Numerical modelling of colmation and decolmation processes for gravel-bed river restoration schemes

Stubbs, A. , Bockelmann-Evans, B. , Stoesser, T.

Hydro-environmental Research Centre, Cardiff School of Engineering, Cardiff University, UK (stubbsa1@cardiff.ac.uk)

Background

- Salmonid spawning in gravel-bed rivers has been severely affected by man altering suspended sediment loading.
- A balance between colmation, or infiltration, and decolmation, or entrainment, processes is required for successful spawning.
- Sediment oxygen demand and interstitial flows can be influenced by these processes.

Figure 1: Salmon leap [1]

- River restoration schemes aim to emulate the balance between colmation and decolmation.
- Though understood conceptually, the physics behind these processes is at best poorly described.
- It is only with recent advances in technology that the complexities of these processes, in particular microscopic turbulent flows, are beginning to be understood.

Modelling turbulent flow

- Rough channel boundaries create drag forces that influence boundary fluid velocities and cause turbulent flows to develop.
- Turbulent flows are difficult to model as the velocity field is 3D, time-dependent, random and constantly changing [2].
- Several simplified computational approaches to turbulent flow routing exist:
  - LES
  - DNS
  - RANS
  - PDF
- This research employs the RANs method since it is arguably the most practical and widely used numerical method [3].

The four zones of sediment transport mechanisms

The depth profile of a river can be divided into four different zones by the transport processes that occur within them, as shown in Figure 2.

1) Open channel zone
2) Near-bed zone
3) Infiltration zone
4) Subsurface zone

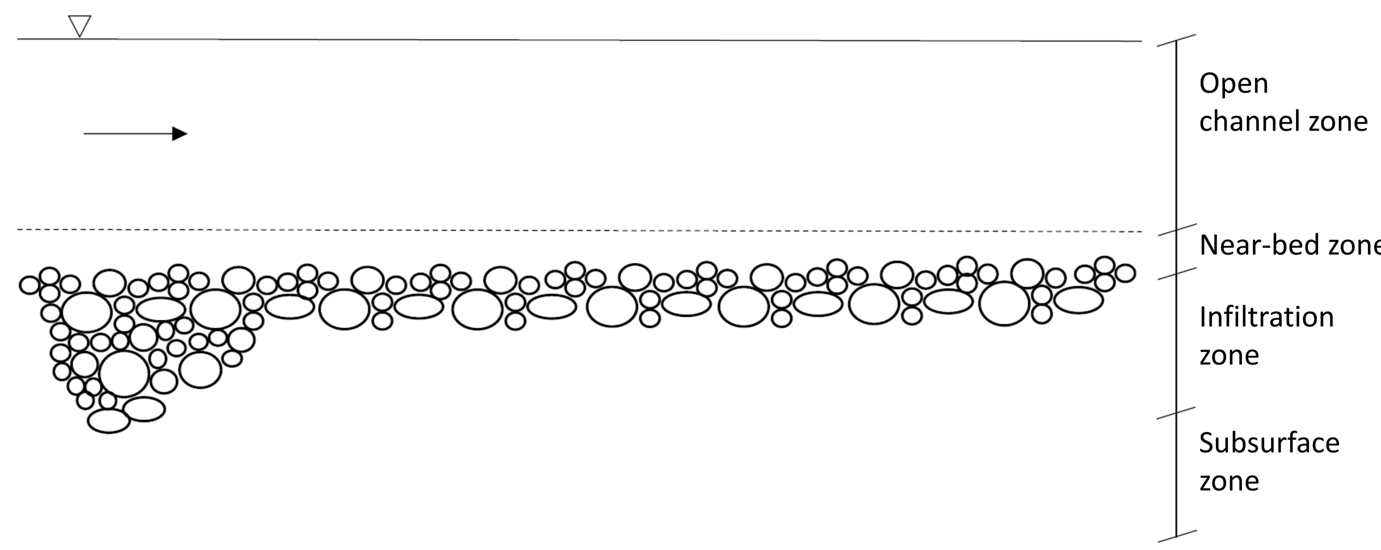

Figure 2: The four different zones within the depth profile of a river

Near-bed zone

Within the near-bed zone, several processes occur:

- Deposition
  - Equations are quasi-empirical and none consider all the factors affecting sediment settling velocity.
- Traction
  - Many empirical and physically based equations have been developed with varying degrees of success.
  - Only that proposed by van Rijn can reasonably be used in computational simulations as the formulation is physically and not empirically based [4].
- Entrainment
  - Conceptually well understood, however, the physics of this process are an evolving and developing research area with the affects of turbulent bursting often ignored.

Infiltration zone

- Darcy's Law describes a linear relationship between fluid velocity and hydraulic gradient based on many assumptions.
- It is well established that due to such assumptions, Darcy's Law is not applicable to flows subject to relatively high or low hydraulic gradients.
- Microscopic turbulence within the pore space of the riverbed causes flow non-linearity to occur [5]. This turbulent flow distorts the fluid streamlines, as shown in Figure's 3 and 4, by enhancing the effects of inertia on fluid particles [6].

