Bedform morphology across the fluvio-tidal-marine hydraulic transitions: Lower Columbia River, USA

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ABSTRACT: Multibeam Echo Sounder (MBES) data collected within the main channel of the lower Columbia River (LCR), USA, from river kilometer (rkm) 0 to 90, provides insight into the spatial changes in bedform morphology across the marine-tidal-fluvial hydraulic transitions. Preliminary results suggest both bedform height and wavelength increase in magnitude from the (downstream) tidally-dominated, hydraulic regime to the (upstream) fluvially-dominated, tidally-influenced, hydraulic regime, even although maximum flow depths remain constant at ≥ 15m. Furthermore, the greatest variance in bedform height and wavelength occur within the mixed tidal-fluvial, hydraulic regime, where combined-flows dominate, whilst maximum bedform heights (~ 2m) occur within the tidally-dominated, tidally-influenced, hydraulic regime. However, the maximum bedform heights of ~ 2m are lower than predicted given maximum flow depths of ≥ 15 m. This suggests that the complex structure of unsteady flows may potentially mitigate the growth of bedform height.

1. INTRODUCTION

There currently exists a paucity of understanding regarding the spatio-temporal changes in bedform morphology in combined flow environments such as estuaries, delta distributary channels, and tidal bays. However, a multibeam echo sounder (MBES) data set acquired between 2007-2009 by the National Oceanic and Atmospheric Administration (NOAA), across the lower Columbia River (LCR), USA, fluvio-tidal-marine hydraulic regime transitions, provides rare insight into the along-channel spatial changes in bedform characteristics as a function of differing hydraulic regimes (e.g., fluvially-dominated, tidally-influenced regime, mixed tidal-fluvial regime, and tidally-dominated, wave-influenced regime). Herein, we utilize this data set to compare/contrast LCR bedform metrics such as height and wavelength, in order to identify distinct bedform morphological changes dictated by the along channel transitions in dominant flows.

2. BACKGROUND

The LCR possesses a mean annual discharge of ~ 7300 m^3s^{-1} (Naik & Jay, 2011), with maximum peak flows of 15000-17000 m^3s^{-1} occurring between April and June (i.e. spring freshets) (Gelfenbaum, 1983; Naik & Jay, 2011; Simenstad et al., 2011). The LCR also experiences mixed diurnal and semidiurnal tides where the mean range of tide (MN) and highest astronomical tide (HAT) are 1.7 and 3.6 m at river kilometer (rkm) 0 (mouth of LCR). In contrast to its location along the active Cascadia Subduction Zone (CSZ) margin, the LCR maintains a gentle mean channel slope equal to *c.* $1.15e^{-5}$ (Jay, 1984). During low river flow, the relatively low channel slope promotes: (a) tidal modulations of water surface heights as far upstream as rkm 233 (Kukulka & Jay, 2003), (b) flood-tide induced current reversals to ~ rkm 109 (Clark & Snyder, 1969), and (c) saltwater intrusion to ~ rkm 37 (Fox et al., 1984). Post dam closures, the LCR total sediment discharge (Q_{tot}, where $Q_{tot} = Q_{bl} + Q_{wl}$ (where

Q_{bl} and Q_{wl} represent the bedload and suspended/wash-load components of Q_{tot})) is estimated to be ~ 10 $Mtyr^{-1}$ (Milliman & Syvitski, 1992). The majority of Q_{tot} is conveyed as Q_{wl} in the form of very-fine sand, silt and clay, whereas approximately 10% of Q_{tot} is delivered as Q_{bl} in the form of fine to medium sand (Sherwood & Creager, 1990). Thus, the longitudinal LCR channel reach investigated herein ranges from its mouth (rkm 0) to immediately upstream of the Beaver Army Terminal gauge station (~ rkm 90) (Figure 1). This channel reach covers three basic hydraulic zones defined by Jay et al. (1990) (Figure 1): (a) the tidally-dominated lower river (rkm 0 to 21), (b) the region of minimum "energy flux divergence" (EFD), or mixed tidal-fluvial, hydraulic regime (rkm 21 to 56), and (c) the fluvially-dominated, tidally-influenced regime upstream of rkm 56.

