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Monitoring and modelling particle and reach-scale morphological change in gravel-bed rivers: Applications and challenges

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Abstract

This paper focuses on developments in topographic data acquisition, including airborne remote sensing, digital photogrammetry, differential GPS, and laser profiling (e.g. LiDAR) technologies that allow rapid acquisition of high resolution and high precision topographic data sets over a range of spatial scales. These developments have offered new opportunities for investigating spatial and temporal patterns of morphological change in gravel-bed rivers and have contributed to revitalization in three key areas: (1) morphometric estimates of sediment transport and sediment budgeting; (2) boundary conditions for numerical models, including computational fluid dynamics and cellular modelling; (3) three dimensional characterisation of morphology that is independent of flow stage. The potential is clear but there remain a number of significant challenges, including quality control and the effects of error on specific applications and morphologies. This paper presents results from two investigations, representing field and laboratory analyses of gravel-bed river morphology at different spatial scales and for different applications. Case study 1 is concerned with monitoring and modelling morphological change in a large, braided gravel-bed river, using ground-based GPS survey and digital photogrammetry derived from airborne imagery. Case study 2 is an investigation of the mechanisms for infiltration of fine sediment into gravel-bed rivers, which applies close range laser altimetry in flume experiments to derive very high resolution digital elevation models (DEMs) that are used to quantify and analyse changes in bed texture. These case studies highlight the strengths and weaknesses of specific technologies and approaches to analysis of channel and floodplain morphology and change, and suggest key areas that remain to be fully resolved. In particular, the critical need to define a specific threshold level of detection associated with each acquisition method, and for different fluvial settings (e.g. bar surface, sub-aqueous zone), is emphasised.

Keywords: Gravel bed; GPS; Photogrammetry; DEM; Flume; Laser altimetry

1. Introduction

The last two decades or so have seen a major focus in fluvial geomorphology on developing topographic monitoring and modelling techniques to better quantify channel and floodplain morphology and morphological change in three dimensions. This represents a markedly different approach to many investigations of process–form relationships that prevailed in the mid to late twentieth century, which tended to emphasise process measurements over form analysis, including quantifying flow competence and sediment transport rates. In this type of approach, different morphological elements tend to be treated separately, with

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change analysis restricted to one or two dimensions (cross-section, planform, long profile), or specific morphological contexts (confluence, meander bend). The growing interest and attention given to three dimensional morphological analysis has been driven in part by developments in survey technology and data processing software, and by the increasing need for high resolution topographic data to better model fluvial systems (both numerically and physically). A major motivation for the latter is the concern of river scientists and engineers about the impacts of climate variability on river basins, and the challenge of improving flood prediction and risk assessment (Rumsby, 2001; Macklin and Rumsby, 2007). Increasingly sophisticated numerical models applied to flood inundation prediction highlight the importance of topography in determining 3D flow structures (Nicholas and McLelland, 2004). Such models require definition of channel and floodplain topography at high spatial resolution over the reach-scale. Quantifying the geomorphological consequence of changes in flood magnitude and frequency is also a concern, and identification of locations most susceptible to erosion and deposition requires knowledge of fluvial sediment transport rates and trajectories, and sediment budgets. In gravel-bed systems, where bedload forms a large proportion of the sediment load, monitoring of sediment transfer is notoriously unreliable due to its episodic occurrence in space and time, and experimental design is often the main control on observed sediment transport (Brasington et al., 2003). The morphological approach, involving volumetric analysis of 3D change over time, offers a significant improvement (Ashmore and Church, 1998).

The technological developments which have facilitated rapid topographic data capture and high resolution modelling over increasing spatial scales include new survey instrumentation and platforms, automation of previously manual procedures, and GIS software for processing and visualisation of large data sets. Robotised total stations and differential GPS have increased the speed and resolution of ground survey, although there is still a trade-off between spatial resolution and survey duration which often limits the areal extent of the survey (Brasington et al., 2003). Remote survey technologies, deployed on airborne and terrestrial platforms, provide almost instantaneous data capture and allow rapid survey of large areas. Semi-automation of the triangulation and DEM extraction procedures has led to wider use of digital photogrammetry and application in a range of fluvial studies (Lane and Chandler, 2003). Laser altimetry (e.g. LiDAR — light detection and ranging) has been less widely adopted as yet, but shows great potential for mapping gravel-bed river environments (Charlton et al., 2003).

Studies utilising high resolution topographic data in fluvial contexts divide into two types, static and dynamic. Static applications are concerned with high resolution modelling of topographic surfaces, often as initial or boundary conditions for numerical models, for model validation, or for landscape classification and mapping. Numerical models of flood propagation and inundation are highly influenced by topographic boundary conditions and the parameterisation of roughness, and incorporation of high resolution topographic data derived from airborne LiDAR has been shown to significantly improve finite element discretization (Bates et al., 2003; Cobby et al., 2003). In a flume study, Lane et al. (2004) demonstrated improvements in the prediction of flow processes in 3D computational fluid dynamics models (CFDs) with high resolution topographic representation (in this case derived from two media digital photogrammetry). Airborne laser altimetry (principally LiDAR), often coupled with multispectral imagery, has been used for classification of stream features (Leckie et al., 2005), mapping gravel-bed river geomorphology (Charlton et al., 2003), and characterising estuary hydromorphology (Gilvear et al., 2004). LiDAR also offers the advantage of being able to differentiate topographic height and vegetation height based on analysis of first and last return (Cobby et al., 2001). Whilst these applications highlight the clear potential of airborne laser altimetry, most of the authors express a note of caution over data quality. Significant errors have been reported in LiDAR surfaces associated with the presence of vegetation and deep water (Charlton et al., 2003) and in areas with variable terrain and large relative relief (Bowen and Waltermire, 2002). Dynamic applications are concerned with quantifying morphological *change*, and usually involve comparison (differencing) of DEMs of different epochs to obtain distributed patterns and volumes of erosion and deposition. In a laboratory study of drainage basin evolution, Brasington and Smart (2003) employed close range digital photogrammetry to derive DEMs with a vertical precision of 1.2 mm and threshold level of detection of change between surfaces of 3 mm. Field applications have been used to quantify bank erosion (Thoma et al., 2005), morphological change after chute cut-off (Fuller et al., 2003), and braided river dynamics (Brasington et al., 2000, 2003; Lane et al., 2003).

This paper employs two case studies, concerned with modelling topography and quantifying morphological change in gravel-bed systems at the particle and reach-scale, to explore more fully some of the issues raised above and highlight key challenges. Three point-collection technologies are applied, photogrammetry and differential GPS survey in the field, and laser altimetry in the flume.