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# FLOW MEASUREMENTS OVER LOW-ANGLE BEDFORMS IN A LABORATORY FLUME SETUP

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## 1 INTRODUCTION

In many coastal and estuarine environments, bedforms develop due to the complex interactions between hydrodynamics, sediment transport and morphology which affect hydro-morphodynamic processes at various spatio-temporal scales. Furthermore, bedforms are considered main drivers of flow resistance via turbulence and affect near bottom processes such as bed roughness, bottom shear stress and turbulent structures. A detailed study and characterisation of flow over bedforms is therefore significant to many fundamental and engineering applications such as sediment transport calculation and prediction, channel managements, or burial of submarine cables.

Asymmetric dunes with an angle-of-repose (30°) lee side have been well studied (Best, 2005; Venditti, 2013). They are representative of dunes commonly found in laboratory flumes and small rivers. Over such bedforms, flow is characterised by a permanent flow separation zone and intense turbulence over their lee side. Recently, it was shown that bedforms in large rivers are mainly low- to intermediate-angle dunes (mean lee side ca. 5-20°) having their steepest slope located close to the trough (Cisneros et al., 2020). Over such low- and intermediate-angle river dunes, flow separation is inexistent or intermittent and only little turbulence is generated (e.g. Kwoll et al., 2016; Lefebvre and Cisneros, 2023).

Estuarine bedforms also possess mostly low- to intermediate-angle mean lee slopes between 5° and 20° (Dalrymple and Rhodes, 1995; Lefebvre et al., 2021). However, contrary to river bedforms, estuarine bedforms usually have a sharp pointed crest with the steepest slope situated near the crest and a relatively flat trough (Aliotta and Perillo, 1987; Lefebvre et al., 2021). It is not clear yet how much flow properties vary between high-angle flat-crested dunes and low-angle sharp-crested dunes. In particular, it is unknown whether a permanent or an intermittent flow separation can be observed over some segments of the lee side. Furthermore, the relation between the reversing tidal flow and natural estuarine morphology is not well understood yet.

In this study, laboratory flume experiments will be conducted to measure the mean flow and turbulence over estuarine bedforms. Previous experiments performed by Carstensen and Holzwarth (2023) demonstrated the potential of high-resolution measurements over a large-scale estuarine dune in a laboratory flume. Building on this, experiments will be carried out over a fixed concrete low- and intermediate- angle estuarine bedform field. The results from this study can be used to characterise in detail the flow dynamics over estuarine bedforms.

## 2 EXPERIMENTAL METHODOLOGY

### 2.1 Planned flume experiments

Laboratory experiments will be conducted at the large flume facility of BAW (Federal Waterways Engineering and Research Institute), Hamburg. The facility is a recirculating flume consisting of two straight sections connected at their respective ends by a semi-circular segment to form a closed recirculating channel. The total length of the flume is 220 m with a straight channel section having a length of 70 m, a width of 1.5 m and a maximum water depth of approximately 1.3 m. A maximum flow velocity of around 1 m/s can be generated in two opposite directions through an underground pump. Three sets of experiments are planned with modelled shapes resembling that of the estuarine dunes observed in the Weser Estuary, Germany (Lefebvre et al., 2021) scaled down by a factor of 10. The three modelled dune shapes are described as steep asymmetric, low-angle asymmetric and low-angle symmetric, respectively. For each experiment, a set of 10 prototype two-dimensional fixed concrete dunes will be installed. The three prototypes each have different geometries and slope angles, with the position of the maximum lee side slope near the crest. The water depth, dune overall



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length and height are kept constant for all the experimental cases and only the dune profile is changed to allow comparison of the results between the experiments. Furthermore, measurements with reversed flow direction will be carried out for each experimental set. Figure 1 shows the details of the setup and design of the flume experiments.

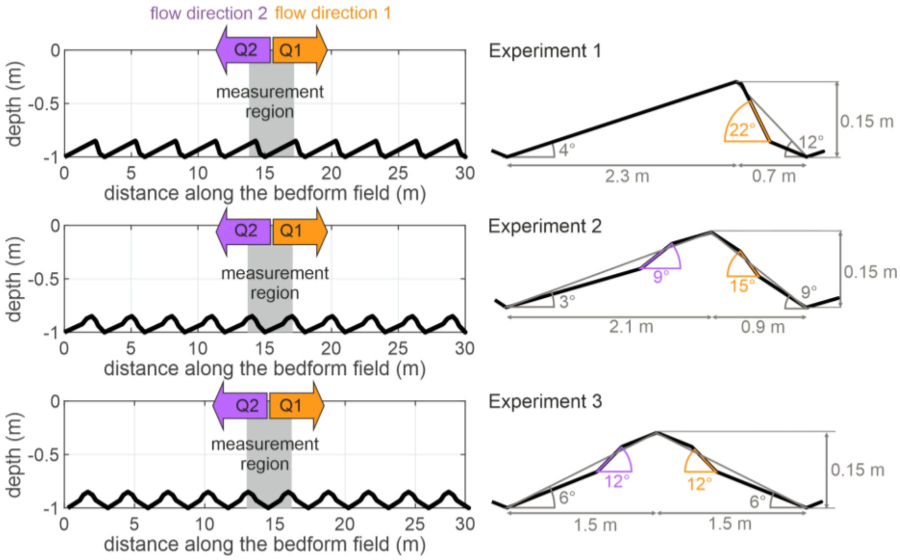


**Figure 1. Setup and design of the flume experiments.**

### 2.2 High-resolution flow measurements

Instantaneous flow velocities will be measured for each experiment using a sideward-looking Acoustic Doppler Velocimeter (ADV), Nortek Vectrino. Data will be collected at the centerline of the flume over the 5$^{th}$ dune where the flow is expected to be fully adapted to the bedform field and unperturbed by the end boundaries. To facilitate the high-resolution flow measurements required for this study, a motion unit has been installed in the flume. The motion unit is an assemblage of a metal structure holding the ADV and automatically moves it to predetermined point measurement locations. It greatly increases the efficiency of data acquisition and enhances the precision of measurement position which is difficult to achieve when placing the instrument manually.

Prior to the flume experiments with estuarine dunes, flow measurements over a 6 m span in the middle of the flume over a flatbed were conducted to ascertain that the flow is hydrodynamically turbulent and that flow velocities in opposite directions and over the whole measurement section have similar properties. The results show that the velocity magnitude and turbulent kinetic energy (TKE) profiles are comparable in both directions and for the different sections measured.

## 3 EXPECTED RESULTS

For the three experimental cases, mean flow and turbulence structures will be measured over dunes with varying morphology. High temporal resolution horizontal and vertical velocities will be used to define the (intermittent) flow separation zone, the turbulent kinetic energy will be used to define the turbulent wake structure, and the vertical gradient of the horizontal velocity to define the region of shear layer. Based on the results, a detailed description of velocity and turbulence over large-scale low-angle sharp-crested bedforms will be provided.

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