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Sediment Nourishments for Degradational Engineered Rivers

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Introduction

Degradation of engineered rivers occurs due to natural and human-induced changes to planform geometry and boundary controls. Sediment nourishments are a common measure to mitigate channel bed degradation in engineered rivers (e.g. Golz, 2008). However, due to problem complexity, modeling sediment nourishments numerically remains a challenge.

Here we use equilibrium solutions to investigate the role of magnitude and grain size distribution of the nourished sediment on equilibrium slope. We consider the equilibrium profile of a river transporting mixed grainsize sediment. It can be argued that in natural systems equilibrium may never be achieved. However, the comparison between equilibrium states expresses the long-term trend for either aggradation or degradation. In particular, an increase in equilibrium slope S_{eq} is equivalent to net-aggradation, and a reduction of S_{eq} corresponds to net-degradation.

Methodology

We use the equilibrium solution of Blom et al. (2017) to study the long-term impact of sediment nourishments on a schematic river reach whose characteristic geometry, flow regime, sediment supply and bed material are loosely based on the Niederrhein River. In our calculation, the non-uniformity of the bed material is modeled in terms of two and three grainsize classes with characteristic diameters $D_1 < D_2 < D_3$. In the calculations presented below D_1 = 1mm, D_2 = 9mm, and D_3 = 30mm.

To determine if and how S_{eq} varies with the bed material grain size distribution, the total sediment flux is held constant and its grain size distribution is systematically varied. Equilibrium conditions are then plotted in a phase space of S_{eq} representing the possible values. Here we use the Ashida and Michiue relation (Ashida and Michiue, 1972).

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The sediment flux is then doubled to identify how S_{eq} may vary for the combined effect of changes in size and magnitude of the sediment supply.

Results

Equilibrium conditions in the case of a mixture of two characteristic grains sizes, D1 and D3, for different values of the volume fraction content of each grain size are presented in Figure 1, where the sediment size distribution of the sediment supply is represented win term of its geometric mean diameter $D_{g,feed}$. As $D_{g,feed}$, the geometric mean grainsize of the sediment feed, increases, S_{eq} increases, as expected. It is interesting to note as $D_{g,feed}$ coarsens from D_1 to D_3 the equilibrium slope practically doubles.

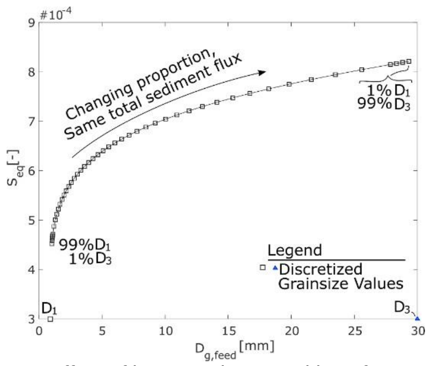

Figure 1: Effect of increased composition of D_3 sediment with a fixed total sediment load on equilibrium slope S_{eq}.

Equilibrium results in case of three characteristic grain sizes are presented in Figure 2.

When three characteristic grain sizes are used to model the sediment size distribution, each value of $D_{g,feed}$ corresponds to different grain size distributions of the sediment supply, i.e. the geometric mean remains the same but the volume fraction content of sediment with grain sizes D_1, D_2, and D_3 may vary. Consequently, different Seq can be obtained for each value of $D_{g,feed}$ (Fig. 2).
A close look at Fig. 2 reveals that for a given $D_{g,feed}$, S_{eq} is steepest when the sediment supply is a mixture of the finest and the

coarsest grain sizes (D_1 and D_3). Seq is mildest when the sediment supply is composed of relatively coarse material, D_2 and D_3.

Thus, in the case of sediment nourishments specifically designed to reduce/reverse channel bed degradation, adding material with characteristic grain size similar to the median/mean diameter of the bed sediment may not optimal.

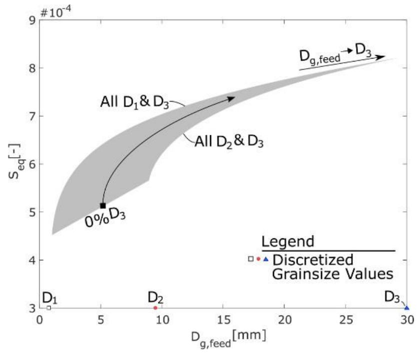

Figure 2: Possible S_{eq} values for a given total flux. The space is computed by varying the ratios of grainsize-specific sediment flux.

In addition, when the bed material is relatively fine, i.e. it is composed of D_1 and D_2, a change in grain size distribution corresponds to minor changes in Seq. This analysis clearly shows that the volume fraction content of coarse sediment plays a relevant control on S_{eq}.

When the total sediment flux Q_t is doubled the phase spaces, grey areas in Figure 3, largely overlap.

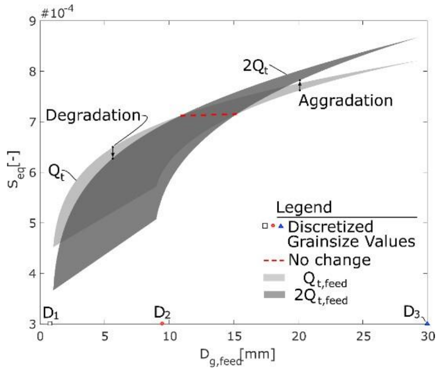

Figure 3: Comparison between possible S_{eq} values for total fluxes Q_t and $2Q_t$. The space is computed by varying the ratios of grainsize-specific sediment flux.

Fig 3. shows a dashed red line of no-change, where increasing Q_t does not affect S_{eq}. Above/right of this line, an increase in sediment supply results in a tendency for the river to aggrade; below/left of the line an increase in sediment supply tends to induce channel bed degradation.
These results disagree with previous work (e.g. Parker et al. 2007) suggesting that an increase in sediment supply always leads to steeper Seq, which is true for the case of uniform sediment and if we repeat the calculations by assuming equal mobility of the sediment particles differing in grain size. The results presented herein clearly show that the response of rivers transporting mixed size sediments to changes in sediment load depends on hiding/exposure effects that should not be neglected in the calculations.

In regards to sediment nourishments, the results in Fig 3. suggest that care should be taken in increasing the sediment supply because if the mixture is not properly designed the nourishments may have potentially detrimental effects, i.e. they enhance degradation. When sediment composition is well known, an increase in $D_{g,feed}$ (coarse sediment nourishment) can increase the number of conditions that cause net-aggradation.

Conclusions

Equations for the equilibrium conditions of mixed-grainsize rivers are used to understand how changes to the grain size distribution and sediment flux may result in aggradation. These results are interpreted to provide guidance regarding implementations of sediment nourishments to mitigate channel bed degradation.

For mixtures with equal means, bimodal (fine and coarse, D_1 & D_3) size distributions result in larger equilibrium slope than those that contain uniform, grainsizes. The composition of the largest grainsize is the most important factor to predict equilibrium slope. Finally, increasing the sediment load can cause net-degradation if the feed material is too fine.

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