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Can Linear Stability Analyses Predict the Development of Riverbed Waves With Lengths Much Larger Than the Water Depth?

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Abstract

Sustainable river management can be supported by models predicting long-term morphological developments. Even for one-dimensional morphological models, run times can be up to several days for simulations over multiple decades. Alternatively, analytical tools yield metrics that allow estimation of migration celerity and damping of bed waves, which have potential for being used as rapid assessment tools to explore future morphological developments. We evaluate the use of analytical relations based on linear stability analyses of the St. Venant-Exner equations, which apply to bed waves with spatial scales much larger than the water depth. With a one-dimensional numerical morphological model, we assess the validity range of the analytical approach. The comparison shows that the propagation of small bed perturbations is well-described by the analytical approach. For Froude numbers over 0.3, diffusion becomes important and bed perturbation celerities reduce in time. A spatial-mode linear stability analysis predicts an upper limit for the bed perturbation celerity. For longer and higher bed perturbations, the dimensions relative to the water depth and the backwater curve length determine whether the analytical approach yields realistic results. For higher bed wave amplitudes, non-linearity becomes important. For Froude numbers ≤0.3, the celerity of bed waves is increasingly underestimated by the analytical approach. The degree of underestimation is proportional to the ratio of bed wave amplitude to water depth and the Froude number. For Froude numbers exceeding 0.3, the net impact on the celerity depends on the balance between the decrease due to damping and the increase due to non-linear interaction.

Key Points

- Rapid assessment metrics from linear stability analysis predict the propagation of low bed waves provided that $Fr \leq 0.3$
- For $Fr > 0.3$ bed waves are more diffusive and migrate slower in time than predicted from linear stability analysis
- Linear stability analysis results can validate numerical models, which in turn may verify the validity range of the former