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Modelling gravel transport and morphology for the Fraser River Gravel Reach, British Columbia

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Abstract

A two-dimensional (2D) numerical hydrodynamic-morphological model is developed to investigate gravel transport and channel morphology in a large wandering gravel-bed river, the Fraser River Gravel Reach, in British Columbia, Canada. The model takes into count multi-fraction bedload transport, including the effects of surface coarsening, hiding and protrusion. Model outputs together with river discharge statistics were analyzed, producing distributed sediment budget and well-defined, localised zones of aggradation and degradation along the gravel reach. Long-term channel response to gravel extraction from aggrading zones as a flood hazard mitigation measure was also investigated numerically to assess the effectiveness of such an extraction. The total computed sediment budget agrees well with results based on field measurements of gravel transport available to us. This study points to the importance of a number of factors to bedload predictions: the gravel-to-sand ratio, the adequacy of resolving the wandering planform, and the distinction between bed shear stress driving bedload transport and bed resistance on the flow. These are in addition to the physical processes governing the flow field and gravel mobilization. The methodology presented in this paper can provide a scientific basis for gravel management including monitoring and extraction in order to maintain adequate flood protection and navigation, while preserving the ecosystem.

Keywords: Bedload transport; Gravel-bed river; River morphology; Hydrodynamic model; Fraser River; Gravel management

1. Introduction

River flow, sediment transport and river morphology are interrelated, mutually adjusting over a wide range of time and length scales. Their interrelationship has been used to estimate sediment transport rates and sediment budgets for river reaches by monitoring morphologic and bathymetric changes between repeated surveys (see e.g. Lane et al., 1994; Martin and Church, 1996; Brasington et al., 2000). This is known as the morphological approach to the study of bed material transport. The approach has a number of inherent limitations. Firstly, there is a practical tradeoff between spatial resolutions used and the size of the survey area. Channel surveys either target a small area with sufficiently high resolutions so as to derive meaningful local erosion and deposition within the channel, or cover a relatively large area with coarsely spaced resolutions. Secondly, the approach at best provides a time-average transport rate between repeated surveys. Such an average does not

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reflect the threshold behavior of bedload transport in a gravel-bed river. More importantly, the dynamic evolution through time cannot be established through the channel surveys.

Another type of surveying approach is to directly measure gravel transport rates, using a mechanical sampler (e.g. Helley and Smith, 1971; Bunte et al., 2004) or ADCP technology (e.g. Rennie et al., 2002; Rennie and Millar, 2004; Kostaschuk et al., 2005). Sampling uncertainties and instrument errors associated with mechanical samplers can be substantial. The measured transport rates reportedly depend on the sampler used (Ryan and Porth, 1999) and the sampling time interval (Bunte and Abt, 2005), which may result in unacceptable data errors. Moreover, it is impractical to use mechanical samplers over a large area because of problems of low frequency sampling. The ADCP technology presents the opportunity to cover comparatively large areas. But it is difficult to sample intensively within the bottom-tracking volume, which is needed to characterise the bedload transport field, and it is also difficult to handle a wide range of particle velocities. Another complexity using the technology is the interference possibly by near-bed suspended sediment, which causes biased bedload velocities (Rennie and Millar, 2004).

This paper presents an alternative approach to the study of gravel transport and its link to river morphology. The problem is approached through the use of a two-dimensional numerical model. Very few numerical models have been developed to date for the simulation of gravel transport and river morphology, and almost all of the existing gravel-bed river models (Armanini and di Silvio, 1988; Hoey and Ferguson, 1994; Cui et al., 1996; Van Niekerk et al., 1992; Nicholas, 2000; Ferguson et al., 2001; Cui and Parker, 2005) are one-dimensional. One-dimensional models allow for the along-channel variations in the flow and sediment transport fields, but do not explicitly resolve the cross-channel variations. Under many circumstances, both the along-channel and cross-channel variations are important. This paper predicts these variations using a two-dimensional model. The model is an extension by Li and Millar (2007) of an existing hydrodynamics model (DHI, 1999). The extension provides bedload predictions suitable for gravel-bed river applications.

The main features of the bedload predictions are as follows: the model takes into account the effect of particle hiding and exposure of mixed-size sediment, the quantity of each grain size available on the bed, the effect of grain size sorting, sediment transport relative to

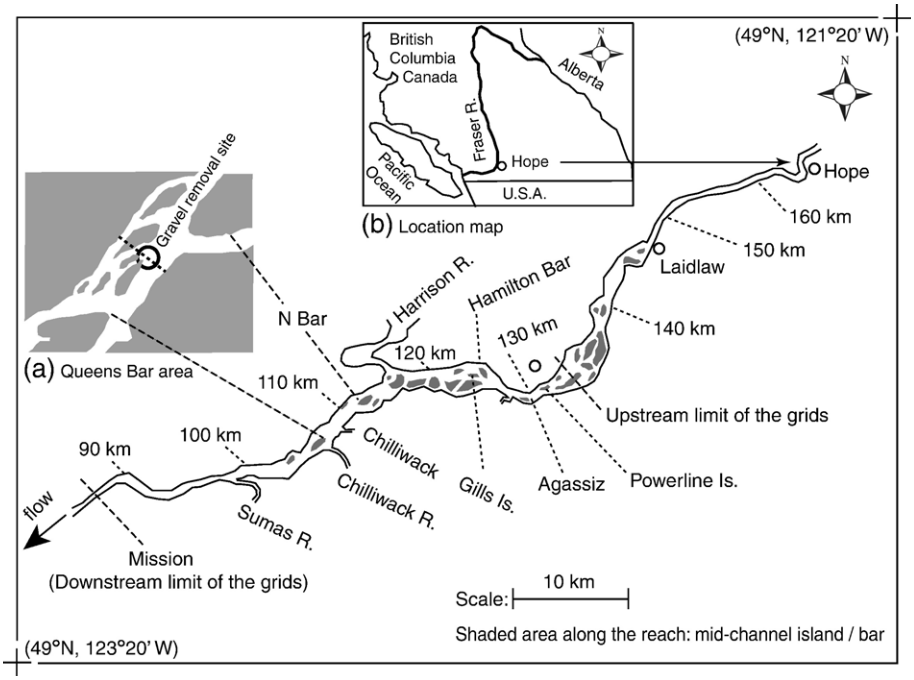

Fig. 1. Map of the Fraser River Gravel Reach area, showing river kilometers upstream from the river mouth. Between about 95 and 150 km is the gravel reach. The morphology is shown at moderate flow. Inset (a) shows Queens Bar area, where the circle indicates the site of gravel removal. Inset (b) shows the Fraser rising in the Rocky Mountains and flowing into the coast water of British Columbia, Canada. The shaded areas within the gravel reach are stable islands. The model area extends from Mission (river kilometer 85) to just upstream of Powerline Island at river kilometer 133.