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PAPER

Sedimentary roles on hyporheic exchange in karst conduits at low Reynolds numbers by laboratory experiments

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Abstract The relative roles of the sediment grain size/permeability, conduit flow rate and conduit geometry/angle on the hyporheic exchange between a karst conduit and its underlying sediments under low Reynolds numbers (Re) were investigated by means of laboratory experiments and numerical simulations. Two laboratory analogues consisting of siphon structured glass tubes (with bend angles of 15 and 45°) were used for the experimental studies. Tracer experiments were performed in each analogue with sediments of variable grain size (0.45 mm, 0.4–0.7 mm, 1 mm) to characterize the transport properties of contaminants originating from the sediments. Numerical simulations were used to probe the exchange flow patterns and exchange flux magnitudes between the conduit and sediment. Tracer experiments demonstrated a zone of forward flow and a zone of reverse flow in the sediments that were independent of grain size, which were reproduced well by numerical simulations. The exchange flux ranged from 0.02% for fine grains to 2% for coarse grains under the experimental flow conditions. A linear relationship between the exchange flux and the conduit Re value, which was independent of the conduit geometry and sediment grain size, was established with numerical simulations. This study demonstrated that sediment grain size/permeability has no influence on the exchange flow patterns; however, relative to the conduit flow rate and conduit geometry/angle, sediment permeability has a much stronger influence on the exchange rate of hyporheic flow.

Keywords Hyporheic exchange · Karst · Laboratory experiments · Exchange rate · Reynolds numbers

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Introduction

Hyporheic flow plays an important role in surface and subsurface interactions (Cardenas 2015; Cardenas and Wilson 2007a, b; Cranswick and Cook 2015; Hancock et al. 2005). There have been numerous studies dedicated to hyporheic flow in surface-water bodies (Arntzen et al. 2006; Bardini et al. 2012; Cardenas et al. 2008; Findlay 1995; Gomez-Velez et al. 2015; Kaeser et al. 2009; Marzadri et al. 2016; Munz et al. 2016; Packman et al. 2004; Pryshlak et al. 2015). However, hyporheic exchange in karst conduits has received relatively little attention, although some field studies have suggested its potential significance on the fate of contaminants in karst aquifers, such as self-purification (Iker et al. 2010, Morasch 2013, Wilhartitz et al. 2009), nutrients cycling (He et al. 2010), and karst groundwater ecology (Gunn et al. 2000).

The term "karst hyporheic zone" was first proposed by Wilson (2011), who addressed the similarities of hyporheic flow in karst conduits and in surface streams. A karst hyporheic zone refers to the margin of karst conduits where the exchange of flow and solutes occurs between the conduits and the surrounding sediments and bedrock matrix (Wilson 2013). Hyporheic flow in karst conduits plays significant roles in redox cycling,