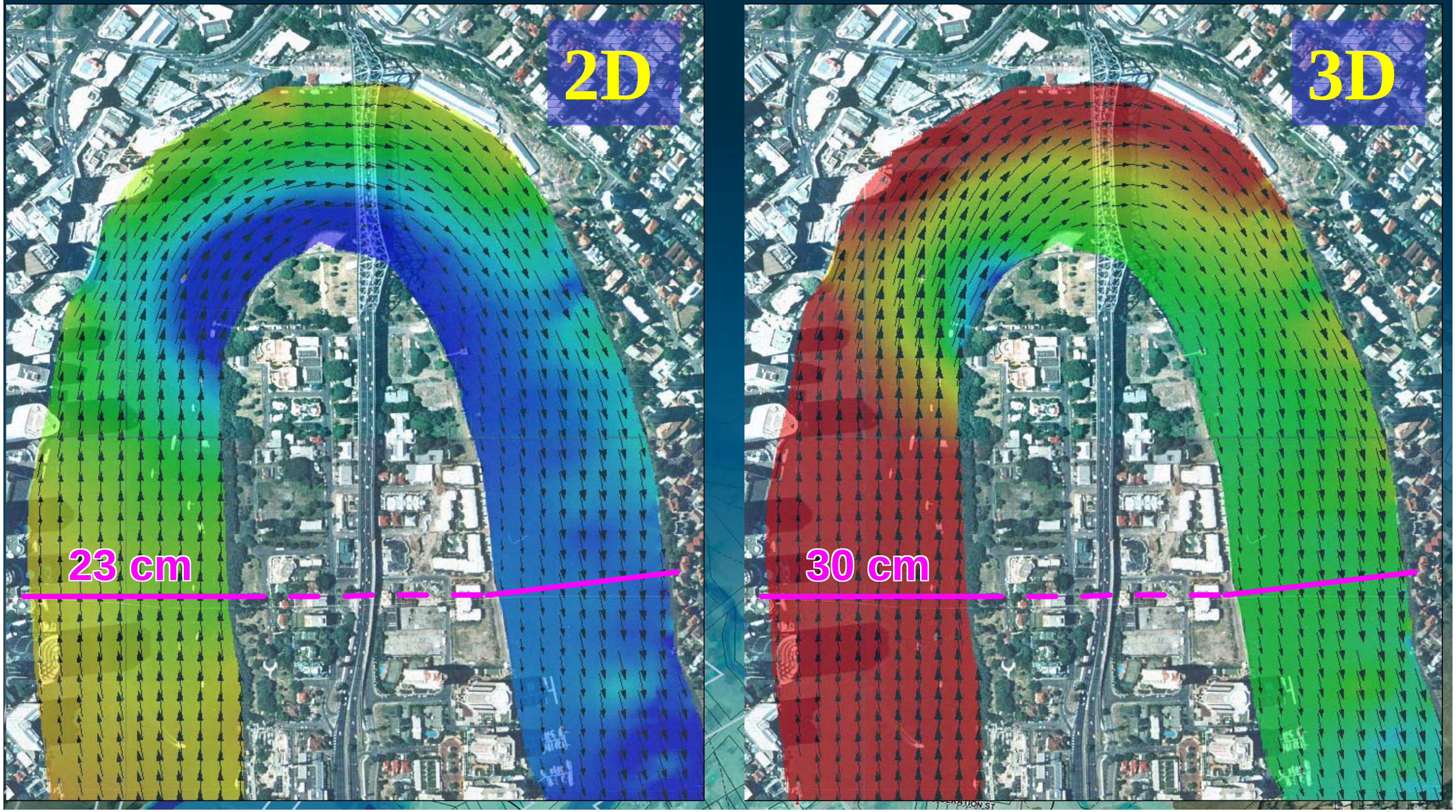


River Bends

- 4 m/s
- 20 m deep
- 0.4m superelevation at bend



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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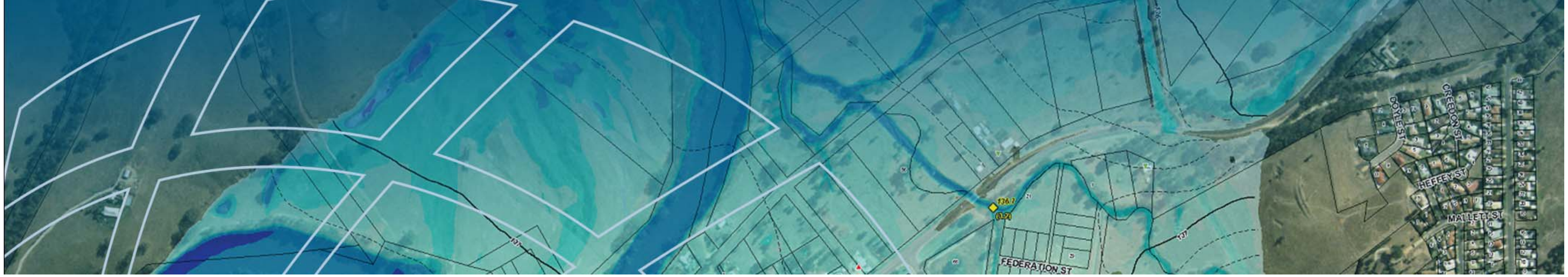
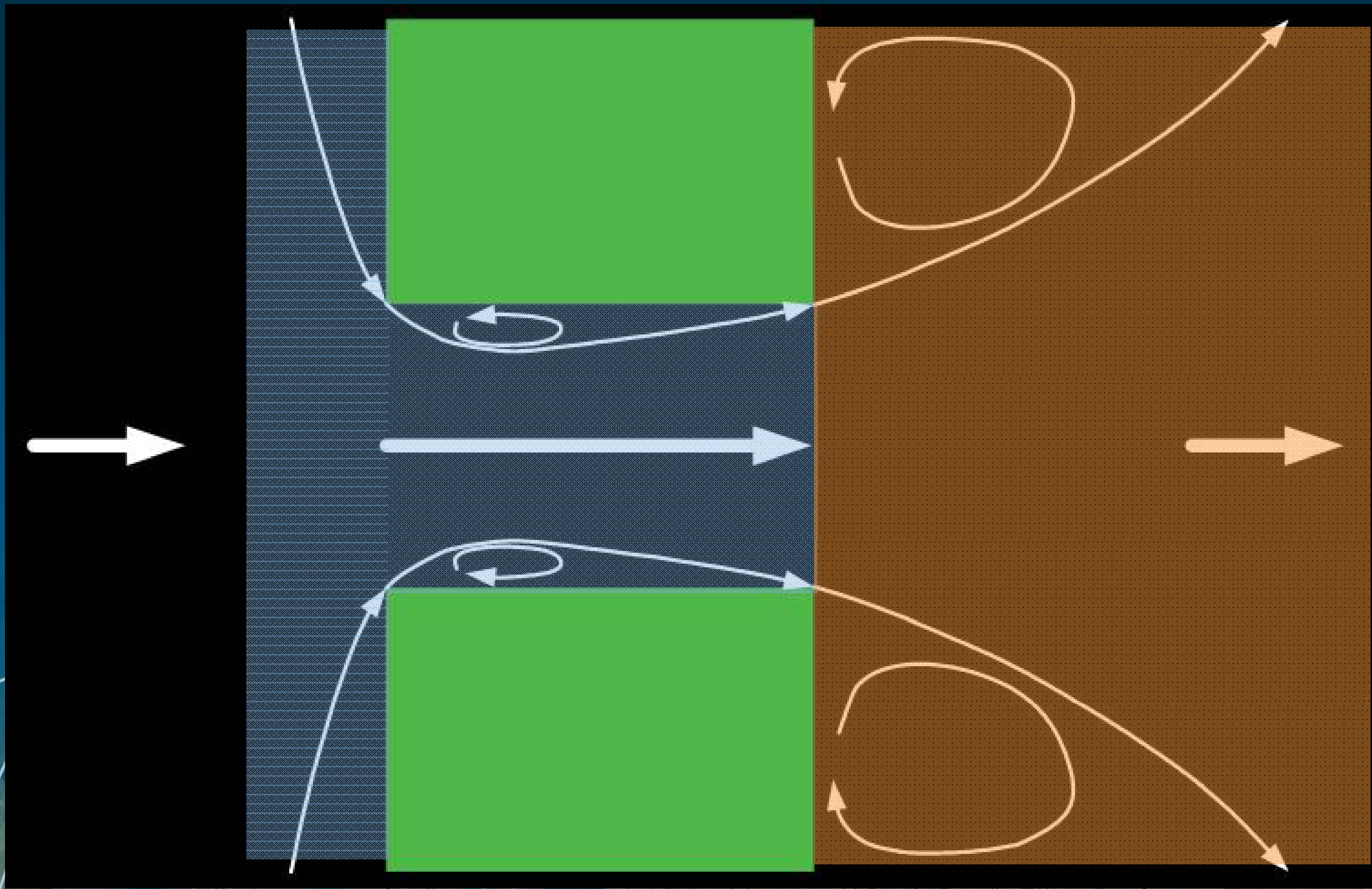
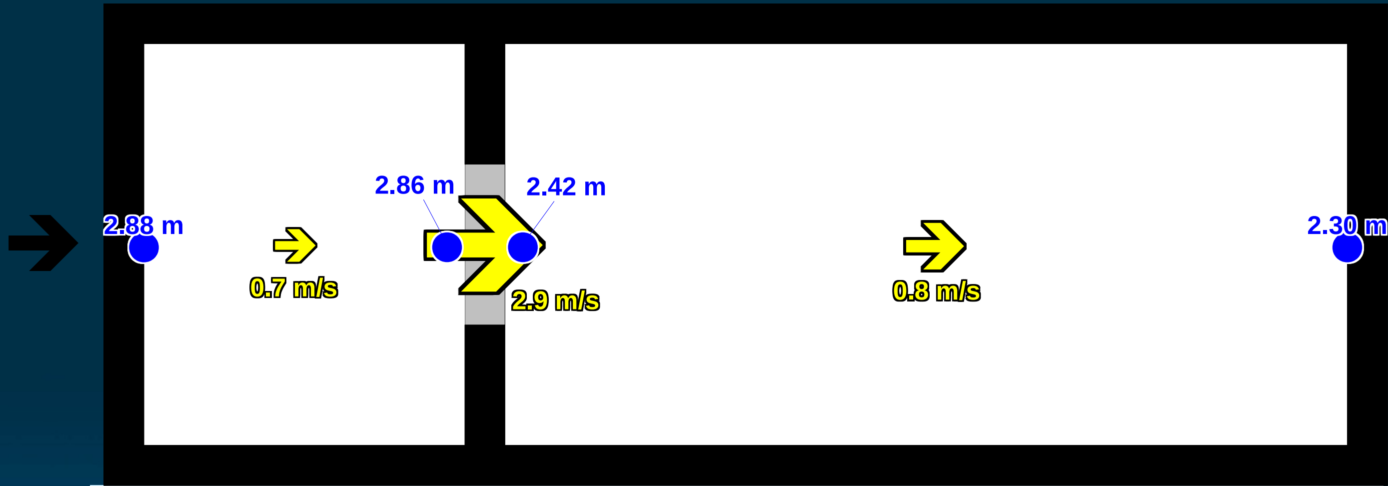
Hydraulic Structures

