Modelling river flow through in-stream natural vegetation for a gravel-bed river reach

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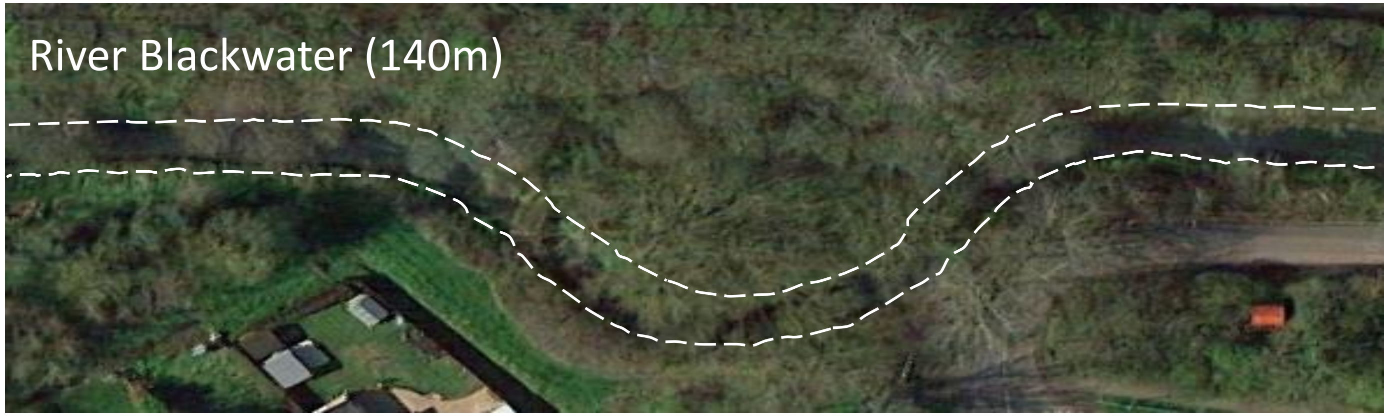
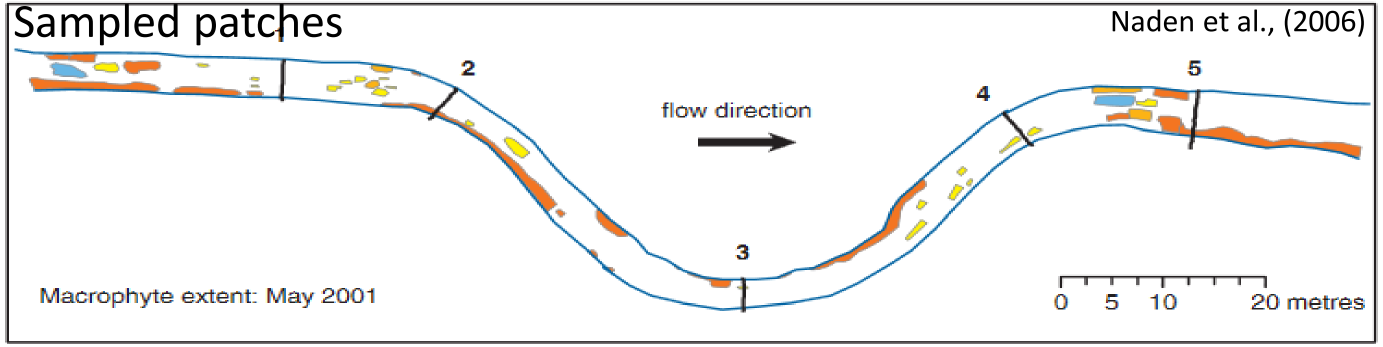
Motivation

- Vegetation slows flow
- Increases fluvial flood risk
- Most research uses 2D or artificial environments (flumes)
- Vegetation effects are 3D
- Field data collected by Centre for Ecology & Hydrology (ceh)

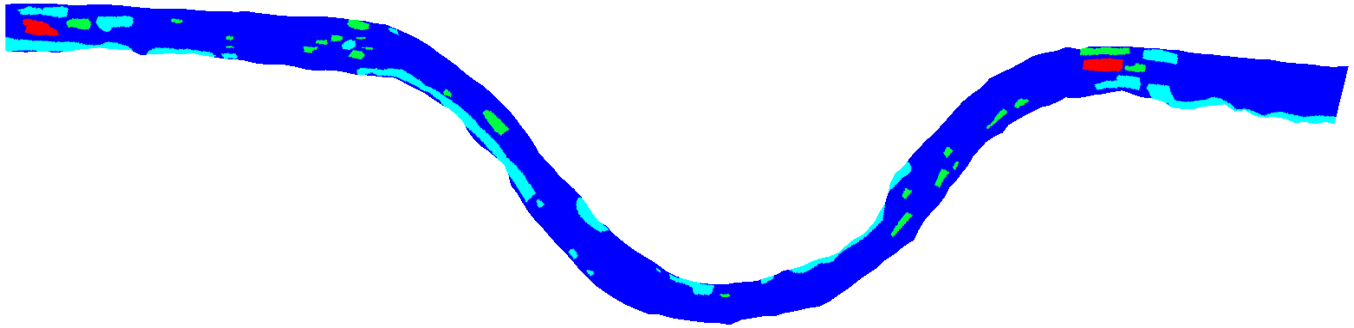
3D model: Telemac

- Finite element approach
- DANS & *k* -ε *t*urbulence closure
- Calibration site: River Blackwater, UK





Mesh-integrated patches



Gravel-bed roughness (method):

