# Feasibility of the porous zone approach to modelling vegetation in CFD


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# The problem

- Hundreds of small ponds exist as treatment devices, with few tools to evaluate their performance
- Dye traces take significant amounts of time but may be impractical for large numbers of ponds
- Traces have no predictive capability for new ponds
  - E.g. type and location of vegetation as design variables
- Computational Fluid Dynamics?

# Computational Fluid Dynamics

- CFD is increasingly being used as a design tool for ponds, but without taking into account vegetation
- The porous zone approach (Fluent) adds a momentum term to the Navier-Stokes equations, with parameters being determined by the Ergun equation from diameter (*d*) and porosity (*φ*)

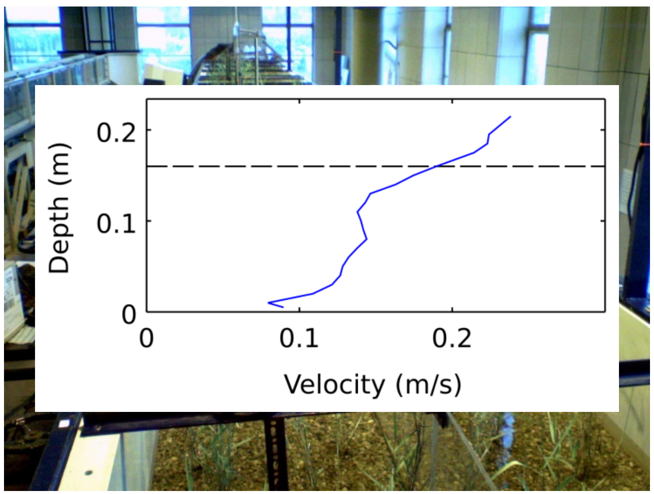
$$\frac{\partial \rho u u}{\partial x} + \frac{\partial \rho u v}{\partial y} = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + -\left(\frac{\mu}{\alpha} u + C_2\left(\frac{1}{2}\rho u|u|\right)\right)$$

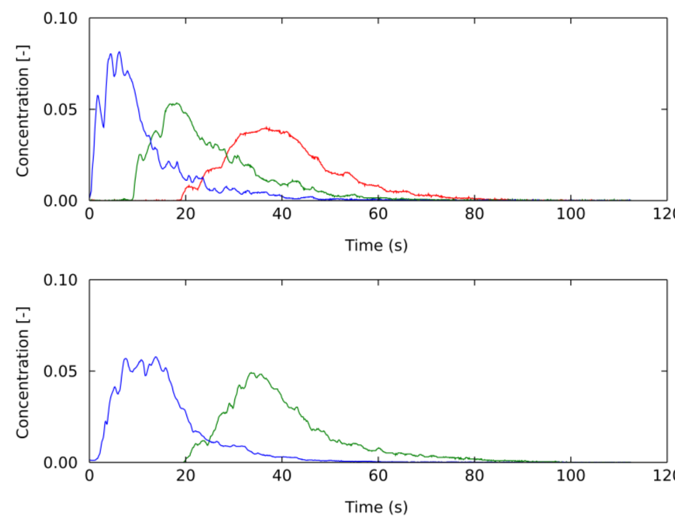
$$\alpha = \frac{d^2}{150}\frac{\varphi^3}{(1-\varphi)^2} \qquad C_2 = \frac{1.5}{d}\frac{(1-\varphi)}{\varphi^3}$$