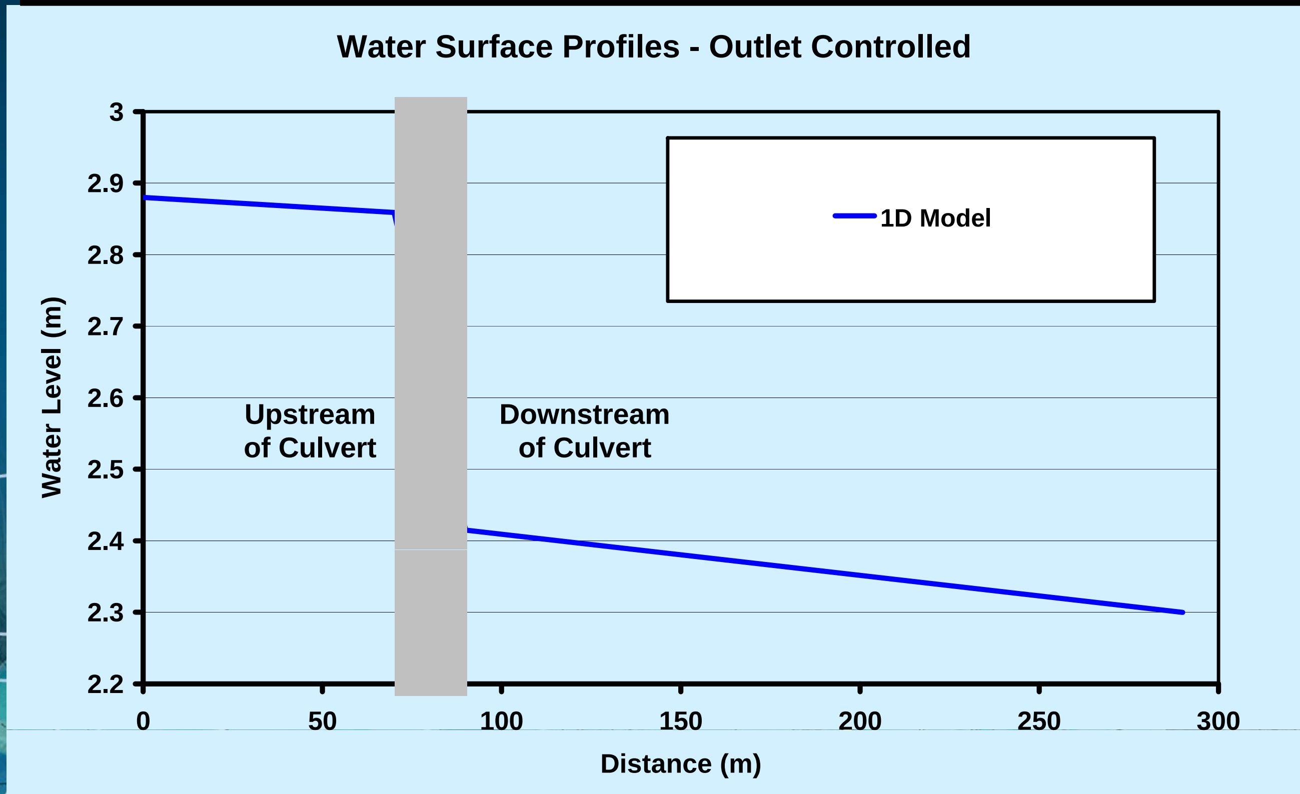
- Hydraulic Structures
  - Bridges and Embankments
  - Large Culverts
- Hydraulics is Complex (3D)
  - 1D: Traditional Approach
  - 2D: Looks impressive, but is it accurate?
  - 1D/2D: Best of both?



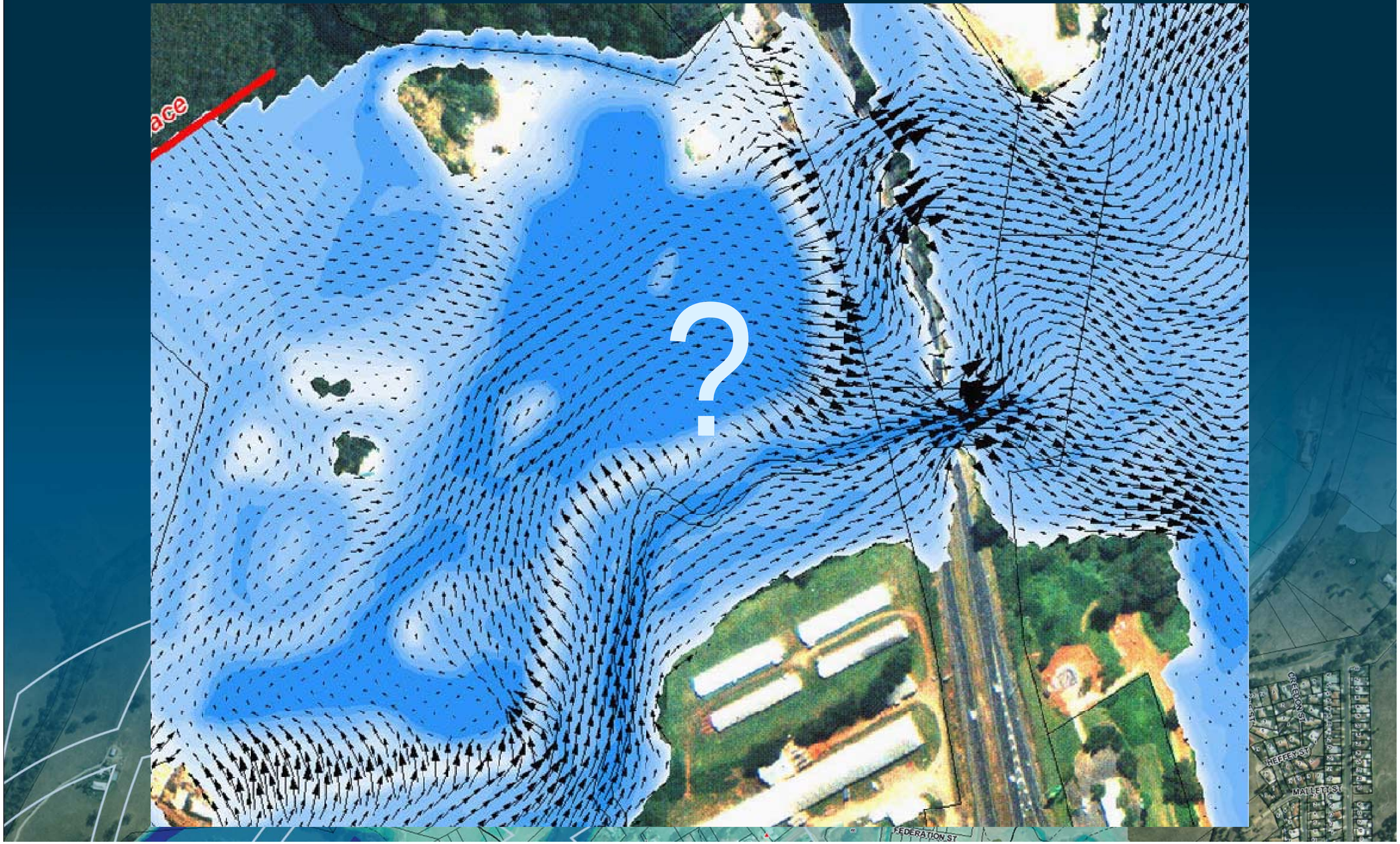
1D: Traditional Approach
Uses Contraction/Expansion Losses



