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中文题名	河流泥沙与磷相互作用及迁移过程的数学模型研究
英文题名	Mathematical Model for Interactions and Transport of Phosphorus and Sediment
中文关键词	泥沙,磷迁移,表面电荷分布,表面络合模型
英文关键词	Sediment, Phosphorus transport, Surface charge distribution, Surface complexation model
中文文摘	磷的迁移转化过程，对于河流、湖泊等生态环境有着至关重要的影响。传统的水质模型缺乏泥沙颗粒对磷迁移转化过程影响的深入探讨与分析。本文从微观层面出发，研究泥沙颗粒与磷的相互作用机制。借助高分辨率测量技术，测量泥沙颗粒表面的微形貌和电荷分布，并统计两者间的关系。结果表明：泥沙颗粒表面形貌复杂，表面形貌对电荷分布影响较大，电荷大多集中在颗粒表面的鞍部、凸起和凹地部位，而在凹槽、凸脊和平坦部位分布较少，且表面电荷性质与非球状曲率存在较好对应关系。然后，基于天然泥沙表面电荷非均匀分布，建立统计意义上的表面电荷分布~表面电位数学关系，对传统表面络合模型进行修正，得到泥沙颗粒对磷的吸附解吸规律。在水流运动与泥沙输移模拟的基础上，综合考虑泥沙运动对磷迁移的影响，建立水环境中水动力-泥沙-磷迁移过程的分相模型。利用修正表面络合模型，模拟不同水化学条件下泥沙颗粒对磷的吸附解吸，以克服分配系数和吸附等温式缺乏普遍性的不足；通过河床冲淤计算，结合泥沙颗粒对磷的吸附解吸，得到磷在床面的沉积与再悬浮；对底泥层进行分层处理，分析有氧与无氧条件下泥沙颗粒中铁/铝（氢）氧化物形态的差异，以描述磷在底泥中的不同分配比例，进而模拟了底泥磷释放。模型涉及对流扩散、吸附解吸、沉积和再悬浮，以及水体层和底泥层间的层间交换等物理化学过程，构建了微观过程与宏观规律之间的桥梁。设计磷释放过程水槽试验，分析泥沙颗粒运动对磷迁移的影响，并对建立的模型进行验证。结果表明：泥沙运动对磷迁移有显著影响，磷浓度沿程分布与含沙量间存在较好的相关关系，尤其是溶解相磷；模型可以合理地反映磷随着泥沙颗粒的迁移过程。模型被进一步应用到三峡水库和太湖中，研究水库运行对磷的拦截效应，以及太湖底泥的磷释放过程。结果表明：三峡水库自 2003 年运行以来，超过 70%的泥沙在库区发生淤积，导致一半以上的磷迁移被拦截，对库区以及下游河流的生态环境都带来严重影响。太湖水体中的磷分布是风、浪、流等多种动力因素综合作用的结果，风浪作用影响着底泥磷释放，是太湖水质的关键控制因子，而湖流作用则是磷在湖区内迁移的主要动力。模型计算为解决天然情况下的水环境问题提供了重要参考。
外文文摘	Phosphorus transport in natural water plays a crucial role in ecological environment. Traditional models of water quality mostly simplify such processes into some empirical parameters, without a comprehensive understanding of the intrinsic mechanisms. In this paper, the mechanisms of interactions between sediment particles and phosphorus were studied at the micro-level. The surface morphology and charge distribution was first observed using high-resolution microscopy and the statistics of micro-morphology and surface charge distribution was then obtained. Results show that sediment possesses complex surface morphology, which has great impact on the charge distribution. Positive and negative charges mostly concentrate on the saddle, convex and concave parts of the surface, while distribute less in the groove, ridge and flat parts. And Surface charge has a good correspondence with non-spherical curvature. Through the potential calculation, a statistical relation between surface charge distribution and surface potential was established. The surface complexation model was then modified using a more reasonable correction of electrostatic factor to simulate the adsorption of phosphorus by sediment, including the effects of non-uniform charge distribution. A model of hydrodynamic-sediment-phosphorus transport was established, in which the chemical and sediment dynamics were integrated to study the phosphorus transport with river sediment. The phosphorus adsorption by sediment was considered using the modified surface complexation modeling based on the heterogenous surface charge distribution of natural sediment. The riverbed deformation was introduced to analyze the deposition and release of phosphorus at the bed surface. In addition, the aerobic layer and anaerobic layer were distinguished to study the distribution of phos

	phorus between dissolved phase and particulate phase in the active sediment layer. The proposed model involved the convection-diffusion, adsorption-desorption, deposition-resuspension, as well as other physical and chemical processes between the water and sediment layer, which built a bridge between the micro-processes and macro-laws.A flume experiment was designed to study the effects of sediment on phosphorus transport and validate the model. Results show that the phosphorus concentration is linearly correlated with sediment concentration, and the model can reasonably reflect the phosphorus transport with sediment. Further, the model was applied to study the interception effects of phosphorus by the Three Gorges Project (TGP), and also the phosphorus release in the Taihu Lake. Results show that over 70% of the sediment has deposited in the reservoir since the TGP first operated in 2003, resulting in more than half of the phosphorus is intercepted, which has a serious impact on the ecological environment of both the reservoir and the downstream river. The phosphorus distribution in the Taihu Lake is affected by various dynamic factors, such as wind, wave and flow. Mostly the wind and wave cause the phosphorus release at the bed surface, which is a key controlling factor of water quality. And the wind-induced flow is the main driving force for the phosphorus transport. The model provides references for solving water environment problems under natural conditions.
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