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Effect of in-stream turbulent coherent structures on surface-subsurface exchange

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The penetration of turbulent eddies in stream sediments represents one of the most recognized interaction processes between surface and subsurface water in rivers, and it provides dissolved oxygen and nutrients that are vital for the life of hyporheic macroinvertebrates and salmonid embryos. Turbulence penetration is known to be rapidly dampened by the granulometry of the porous medium, which limits the depth of this exchange process to a thin sediment layer of a few grain diameters. Because of this small depth, it is commonly assumed that turbulence contributes to hyporheic exchange only in streams flowing on highly permeable gravel sediments. However, another effect of stream turbulence is to determine unsteady spatial variations of pressure over the streambed. These pressure variations are caused by the interaction between the streambed surface and the large turbulent coherent structures in the surface flow, and they result in hydraulic gradients and water seepage velocities deep within the sediments. In order to examine the significance of this exchange process, the present work presents a numerical analysis of the hyporheic flow induced by an idealized turbulent pressure profile on a streambed. The combined action of pressure-induced advection, underflow, and hydrodynamic dispersion is considered, and penetration depths and residence times of exchange water are evaluated. The simulation results show that stream turbulence has the potential to drive surface-subsurface exchange even if the penetration of eddies is prevented by the filtering action of the sediments.