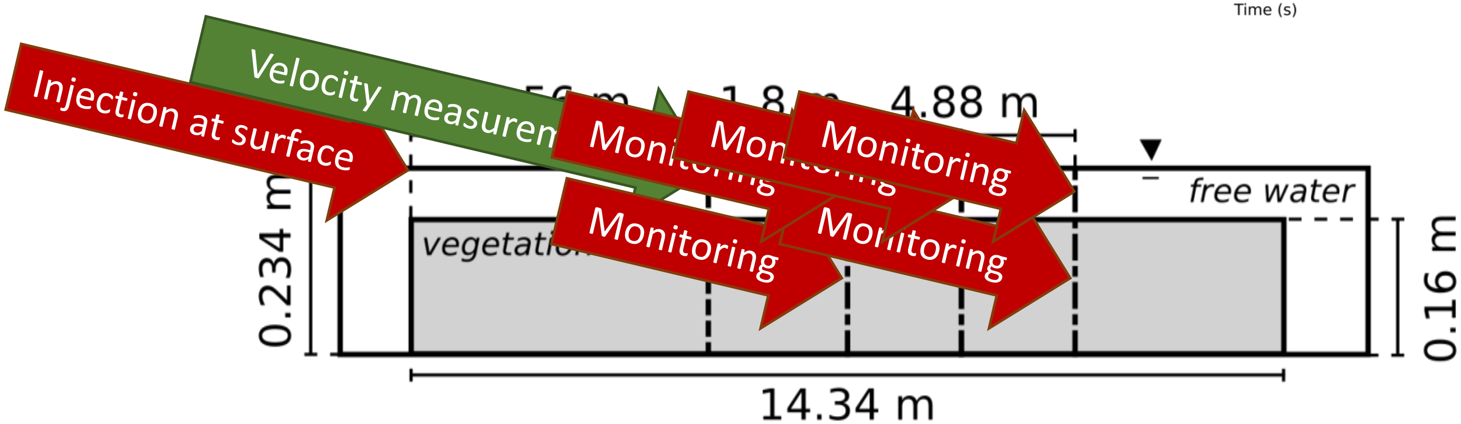
- More investigation is required to evaluate this approach

