Editor: Liquan Xie

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Hydraulic Engineering II

Editor

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Preface

Hydraulic research is developing beyond traditional civil engineering to satisfy increasing demands in natural hazards, structural safety assessment and also environmental research. In such conditions, this book embraces a variety of research studies presented at the the 2nd SREE Conference on Hydraulic Engineering (CHE 2013) and the 3rd SREE Workshop on Environment and Safety Engineering (WESE 2013), held in Hongkong, China on November 2–3, 2013. The series of conferences was conceived and organized with the aim to promote technological progress and activities, technical transfer and cooperation, and opportunities for engineers and researchers to maintain and improve scientific and technical competence in the field of hydraulic engineering, environment and safety engineering, and other related fields.

44 technical papers are published in the proceedings. Each of the papers has been peer reviewed by recognized specialists and revised prior to acceptance for publication. The papers embody a mix of theory and practice, planning and reflection participation, and observation to provide the rich diversity of perspectives represented at the conference. The papers related to hydraulic engineering mainly focus on river engineering and sediment transport, flood hazards and innovative control measures, rainfall modelling, dam safety, slope stability, environmental hydraulics and hydrology. The papers related to environmental issues address on environmental prediction and control techniques in environmental geoscience, environmental ecology, water pollution and ecosystem degradation, applied meteorology, coastal engineering, safety engineering and environmental pollution control.

Last but not least, we would like to express our deep gratitude to all authors, reviewers for their excellent work, and Léon Bijnsdorp, Lukas Goosen and other editors from Taylor & Francis Group for their wonderful work.

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The 2nd SREE conference on hydraulic engineering

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Evaluating bottom sediments impact on faecal bacteria transport in surface water

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ABSTRACT: The faecal bacteria concentration distribution in bottom sediment affect its concentration in over-lying water greatly. The partition coefficients and porosity affect the concentration distribution of free-floating and adsorbed bacteria in bottom sediment, so they should have a great impact on faecal bacteria movement in surface waters. Both theoretical analysis and numerical computation are employed in this research. The bottom sediment partition coefficients and porosity impacts on faecal bacteria concentration in water column was studied by a simplified case. The results indicated that the concentration in over-lying water decreased with partition coefficients and porosity decreasing, but the concentration decreased caused by partition coefficients was much larger than that of porosity. The free-floating faecal bacteria concentration decreased and the adsorbed one increased with partition coefficients increasing, so the weakened direct resuspension decreased concentration in water column and the enhanced resuspension with sediment raised that concentration. Both free-floating and adsorbed bacteria concentration decreased with porosity increasing, therefore, the weakened direct resuspension and resuspension with sediment decreased the concentration in water column, but the decrease caused by resuspension with sediment was much larger than that caused by direct resuspension.

1 INTRODUCTION

Faecal bacteria such as faecal coliform, Escherichia coli are widely used to monitor the fecal contamination of water bodies around the world (Bai and Lung, 2005). Faecal bacteria, either free-floating or absorbed to suspended sediments, can be transported or transformed in surface water (Pachepsky and Shelton, 2011). Modeling faecal bacteria transport and transformation plays an important role in assessing and managing the natural water resources. Numerical models are usually developed to link faecal bacteria concentration in water column and sources under complex flow conditions. Sediment particles and sediment transport processes may affect fecal bacteria in several ways (Jamieson, 2006, Burton et al., 1987, Davies et al., 1995). To date, several fecal bacteria modeling efforts have been made to include the impact of sediment on fecal bacteria in the water column (McCorquodale et al, 2004, Dortch et al, 2008, Wilkinson et al, 1995, Tian et al, 2002, Steets and Holden, 2003, Collins and Rutherford, 2004, Jamieson et al, 2005, Bai and Lung, 2005, Yang et al, 2008, Gao et al, 2011). In these models, much attention has been paid to bacteria settling and resuspension with sediments, the free-floating and absorbed faecal bacteria concentration in bottom sediments are usually assumed as separated constants. In actual, the free-floating and absorbed faecal bacteria, influencing by many factors in bottom sediments, are related with each other. Because that the bottom sediment can be regarded as porous media composed by sediment and water, the faecal bacteria, existing in bottom sediments, can be free in pore water or absorbed to sediments. In most cases, faecal bacteria in bottom sediment affect its concentration in over-lying water by direct resuspension and resuspension with sediments. The flux of direct resuspension is governed by free-floating bacteria concentration in pore water and the flux of resuspension with sediments is related with absorbed bacteria concentration. Therefore, the concentration distribution of faecal bacteria in bottom sediments, affected by partition coefficients and porosity, has an important impact on bacteria concentration in over-lying water.

