Water Research Laboratory

Assessing Bridge Afflux

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Never Stand Still | Faculty of Engineering | School of Civil and Environmental Engineering

Methods for Estimating Bridge Afflux

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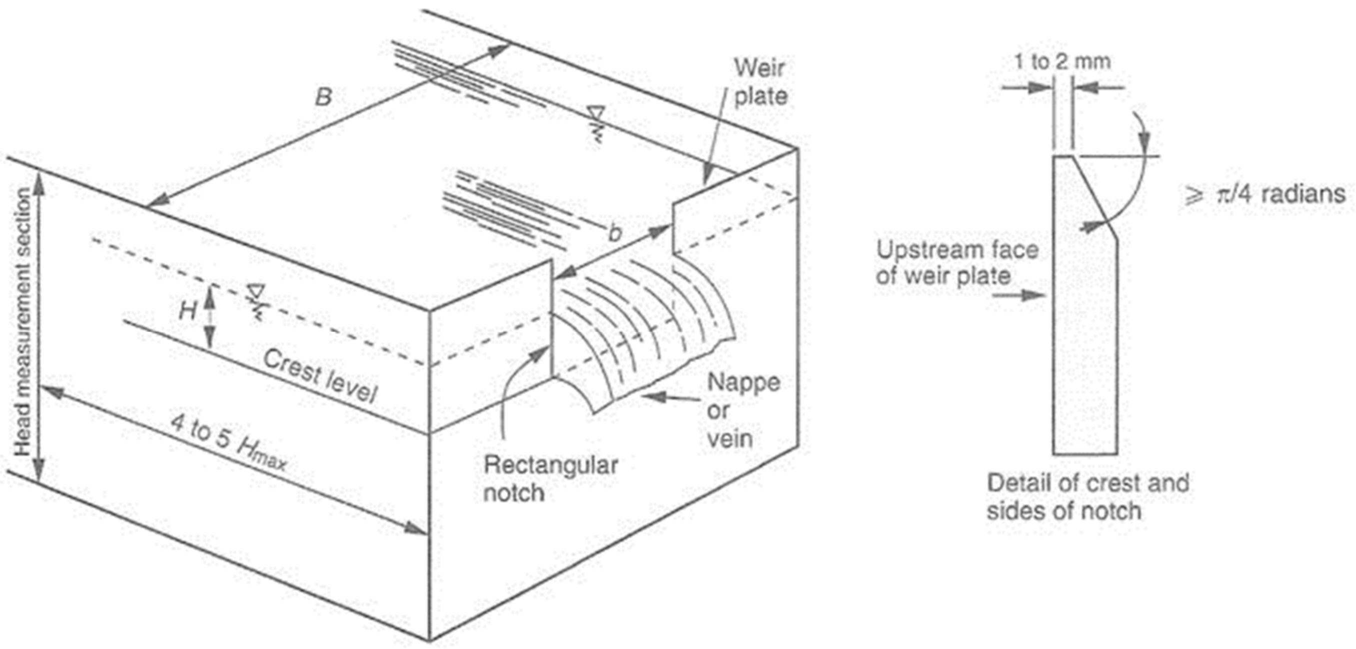
Some commonly used alternative methods

- Another model …
  - HEC RAS (1D)
  - Physical model
- Empirical approaches
- Engineering judgement (??)

Are you qualified?

- Who has seen a flood?
- Who has gauged a flood?
- Who has gauged at a bridge?

What do you know?



Sharp Crested Weir

$$Q = C L H^{3/2}$$

Wide Sharp Crested Weir

$$Q = \frac{2}{3} C_d \sqrt{2g}.L.H^{1.5}$$

$$C_d = 0.605 + 0.08 \frac{H}{P}$$

This is an infallible rule of open channel flow isn't it?

Its all in the C_d…

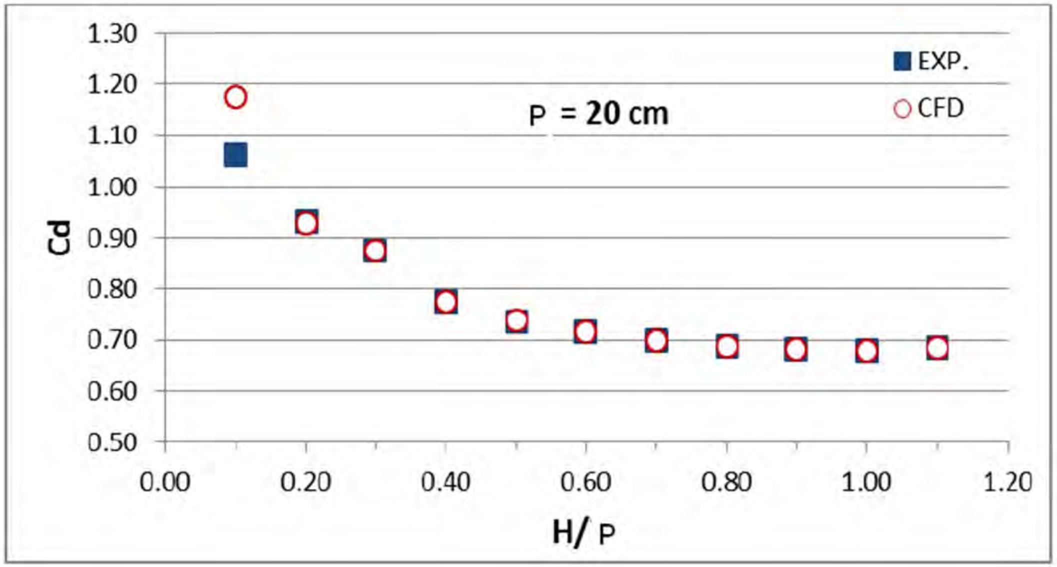
$$C_d = 0.605 + 0.08\,\frac{H}{P}$$

Did you know that there is a minimum H for this relationship?

Did you know that H/P should not be greater than 2.5?

Did you know that P has a minimum?

If you are outside the intended range then the rules change!



Methods for Estimating Bridge Afflux

- Can you make a first pass estimate of head loss?

UK – Environment Agency / DEFRA (August 2007)

- http://www.river-conveyance.net/aes/documents.html

  Professionals estimating afflux or blockage in the UK typically have a minimal background in hydraulics and are unlikely to have used hand methods for afflux estimation.