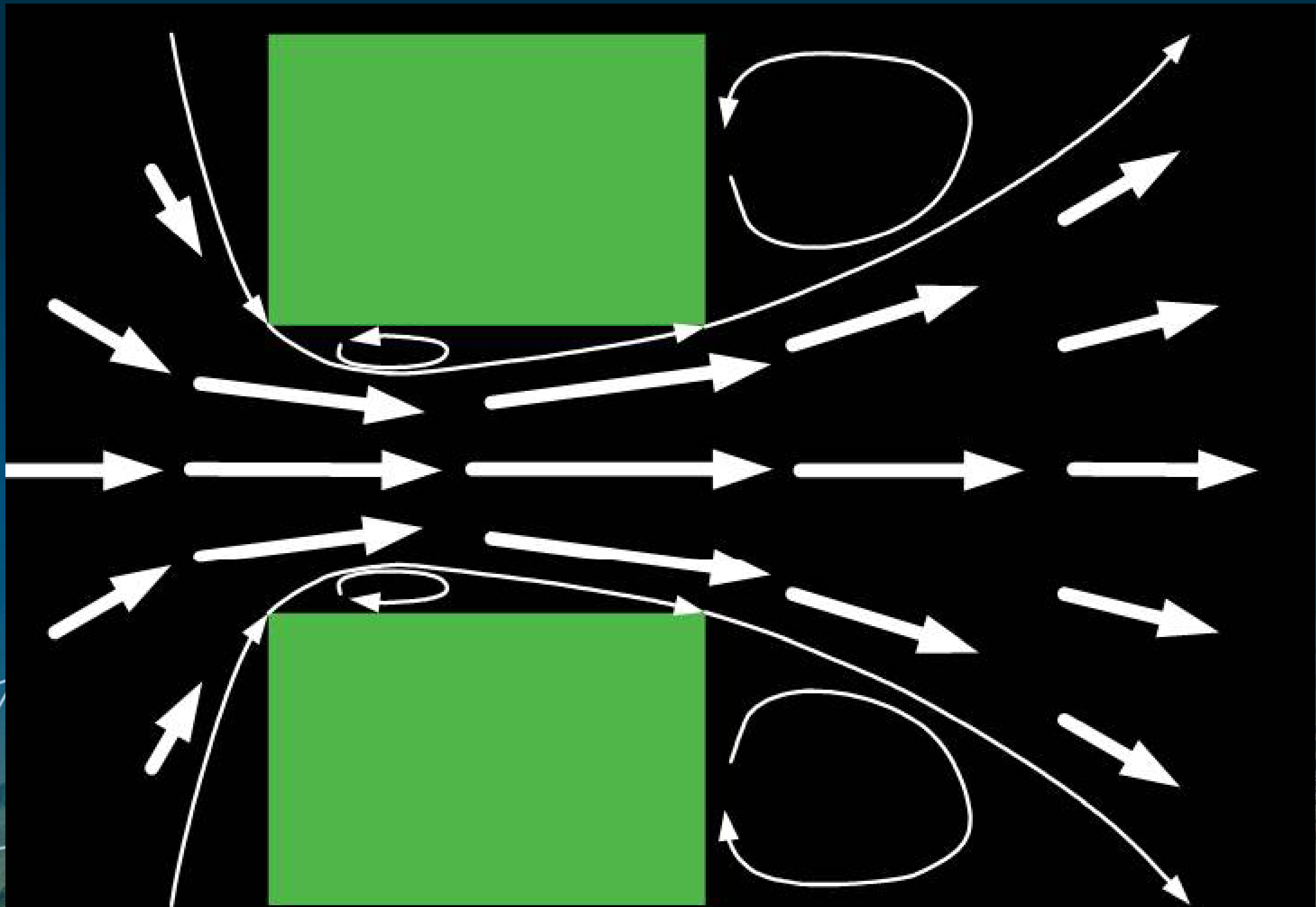

2.88 m
0.7 m/s
2.86 m
2.42 m
2.9 m/s
0.8 m/s
2.30 m

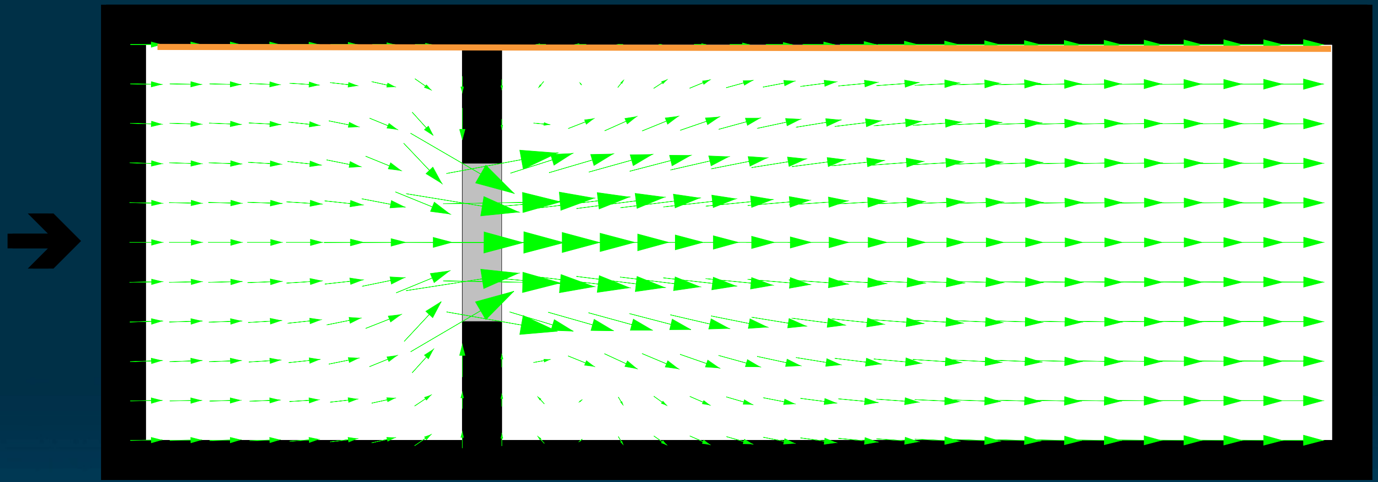

Water Surface Profiles - Outlet Controlled
Water Level (m)
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
0
50
100
150
200
250
300
Distance (m)
1D Model
Upstream of Culvert
Downstream of Culvert