The aim of this paper is to research the bottom sediment partition coefficients and porosity impacts on faecal bacteria concentration in over-lying water. First the faecal bacteria concentration in water column and bottom sediments was investigated and an empirical formula was proposed to calculate bottom sediment faecal bacteria concentration depending on field bacteria concentration in water column. Then a formula calculating free-floating and adsorbed faecal bacteria concentration depending on bacteria concentration, partition coefficients and porosity in bottom sediment was deduced. Finally the partition coefficients and porosity impacts on faecal bacteria transport in water column was studied by numerical computation.

2 NUMERICAL MODEL

One dimensional velocity can be obtained by solving Saint-Venant equations. One dimensional sediment concentration can be obtained by solving sediment advection equation and one dimensional faecal bacteria concentration can be obtained by solving faecal bacteria advection and diffusion equation. The sediment and bacteria transport equations are expressed in the following form:

$$\frac{\partial AS}{\partial t}+\frac{\partial AUS}{\partial x}=BF_{net-flux-sed} \tag{1}$$

$$\frac{\partial AC}{\partial t}+\frac{\partial AUC}{\partial x}-\frac{\partial}{\partial x}\left(D_x A\frac{\partial C}{\partial x}\right)=B(E+F_{net-flux-bac})+Aq \tag{2}$$

Where A = cross section area, m^2; S = cross-sectional mean suspended sediment concentration, kg/m^3; C = cross-sectional mean total faecal bacteria concentration, cfu/m^3; U = cross-sectional mean velocity, m/s; D_x = diffusion coefficient, m^2/s; E = faecal bacteria direct resuspension flux, cfu/m^2/s, $E=\varepsilon\,(C_{fb}-C_{fw})$; C_{fb} = free-floating faecal bacteria concentration in bottom sediments, cfu/m^3; C_{fw} = free-floating faecal bacteria concentration in water column, cfu/m^3; q = bacteria inactivation flux, cfu/m^3/s; B = river width, m; $F_{net\text{-}flux\text{-}sed}$ = net sediment flux near bed, kg/m^2/s; $F_{net\text{-}flux\text{-}bac}$ = net bacteria flux near bed, kg/m^2/s. The $F_{net\text{-}flux\text{-}sed}$ and $F_{net\text{-}flux\text{-}bac}$ can be found in Jiang (2011). Two critical conditions, namely as critical sediment concentration and critical shear stress, are used to determine bacteria settling or resuspension with sediments.

Depending upon the study, the hydrodynamic equations were discretized with Preissmann scheme and the nonlinear equation system is solved by Newton-Raphson method. An operator-splitting method is adopted to calculate the sediment and bacteria transport equations, the equations (1) and (2) can be split into the advection, source/sink, and longitudinal dispersion terms. The detailed description can be found in zhu (2012).