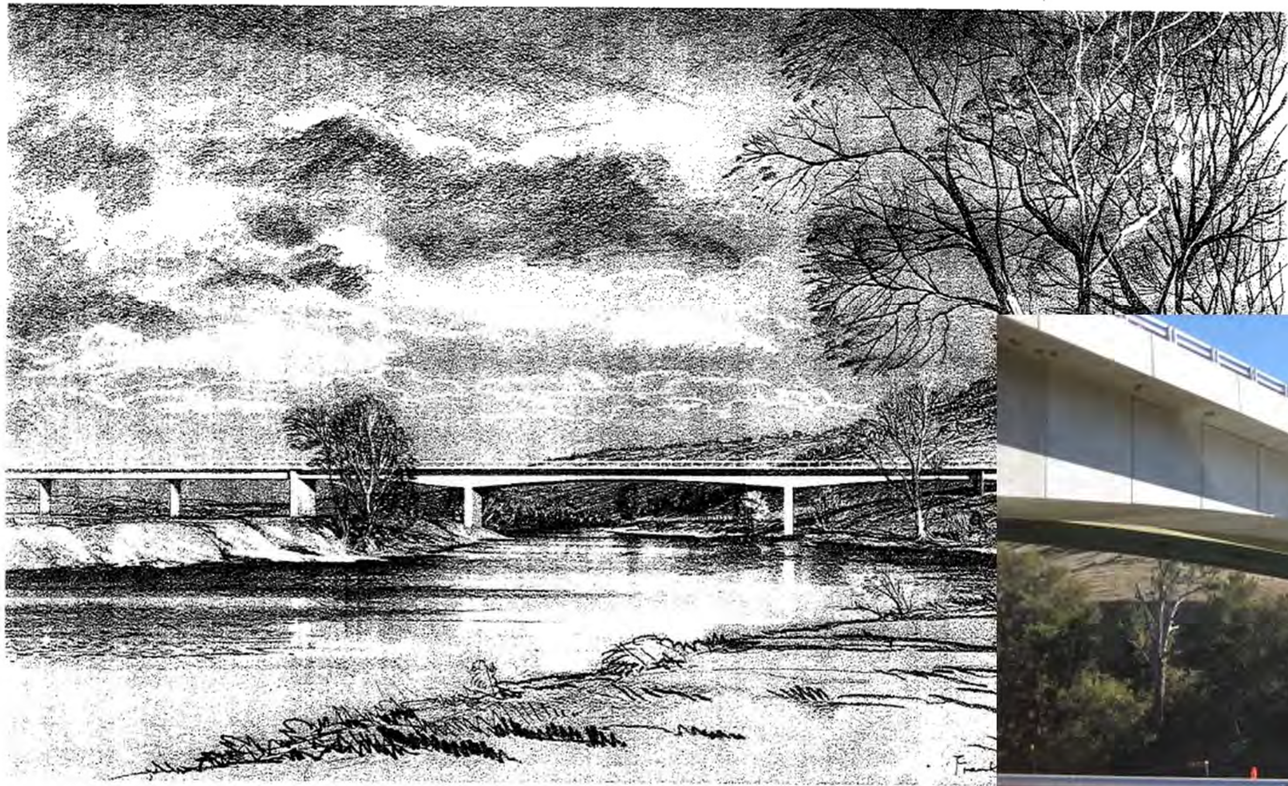
- The implementation of existing afflux formulae in river modelling software is poor.
- The available datasets on afflux are largely from laboratory studies and are poorly documented.
- Physical models will still require prototype (field) data for validation.
- There is little awareness or agreement of how afflux should be measured in the field – probably because it is rarely done.

UK – Environment Agency / DEFRA (August 2007)

- Blockage is not well understood
- Field data is required for bridges and culverts where overtopping occurs and for structures blocked with floating debris in order to confirm the adequacy of existing estimation methods.

Physical Models

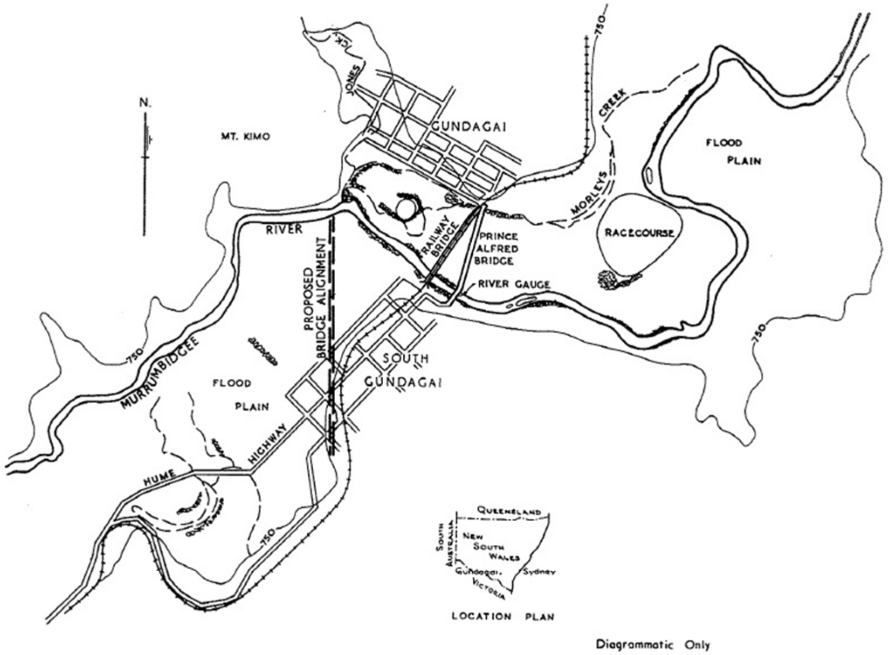
Physical Modelling (Foster and Ewers, 1963)



AN ARTIST'S IMPRESSION OF A PRELIMINARY PROPOSAL
THE NEW BRIDGE OVER THE MURRUMBIDGEE RIVER AT GUN

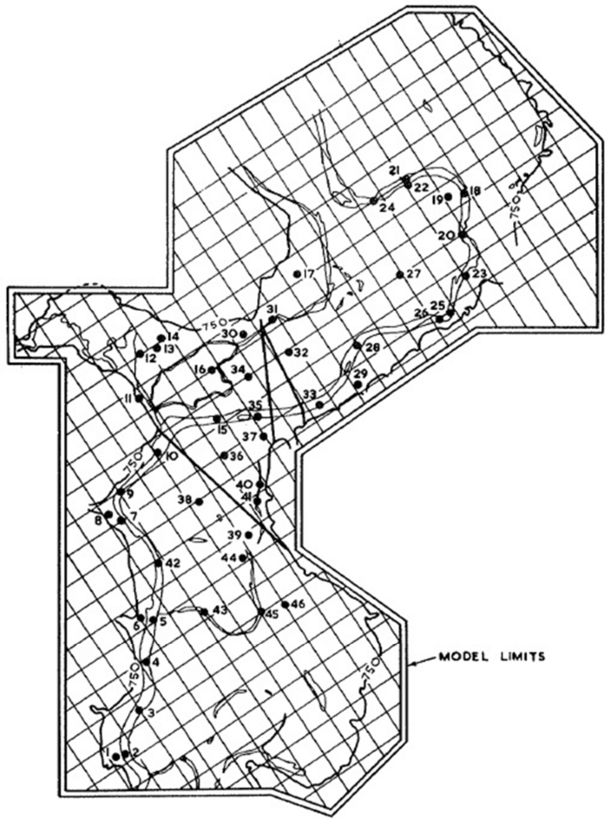
Photo by courtesy of Sir Alexander Gibb and Partners, Consulting Eng

Physical Modelling (Foster and Ewers, 1963)



Locality Plan

FIGURE I.

