QUANTIFYING BED STABILITY: THE MISSING TOOL FOR ESTABLISHING MECHANISTIC HYDROLOGICAL LIMITS

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Abstract

Sediment transport processes are a key mechanism of ecological change in riverine systems, and certain levels of sediment flux are necessary for healthy ecosystem functioning. Altered flow regimes and sediment mobility are contributing to a global problem of higher substrate embeddedness reducing the frequency of substrate scour events and leading to increases in periphyton accrual. Excess periphyton accrual leads to fish and invertebrate kills from oxygen depletion, degraded ecological health, altered sediment dynamics, deterioration in water taste, and odour nuisance. In recent decades, reports of toxic periphyton proliferations have increased and are linked with health problems in humans including asthma, skin rashes, liver damage, and the death of domestic dogs. Excess periphyton accrual is prominent in impounded catchments where dams have a considerable impact on flow and sediment regimes. With at least 3,700 large dams currently under construction or in the planning phase the problem is set to increase in the foreseeable future.

Hydrological limits are widely implemented by authorities in an attempt to manage periphyton accrual. Hydrological limits are frequently based on flow-ecology relationships but are often ineffective. Sediment transport thresholds have been found to have a better relationship with periphyton accrual than hydrological metrics. Flow-ecology relationships do not account for the mechanisms of periphyton removal (scour, abrasion, and molar action) which are likely to vary between sites at equivalent flows, and the species-specific resistance to each mechanism also likely varies. Abrasion and molar action result from transport of sediment. Improving the effectiveness of hydrological limits as a tool for river management therefore relies on setting flows with the aim of inducing sediment transport to initiate mechanisms of periphyton scour. This will require models which can accurately predict the flow required to induce different phases of sediment transport. The research presented in this thesis focuses on improving the estimation of gravel entrainment to advance entrainment models as a means of setting hydrological limits to induce molar action and improve the effectiveness of periphyton removal.

A literature review of methods for estimating gravel particle entrainment thresholds in natural channels revealed a considerable gap in methods being available to quantify substrate characteristics to calculate resistance thresholds. The review also found significant challenges in identifying the onset of gravel transport in natural channels, and difficulty obtaining corresponding hydrodynamic data to identify entrainment thresholds. Further, the review found seepage was an important component of hydrodynamic forces for inducing particle entrainment in flumes, but seepage is not considered in conventional entrainment formulae, and is not measured alongside bedload transport data in the field.

A suite of tools is identified and developed to improve the quantification of substrate structure and resistance, identification of incipient motion, and quantification of entrainment thresholds in natural gravel beds to advance the assessment of bed mobility. Optical and ranging techniques are compared to identify an optimal approach to remotely quantify substrate structure. Both approaches were found to produce a comparable quantification of surface roughness using point cloud elevations, but identified different trends in surface layer development. Quantification of surface layer development was found to be sensitive to the cell size used to grid the data, and this sensitivity increased with higher-order statistical moments which were used to describe armouring. Airborne optical sensors were found to be the most versatile method for remote characterisation of gravel-bed surface structure, with a larger range of metrics being derivable from the same dataset to quantify a wider range of substrate structural and textural characteristics.

Whilst quantifying bed structure is critical for developing bed mobility models, measuring the resistive force of the bed created by the structural arrangement of particles is required for model calibration and empirical data collection. A protocol was developed to use a modified penetrometer to quantify the resistive force of the armour (active) layer in gravel-bed channels. The modifications made to the penetrometer made it sensitive to variations in armour layer compactness, and allowed for adaptive penetration depths enabling variations in armour layer thickness to be accounted for. The protocol and modified penetrometer provide a significant advancement in the ability to empirically quantify bed resistance and relate bed structure to potential bed mobility, and build on the remote sensing methods to provide a suite of bed resistance parameters for entrainment models.

Measurement of bed mobility is also critical for calibrating entrainment models and relating ecological metrics to bed mobility thresholds. Both direct and indirect measurement of bed mobility have benefits for research and river management. Tick-box indices are frequently used in ecological studies to provide an indirect assessment of substrate (in)stability (i.e. bed mobility). These indices often provide a poor approximation of bed mobility, and do not relate well with biotic communities, but their low-cost and rapidity make them a valuable tool for research and management. An improved index is developed to provide rapid, low-cost assessment of bed mobility. This index improves on previous methods by focusing on objective measurements of parameters where low-cost approaches are available, or providing a framework for scoring parameters where visual assessment is required. The index scores correlated well with tracer particle data, and were found to relate to accrual of *Phormidium* biomass. This index therefore provides a means to rapidly and cost-effectively estimate bed mobility and predict periphyton accrual.

Direct measurement of bed mobility is also required to provide an empirical dataset for the calibration of particle entrainment and transport models, and for the empirical derivation of hydrological limits. A multi-sensor system was developed to measure the onset of particle movement, and record corresponding hydrodynamic data, including bed seepage, to identify hydraulic entrainment thresholds in natural channels, and therefore address the challenges of identifying bedload entrainment thresholds identified in the literature review. A pilot study testing the system identified bed seepage and turbulence intensity as key predictors of particle entrainment, and discharge and mean velocity as the worst predictors. These findings challenge the use of discharge and mean velocity as the metrics used to set hydrological limits if mechanistic limits based on bed mobility-ecology relationships are to be established effectively.

These tools provide a means for scientists to study bedload entrainment and transport, identify their thresholds, and relate the frequency and magnitude of these processes to benthic community dynamics. This research will form the basis for establishing the mechanisms required to achieve removal of excess periphyton and establish hydrological limits to ensure these mechanisms function and effective removal of periphyton is achieved to maintain ecosystem health.

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