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Tank experiments with stratified and pure plane-wall jets flows – observations of flow morphodynamics and implications for the depositional record

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Submerged plane-wall jet flows, which emerge from an orifice into a standing water body, can be considered as basic model for depositional processes related to expanding, point-sourced flows, like submarine fans and subaqueous ice-contact fans. The densimetric Froude number exerts a primary control on the evolution from inertia-driven supercritical jets into buoyancy-driven subcritical plume. Jet flows and their deposits display a distinctive proximal to distal zonation.

3D tank experiments with jet flows were conducted in a large tank with a controllable slope and glass walls (Sedimentology and Stratigraphy Experimental Facility, ExxonMobil Upstream Research Company, Houston, USA). The densimetric Froude number, flow density, sediment-grain size and sediment-supply rate were systematically varied to test their impact on the flow and the resulting deposit. The discharge and the orifice diameter were kept constant. Tested experimental configurations include (i) sediment-free jets on a non-erodible bed, (ii) sediment-free jet on an erodible bed, and (iii) sediment-laden jets on an erodible bed.

The initial supercritical plane-wall jet rapidly expands and decelerates by the entrainment of ambient water. Hydraulic jumps were never observed. A concentric set of low, asymmetric bedforms rapidly evolves in the earliest flow stage. In set-ups with erodible beds scours form due to the entrainment of sediment by turbulent vortices. With increasing incoming Froude numbers the aspect ratio (length vs. width) of the scour increases, while the scour depth decreases. The entrained sediment is flushed out of the scour to build a mouth bar around the scour margin. Slope failures occur at the inner margin of the mouth bar, producing upflow-directed transport of sediment, which is mostly re-entrained. Very low bedforms may occur on the distal slope of the mouth bar. The dimensions and steepness of the mouth bar and bedforms are controlled by the sediment-grain size, with coarser grain sizes causing the formation of higher and steeper bars and bedforms. The transition from jet to plume occurs already within the scour. The turbulent plume remains at the distal margin of the scour and is slowly pushed over the mouth-bar crest by the incoming jet flow, forming a density flow down the bar front. The further evolution of the density flow is controlled by the slope of the mouth-bar and the superimposed bed slope.

For natural jet flows, the experimental observations imply that (i) the role of hydraulic jumps for the morphodynamics of expanding flows may need to be re-considered; (ii) the aspect ratio and the depth of scours provide indicators for the flow conditions at the orifice; and (iii) gravity-controlled processes rapidly take-over the control on the morphodynamic evolution of the flow.