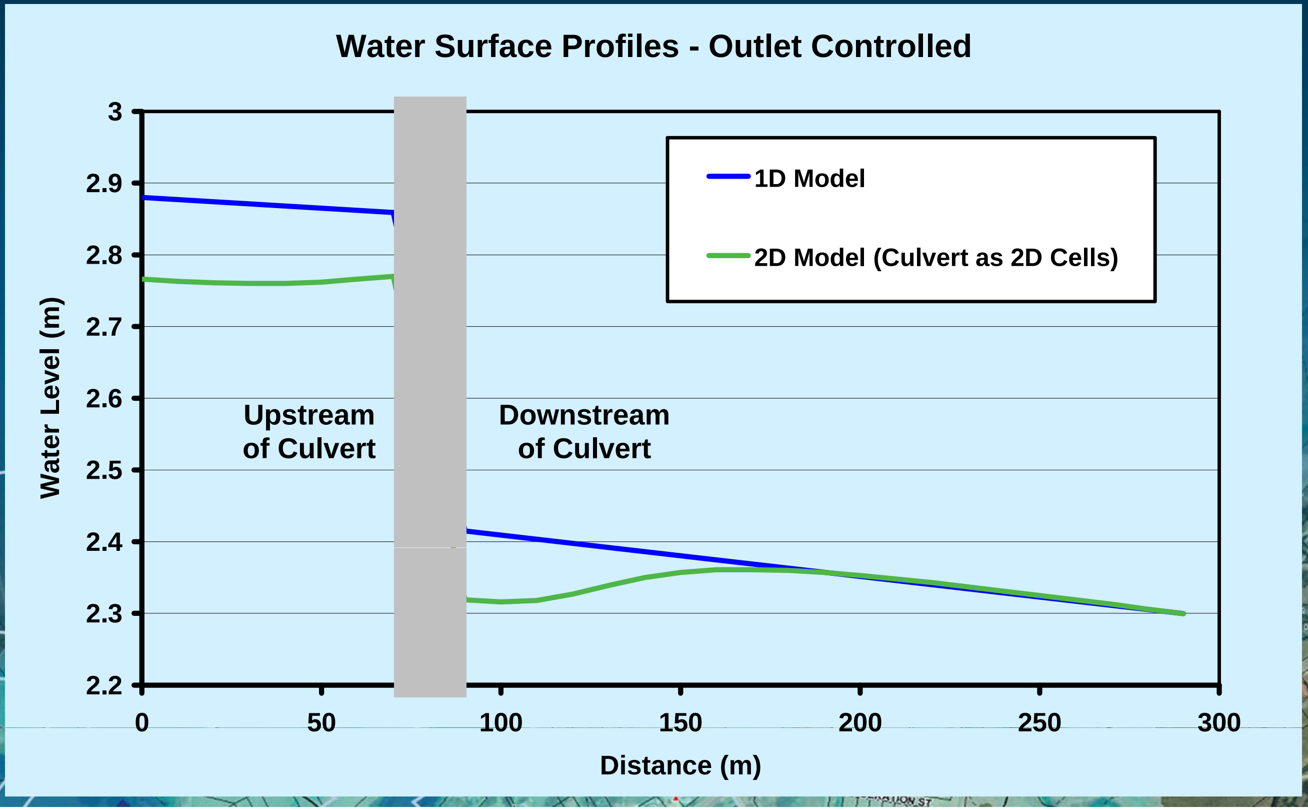
2D: Looks impressive, but is it accurate?



2D: No Contraction/Expansion Losses?



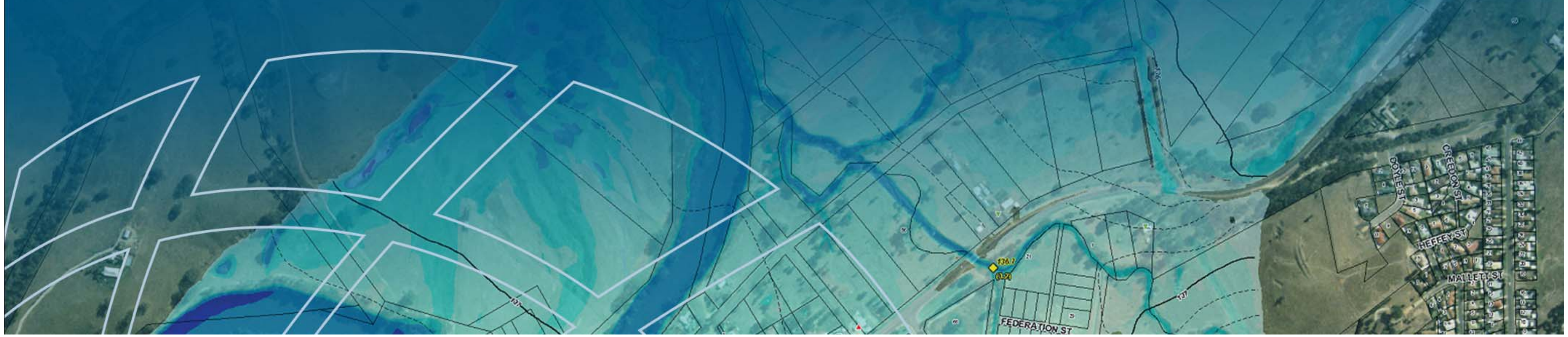




Water Surface Profiles - Outlet Controlled
Water Level (m)
Distance (m)
1D Model
2D Model (Culvert as 2D Cells)
Upstream of Culvert
Downstream of Culvert
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
0
50
100
150
200
250
300

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

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



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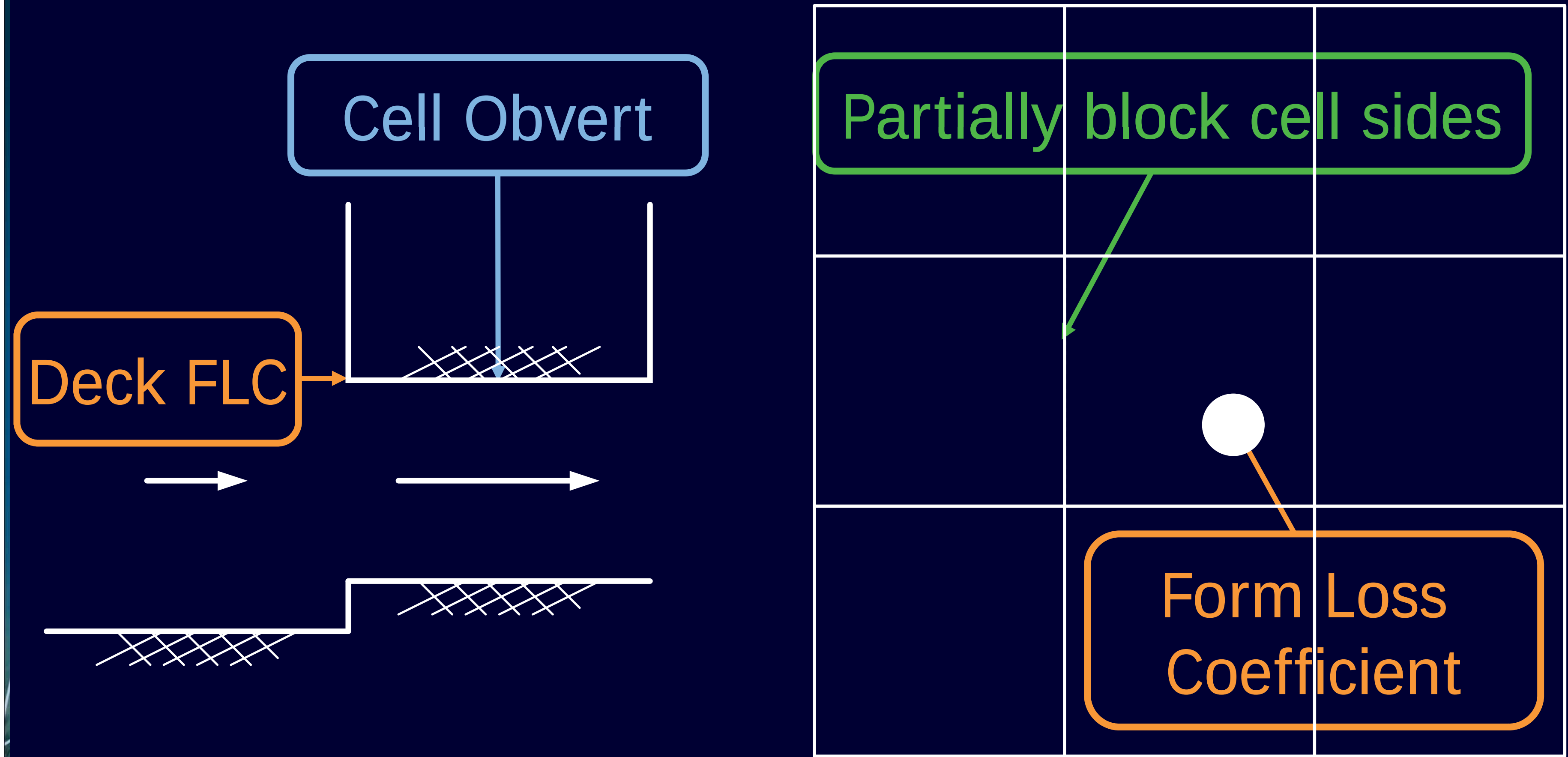
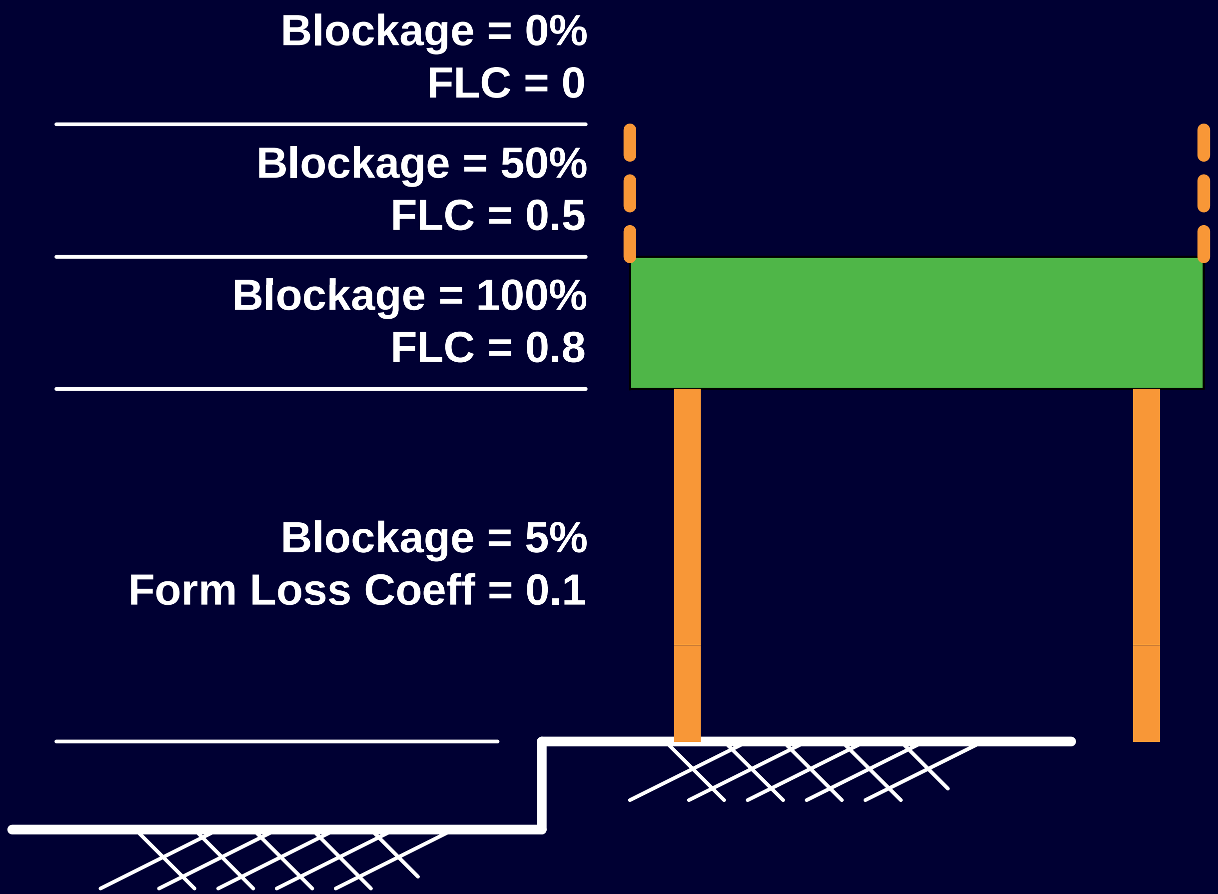
2D Scheme Modifications