3. METHODOLOGY

3.1 Bedform Measurement Techniques

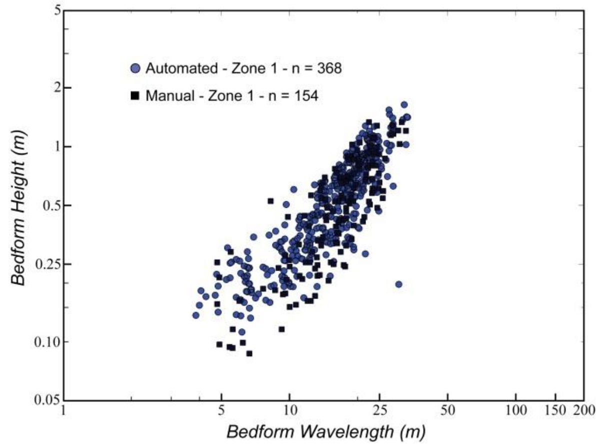
Bedform heights and wavelengths were measured at thirteen zones along the LCR study reach (Figure 1). Two different measurement techniques were utilized: (i) manual measurements conducted at five out of thirteen zones (Z-1, Z-6, Z-7, Z-8, and Z-13) using cross-sections oriented perpendicular to bedform crestlines produced from MBES XYZ surface maps viewed within Global Mapper geographic information system (GIS) software, and (ii) automated measurements performed at all thirteen zones using exported XYZ values (sampled at 0.01m spacing) taken from cross-sections generated from MBES XYZ surface maps, where bedform heights and wavelengths were computed within Matlab software using the procedures outlined in Perillo et al. (2014).

4. RESULTS

4.1 Manual vs Automated Metrics

Manual versus automated bedform height and wavelength computations were compared and contrasted at Z-1, Z-6, Z-7, Z-8, and Z-13 along the LCR study reach (Figure 2). From this analysis, the automated computed bedform metrics from identical cross-sections, show that results from the automated procedure: (i) is consistent with manually-derived values (see Figure 2), (ii) circumvents human introduced measurement errors, and (iii) significantly reduce the total time necessary for bedform metric calculations, thus permiting a more robust investigation of the wider LCR study reach.

Figure 2. Comparison of manual versus automated



bedform height and wavelength measurements at Z-1 located within the marine to tidally-dominated, hydraulic regime (see Figure 1 for location).

4.2 Bedform Metrics : LCR Study Reach

The values of computed bedform heights and wavelengths across all thirteen zones investigated are shown in Figure 3. These results suggest that within the main channel of the LCR, bedform heights and wavelengths increase from the tidally-dominated, hydraulic regime to the fluvially-dominated, tidally-influenced hydraulic regime. The greatest variance between measured bedform heights and wavelengths exists within the mixed tidal-fluvial, hydraulic regime. This variance is hypothesized to be a function of the presence of multiple groups of bedforms produced by differing ratios of combined-flow energy sources operating within the thalweg of the main LCR channel, and within immediately adjacent shallower channel depths. Furthermore, the largest bedform heights (~ 2m high) are found in the fluvially-dominated, tidally-influenced, hydraulic regime, but are significantly lower than would be hypothesized given maximum flow depths of > 15m. This finding stimulates the question of whether unsteady flows driven by tidal forces may limit maximum bedform heights preserved within the fluvially-dominated, tidally-influenced, hydraulic regime. However, a much greater number of bedform height measurements are required, accompanied by rigorous statistical analysis, to officially test this hypothesis.

5. CONCLUSIONS

- Measured dune heights and wavelengths systematically increase from the (downstream) tidally-dominated, hydraulic regime to the (upstream) fluvially-dominated, tidally-influenced, hydraulic regime.
- Given flow depths of ≥ 15m, maximum dune heights are lower than would be hypothesized across all hydraulic regimes.
- The greatest variance in bedform height and wavelength is found within the mixed tidal-fluvial, hydraulic regime, where combined flows are most prominent.

6. ACKNOWLEDGMENT

This research was funded by UK Natural Environment Research Council (NERC) grant award NE/H007954/1, NE/H006524/1, NE/H007261/1 and NE/H00582X/1. We thank the Clatsop Community College Marine and Environmental Research and Training Station; we thank António Baptista, Michael Wilkin and Katie Rathmell for all their help and services. Lastly, we offer a special thanks to Pat Killion whose local knowledge of the lower Columbia River made all research possible.

