Bedform dimensions under supply limited conditions

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Abstract
The volume of mobile sediment on the river bed is the primary control on the dimensions of the bed forms that develop. If an unlimited supply of sediment is available the bed form dimensions which develop are determined by the water depth, the flow velocity and the sediment characteristics. This relation is described by the various models for the prediction of bed form dimensions which have been formulated (e.g. Van Rijn, 1984, Zhang, 1999). When the volume of mobile sediment is smaller than the volume required for equilibrium dimensions, the bed forms are supply limited and will remain smaller.

Introduction
In rivers, bed load transport sometimes takes place over a layer of sediment that is not erodible. The volume of bed load on the coarse layer is small, if the supply of sediment from upstream to the armoured section is small, compared to the transport capacity. In this case only small bed forms can form and this results in a small bed form roughness. With an increase of the sediment supply relative to the transport capacity the volume present on the armour layer increases. This allows larger bed forms to develop and results in an increasing bed roughness. Bed forms are an important factor determining the resistance to flow of the riverbed and therefore they are an important factor determining the water levels. Very little quantitative data on the behaviour of dunes under supply limited conditions is available. Therefore we have studied the dependency of the bed form dimensions on the availability of sediment in flume experiments.

Experimental Set-up
For the experiments we used a sediment-recirculating flume (Fig. 1). The flume had a width of 1 m and a length of 30 m; the effective length for measurements of dune morphology was approximately 17.5 m. The slope of the flow could be varied, so it was possible to realize a uniform flow at the desired discharge and water depth.

A gravel layer was installed in the flume prior to the experiments. The gravel layer consisted of almost uniform gravel with 86% of the weight between 8 and 16 mm. The grain size of the gravel layer had been chosen such that it remained stable under the shear stresses observed in the experiments. The sediment that was transported over the coarse layer consisted of uniform quartz sand with a d50 of 0.8 mm.

Table 1. Hydraulic boundary conditions in experiments.

<table>
<thead>
<tr>
<th>Series</th>
<th>h [m]</th>
<th>u [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.20</td>
<td>0.52</td>
</tr>
<tr>
<td>2</td>
<td>0.30</td>
<td>0.52</td>
</tr>
<tr>
<td>3</td>
<td>0.15</td>
<td>0.52</td>
</tr>
<tr>
<td>4</td>
<td>0.20</td>
<td>0.58-0.67</td>
</tr>
<tr>
<td>5</td>
<td>0.20</td>
<td>0.46</td>
</tr>
</tbody>
</table>

The experiments formed five series, each with a constant water depth and flow velocity (Table 1). During each experiment the volume of sand remained constant because the sediment was recirculated. For each series, the volume of sand on the coarse layer increased with each experiment, thereby decreasing the supply limitation. The volume of sand - including pores - on the coarse layer is expressed per square meter as the average layer thickness d (Fig. 2 and 3).

Results
Figure 2 shows a height map of a section of 5 m from the laser surface scans. Fig. 2 Exp. 1-1, shows a scan of the gravel layer. In Exp. 1-3, a layer sand of 1 cm in depth had been distributed over the coarse layer. The morphological pattern that emerged in the sand layer during the experiment is visible in Fig. 3 Exp. 1-3. Two flow parallel stripes formed where the sand transport concentrated. Ripple-like bed forms are present in the stripes. In Exp. 1-5, which had the same flow conditions, the sand layer thickness has been increased again with 1 cm.
In this experiment, straight-crested dunes appeared with a very regular topography. When we continued adding more sand, the bed forms grew bigger and became more irregular. This is illustrated in Fig. 2 Exp 1-6 - 1-9 by the disappearance of the straight crests, the appearance of the overlapping of dunes and the development of secondary bed forms on top of the larger dunes. With an increasing sand layer thickness, the influence of the coarse layer vanished and the dune dimensions increase to the alluvial dunes dimensions. In the other series (Series 2 to 5), the same experiments were performed at water depths and flow velocities different from those in Series 1. In these series similar trends were observed as will be shown in the following section where the relation of the bed form dimensions with thickness of the sand layer is explored.

**Bedform dimension reduction**

Using the data gathered in the experiments, the relation between the average active layer thickness and the dune dimensions has been studied. Figure 3 shows the measured dune heights ($\Delta$) against the active layer thickness. Both axes have been made dimensionless by dividing by the alluvial dune height ($\Delta_0$). It can be seen that although the series were done using different hydraulic boundary conditions, the results from all series collapse to one relation. This relation can be expressed using the function:

$$\frac{\Delta}{\Delta_0} = 1 - \exp \left( \frac{-d}{\alpha_h \Delta_0} \right)$$

This function is plotted as a solid line in Fig. 3. The parameter $\alpha_h$ determines the rate of growth of the dunes with increasing sediment supply. For dune length a similar relation has been derived. The series Dreano 1 and 2 are results from experiments using a similar setup but with much smaller dimensions (Dreano et al., 2008). This data also plots on the same line. This indicates that the relation also works for much smaller dimensions and may be scale independent.

**Conclusions**

A reduction function for the bed form dimensions under supply limited conditions has been derived using the experimental results. This function extends the use of bed form dimensions predictors to supply limited conditions.

**References**


A more extensive description of this work has been submitted to sedimentology.