# Reproduce experimental configuration and results in CFD

- Shucksmith et al 2010



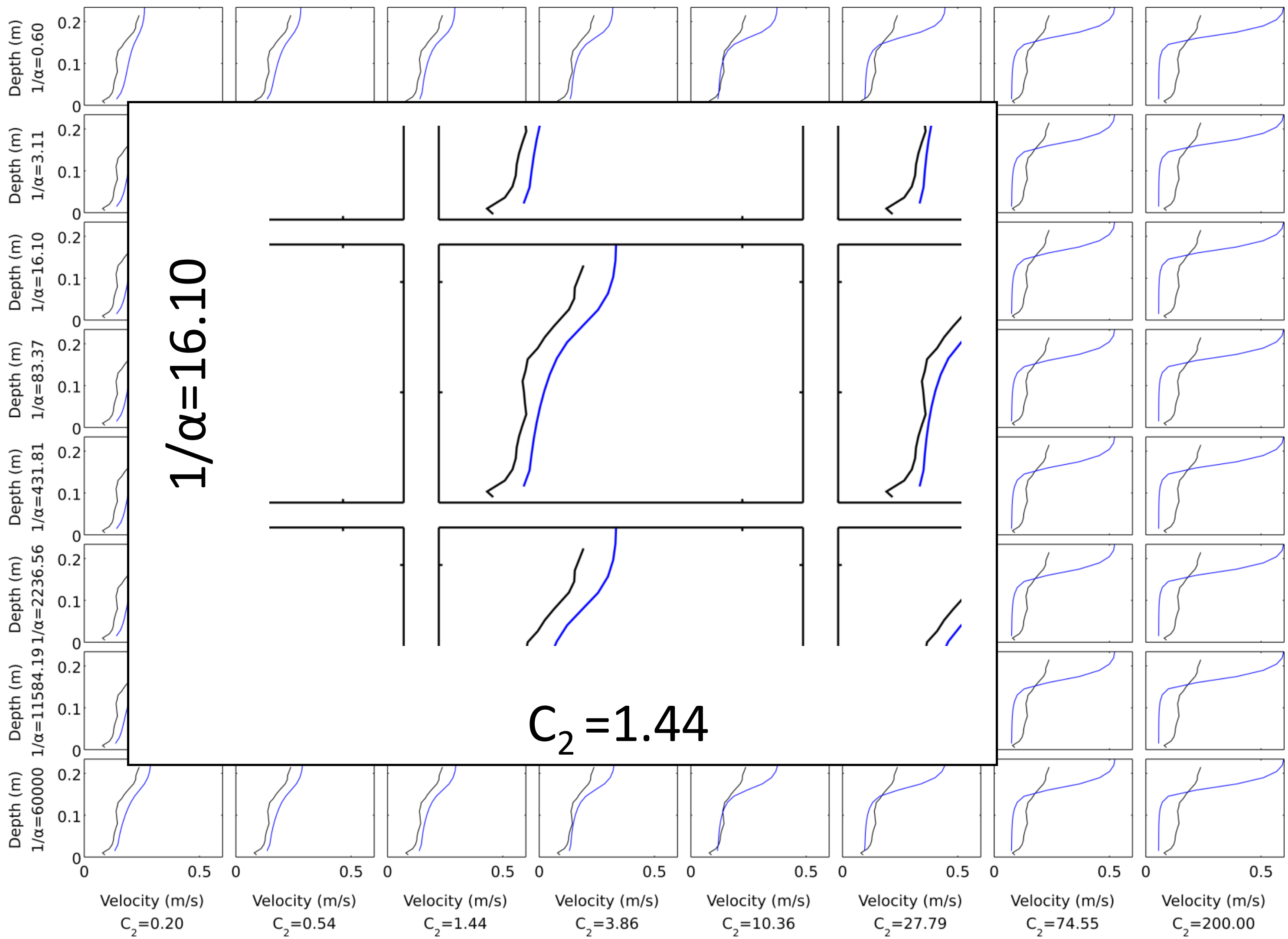



# Investigate…

- Mesh independence & discretisation settings
- Model sensitivity to 1/α and $C_2$
  - Apply a range of values to the one model of one experimental configuration to examine how different values impact the model results
