In this talk, I will describe our recent work on the dynamics of water moving through porous two-dimensional crystals, like perforated graphene. These systems are promising candidates for the next generation of reverse osmosis membranes because they are atomically thin. But they also remain challenging to model because the motions of a few water molecules moving through the pores of the membrane bottleneck the macroscopic current across it. I will briefly describe the method that we have developed to perform atomistic simulations for systems under hydrodynamic flow and then use it to establish a connection between fast water passage and the types and strength of intermolecular interactions accessible in the burgeoning library of two-dimensional crystals. Out-of-equilibrium, the hydrophobic effect exhibits competing static and dynamical aspects that have analogs to capillary action and hydrodynamic friction. Using a random walk model, we find a surprising connection between the transport of individual water molecules and the clogging dynamics of granular flows.