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| 中文题名 | 生物膜泥沙输移规律及潜在的环境效应研究 |
| 英文题名 | Biofilm-coated sediment transport and its potential environmental effects |
| 中文关键词 | 细颗粒泥沙，生物膜，絮凝，三维模型，微生物群落 |
| 英文关键词 | Fine-grained sediment, Biofilm, Flocculation, Three-dimensional model, Microbial community |
| 中文文摘 | 细颗粒泥沙普遍存在于河流、湖泊和海洋等天然水体中，水中大量微生物往往会附着于泥沙颗粒表面，并生长、发育和增殖形成生物膜结构，生物膜是由微生物及其胞外聚合物（EPS）构成的复杂微型生态系统。目前生物膜已广泛存在于天然水环境中，传统泥沙研究常常基于干净沙而忽略了生物过程的影响。生物膜在泥沙表面生长后不仅显著改变了泥沙输移过程，还通过其吸附解吸和微生物分解等过程对水环境产生影响。本文从生物膜与泥沙的相互关系出发，研究了生物膜对泥沙输移的影响及其潜在的生态环境效应。综合考虑附着态生物膜和游离态 EPS 长链的作用，改进了生物膜泥沙絮凝生长模型，并利用改进的 DLA 和 DLCA 模型，研究生物膜对泥沙絮体形态的影响。两个模型都表明附着生物膜含量越高，絮体的回转半径和空隙率明显增加，而分形维数无明显变化；在游离态 EPS 长链作用下，絮体的回转半径和空隙率都显著增大，分形维数明显减小。但 DLCA 模型得到的变化幅度明显小于 DLA 模型，尤其是在游离态 EPS 长链作用下。通过生物膜影响泥沙颗粒的形貌、密度、粒径等基本特征，修正了泥沙沉降、起动及床面形态和阻力的计算方法，构建了三维生物膜泥沙全沙输移数学模型及其边界条件。利用室内直槽和扩展槽实验对模型进行了验证，研究发现：相同水流条件下，生物膜泥沙形成的床面，其形态尺度和床面阻力都减小，断面平均流速略微增大，近床紊动能降低；且生物膜泥沙的悬沙浓度减小，床面泥沙稳定性增强，侵蚀量明显降低。结合生物膜泥沙冲淤变化、生物膜生长模型和生物膜中微生物群落结构分析，研究了长江三峡库区生物膜对磷的埋藏影响，及长江干流微生物群落变化对碳氮循环等环境功能的影响。研究表明：（1）库区床面生物膜的平均生物量和磷浓度与泥沙淤积量呈负相关，多年累积生物量和磷浓度与淤积量和淤积速率都有关，冲淤速率是影响床面生物膜生物量的重要因素；（2）库区底泥微生物丰富度和多样性大于坝下，三峡建坝后库区和坝下的底泥微生物群落组成有明显变化；（3）长江干流底泥微生物群落的有机碳分解和硝化作用沿程变化较小，而库区有机污染物降解和反硝化作用强于坝下。 |
| 外文文摘 | Fine-grained sediment is a complex assemblage of various minerals and exists extensively in the river, lake and reservoir. Fine-grained sediment serves as an excellent substratum for microorganism colonization, resulting in the formation and growth of biofilms on sediment surfaces. A biofilm is a complex structure consisting of living microorganisms and their metabolic products known as extracellular polymeric substances (EPS), and the formation of biofilms has been found ubiquitously distributed in aqueous ecosystems. However, most models for sediment transport are based on experiments using clean sediment without biological materials. The development of biofilms can influence sediment properties (e.g., architecture, density, morphology and size gradation) and their transport processes, but also has potential environmental effects due to the absorption and microbe decomposition of biofilms. This paper aims to explore the roles of biofilms on sediment transport and the potential environmental effects in aqueous ecosystems.The improved flocculation evolution model for biofilm-coated sediment is presented with a comprehensive consideration of both the attached biofilms and dissociative long-chain EPS, based on the conceptual model of sediment bioflocculation. Then, the diffusion-limited aggregation and diffusion-limited aggregation cluster model are developed to study the influences of biofilms on sediment bioflocculation. Both the two models show that the turning radius and porosity of the floc increase and the fractal dimension of the floc have no obvio |

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| | us change with the increase of attached biofilm content, while the turning radius and porosity of the floc increase significantly and the fractal dimension of the floc decrease with the role of long-chain EPS. Moreover, the effects of attached biofilms and long-chain EPS are more obvious in the DLA model.A three-dimensional model of hydrodynamics and bio-sediment transport is proposed with a comprehensive consideration of the biofilm effects. In this model, the main properties, bedform dynamics and transport characteristics for bio-sediment are comprehensively analyzed to explore the distinctions between the transport of clean sediment and bio-sediment. The proposed model is validated by the measured flow and sediment transport in the flume experiments, and the results show that the simulated results agree well with the measurements. Then, the proposed model is applied to evaluate the biofilm effects on the hydrodynamic characteristics and sediment transport. It shows that the bedform dimensions and bed resistance decrease due to an enhanced stabilization after the biofilm growth under the same flow condition, resulting in an increase of mean velocity and a decrease of turbulence intensity near the river bed. Moreover, the suspended sediment concentration and erosion quantity of bio-sediment are significantly smaller than those of clean sediment under the same flow condition.The dynamic model of biofilm growth is developed to represent the influences of sediment erosion and deposition. The biofilm effects on the phosphorus accumulation in the Three Gorges Reservoir (TGR), and the change of microbial community and corresponding microbial function along stem stream of Yangtze River are studied based on the model of hydrodynamics and sediment transport, developed biomass dynamics model and the analysis of microbial community structure. It shows that (1) the spatial distribution of mean concentration of biofilms and phosphorus in the sediment is negatively correlated with the sediment deposition, while the spatial distribution of the cumulative amount of biofilms and phosphorus is affected by both the sediment deposition and the deposition velocity in TGR. (2) The microbial richness and diversity in TGR are greater than those at downstream of the dam. Meanwhile, there is an obvious change in the microbial community composition after the Three Gorge Dam construction. (3) The functions of decomposition of organic carbon and nitrification change little along stem stream of the Yangtze River, while the functions of denitrification and organic pollutants degradation in TGR are greater than those at downstream of the dam. |
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