- Parameter fitting
  - Examining multiple laboratory configurations and compare CFD generated solute traces to experimental solute traces using $R^2$ to find values that best describe the experimental results

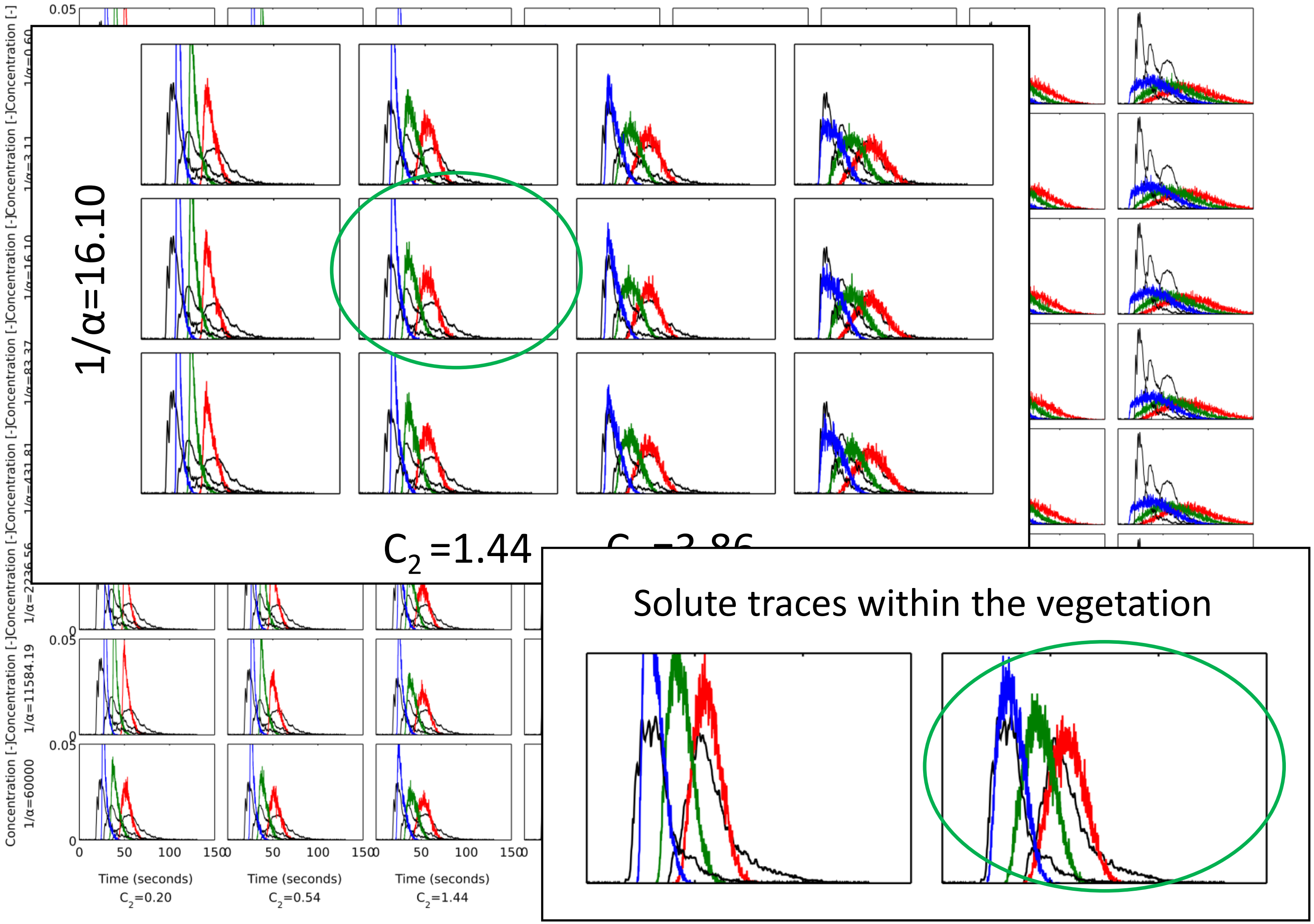
# Results: sensitivity to $1/\alpha$ and $C_2$

