Bankfull characteristics of alluvial rivers: evolution toward macroscopic equilibrium

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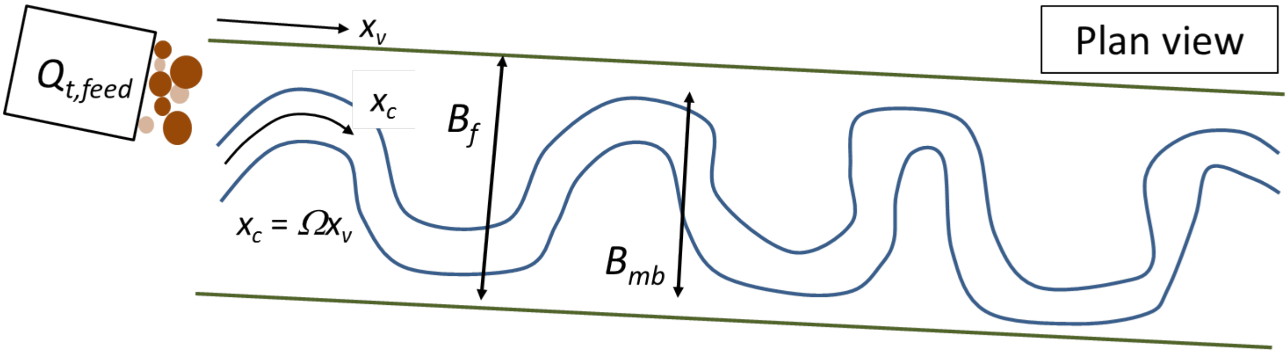
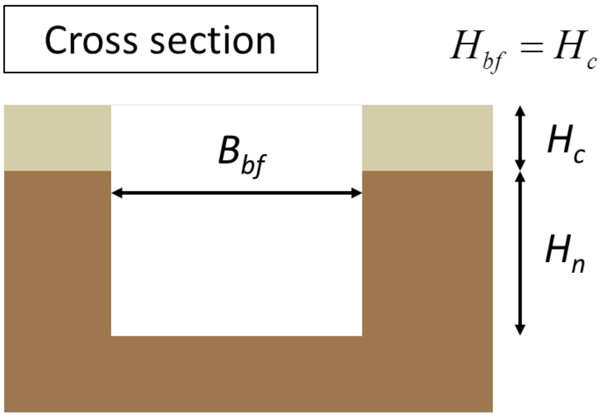
Alluvial rivers are often characterized in terms of their bankfull characteristics (i.e. bankfull discharge, bankfull width, bankfull depth, and channel slope). Studies on bankfull hydraulic geometry relations have shown that bankfull characteristics change in a consistent way with bankfull discharge. This suggests that if bankfull discharge is changed, bankfull geometry should change accordingly. Another problem of interest is the recurrence interval of bankfull discharge, which is often found to be 1 to 2 years. None of these studies, however, reveals what determines bankfull discharge to begin with. As a result, the parameters which determine bankfull characteristics and processes remain unknown. A better understanding of bankfull characteristics would lead to better prediction of how bankfull characteristics change. This knowledge is of great usefulness in many fields including geomorphology, engineering, ecology, and water management. In this study, we propose a framework for the establishment of and evolution to bankfull characteristics of alluvial rivers. It is commonly accepted that an alluvial river should self-evolve toward an equilibrium state, in which the net sediment flux within the reach of interest is zero. Applying this concept, we anticipate that such an equilibrium channel is able to maintain the balance between the fine sediment that is deposited onto the floodplain due to overbank flow (referred as floodplain construction herein) and the fine sediment that is removed from the floodplain throughout lateral channel migration (referred as floodplain destruction herein). Lateral channel migration leads to floodplain destruction because of the average elevation difference prevailing between the (older, thus thicker) outer eroding bank and the (freshly-deposited, thus thinner) inner depositing bank. The equilibrium channel must also be able to transport the supply of bed material without causing overall aggradation or degradation of the reach. In order to quantify floodplain construction and destruction, as well as the bed material sediment transport rate, we use a flow duration. We use this proposed framework to develop a numerical model to find the reach-average equilibrium bankfull characteristics for specified flow duration curve and bed material supply rate. The model not only predicts equilibrium, but can also be used to investigate the adjustment time scale of the system from one equilibrium state to another when it is disturbed. In the model, bankfull width adjustment is accomplished by modeling outer bank erosion and inner bank deposition independently; if outer bank erosion occurs at a faster rate than inner bank deposition, bankfull width increases in time. Bankfull depth adjustment is accomplished by modeling the morphodynamics of fine sediment, which deposits onto the floodplain, and the morphodynamics of bed material. That is, if the incoming bed material discharge is greater than outgoing bed material discharge, the channel bed of the reach in question should increase in elevation, leading to a decrease in bankfull depth. Likewise, if the effect of floodplain construction is greater than that of floodplain destruction, bankfull depth would increase. At the equilibrium state, the reach-averaged rate of outer bank erosion and inner bank deposition are expected to be the same, and the inflowing transport rates of both bed material and fine sediment should be equal to their corresponding outflowing values over a reach of interest. The model is applied to the Minnesota River near Jordan, MN, USA, in order to demonstrate the response of the system to changes in e.g. sediment supply rate and flow duration curve.

Keywords: Bankfull characteristic, Alluvial river, Overbank floodplain deposition, Lateral channel migration



$$H_{bf} = H_c + H_n$$



B_{bf}: Bankfull width [L]
B_f: Floodplain width [L]
B_{mb}: Meander belt width [L]
H_{bf}: Bankfull depth [L]
H_c: Upper cohesive layer thickness [L]
H_n: Lower non-cofesive layer thickness [L]
$Q_{t,feed}$: Bed material supply [L^3/T]
Ω: Channel sinuosity [1]