Numerical Modeling of Intrusive Gravity Currents at a River Confluence: from flow kinematics to hydrodynamics

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Abstract

Gravity currents, also known as density currents, constitute a ubiquitous phenomenon in hydraulics and geophysics. These flows are primarily driven by hydrostatic pressure gradients resulting from density variations due to differences in temperature, dissolved materials, or suspended particulate matter within fluid bodies. Understanding these flows is crucial for accurate prediction of suspended sediments in rivers and reservoirs, which ultimately governs sediment transport dynamics. In recent years, Taiwan has encountered significant challenges related to siltation in natural environments. To address these problems effectively, it is imperative to comprehend the evolution of flow morphologies and the propagation dynamics of gravity currents. While numerous studies have thoroughly investigated the morphodynamics of individual channels, sinuous submarine channels, and reservoirs, comparatively limited research has focused on fluvial network junctions. The flow characteristics at river confluences exhibit considerable complexity due to turbulent transport mechanisms, which stem from tributary convergence and inflows that generate mutual flow deflections and alterations in bed topography. This study examines how these flow phenomena impact environmental systems, with particular emphasis on high-resolution numerical modeling of gravity currents occurring at river confluences subject to constant inflows. For comprehensive analysis of turbulent transport processes, we implemented three-dimensional depth-resolving models based on the Navier-Stokes equations, incorporating the Boussinesq approximation and large-eddy simulation. Our investigation addresses several key aspects: (1) flow morphologies and kinematics, (2) quantification of mass and momentum fluxes, (3) turbulent transport mechanisms, shear layer development, and baroclinic pressure effects, and (4) evolutionary patterns of vertical flow structures and their dynamic properties.