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Why river dunes do not form by a linear instability

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It is widely accepted that both ripples and dunes form in rivers by primary linear instability, the wavelength of the former scaling on the grain size, that of the latter being controlled by the water depth. We revisit here this problem, starting from the derivation of the turbulent flow over a wavy bottom, with or without a free surface. We show that the presence of a free surface always has a stabilising effect, whatever the choice of the turbulence closure and of the sand transport model. Consequently, dunes cannot result from a primary instability. We propose a weakly non-linear description suggesting that dunes result from a pattern coarsening process, the final wavelength being that for which the bedform amplitude is maximum.