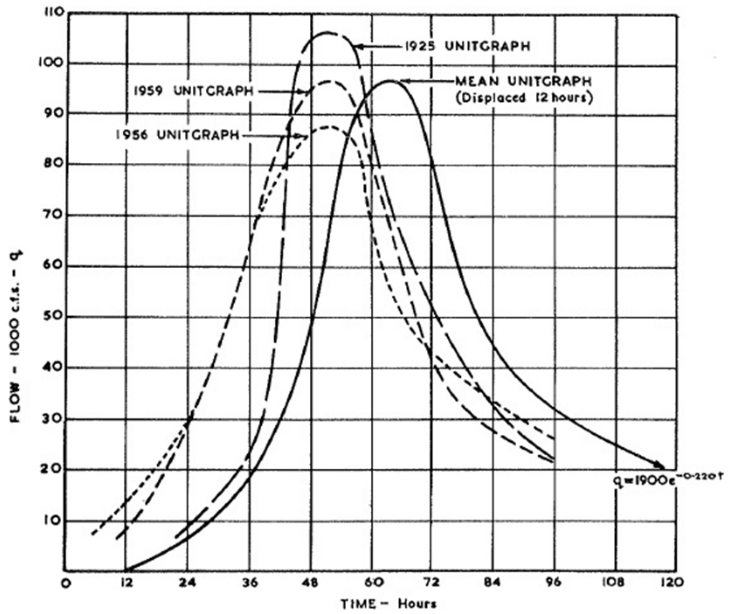


Location of Manometers

FIGURE 4.

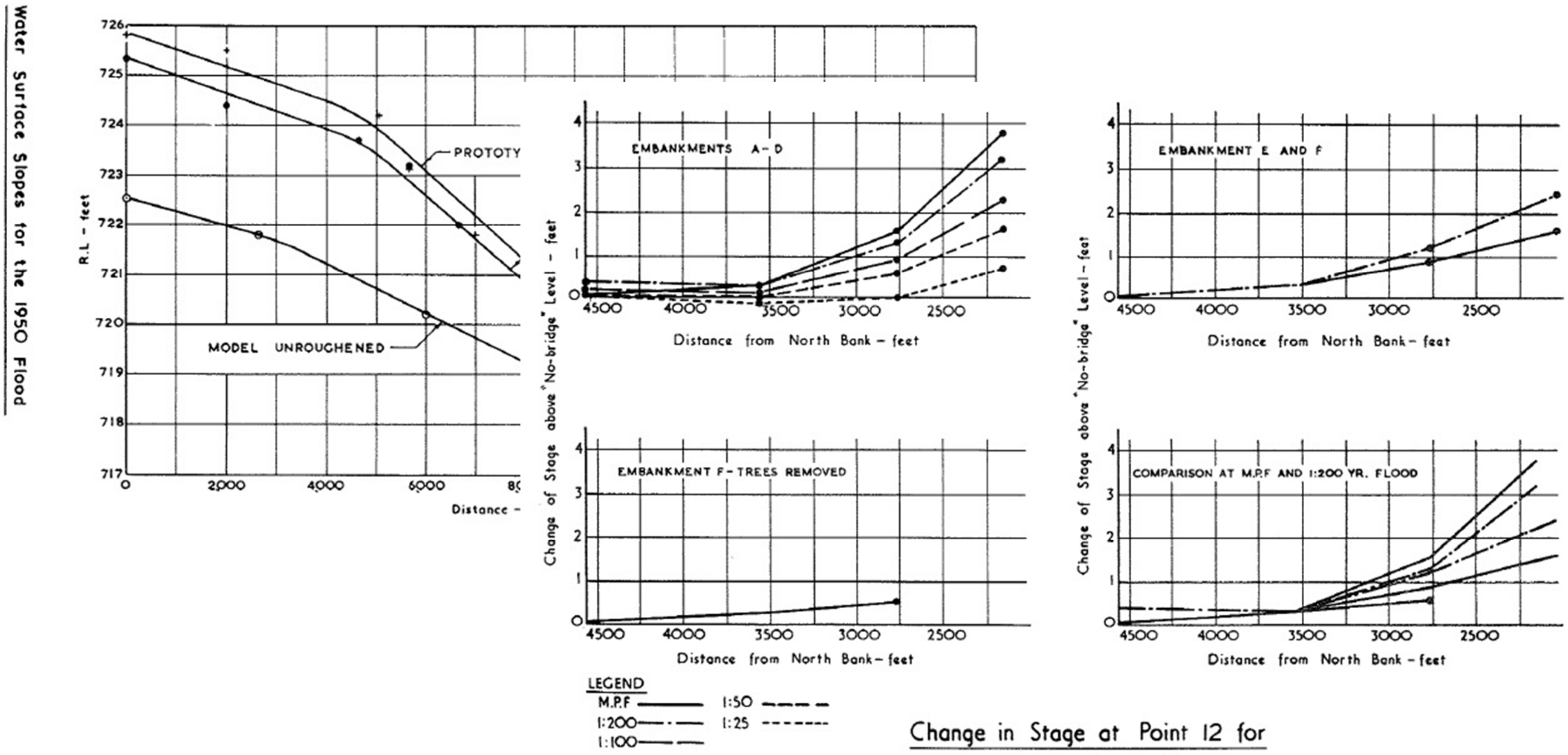
Physical Modelling (Foster and Ewers, 1963)

- Verified against 1925 and 1950 floods
- Limited historical levels
- BOM estimate of 'storm maximisation'
- Unitgraph from historical floods using UTECOM
- Distorted scale
  - 1:500 horizontal
  - 1:120 vertical
- Tested for flows up to 660,000 c.f.s



