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Flooding, flow path selection and growth of alluvial fans and deltas

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The surfaces of alluvial fans and river deltas (collectively fans) are often dissected by a small number of channels radiating from the fan apex. On long timescales, channels migrate via avulsion, the process of channel bed deposition and abandonment that often results in catastrophic flooding and loss of life on densely populated fans. What governs the selection of new flow paths, or the ultimate number of active channels, is poorly understood. Here we present results of an experimental noncohesive fan that creates realistic channel patterns by avulsion. The system strongly channelizes in one location until localized shoreline progradation diminishes transport capacity of the channel, resulting in backfilling and subsequent widespread flooding; avulsion is completed when a new channel path is selected. This cycle occurs with a periodicity that is predictable from conservation of mass, and results in fluctuations around an equilibrium slope analogous to sand piles. Selection of a new flow path is inherently stochastic; we observe, however, that previously abandoned channels act as significant attractors for the flow, so that the system tends to oscillate among the same 3-5 channels indefinitely. We demonstrate that a directed random walk model with memory quantitatively reproduces these dynamics and limiting behavior, and is consistent with natural fans. Thus, channel migration behaves as a history-dependent, threshold-driven, stochastic process. Because our experimental fan is built by the recurring avulsion sequence, its shoreline shape is a series of lobes that indicate persistent channel locations. Progradation lengthens lobes, while backfilling results in diffusive widening. These dynamics result in self-similar radial growth of fan lobes, which can be described using a simple geometric model. Together, this work provides a complete description of the statistical spatio-temporal dynamics of fan growth. Experiments also provide another example of realistic morphodynamics arising in (near-)laminar flows, indicating that macroscopic fan evolution does not depend on the details of within-channel sediment transport.