Modelling depth-averaged flow in the fluvial-tidal zone: the spatio-temporal interaction of river discharge and tidal cycle

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The Columbia River has a strong seasonal variation in discharge, with a discharge around 3 000 m^3/s during the fall-early spring increasing to 12 000 m^3/s during the spring freshet. In this paper, we present flow predictions obtained using a 2D depth-averaged model (Delft3D) and flow measurements obtained using an Acoustic Doppler Current Profiler (ADCP). The 80 km-long and 3-5 km-wide modelled reach of the Columbia River Estuary (USA) extends from an upriver boundary at the Beaver Army Terminal (BAT) to the downstream water level boundary at the Hammond Tide Gauge (HTG) in the lower part of the estuary. The simulations were conducted using a boundary-fitted mesh with 120 000 ~40 m grid cells. Gauged discharge at BAT and water levels at HTG provide boundary conditions for the model. The bed topography was derived from a series of bathymetric (multi- and single-beam echo soundings) and LiDAR surveys conducted during 2009 and 2010 by NOAA, USACE and LCREP, and collated to generate a Digital Elevation Model (DEM). Bed shear stress was estimated using a variety of roughness parameterisation methods including Chezy, Colebrook-White and Manning and a uniform eddy-viscosity turbulence closure. The ADCP data were collected during low river flow in October 2011 (~4 000 m^3/s) and high river flow in June 2011 (~14 000 m^3/s) and June 2012 (~12 000 m^3/s). ADCP data were collected from six transects located within the fluvial-tidal zone for each data collection period. The width of these transects ranged from 0.5-2 km and the data were collected during both flood and ebb. The model was calibrated using water level measurements within the modelled reach and these results compare well with the measured ADCP data.

Both field data and model results reveal the importance of the balance between the hydrodynamic forcing of the tidal flood and river flow, combined with the resultant interaction with bar topography and bed roughness. These complex interactions result in the flow reversals during the rising flood being spatially distributed along cross-sections through the tidal zone. The findings reveal that these reversals occur across the shallower tidal-bar areas of the cross-section first, leading to bi-directional flow within the transect. The model predictions confirm that this spatial variation in flow is dictated by the momentum of the river flow through the deeper channels. As the stage increases during the tidal-flood, the flow reversals accelerate into the deeper areas of the channels. For the downstream part of the reach, the reversed velocities in the deeper channels increase to become larger than the flow velocities in the shallower regions. Upstream, where the tidal influence declines, flows only reverse across the shallower bar tops, whilst remaining downstream within the deeper channels. As flow stage begins to fall after high water, flow begins to accelerate and ebb, and a similar bi-directional flow pattern is observed. This bi-directional flow pattern during the ebb is less pronounced and has a shorter duration. The implications of this complex hydrodynamic forcing pattern during the tidal cycle for the sedimentology of the tidally-influenced zone include evidence of flow reversal being concentrated into higher bar-top areas.

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