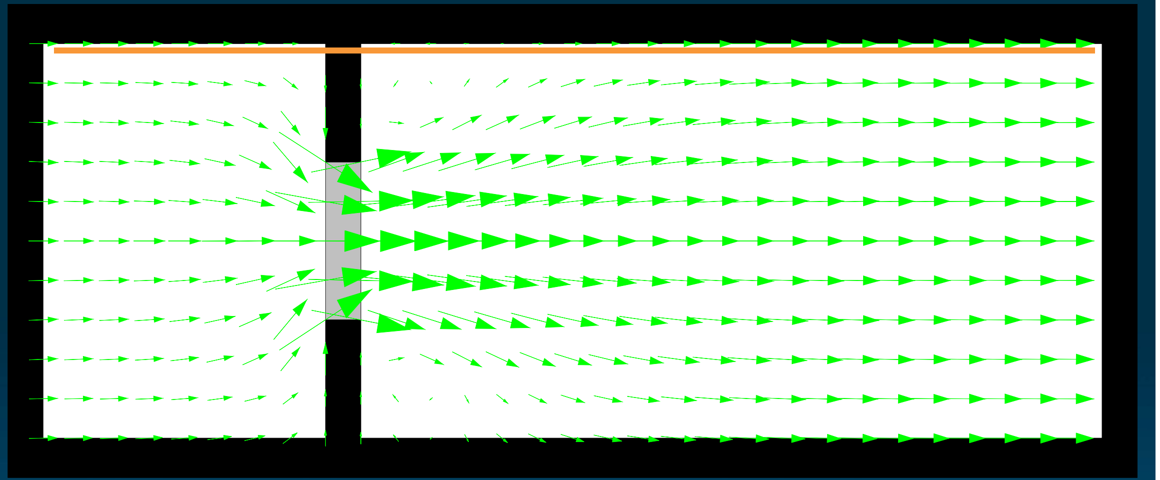


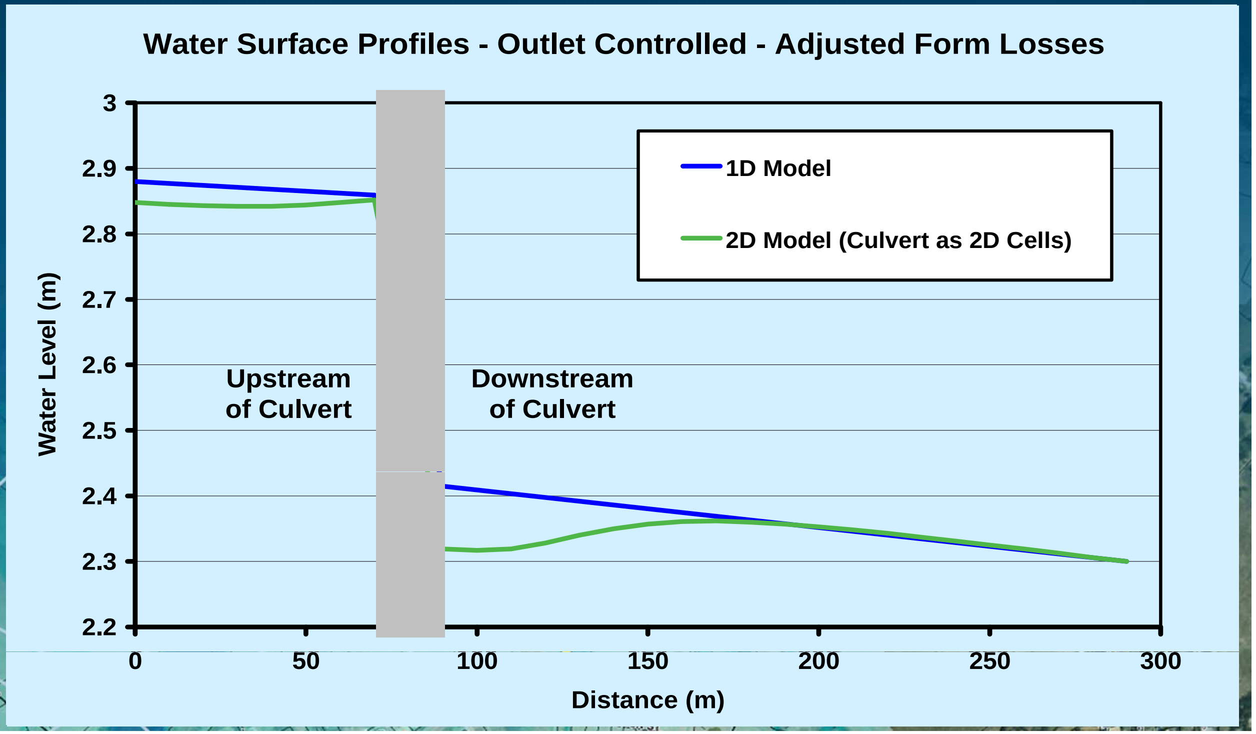
2D Layered Adjustments



"Calibrating" a 2D Solution

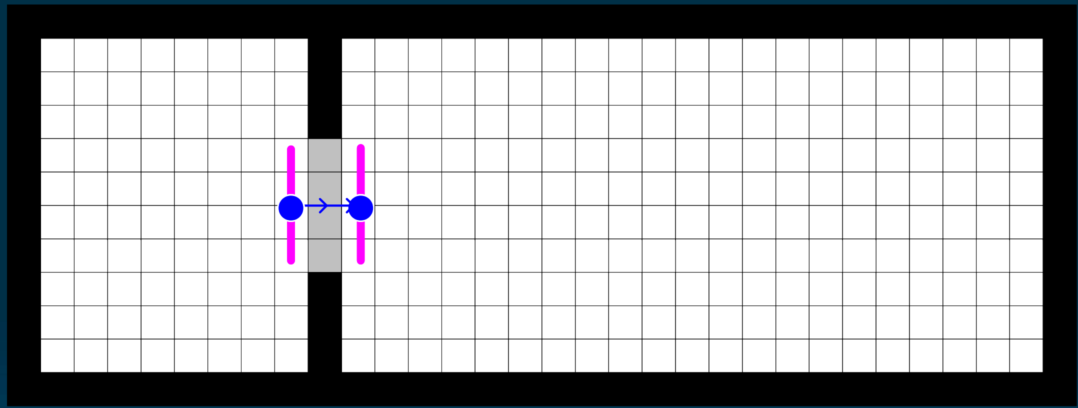
- For example, if we apply a 0.2 FLC, ie. add $0.2*V^2/2g$ energy loss