## Velocity profiles



# Results: sensitivity to 1/α and $C_2$

Solute traces within the water above the vegetation

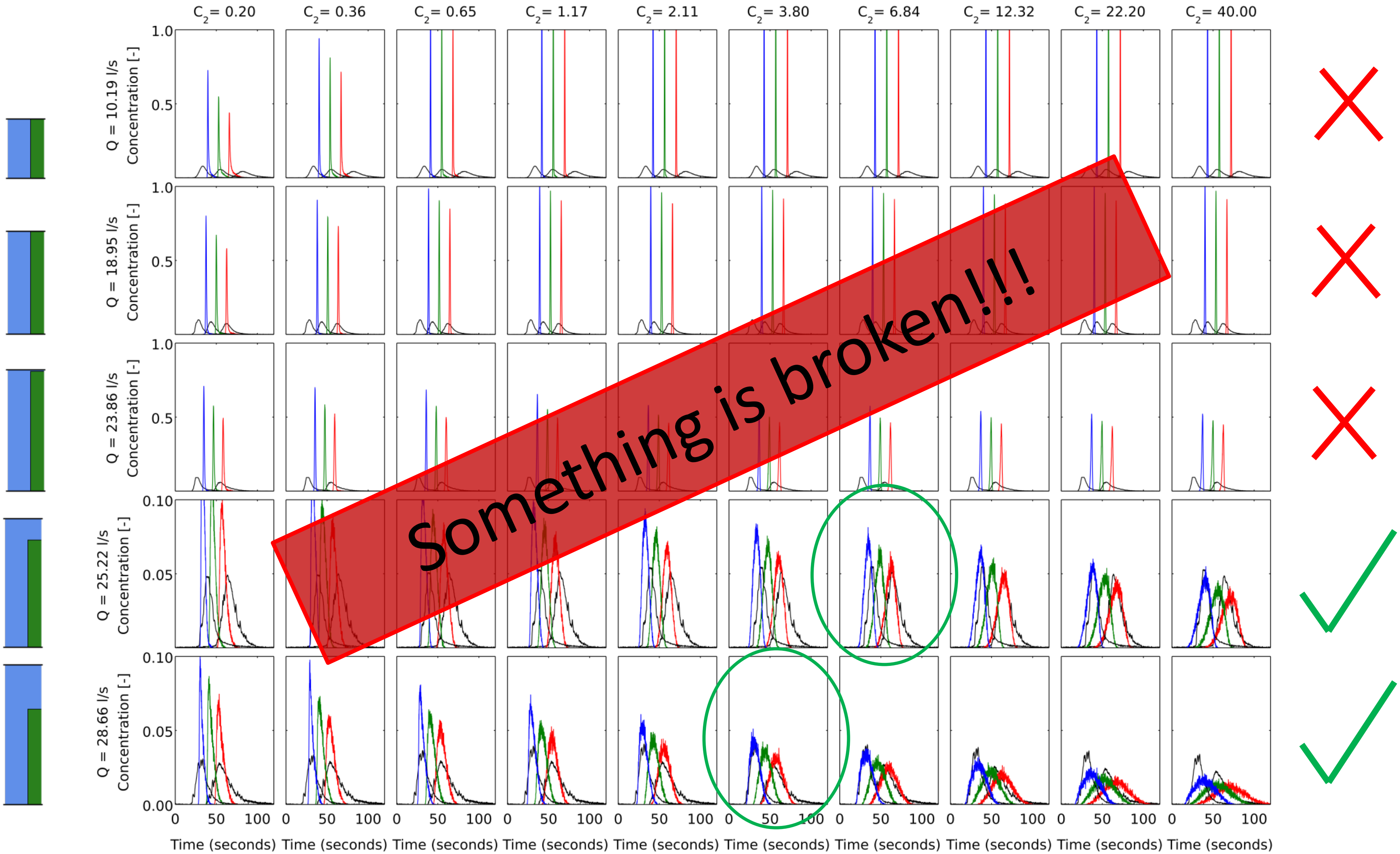


# Model sensitivity to $1/\alpha$ and $C_2$

- For this experimental configuration the model appear to be insensitive to $1/\alpha$ and very sensitive to $C_2$
- Given the inherent variability in measuring vegetation, the Ergun expression for $C_2$ may not be suitable
  - For example, a difference in stem diameter of 5 mm can double or halve $C_2$
- $C_2$ needs more investigation

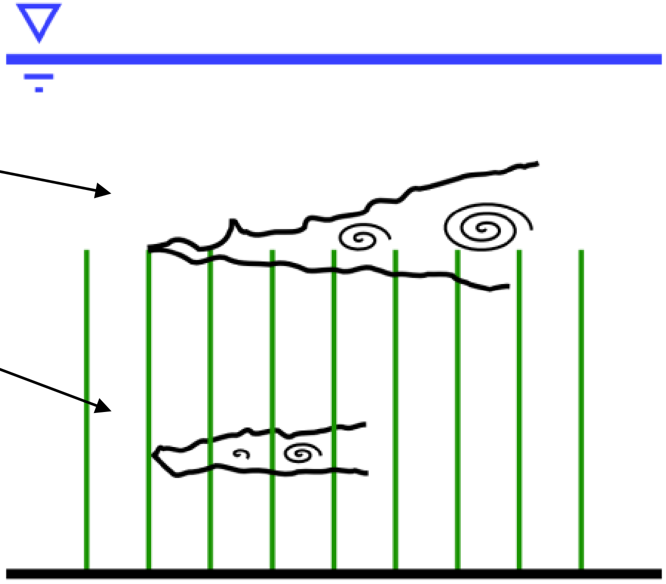
# Results: best fit values of $C_2$

## Measurement set 3



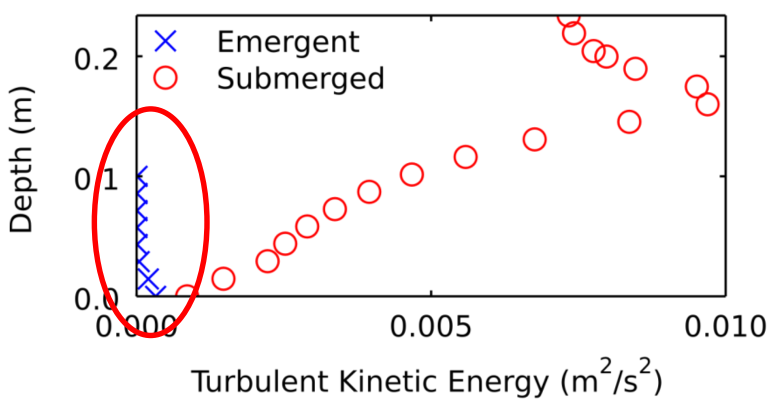
# Simplified vegetated channel physics

- Sources of mixing in a vegetated channel:
  - Molecular diffusion
  - Turbulent diffusion
- Sources of turbulence in a vegetated channel:
  - Shear layer at the interface
  - Stem wake eddies