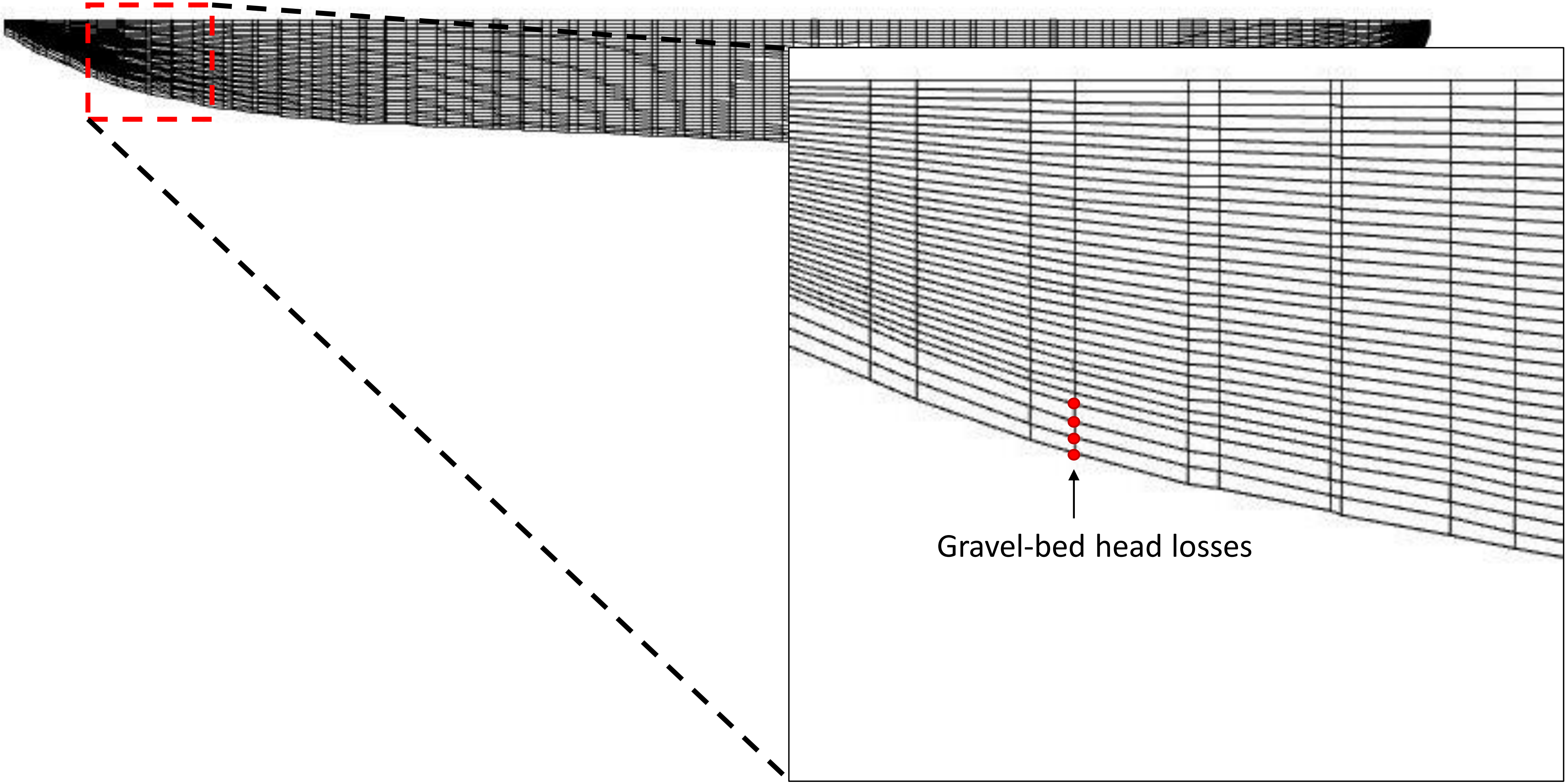
- Drag-force approach
- Spatially-averaged riverbed parameters
- $C_d\ S_f$ = density/size/wake of roughness elements
- Head-losses applied at 4 layers