3 BOTTOM SEDIMENT CHARACTERISTICS

The faecal bacteria concentration in bottom sediment has an important influence on faecal bacteria concentration in over-lying water without other sources. According to investigations (Pachepsky and Shelton, 2011, Xia et al., 2011, Lin et al., 2004), the relations between faecal bacteria concentration in bottom sediments and that in over-lying water are shown in fig. 1. From these plots, it can be seen that the preferable positive relations between them exist and the correlation coefficient is about 0.82. So the liner regression can be employed to determine the empirical relation between them in the absence of field data. After some deducing, the empirical formula can be expressed in the following form:

$$C_{b-drysed} = 74.13C^{0.82} \tag{3}$$

Where $C_{b-drysed}$ = field faecal bacteria concentration in bottom sediments, cfu/unit weight of dry sediments. The faecal bacteria concentration by volume (cfu/m^3) can be obtained by the following formula:

$$C_b = C_{b-drysed}\rho_s(1-\varphi) \tag{4}$$

Where ρ_s = sediment density, 2650 kg/m^3; φ = bottom sediment porosity. Supposing equilibrium adsorption is valid in bottom sediment. So the linear partition approximation can be introduced. Then the free-floating bacteria concentration C_{fb} and adsorbed bacteria concentration C_{sb} in bottom sediments can be expressed as:

$$C_{fb} = \frac{1}{1+k_1(1-\varphi)\rho_s}C_b \tag{5}$$

$$C_{sb} = \frac{k_1(1-\varphi)\rho_s}{1+k_1(1-\varphi)\rho_s}C_b \tag{6}$$

Where k_1 = partition coefficient in the bottom sediment, m^3/kg. The literature values for partition coefficients are only for the bacteria in groundwater with magnitude of 0.1~0.0001 m^3/kg (Bai and Lung, 2005).

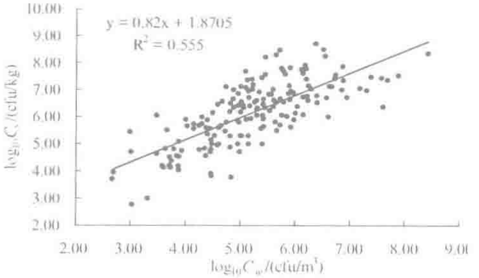

Figure 1. Examples of relationships between faecal bacteria concentrations in water and bottom sediment.

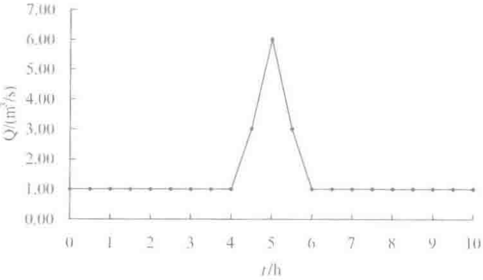

Figure 2. The upstream discharge boundary for simulation.

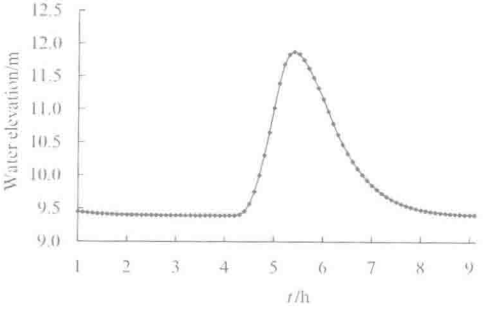

Figure 3. The modeled water elevation.

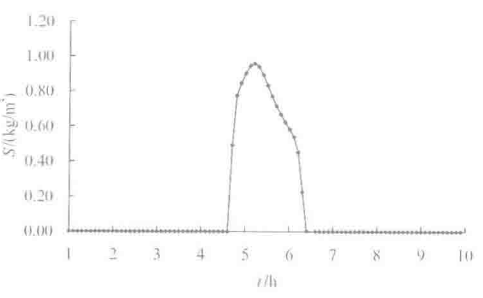

Figure 4. The modeled sediment concentration.