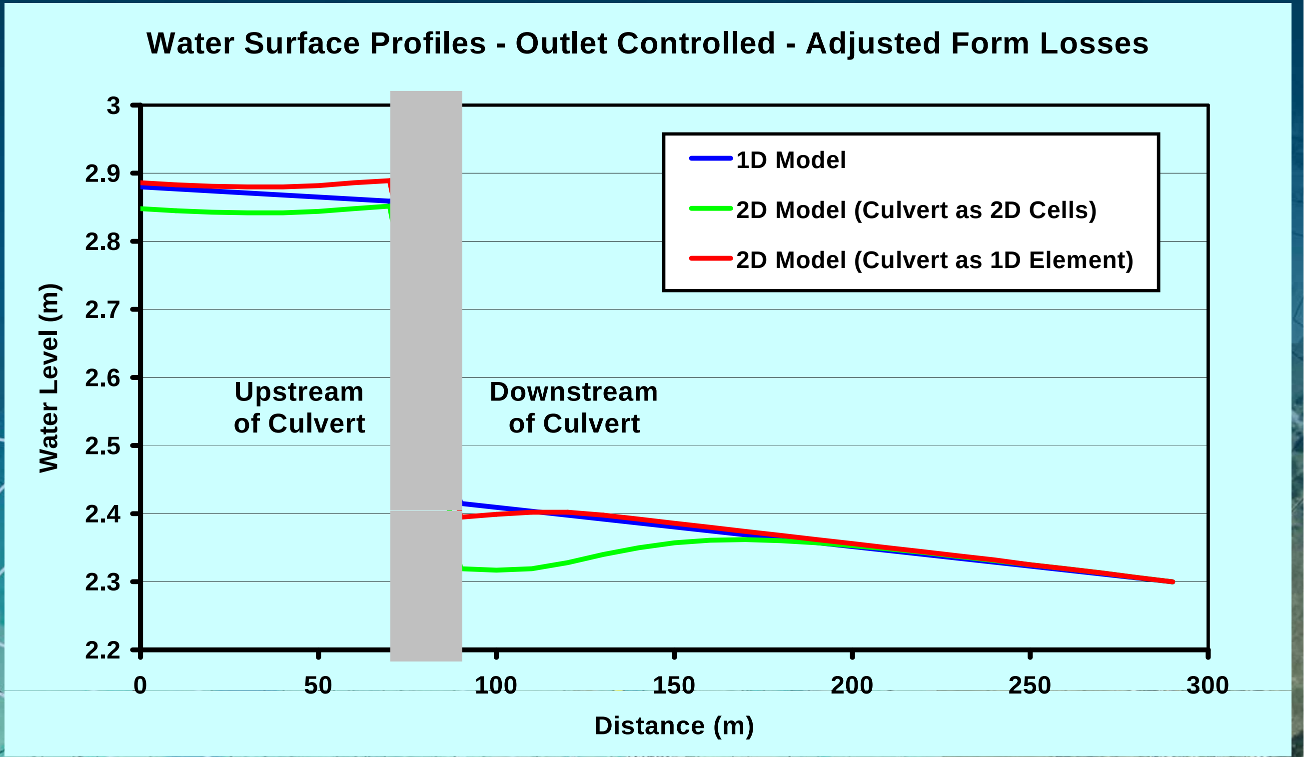




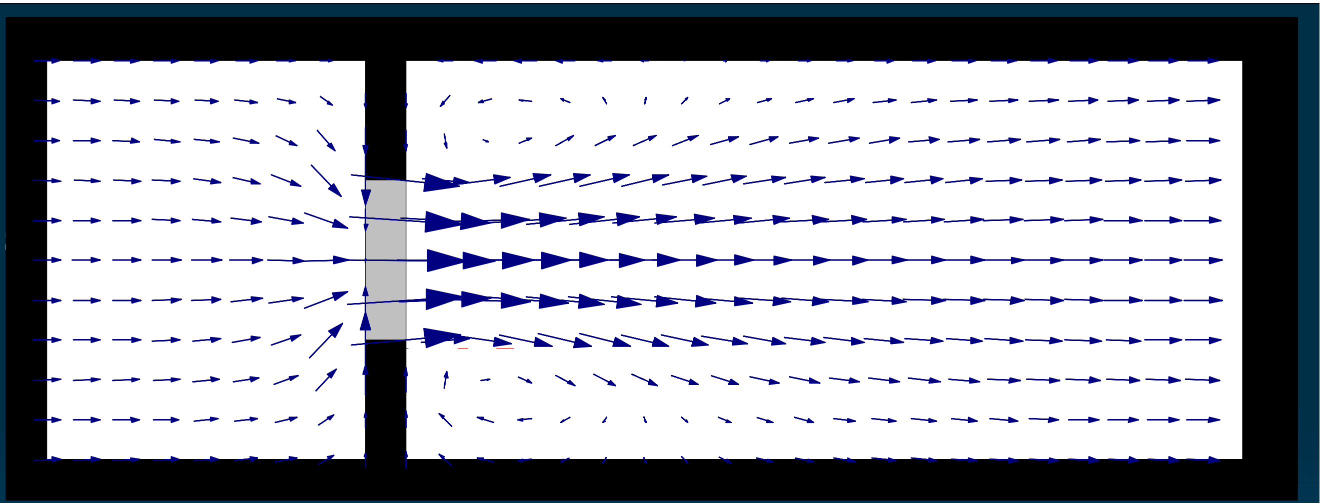
"Calibrating" Box Culverts

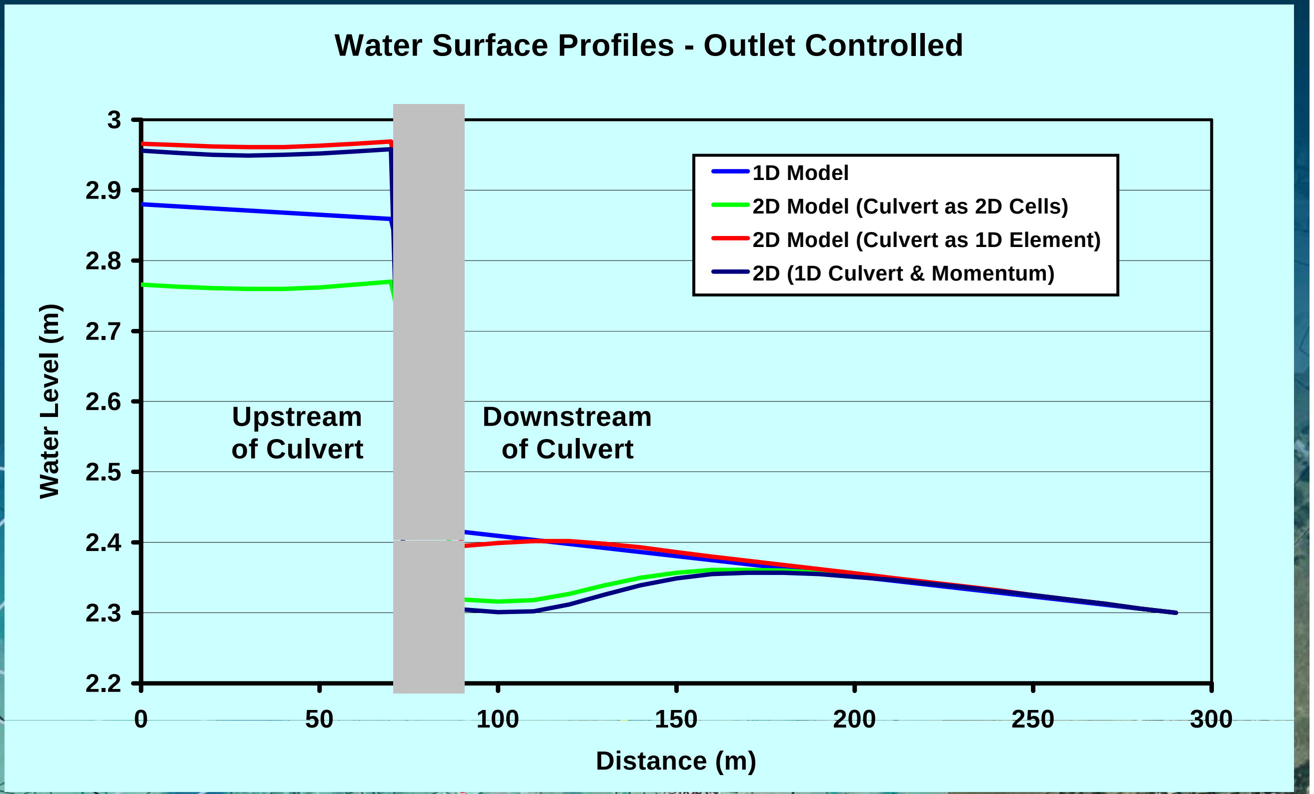
- Culvert as 1D Element
  - Reduce Outlet Loss Coefficient by 0.2