$$F_x = \frac{1}{2} C_d S_f A_{px} U^2$$

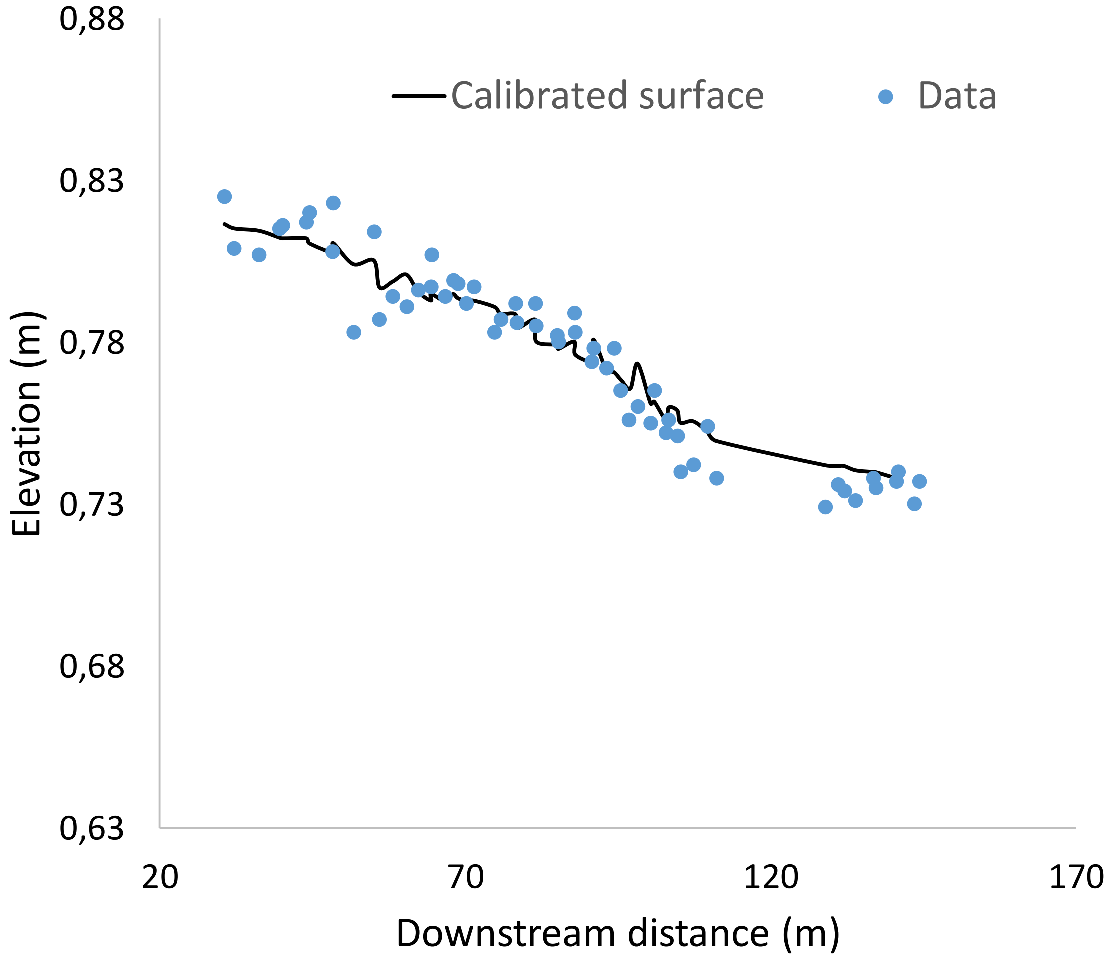
$$F_y = \frac{1}{2} C_d S_f A_{py} V^2$$

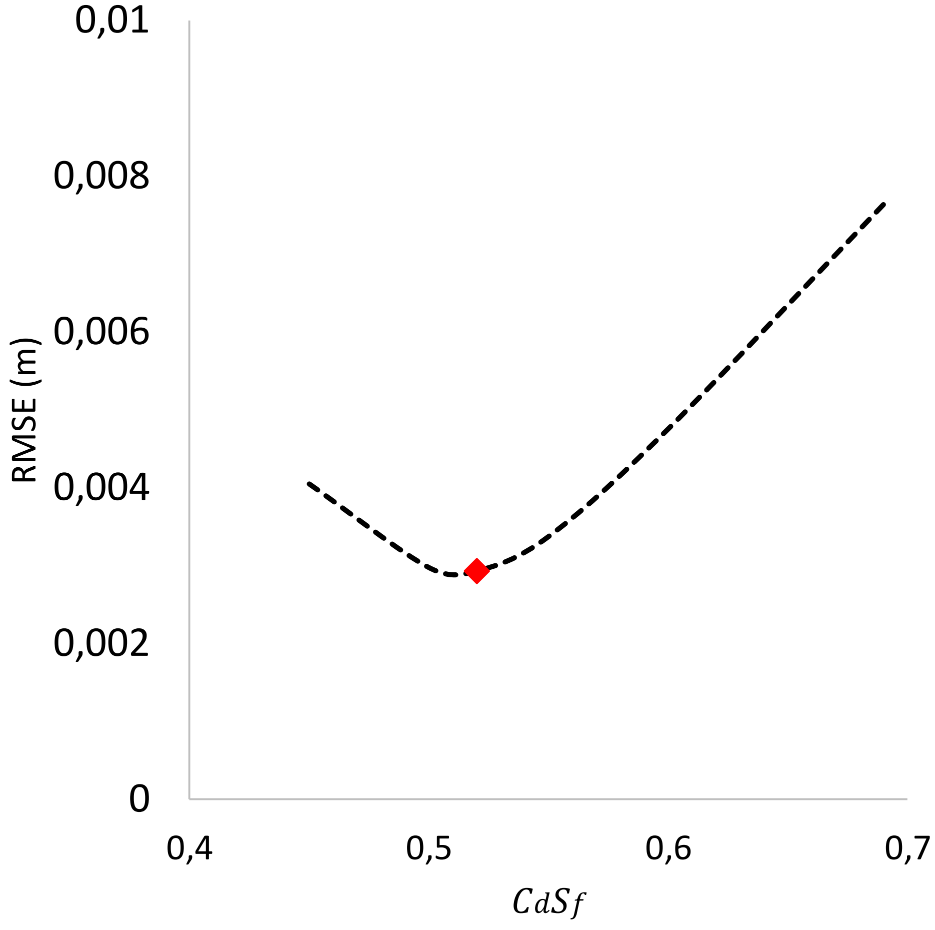
$$F_w = \frac{1}{2} C_d S_f A_s W^2$$

Layer	Layer height (mm)	Frontal projected area A_{px} (m²/m³)	Frontal projected area A_{py}(m²/m³)	Frontal projected area A_s(m²/m³)
1	0	1.6546	1.9889	13.8340
2	10	12.0348	15.0840	77.5191
3	20	12.3361	14.8194	76.6161
4	30	2.1330	2.4954	15.3330