4 BOTTOM SEDIMENT IMPACTS

This paper focus on bottom sediment characteristics impacts on faecal bacteria transport in water column. So the inactivation of faecal bacteria has been ignored. A flume with 2500 long and 1 m wide was supposed to evaluate the bottom sediment impacts. The slope and roughness of the flume are set to 0.001 and 0.03. The model domain contains 50 segments, each with 50 m long. The upstream boundary was assigned by a series of discharge (shown in fig. 1). The peak discharge is 6.0 m^3/s and the base discharge is 1.0 m^3/s. The downstream boundary was assigned by a constant water elevation at infinity. The critical shear stress for sediment resuspension is adjusted to 4.0 N/m^2.

The modeled results of water and sediment are shown in Fig. 4. From these plots, it can be seen that the model can reproduce the flood process. The modeled water elevation keeps a constant during base flow periods and it first increases, then decreases during flood periods. The modeled sediment concentration is 0 kg/m^3 during base flow periods and the modeled peak sediment concentration can reach to 1.2 kg/m^3 during flood periods. During base flow periods, the sediment is stationary with the results that the flow intensity is too weak. Only direct resuspension contributes to over-lying faecal bacteria concentration. During flood periods, the sediment resuspension is intense because of the large flow shear stress. Both direct resuspension and resuspension with sediments act as sources to increase the faecal bacteria concentration in water column.

4.1 *Partition coefficients*

The modeled results are shown in fig. 5. From these plots, it can be observed that the simulated faecal bacteria concentration decreases gradually with partition coefficients increasing. The magnitude of decreasing during base flow periods is much larger than that during flood periods. It is worthy noting that the decrease during base flow periods is larger and larger, but that during flood periods is opposite. In actually, the direct resuspension is weakened and the resuspension with sediments is enhanced with partition coefficients increasing. Fig. 6 shows the calculated free-floating and absorbed bacteria concentration in bottom sediments. The free-floating bacteria concentration decreases with partition coefficients increasing. The adsorbed bacteria concentration first increases rapidly below partition coefficient 0.01, then remains at a constant value above partition coefficient 0.01. That means the direct resuspension flux decreases, but the resuspension flux with sediment increases when the partition coefficients are less than 0.01, then keeps a constant value after the partition coefficients are more than 0.01. This is consistence with the modeled results.

4.2 *Porosity*

The model results are shown in fig. 7. From these plots it can be seen that the modeled faecal bacteria concentration in over-lying water decreases with the bottom sediment porosity rising. But the magnitude of decreasing is different during base flow periods and flood periods. The modeled faecal bacteria concentration decreases little during base flow periods but significantly during flood periods, specially, the decrease of modeled peak faecal bacteria concentration is the largest. The free-floating and absorbed faecal bacteria concentration depending on porosity in bottom sediment is shown in fig. 8. In general, both free-floating and adsorbed faecal bacteria concentration decreases with bottom sediment porosity increasing. But the decrease of adsorbed faecal bacteria concentration is much greater then that of free-floating bacteria concentration, which is consistent with the modeled results.

According to the modeled results comparison between partition coefficients and porosity, the effect of partition coefficients is much greater than that of porosity, meanwhile they shows opposite relation with parameters increasing. When the partition coefficients increases, the free-floating faecal bacteria concentration in bottom sediment decreases but the adsorbed one increases, so the direct resuspension weakens but the resuspension with sediments grows. When the porosity increases greatly, both the free-floating and adsorbed

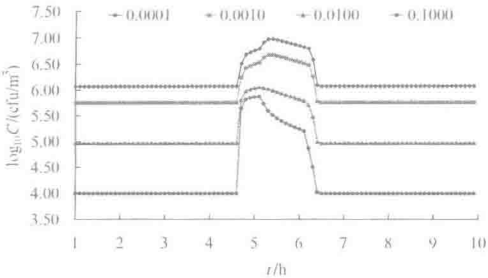

Figure 5. The modeled faecal bacteria concentration comparisons between partition coefficients.