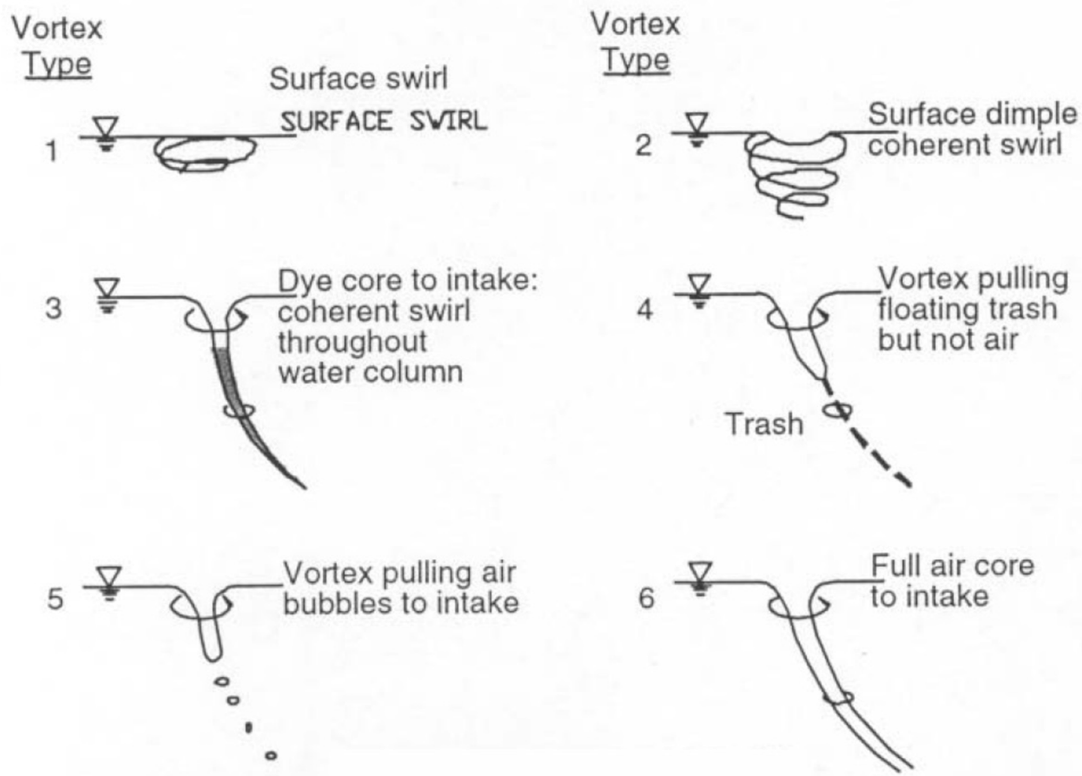
Derived Unitgraphs at Gundagai

Physical Modelling (Foster and Ewers, 1963)



Change in Stage at Point 12 for Different Embankment Conditions

Physical models…



Empirical Methods - Bridge Piers

- Yarnell (1934) *Bridge Piers as Channel Obstructions*
- Nagler (1918) *Obstruction of Bridge Piers to the Flow of Water*
- Aubuisson de Voisons (1852) *A Treatise on Hydraulics, for the Use of Engineers*

Empirical Methods (an example…)

The Yarnell equation reads:

$$h_{us} - h_{ds} = KY_{ds}F_{ds}^2(K + 5F_{ds}^2 - 0{,}6)(\alpha + 15\alpha^4)$$

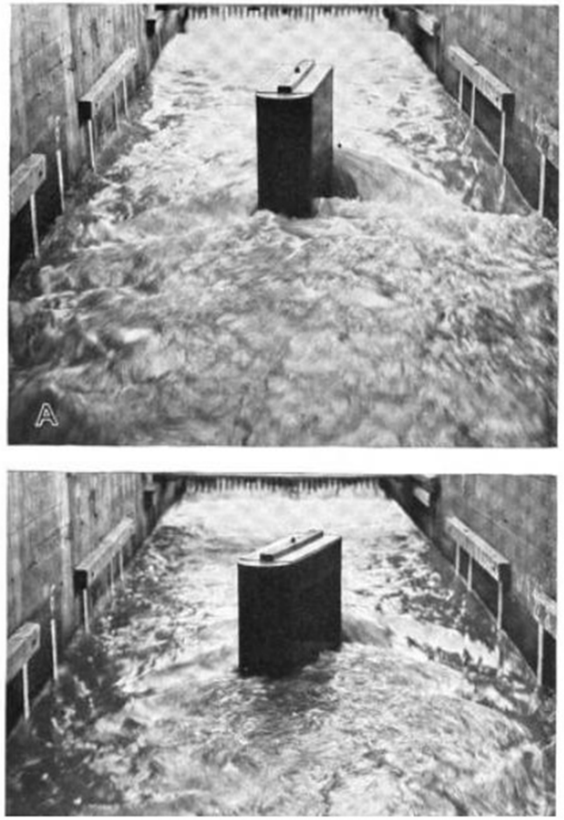
$$F_{ds}^2 = \frac{Q^2}{A_{ds}^2 2gY_{ds}}$$

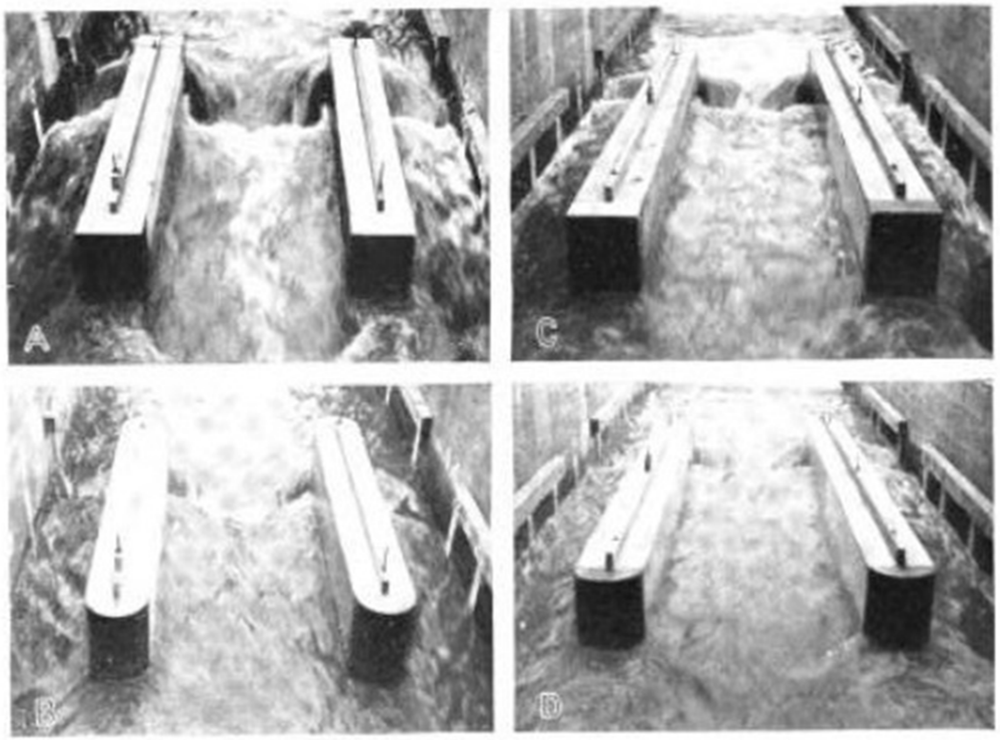
$$\alpha = 1 - \frac{b}{B_{us}}$$

Bridge Piers

- Yarnell (1934) Bridge Piers as Channel Obstructions

Tech. Bul. 442, U.S. Dept. of Agriculture PLATE 7





Bridge Piers (Yarnell 1934)

