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中文题名	潜流带典型床面结构特征、水动力及传质规律研究
英文题名	The Characteristics of the Hyporheic Zone and Effects of Biological Bedforms
中文关键词	大涡模拟,粗糙透水床面,湍流,传质,生物构造地形
英文关键词	Large-eddy simulation, Rough and permeable bed, Turbulence, Solute transfer, Biological bedform
中文文摘	潜流带是天然河流的重要组成部分，是地表水和地下水的连接通道。潜流带内存在较大的水动力、溶质浓度梯度，为许多底栖动物提供了重要生存环境，是水生态与水环境研究的热点区域。在天然河道中，潜流带典型床面结构特征包括粗糙透水性以及坑、堆地形。在典型床面结构特征影响下，床面之上与床面内部会产生显著的交互作用，以往的研究缺乏对粗糙透水性及坑、堆地形的综合分析。本文将利用大涡模拟技术，研究潜流带典型床面结构特征、水动力及传质规律。研究潜流带粗糙透水的结构特征对水动力的影响。基于双平均理论的研究表明，床面上的雷诺剪应力会形成展向交替的条带结构，导致展向涡旋结构尺寸增大。双平均应力平衡统计显示，这种时均展向涡旋结构会导致主流中构造剪应力出现异常峰值。由于 Kelvin-Helmholtz 不稳定性产生的大尺度湍流结构和由于粗糙元素间湍流的输运产生的小尺度湍流结构，在高透水率床面上都更为普遍。在近床，随着高程增加，湍流猝发事件从上抛主导向下扫主导过渡。另外，相比通过泥沙粒径无量纲化后的流动变量，通过内部特征尺度，即动力粘性系数与摩阻流速比值无量纲化后的流动变量与透水雷诺数有着更好的相关性。研究潜流带粗糙透水的结构特征对传质规律的影响。基于粗糙雷诺数，将湍流分为光滑区、过渡区与粗糙区，量化分析各区内床面粗糙度对传质过程的影响。结果表明，光滑区内的传质机理可以用与施密特数相关的经典理论反映。过渡区内，随着粗糙雷诺数增大，湍流扩散增强，施密特数的影响逐渐减弱。粗糙区内，向床面内部的传质过程被过渡层内腔涡旋抑制，传质系数受床面透水率的控制。根据粗糙区内的传质机理，选取水深、摩阻流速和床面透水率三个变量，推导得到了预测传质系数的尺度模型。研究潜流带坑、堆地形的结构特征对水动力和泥沙稳定性的影响。验证并分析了单独坑、堆结构上的近床水流和潜流交换。单独坑的模拟结果表明，下涌区顺流向长度小于上涌区，下涌区的孔隙水流速大于上涌区。单独堆的模拟结果表明，在堆上游侧，水流挤压进入床面，之后在堆顶涌出。堆后的回流区尺度较小，仅限于背水面。随着水流流速增大，堆背水面的上涌区深度明显增加。关于泥沙稳定性分析表明，坑上游边缘和堆背水面处泥沙比较不稳定。
外文文摘	The hyporheic zone is an important part of natural rivers, which connects the underground and surface water. The velocity and scalar concentration gradients are high in the hyporheic zone. That zone also provides living environment for benthic animals. The bed surface over the hyporheic zone is usually both rough and permeable, leading to strong interactions between the overlying and inner water. Most previous studies ignored the effects of bed roughness or bed permeability. In this paper, the turbulent flow and solute transfer over rough and permeable beds were investigated using the large-eddy simulation, and the impact of biological bedforms on the near-bed and subsurface flow was also analysed. The characteristics of turbulence dynamics and the effects of bed permeability were investigated by applying the double-averaging (DA) methodology. Spheres of different sizes and arrangements were used to form the beds, which were deemed to be permeable granular beds. It was observed that the scales of the spanwise vortical structures over more permeable beds were larger than those over less permeable beds. This was attributed to large-scale spanwise-alternate strips of varying Reynolds shear stress (RSS), emerging from the surface of macro-rough elements for permeable beds. The DA stress balance suggested that the time-averaged spanwise vortical structures led to an unusual peak of the form-induced stress in the main flow. In the streamwise direction, both large turbulent structures

	that originated from the Kelvin－Helmholtz-type instability and small turbulent structures that were associated with the turbulent transport across the gaps of the roughness elements were more prevalent over highly permeable beds. Near the bed, the relative magnitude of turbulent events showed a transition from an ejections-dominating to sweeps-dominating zone with increasing vertical elevation. Further, several hydrodynamic characteristics normalized by inner scales (the ratio of kinematic viscosity to shear velocity) showed a greater dependency on permeability Reynolds number than those normalized by sediment size.The controlling factors in solute transfer under different typical rough regimes were identified. Three rough wall turbulence regimes, i.e., smooth, transitional and rough regime, were separately considered and the effects of bed roughness on solute transfer were quantitatively analyzed. Results showed that the classic laws related to Schmidt number could well reflect the solute transfer under the smooth regime with small roughness Reynolds numbers. Under the transitional regime, the solute transfer coefficient was enhanced and the effect of Schmidt number was weakened by increasing roughness Reynolds number. Under the rough regime, the solute transfer was suppressed by the transition layer (Brinkman layer) and was controlled by the bed permeability. Moreover, it was found that water depth, friction velocity and bed permeability could be used to estimate the solute transfer velocity under the completely rough regime.The impacts of biogenic bedforms on near-bed turbulence, sediment stability, up- and down-welling flow were discussed in gravelly substrates. A large-eddy simulation model of flow over a pit and a mound was validated with flume experiments. Simulations of the pit showed that the length of the downwelling region was smaller than that of the upwelling region and the magnitude of velocity was higher in the downwelling region. Simulations of the mound revealed that the flow was forced into the upstream of the mound and re-emerged near the top of the mound. The recirculation zone was limited at the leeside of the mound. With increasing Reynolds number, the depth of the upwelling region at the leeside of the mound increased. The analysis of shear stress indicated that sediments on the upstream edge of the pit and on the downstream face of the mound were relatively unstable.
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