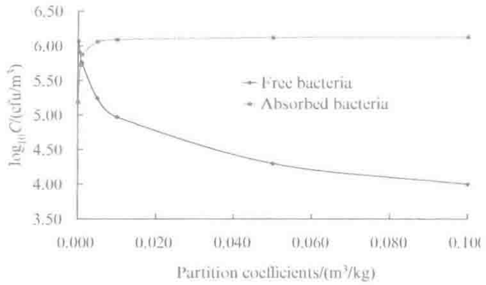

Figure 6. The calculated free-floating and absorbed faecal bacteria concentration in bottom sediments.

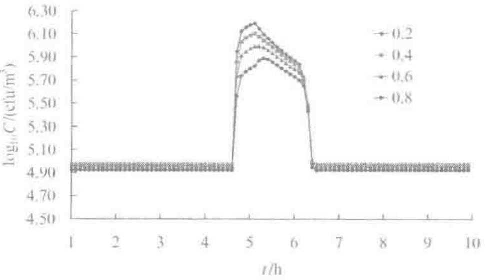

Figure 7. The modeled faecal bacteria concentration comparisons between porosity.

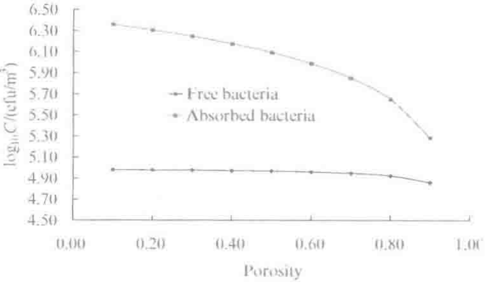

Figure 8. The calculated free-floating and absorbed faecal bacteria concentration in bottom sediments.

faecal bacteria concentration decrease, so does the direct resuspension and the resuspension with sediments, specially, the decrease of resuspension with sediment is much greater that that of direct resuspension.

5 CONCLUSIONS

The main purpose of this study is to evaluate bottom sediments impacts on faecal bacteria transport in surface waters. The investigation study and numerical computation is employed. The main conclusions are as follow:

1. The faecal bacteria concentration in over-lying water decreases with bottom sediment partition coefficients and porosity increasing, but the decrease of partition coefficients is much larger than that of porosity.
2. With partition coefficients increasing, the direct resuspension decreases but the resuspension with sediments increases and trends to a equilibrium level. So the faecal bacteria concentration in over-lying water decreases during base flow periods and increases during flood periods.
3. With porosity increasing, both direct resuspension and resuspension with sediments decreases. Therefore, the faecal bacteria concentration in over-lying water decreases during whether base flow periods or flood periods.

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Study on hydraulic test and optimized design of rainwater-retention well

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ABSTRACT: Rainwater-retention well is an important measure for utilization of rainwater resource in arid regions of China. As well known, the siphon flow is more efficient in storing rainfall than the traditional gravity flow. Hence, five optimized inlets are designed based on the siphon theory, and they are type I with round wall, type I with elliptic wall, type II with round wall, type II with elliptic wall and radial type with flow distribution plates. Then a comparative model test on the hydraulic characteristics of five inlets was carried out by simulating the road surface rainfall field. The results showed that the flow vortex and discharge state were the main factors to influence the flow discharge. So the radial type with top cover and flow distribution plates, which can prevent the formation of vortex, has the most efficient and stable flow.

1 INTRODUCTION

Rainwater-retention well is generally located at the place where rain gathers easily such as two sides of the road, farmland and courtyard. It is an effective measure to utilize rainwater resource in water-deficient area and plays an important role in the utilization of agricultural and living water by the local residents.