Gravel-bed head losses

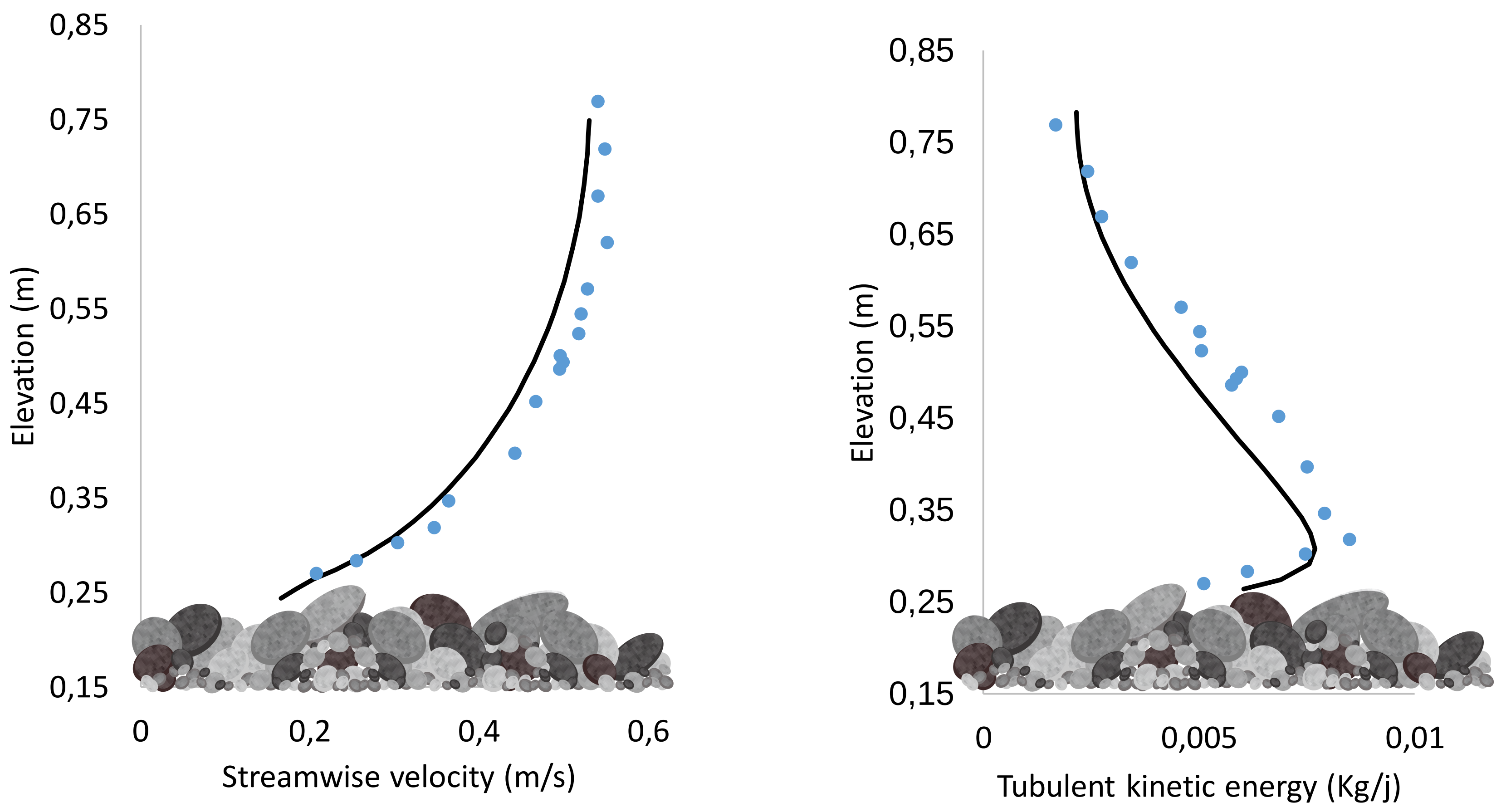
Gravel-bed roughness (calibration):





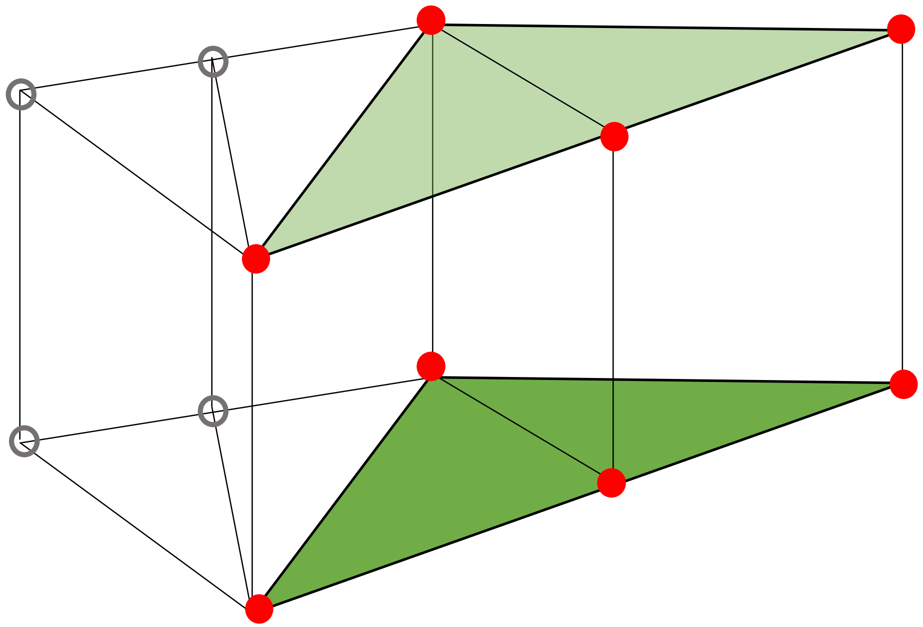
Gravel-bed roughness (calibration):