Box Culverts





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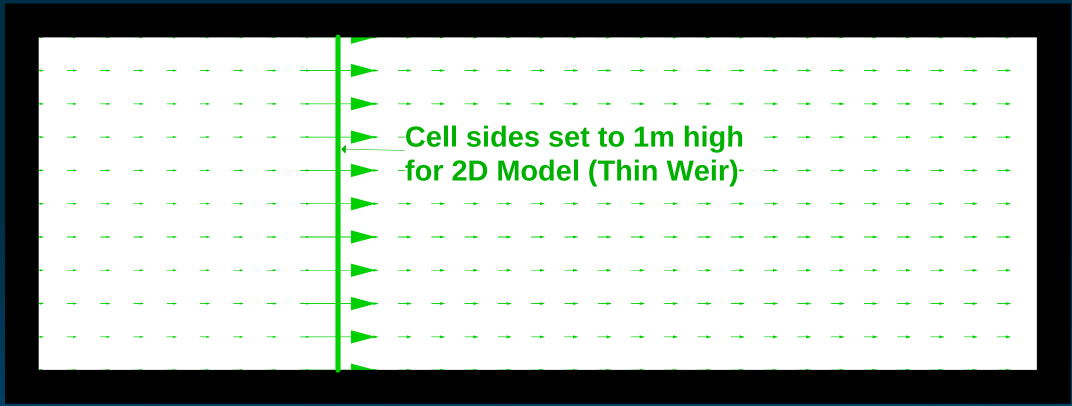
Modelling Culverts - Conclusions

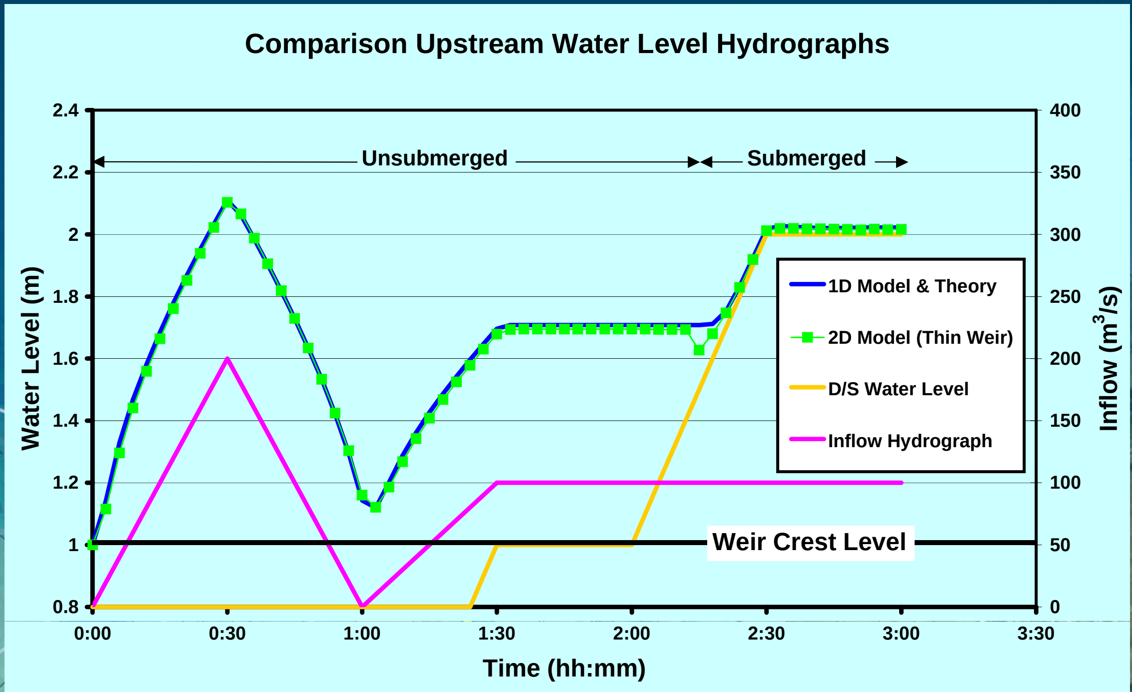
- Culvert as 2D Cell(s)
  - 2D solution models 70 to 80% of losses
  - Need 20 to 30% additional form losses

- 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)

Embankments / Levees (Weir Flow)

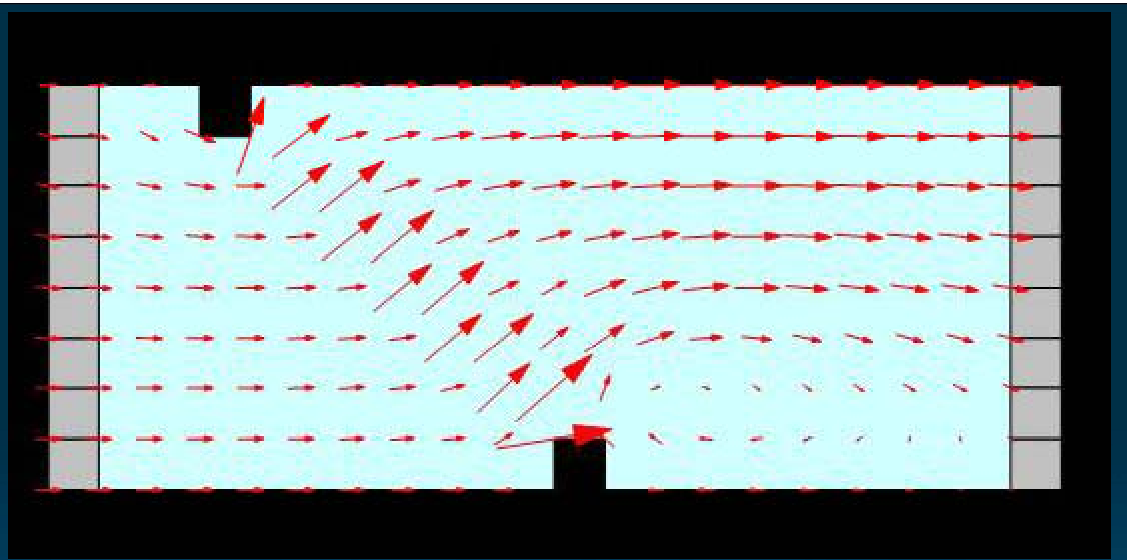
- Approach
  - Test submergence across cell side
  - BC Weir equation if unsubmerged
  - No adjustment if submerged
- Thin Weir Test

