The Critical Flow Hypothesis Revisited – a 20 Year Retrospective

Gordon Grant
Research Hydrologist, USDA Forest Service, Pacific Northwest Research Station

Abstract. Almost 20 years ago, I proposed a hypothesis that hydraulics of flow in steep, mobile bed channels tends to evolve towards critical flow, i.e., Froude Number (Fr) ~ 1.0. This results from feedbacks between the competing processes of flow acceleration and energy dissipation in high gradient channels. Well known to every whitewater kayaker, these feedbacks result in distinctive waveforms on the flow surface (i.e., standing waves, hydraulic jumps) and less obvious bedforms (antidunes, steps). If this tendency for flows to converge towards critical could be confirmed, it would dramatically simplify many complex hydraulic and geomorphic problems, including estimating paleofloods, reconstructing flood hydraulics, and even estimating flows on other planets. But has time been kind to this hypothesis? In this talk I try to answer this question, drawing on two decades of research into diverse fluid flow dynamics and processes -- including floods, hyperconcentrated mudflows and lahars, lava flows, and extraterrestrial flows -- to explore where this hypothesis now stands. Measurements of hydraulics of water flows in many high energy environments do seem to support convergence towards critical flow. Among other things, an assumption of critical flow offers novel approaches to remote measurement of discharge. More intriguing is the possibility that flows with other rheologies and viscosities may also do so. For example, water and lava flows represent two great geophysical fluids present on the surface of the earth. While the hydraulics of water have been extensively studied, the hydraulics of lava flows are much less understood, in large part because of the difficulties involved in making direct measurements on large hot lava streams. Although surface flow velocity and width can be in the field, even as simple a parameter as flow depth must be estimated, resulting in large uncertainties in instantaneous effusion rate, the lava flow analog for stream discharge. However, the same distinctive flow features as seen in water flows, such as standing waves and lateral shocks, have been observed in low viscosity lava flows;. We suggest that these structures suggest that these flows are also near –critical under the right set of circumstances. This hypothesis is supported by measurements of Hawaiian lava flows from Mauna Loa during the 1984 eruption. Application of the critical flow hypothesis to other planets is also considered.