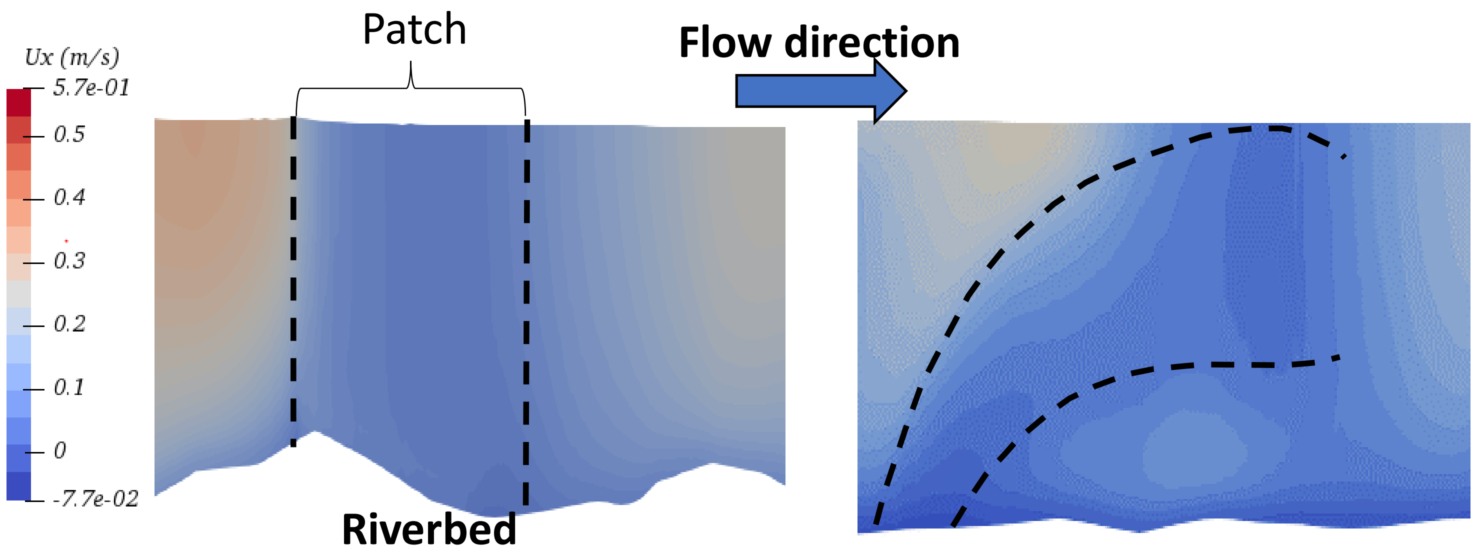
Flow direction



Vegetation: integration

- Head losses applied at occupied nodes
- Plant profiles estimated from site imagery
- Two profiles used:
    - Emergent (uniform)
    - Submerged (trailing)





Vegetation: method

- Method one: classic drag-force approach

$$F_{vi} \approx -\frac{1}{2} C_{dv} S_{fv} A_s |\langle \overline{u_i} \rangle| \langle \overline{u_i} \rangle$$

- S_{fv} = sheltering factor for close roughness elements

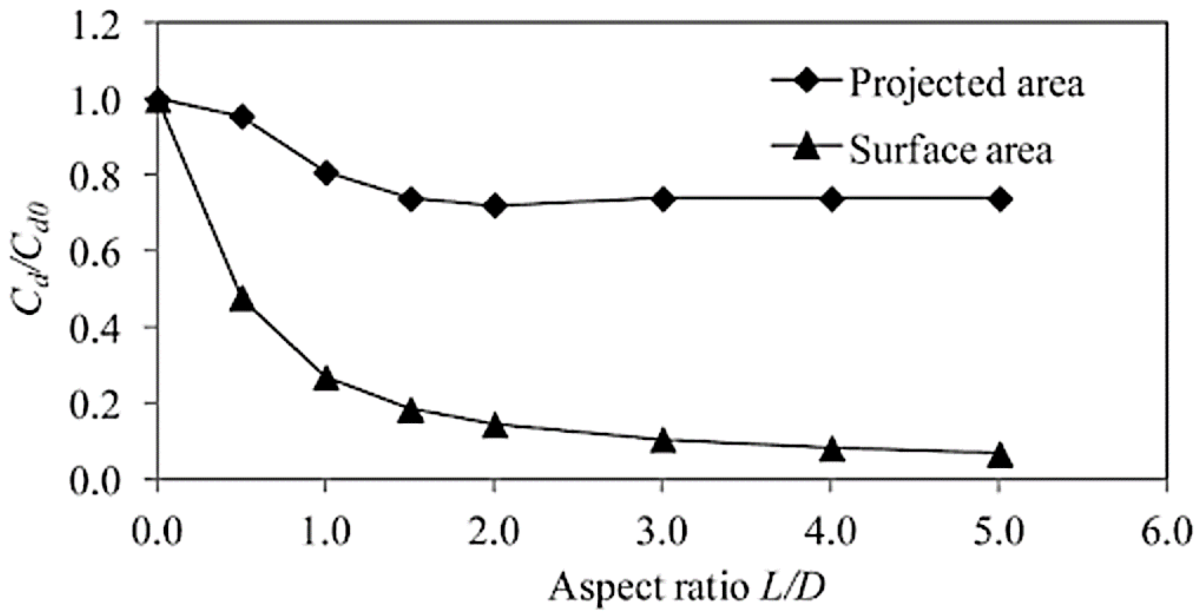
- Method two: patch shape approach

$$F_{vi} \approx -\frac{1}{2} C_{d0} R_f A_s |\langle \overline{u_i} \rangle| \langle \overline{u_i} \rangle$$

- Describes influence of patch geometry using aspect ratio

(Blevins, 2003; Rameshwaran et al., 2012)