- 2800 physical model tests
- Steady state flows

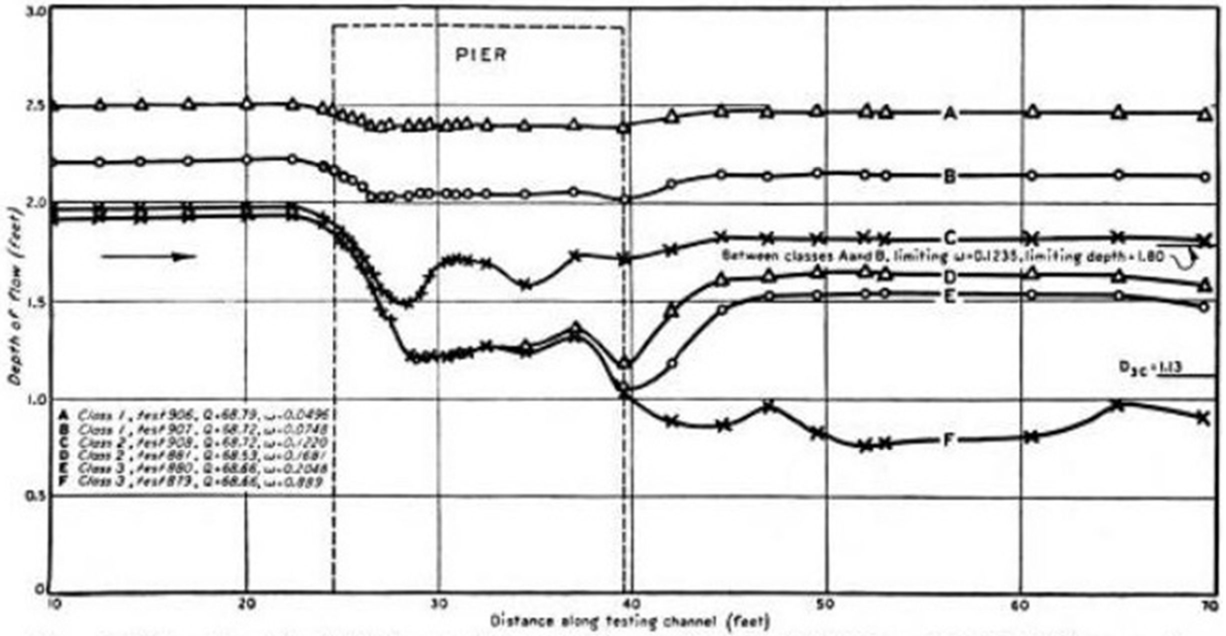


FIGURE 11.—Water surface profiles with twin long piers having semicircular ends. Channel contraction 23.3 percent; flow 68.8 cubic feet per second.

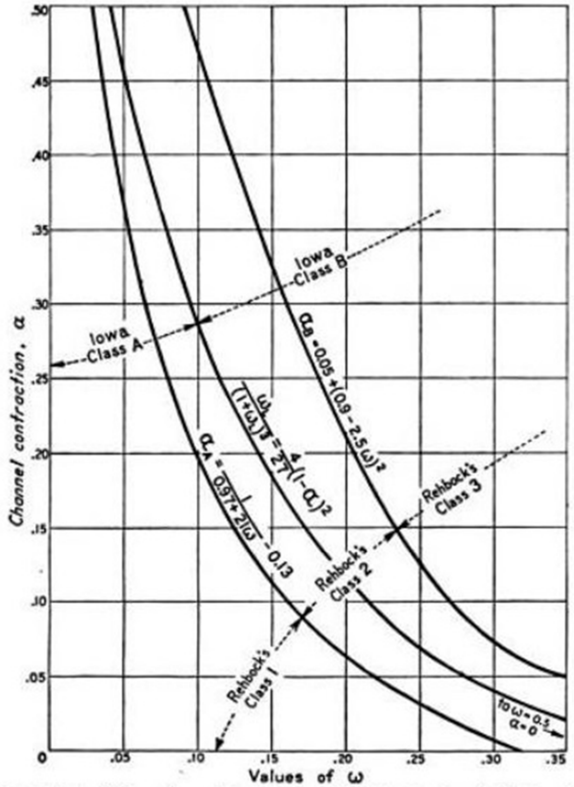


FIGURE 9.—Limits of different classes of flow according to Rehbock's and to Iowa classifications. Note however, that Rehbock's classification is made according to the flow in the unobstructed channel but the Iowa classification relates to the flow through the contracted section.

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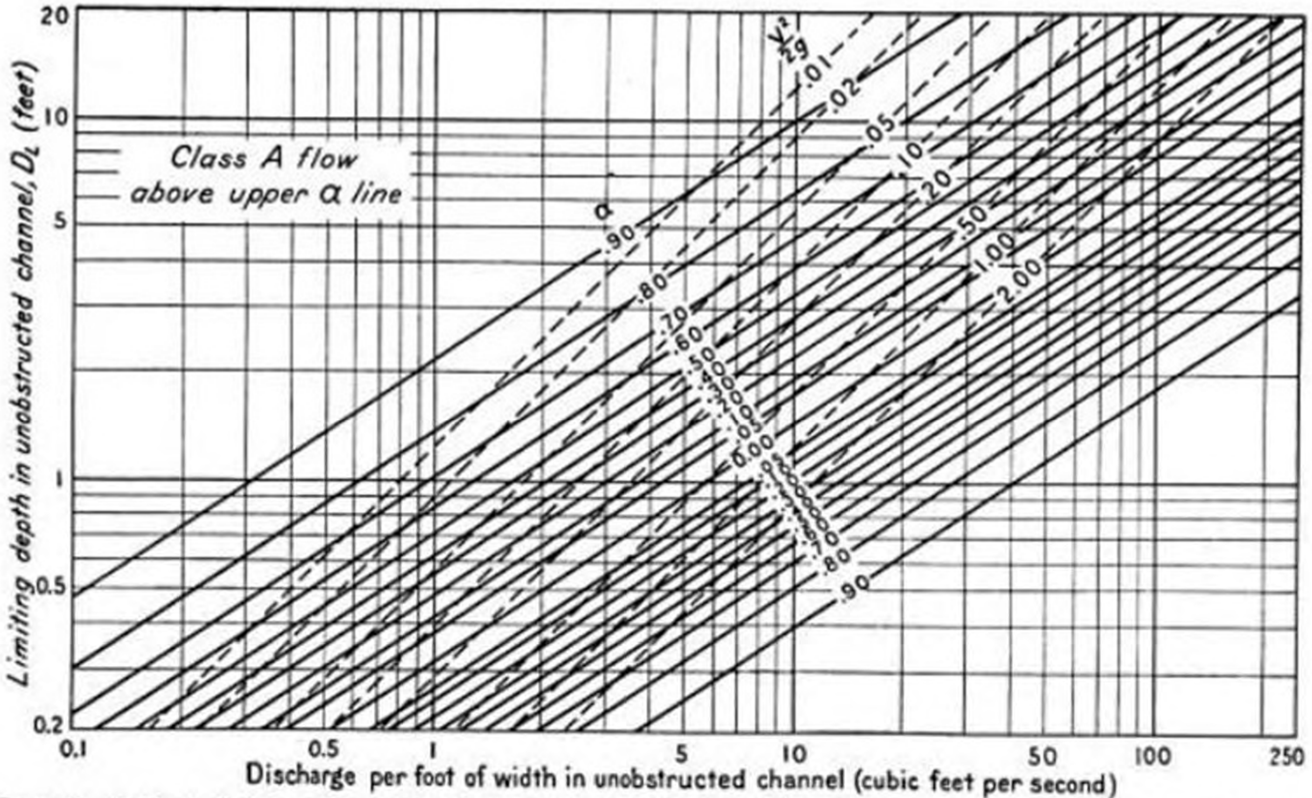