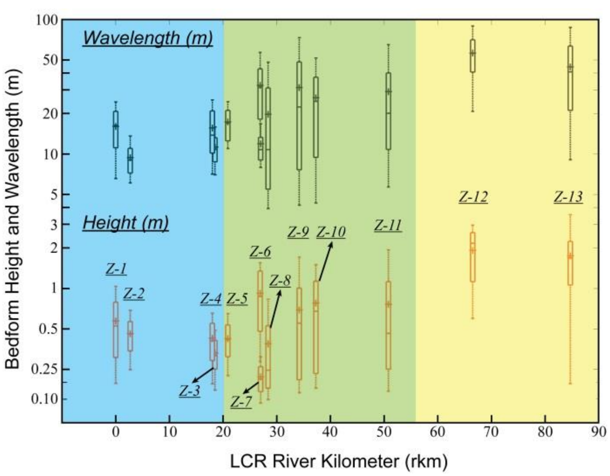


Figure 3. Bedform heights and wavelengths across the LCR study reach (Z-1 to Z-13; see Figure 1) as a function of differing hydraulic regimes. Rkm 0 to 21 (blue) represents the marine to tidally-dominated, hydraulic regime, rkm 21 to 56 (green) denotes the mixed tidal-fluvial hydraulic regime, and rkm 56 to 90 represents the fluvially-dominated, tidally-influenced, hydraulic regime.

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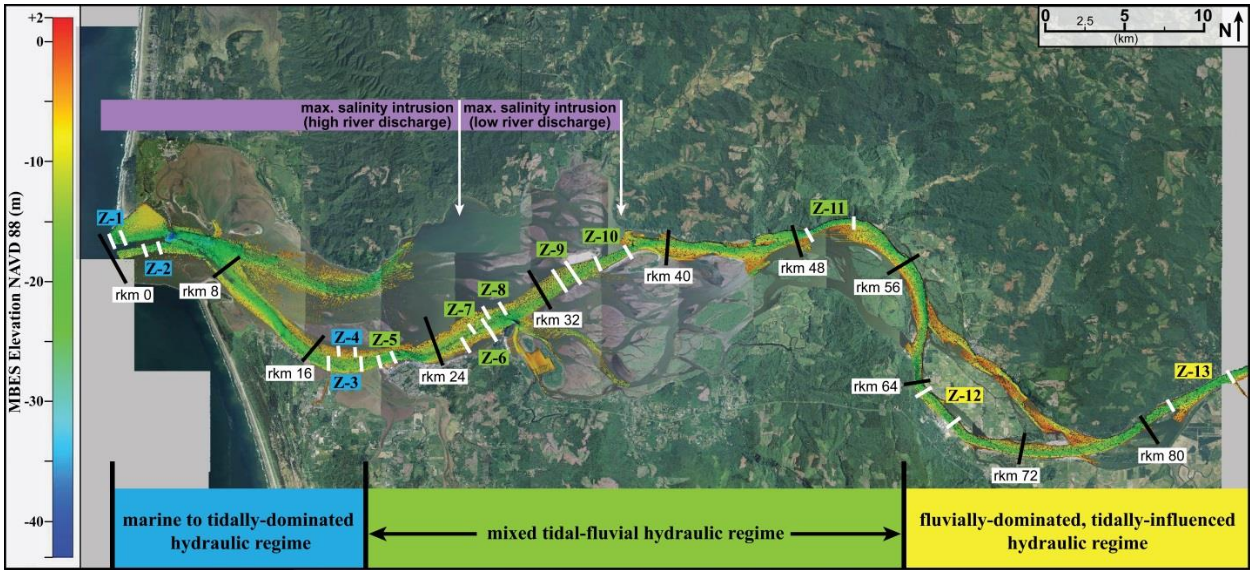

Figure1. Aerial image (2009) of the lower Columbia River (LCR) study reach displaying: (a) NOAA MBES channel surveying coverage (2007-2009), (b) the thirteen zones where bedform metrics were measured (Z-1 to Z-13), and (c) the longitudinal channel extent of the three major LCR hydraulic regimes as defined by Jay et al. (1990). Aerial image from US National Agriculture Imagery Program (NAIP) at https://gdg.sc.egov.usda.gov/.