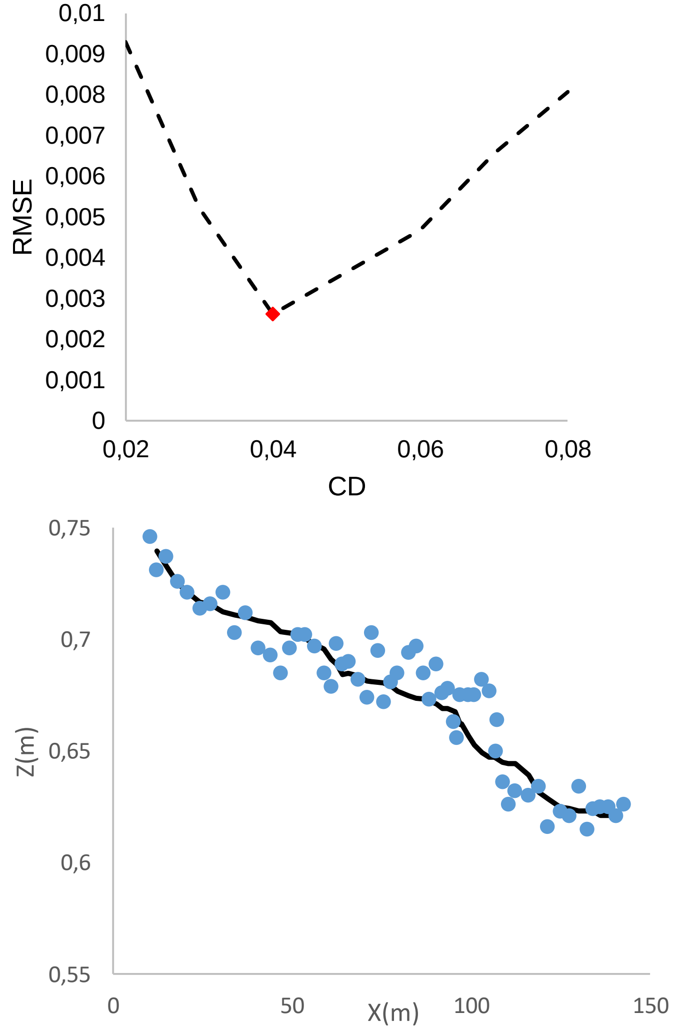
- $R_f = C_{dn}/C_{d0}$



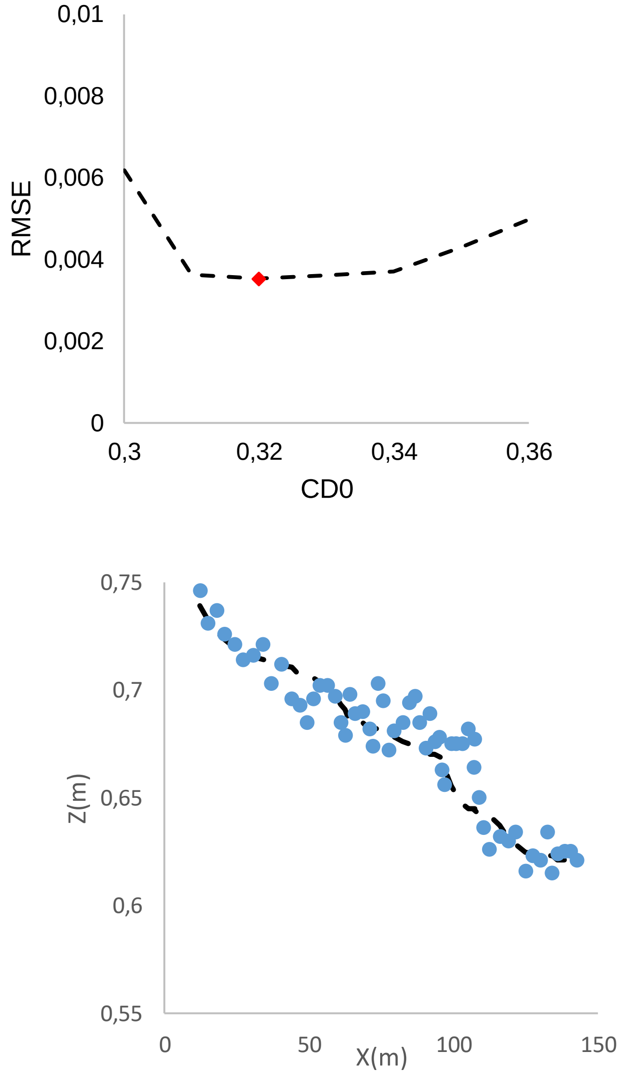
Vegetation: calibration

- Low (May) & high (September) biomass cases calibrated
- Method one Cd = 0.04
- Method two Cd0 = 0.34
- Both capture slope well, M2 within acceptable literature range