FIGURE 13.—Limiting depth D_L in unobstructed channel for various channel contractions and for various discharges per foot of width in unobstructed channel.

Bridge Piers (read the fine print)

- Yarnell (1934) Bridge Piers as Channel Obstructions

SUMMARY AND CONCLUSIONS

The bridge-pier formulas most commonly used in the United States are D'Aubuisson's, Nagler's, Weisbach's, and Rehbock's. The discordant results obtained with the Weisbach formula show it to be theoretically unsound.

None of the above formulas give for a certain shape of pier a constant coefficient for all channel contractions. This factor is of vital importance and is the reason for the inconsistent results obtained in the past by engineers attempting to solve problems involving backwater from bridge piers. The majority of such problems concern cases having channel contractions of less than 20 percent.

As long as the velocities are low enough to keep within what Rehbock calls class 1 flow, any one of the three formulas will give results close enough for practical purposes, if the proper coefficient is used. This coefficient varies with the channel contraction as well as the pier shape, as is shown by table 3 and figure 6. Proper values for channel contractions of less than 11.7 percent were not determined, and for most of the pier shapes they also are not determined for contractions greater than 23.3 percent. However, most backwater problems fall within this range, but as the D'Aubuisson and Rehbock formulas give quite different coefficients at 11.7 percent than they do at 23.3 percent, and as no points are known between them, the shape of the curve remains undetermined. This objection does not apply to the Nagler formula because there is little difference in the coefficients for 11.7 percent and 23.3 percent, and the tests of the square and semicircular shapes indicate that a constant average value can be used throughout the range. The Nagler formula also applies through Rehbock's class 2 and into the beginning of class 3. The other two formulas do not apply at these higher velocities (except

Bridge Piers

- Yarnell (1934) Bridge Piers as Channel Obstructions

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Numerical Model Application …

The Yarnell equation reads:

$$h_{us} - h_{ds} = KY_{ds}F_{ds}^2(K + 5F_{ds}^2 - 0{,}6)(\alpha + 15\alpha^4)$$

$$F_{ds}^2 = \frac{Q^2}{A_{ds}^2 2gY_{ds}}$$

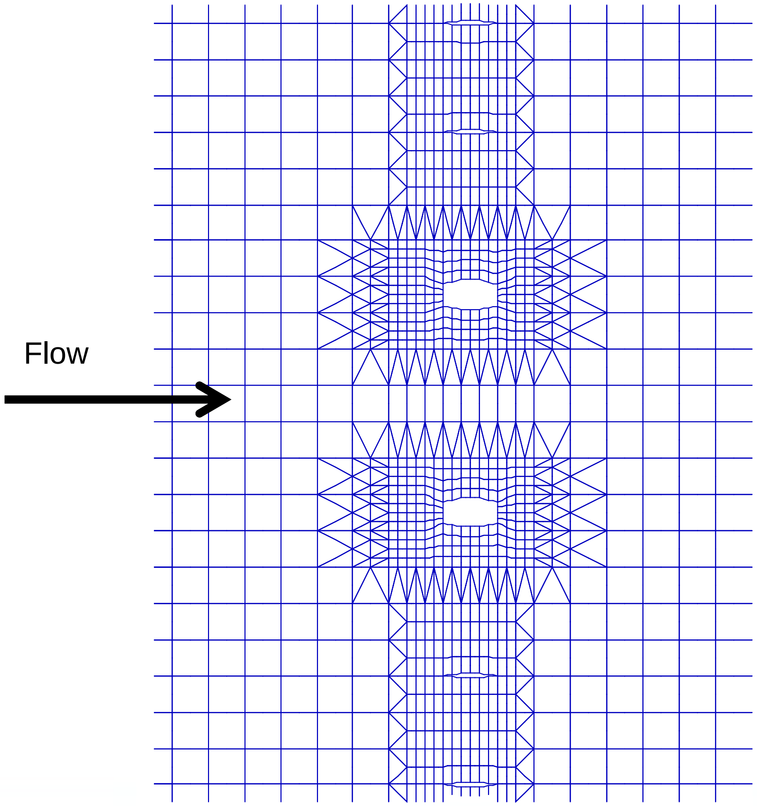
$$\alpha = 1 - \frac{b}{B_{us}}$$

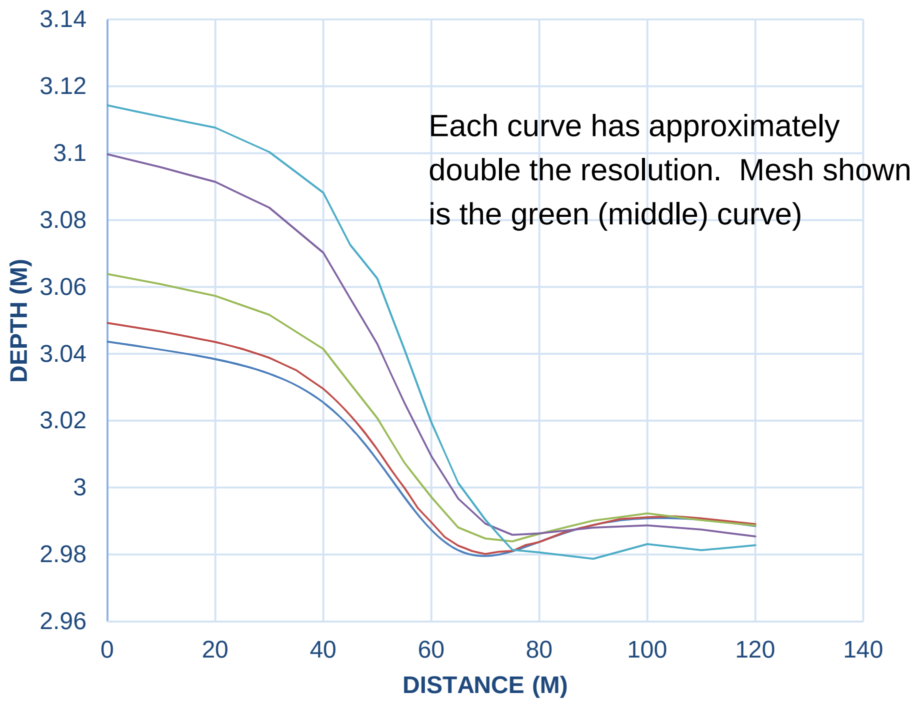
Numerical Model Application …

- No background information on the approach in the model's manual
- No warning's on limitations of the method
- No recommendations on parameters
- No demonstration data set indicating validation of the approach
- No discussion of whether *the solution holds if the flow reverses*
- Onus on the model user to seek these things out