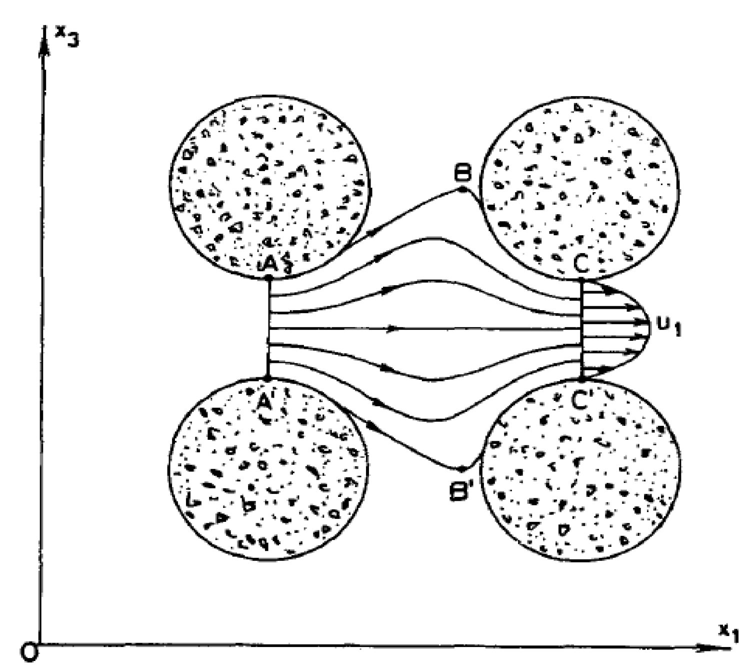

Figure 3: Idealised velocity streamlines [6]

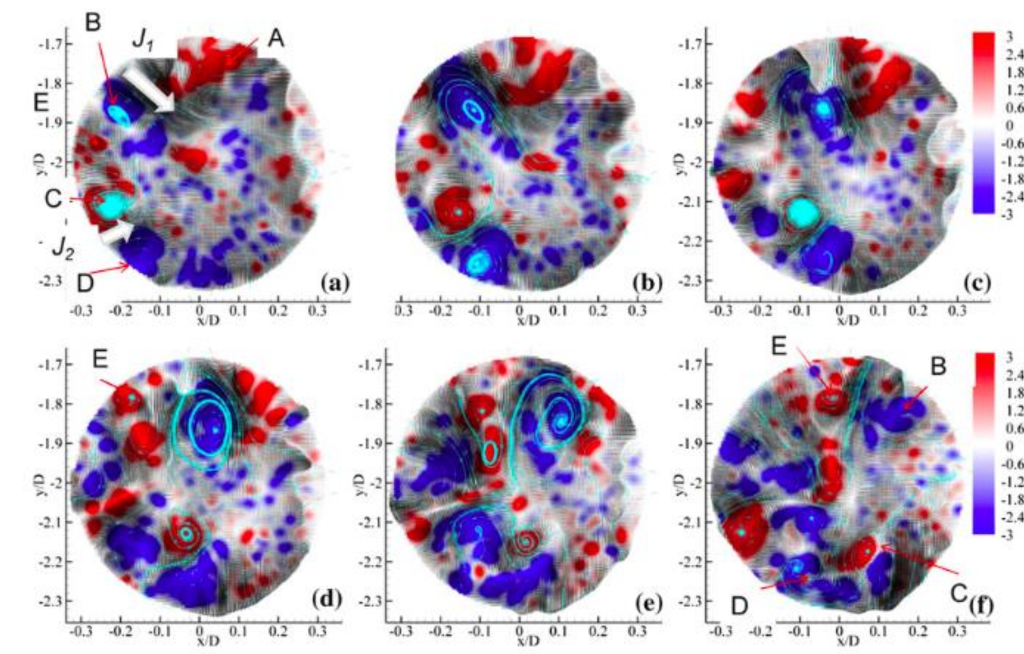

Figure 4: The development of jets within pore space [7]

- Flow conditions within the pore space greatly affects sediment transport no differently to how it is affected by turbulence in the open channel.
- Laminar flow conditions tend to cause sediment to clog pore space whilst turbulent flows keep particles moving [8][9].
- It is unclear from the literature whether sediment particles infiltrate the riverbed as a result of turbulent flows generated by the bursting phenomenon.
- Much is still to be learnt about the physics of microscopic turbulent flow and its affect on sediment transport mechanisms are yet to be simulated.

Project Aims

- To further understanding of sediment infiltration and entrainment by focusing on the quantification of turbulence and its effect on transport mechanisms close to and within the riverbed.
- Refine the 2D numerical modelling package DIVAST (Depth Integrated Velocities And Solute Transport) through improved representation of colmation, decolmation and microscopic turbulent flow processes.
- Ultimately to improve the design and assessment of gravel-bed river restoration schemes.

Moving forward

- Modify DIVAST to allow both near-bed and interstitial turbulent flows as well as the associated sediment transport mechanisms to be modelled.
- Verify the model analytically and use results of flume experimentation for validation.
- Apply the newly developed model to case study river reaches in Wales, UK known to be salmonid spawning sites.

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