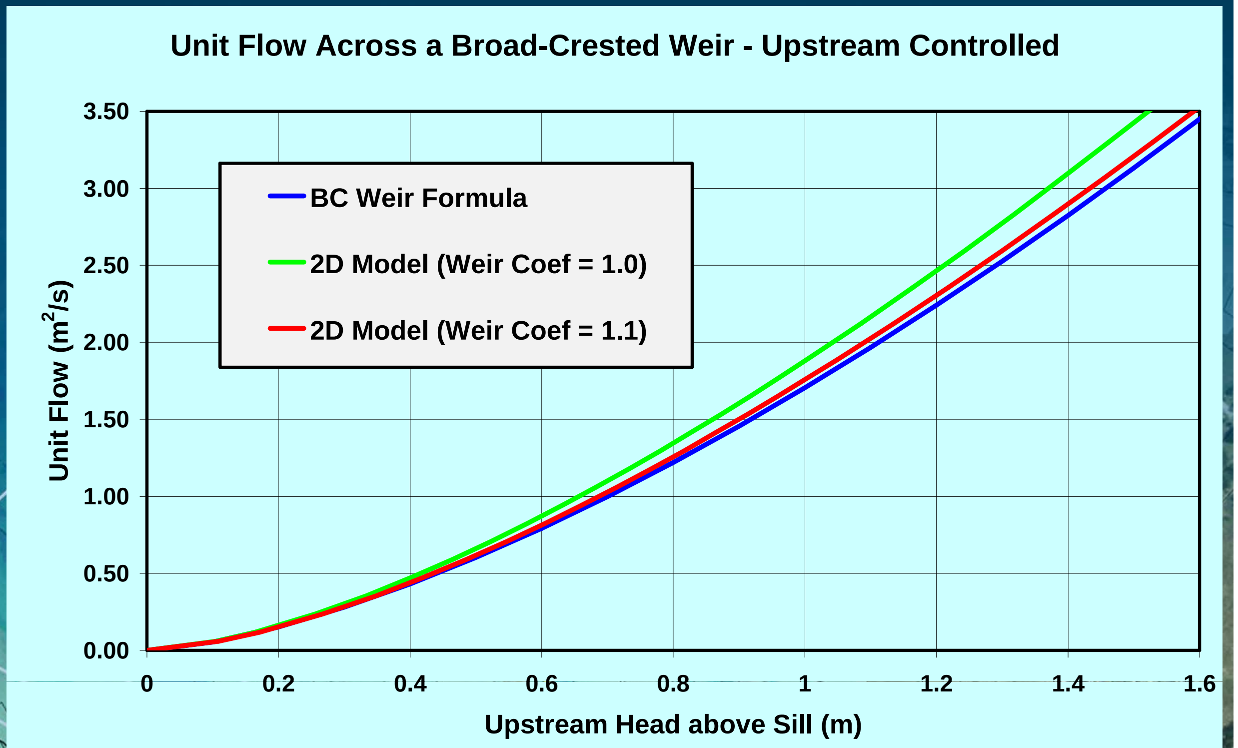




Oblique Weirs

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





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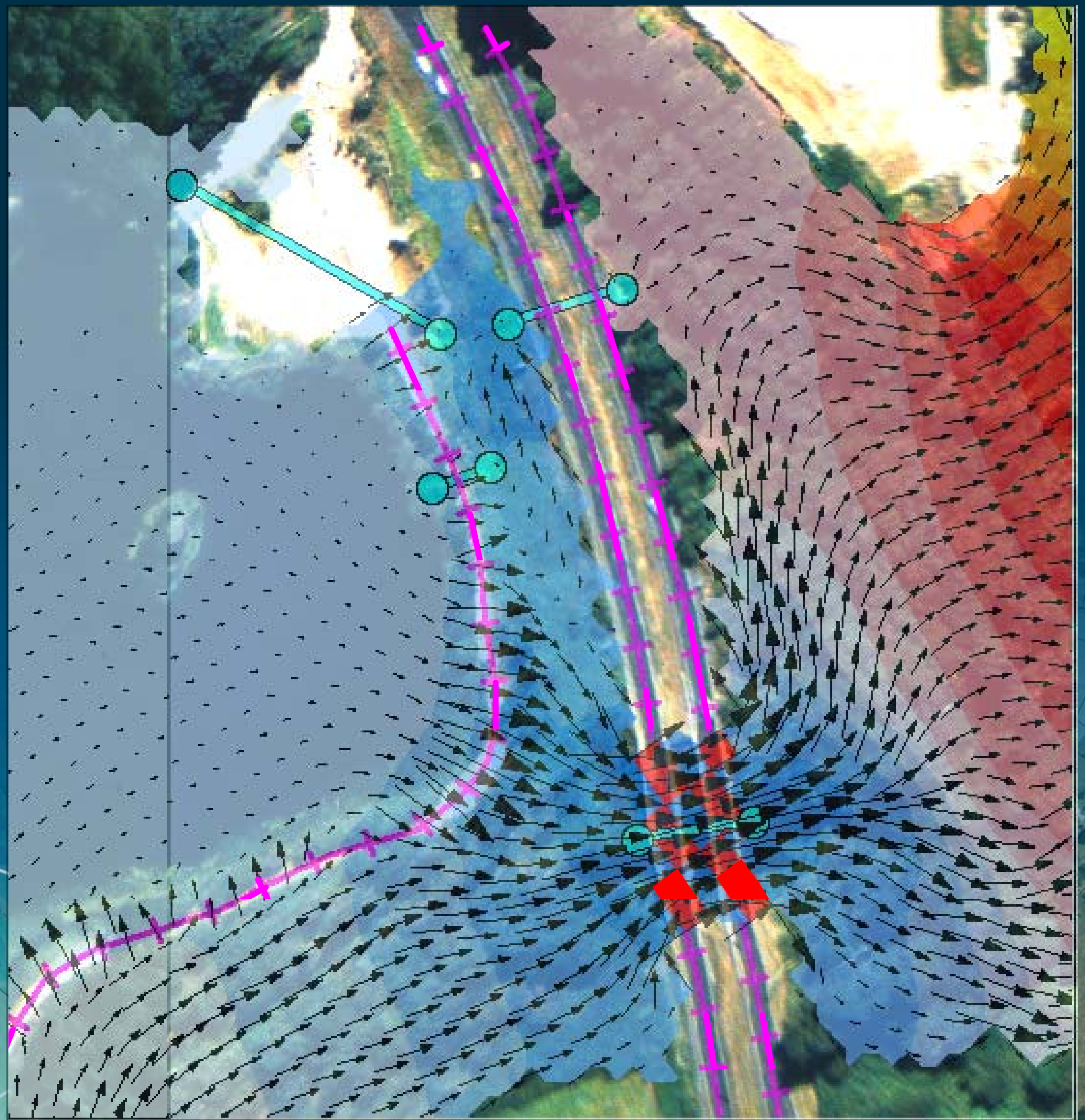
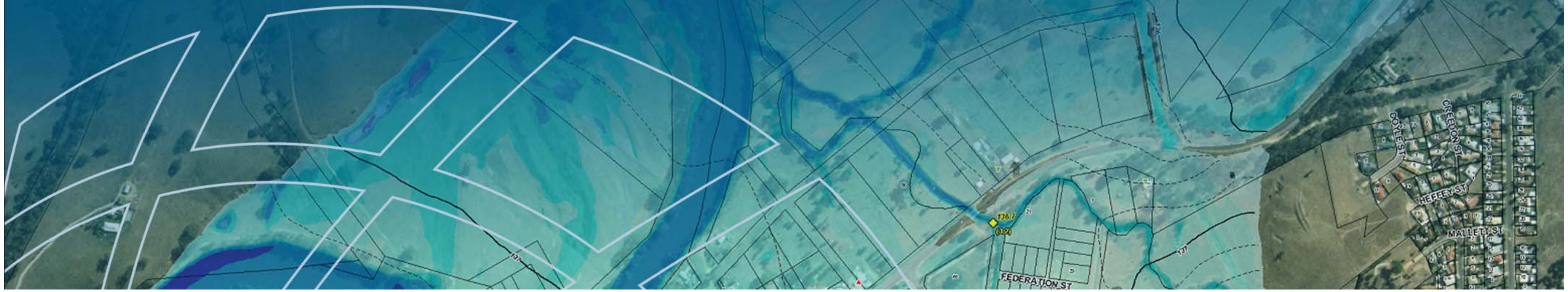
Real World Example

- Bruce Hwy, Eudlo Creek, Qld – 1998
- Bridge Piers and Deck
- Weir flow over levees
- Nested 1D Elements
  - Pipes
  - Weir flow over bridge deck



Real-World Applications

- 2D Schemes need to:
  - Adjust cell: widths / flow areas / wetted perimeters
  - Set cell obverts (lids)
  - Apply additional form losses
  - Handle unsubmerged weir flow
- Nested 1D Elements need to:
  - Reduce inlet/outlet loss coefficients
    (to prevent over prediction of losses)



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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 terms
- Nesting 1D elements
  - Useful when the structure is small
  - May over predict losses
  - Need to reduce inlet / outlet losses (calibrate)
- Check and UNDERSTAND your results

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