Resolving Afflux Simply with Hydrodynamic Solutions

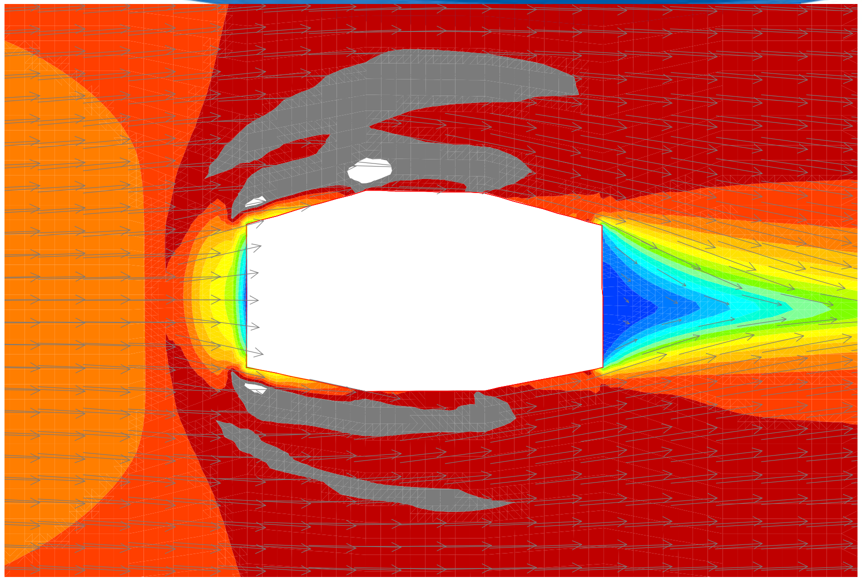
- Recent grid resolutions tests on RMA-2
- The mesh resolution to solve hydro-dynamically alone is prohibitively high.

