Aridity and the Branching of River Networks

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In general, rivers drain water that flows not only over land but also beneath the surface. The latter case occurs when groundwater is recharged, i.e., in humid climates. When groundwater flow dominates, flow into river networks can be calculated by solving a Poisson equation in which rainfall provides the source term and the rivers act as absorbing boundaries. Near the tips of the network, the source can be taken to be far away, and the flow field becomes Laplacian. This Laplacian limit---combined with an assumption that rivers grow in the direction from which streamlines enter their tips---allows us to calculate the angle at which groundwater-fed tips branch: 2pi/5, or 72 degrees. We test this prediction by measuring the angle of nearly 5000 bifurcated tips at a 100 $km^{\wedge 2}$ field site on the Florida Panhandle, where the network is unequivocally driven by groundwater seepage. We obtain a mean angle of 71.9 ± 0.8 degrees. We next measure the angles of nearly 5,000,000 river bifurcations in the continental United States. We find that the branching angles of low-order junctions---the relatively recently bifurcated streams far from an outlet and near a source---strongly correlate with an aridity index A equal to the ratio of precipitation P to potential evapotranspiration PET; i.e. A = P/PET. In humid climates where A>2, rivers branch at an average angle of about 72 degrees, consistent with growth driven by groundwater seepage. In dry climates where A<0.3, the branching angle is much lower, possibly approaching a lower limit of about 45 degrees. These results suggest that erosion by overland flow and erosion by seepage are the two end-members of a continuum that extends from dry to humid climates, respectively.

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