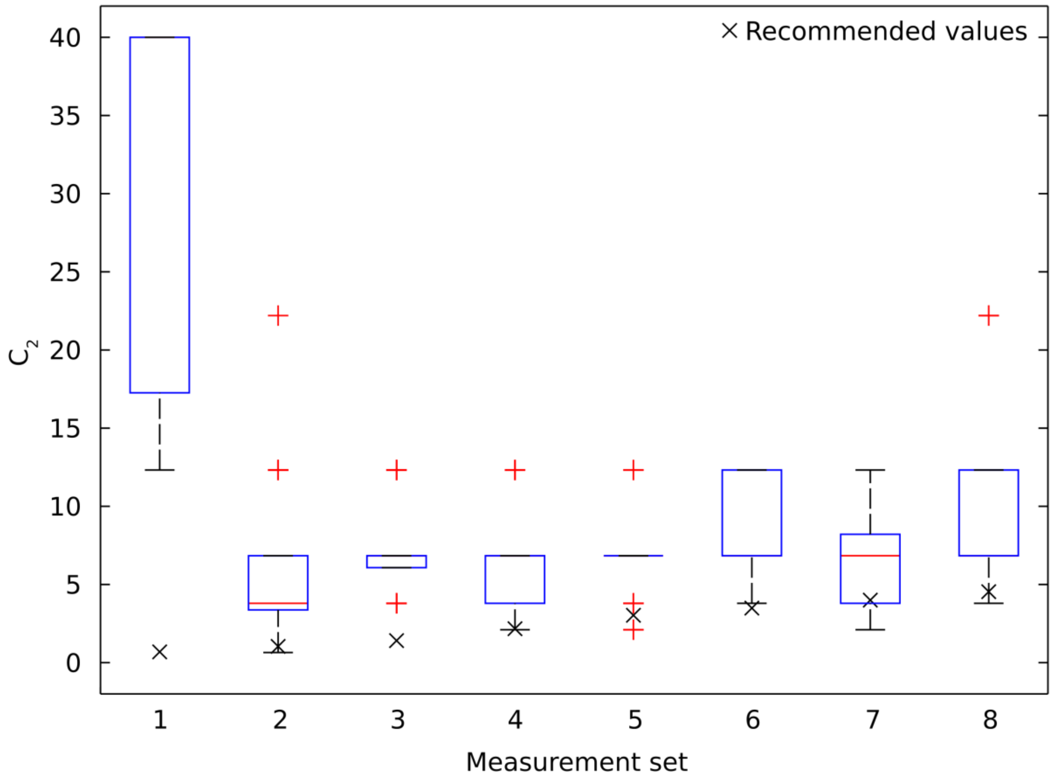
# The porous zone problem

- The model has not produced the expected results in some scenarios (emergent vegetation)
- The emergent vegetation model has no turbulence, although stem wake effects should be producing it




- *This leads to no mixing in the model*
- The porous zone approach currently isn't currently suitable as it does not take into account the stem wake effects