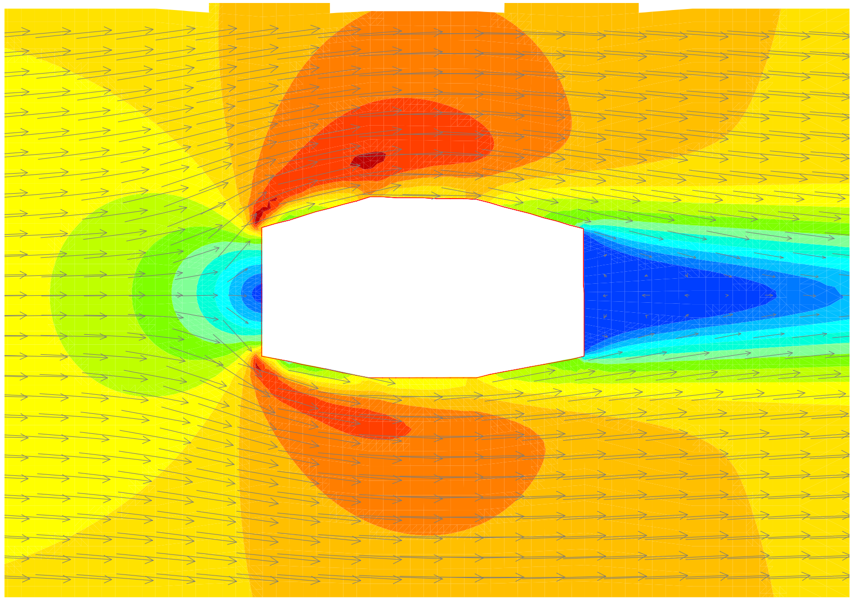




2D vs 3D

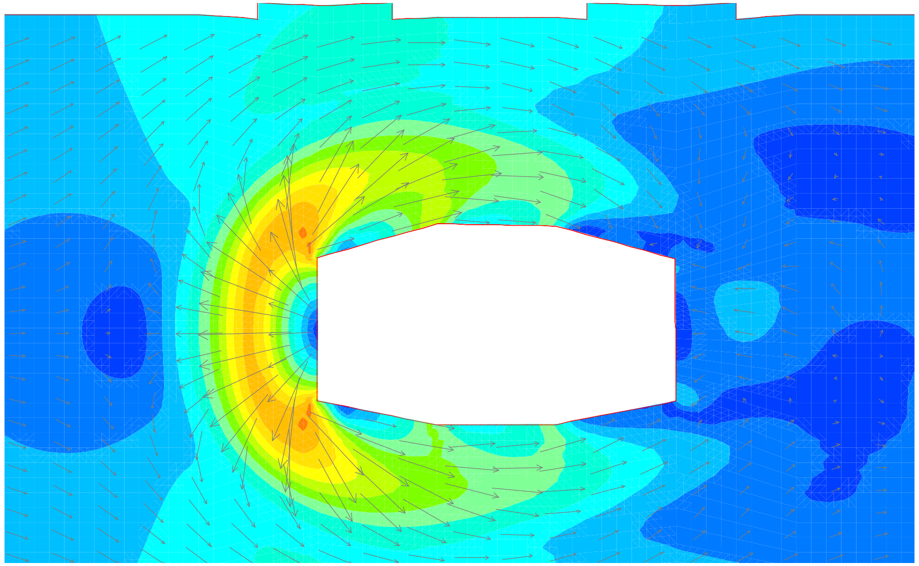
Surface





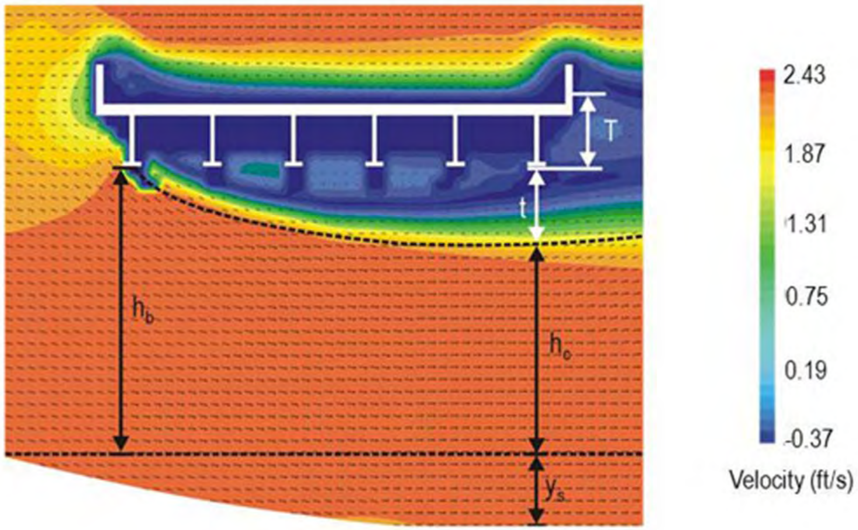
Depth Averaged

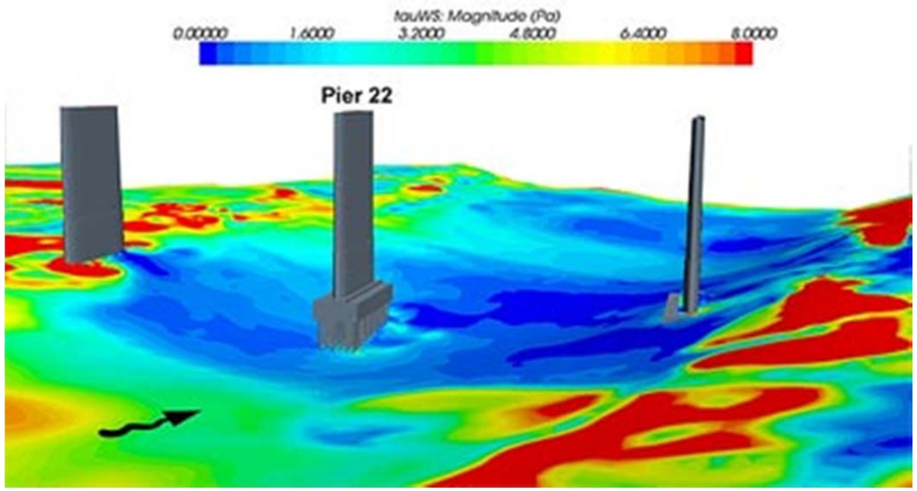
Bed



CFD

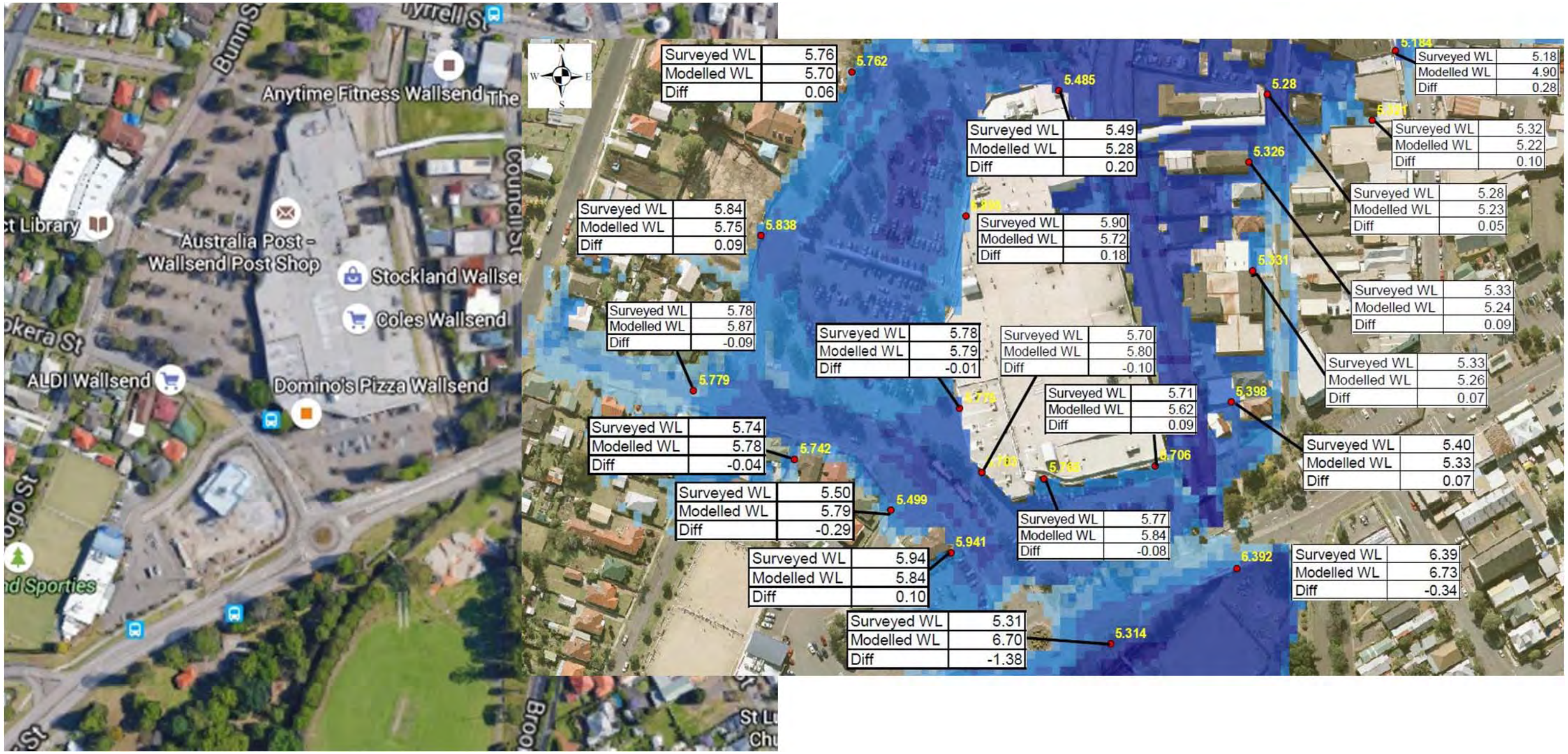
- Looks sexy
- Needs validation…





http://www.fhwa.dot.gov/publications/publicroads/08sep/05.cfm

How will you know if your case is ‘difficult’?



How will you know if your case is ‘difficult’?

High Froude Numbers…

Conclusions and Recommendations

- Know the flow fundamentals intimately…
  - Understand situations where underlying assumptions don't hold
- Do some hand calculations from first principles as a first pass estimate
- Understand the risks and consequences of your analysis
- Make sure you know the warning signs for the 10% of cases where simple methods are inadequate (high Froude numbers, dominant 3D effects)
- Empirical approaches
  - Seek out the original work
  - Make sure it matches your situation
  - Understand the limitations of the method
- Make sure that you know what's in the gizzards of a numerical model before you apply it