In recent years, the researches on rainwater-retention well are increasing gradually with the promotion of national irrigation project with collected rainwater of water-retention well in loess plateau and other areas. In order to improve the rainwater harvesting efficiency, DUAN, et al optimized the design with regard to the form of artificial water harvesting area of rainwater-retention well and structure of desilting basin through artificial rainfall test (DUAN, et al, 1999, 2005, 2006). The existing studies mainly focus on the anti-seepage treatment, construction techniques and construction cost of rainwater-retention well as well as the reasonableness and management countermeasures etc. of micro-irrigation technology (FAN, et al, 2003; YU, et al, 2004, XUE, et al, 2005). However, the hydraulic study is relatively rare. But more hydraulic studies with regard to roof rainwater drainage system were conducted (WANG, et al, 2004; SHI, et al, 2005), and the drainage efficiency is largely improved compared with that of the traditional drainage system.

The water ingress system of rainwater-retention well being widely used in China mainly relies on action of gravity, with which vortex and gas suction is accompanied during water inflowing, and it is characterized by low discharge capacity. In order to improve the water-harvesting efficiency of well, 5 types of water inlets have been designed by the siphon principle instead of gravity flow principle and optimized after comparison by hydraulic model test.

2 OPTIMIZED DESIGN AND HYDRAULIC TEST

2.1 *Design type of inlets*

5 types of water ingress systems were designed in this test: type I with round wall, type I with elliptic wall, type II with round wall, type II with elliptic wall and radial type with flow

distribution plates, which difference and similarities are shown in Table 1. Among them, the type I with round wall is very similar to the commonly used type.

The difference between type I and type II is that: the water inlet of type I is open, and the water inlet of type II and radical type is semi-closed with a circular cover fixed on its top, which is used to prevent the air suction by vortex of vertical shaft, to create conditions for the formation of siphon discharge and to increase flow discharge capacity under the same water depth.

The difference between radical type and type II lies in that it separates the inflowing water into 6 branches with division plate.

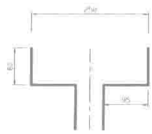
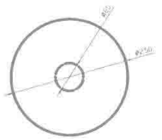
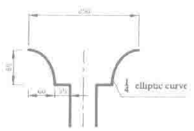
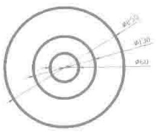
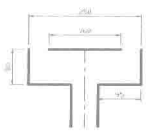
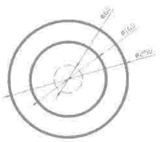
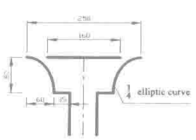
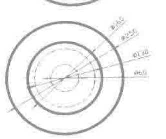
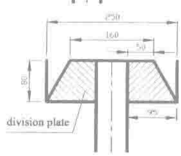
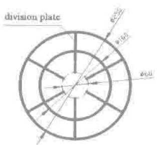
2.2 *Design principles and test*

The water inlet is connected to the drain pipe with the length of 800 mm during test, and the inner diameter at the outlet of pipe is shrunk to 40 mm from 60 mm to prevent air flowing into the vertical pipe, otherwise the siphon state will be damaged. Schematic diagram for its free flow and pressure flow is shown in Figure 1. The head cover and division plate may damage the formation condition of vortex, and the division plate can also evenly distribute the rainwater under vortex state, prevent the air penetration during water discharge, make the rainwater flow into drain pipe steadily, make the flowing water stay under pressure and the drainage system be under one-phase flowing state. The rainwater harvesting process is also a siphon dewatering process. The flow formula derived from Bernoulli equation is shown as Formula (1).

$$Q = \mu A\sqrt{2gH} \tag{1}$$

When the discharged water is free flow, $H = h_1$; if it is pressure flow, $H = h_2$. Thus, it can be seen that the discharge of pressure flow is far greater than that of free flow under the same water level.

Table 1. Inlet design of water-retention well.

Type	Vertical plan/mm	Floor plan/mm	Wall of inlet	Remarks
Type I Type I with round wall			Round	Open
Type I with elliptic wall			1/4 elliptic curve	Open
Type II Type II with round wall			Round	Semi-closed
Type II with elliptic wall			1/4 elliptic curve	Semi-closed
Radial type			Round	Semi-closed, with flow distribution plate