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Valley-width control on gravel-bed river long-profile evolution

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In wide valleys, many gravel-bed rivers evolve their channel widths such that bank sediments are just below the threshold of motion during a geomorphically-effective flood. If we take this threshold channel state as the criterion for self-regulation, we find that the channel width is set by its discharge and slope; the former can change over years to decades, while the latter typically requires centuries to respond. As a result, such gravel-bed river channels widen or narrow in response to changes in the geomorphically-effective (e.g., bankfull) discharge, thereby maintaining a constant flow depth and geomorphically-effective bed shear stress. By widening or narrowing in response to changes in discharge, they maintain a linear relationship between water and bed-load sediment discharge. But what happens when the valley is narrower than the width that a self-formed gravel-bed river with alluvial banks would attain? In this case, increases in discharge always result in increases in depth, rather than overbank flooding. This leads to higher shear stresses that then produce a nonlinear increase in sediment transport rates. If not enough sediment is available, the river is able to erode to bedrock. Furthermore, the geometry of such valley-confined rivers precludes the concept of a "bankfull" flow, meaning that sediments may be moved by a wide range of geomorphically-effective flows, and not simply by a single "bankfull" flood event. Because the bed shear stress is no longer set by the critical shear stress threshold for initiation of particle motion, grain size becomes an additional and significant control on long-profile evolution. Here we demonstrate that these two types of rivers have different governing equations, with the valley-confined rivers being able to transport more sediment and evolve more rapidly. Such rivers are often found in rapidly-uplifting landscapes, in which river widening cannot keep pace with the growth of high valley walls, and in those that are experiencing transient width adjustment to changes in discharge. Understanding the transition from valley-confined to unconfined rivers can help us to understand how they are able to maintain topographic steady-state by transporting material out of tectonically-active mountain belts, and lends insight into the transient behavior of rivers that have undergone rapid changes in discharge or slope due to climate and/or land-use change.