# Best-fit values of $C_2$

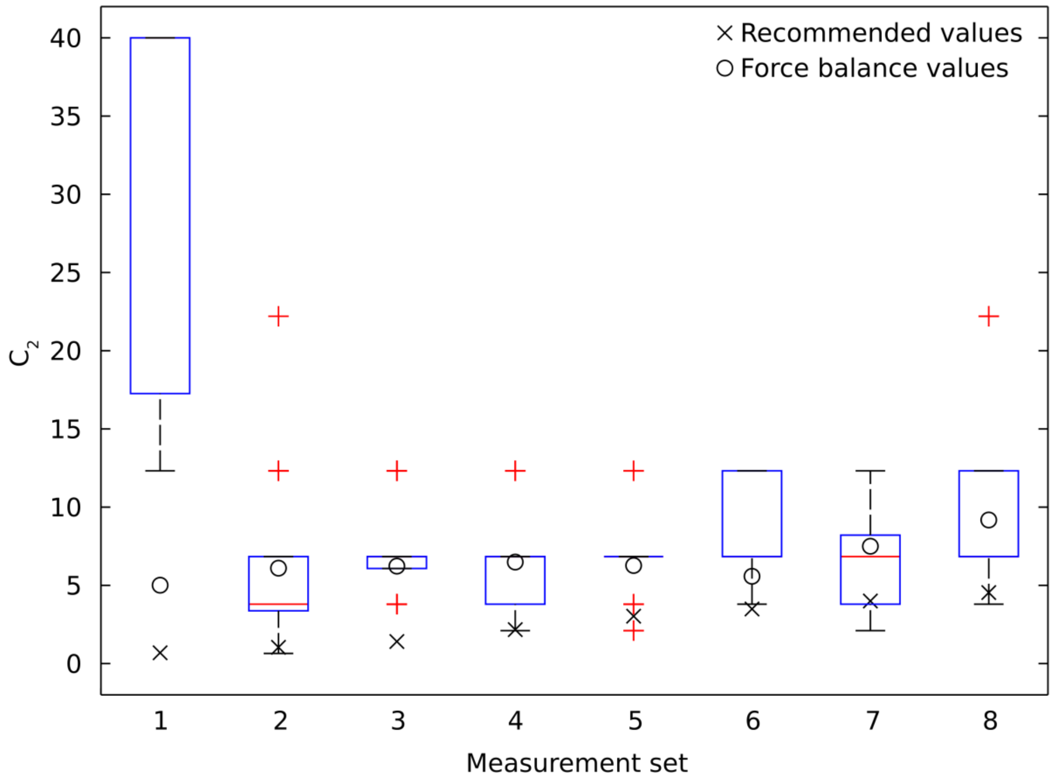



- Fully submerged
- Q=29 l/s

- Potentially over compensating of the lack of stem wake turbulence?

- Under-estimation here further suggests the Ergun approach to deriving $C_2$ values may not be suitable

# Using a force balance instead



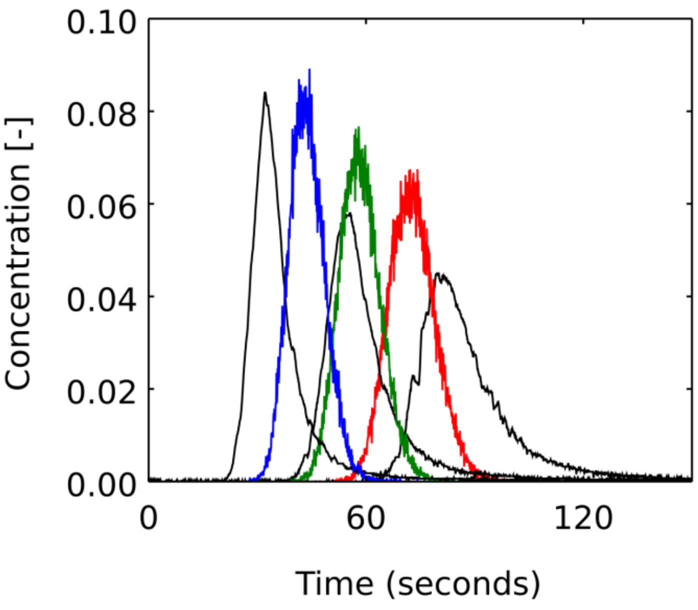

- Balancing $C_2$ with forces…

$$C_2 = \frac{2gS}{u^2 h}$$

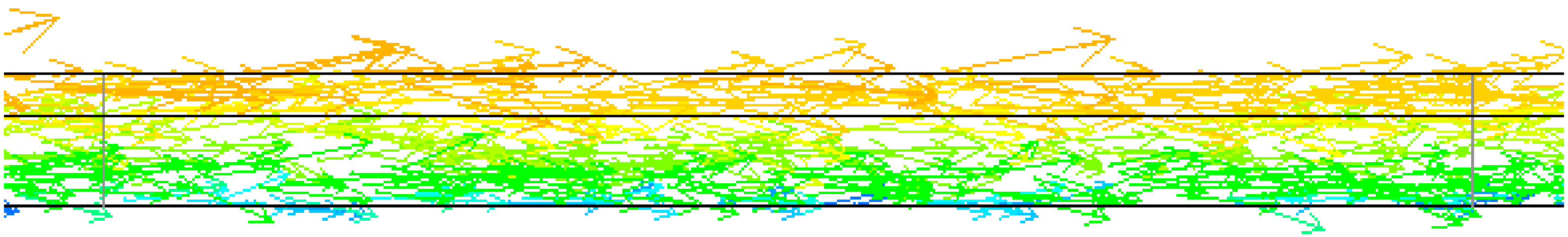
- The best-fit and derived $C_2$ values agree well

# Fixing the turbulence problem

- Extend the CFD model to take into account turbulence generated by the stem wakes
- A simple approach to doing this is to fix values of k and ε (i.e. add in turbulence throughout the vegetation)
- The next steps are to investigate this further



# Thanks for listening!



Questions?

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