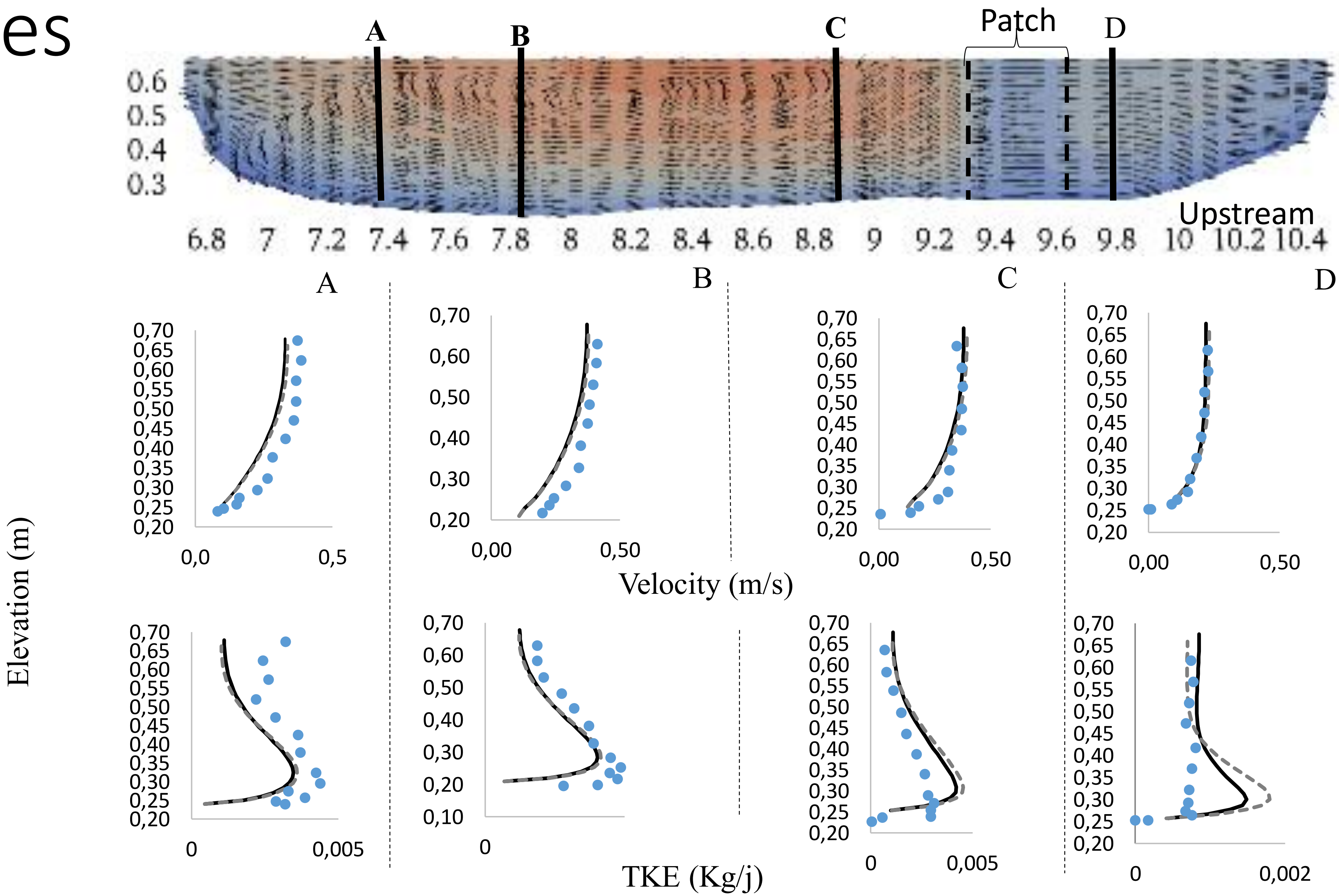
Method one



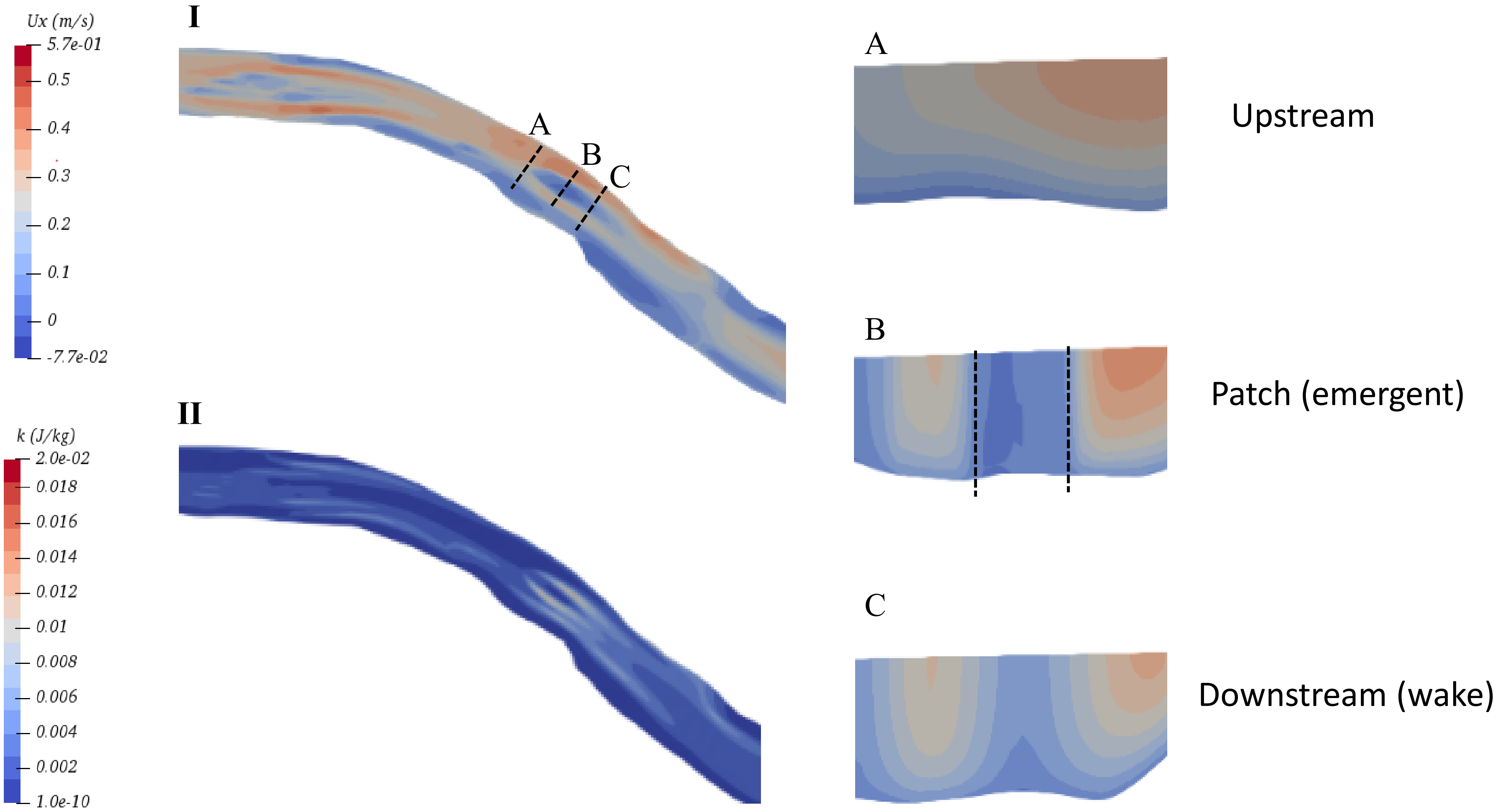
Method two



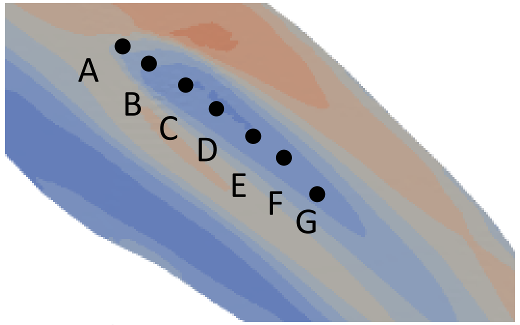
Vegetation: flow profiles

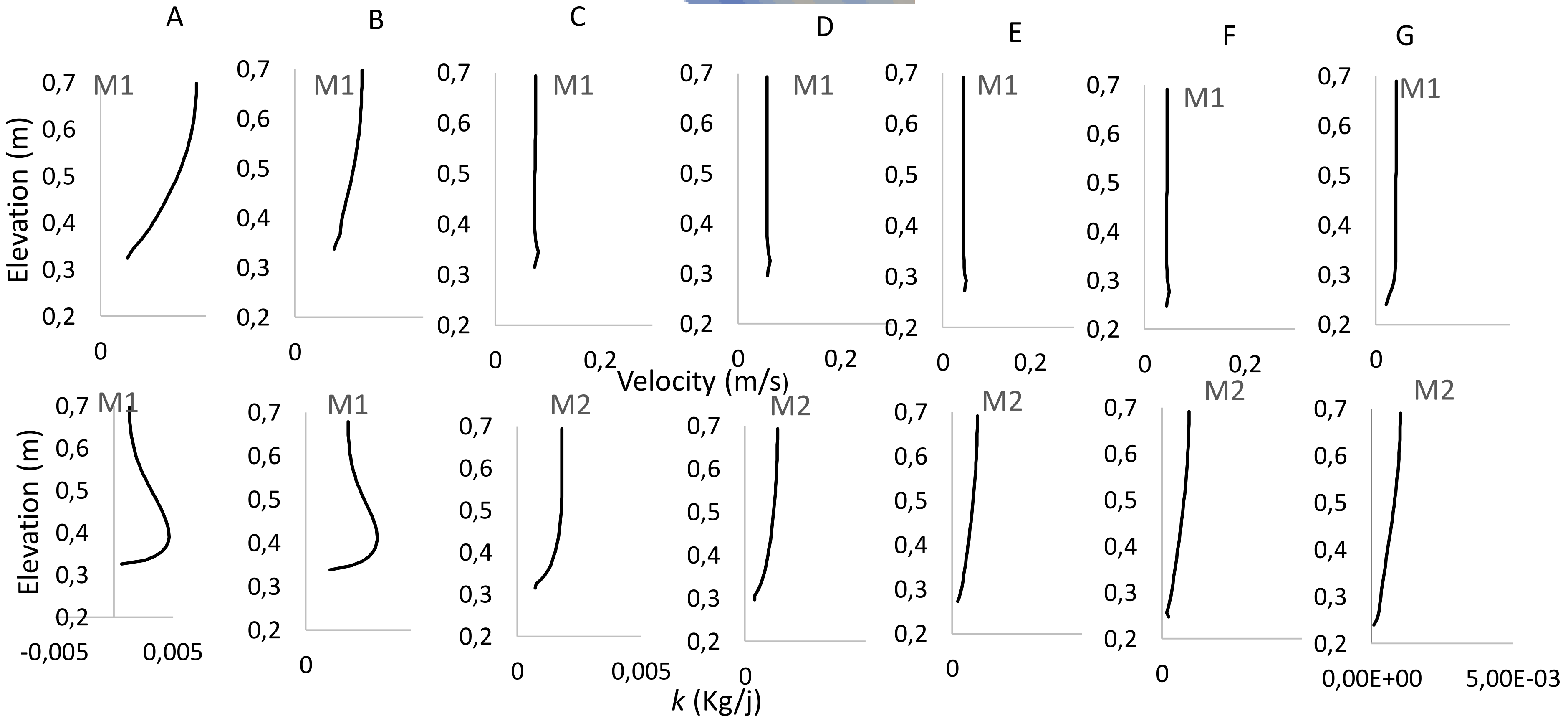


Vegetation: spatial variation



Vegetation: long profile





Conclusions

- Streamwise velocity & TKE matches data reasonably well
- Vegetation patches clearly modify flow
- Both methods perform similarly

Future work

- Simulate impact of vegetation on flow conveyance for:
  - Climate change scenarios
  - Changes to patch areal extent

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