A model of the vertical distribution of suspended sediment in the bottom layer of a natural water body

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Received 27 May 2009, accepted 6 November 2009

Abstract. The paper suggests a stationary model of the vertical distribution of the concentration of suspended sediment in the bottom layer of a natural water body with a flat bottom. The model explains the concentration distribution, formed jointly by the settling of suspended particles and turbulent diffusion. The flow is assumed geostrophic above the bottom-influenced layer, while in the bottom layer the effect of turbulent diffusion by the large-scale turbulence constituent is assumed to dominate over the diffusion effect caused by the small-scale turbulence constituent. It is shown that for the characteristic diffusion length scale of the eddies much smaller than the height of the Ekman bottom boundary layer the model results in an analytic expression for the vertical distribution of the concentration of suspended sediment, which includes also the case with the presence of the lutocline. The model outcome is compared with the results of a laboratory experiment with sand-injected flume flow.

Key words: turbulent diffusion, bottom Ekman layer, suspended sediments, bottom mixed layer, vertical profiles, modelling.

INTRODUCTION

The development of models of the vertical distribution of suspended sediments is essential for solving a number of practical tasks like the prediction of sediment transport and estimation of water quality in bottom layers of natural water bodies. Rouse (1937) initiated the activity in this direction. He suggested a formula for the vertical distribution of the concentration of suspended sediments formed jointly by the settling of suspended particles and turbulent diffusion, with the quadratic dependence of the coefficient of vertical turbulent diffusion on the vertical coordinate. Rouse's idea has been followed in several investigations (e.g. Orton & Kineke 2001; Yu & Tian 2003; Belinsky et al. 2005; Huang et al. 2008), with rather diverse approximations of the dependence of the coefficient of vertical turbulent diffusion on the vertical coordinate. The major disadvantage of these approaches has been insufficient physical justification of the adopted dependences, revealed mostly in attempts to explain the concentration distributions with the presence of the lutocline. The lutocline was first observed in data measured in the Severn Estuary and Inner Bristol Channel (Kirby & Parker 1983) and was thereafter studied in several experimental (Kirby 1986, 1992; Mehta 1988; E & Hopfinger 1989; Wolanski et al. 1989; Mehta & Srinivas 1993) and model investigations performed on semi-empirical background (Smith & Kirby 1989; Gross & Nowell 1990; Noh & Fernando 1991; Toorman & Berlamont 1993; Michallett & Mory 2004; Yoon & Kang 2005).

The model suggested in the current paper differs from the models used in the above-mentioned publications in the following points: (a) the theory of rotationally anisotropic turbulence (the RAT theory) (Heinloo 1984, 1999, 2004) is applied, (b) the dominant effect in the turbulent mixing process is attributed to the large-scale turbulence constituent immediately interacting with the average flow and (c) the concentration distribution with the presence of the lutocline is explained without the necessity to include the buoyancy effect. It is shown that for the characteristic diffusion length scale of the eddies much smaller than the height of the Ekman bottom boundary layer the model results in an analytic expression for the vertical distribution of the concentration of suspended sediment, which includes both cases, with and without the lutocline. According to this expression, the lutocline is present for small settling velocity and/or large bottom shear stress values. The concentration gradient in the lutocline is determined by the scale of diffusion of turbulent eddies. No lutocline was revealed for large settling velocity and/or small bottom shear stress. The derived formula is tested against laboratory data reported in Coleman (1986), where the lutocline was not observed. Data on detailed model testing for the case with the presence of the lutocline are not available, therefore in this case the comparison is limited to showing the qualitative similarity between the model-predicted effects and the respective effects observed and/or modelled in other studies (Kirby & Parker 1983; E & Hopfinger 1989; Noh & Fernando 1991; Michallett & Mory 2004).

Dealing with the geophysical application of the suggested model, the paper belongs to a series of works aspiring to introduce the RAT theory into the solution of geophysical problems (Toompuu et al. 1989; Heinloo & Võsumaa 1992; Võsumaa & Heinloo 1996; Heinloo & Toompuu 2004, 2006, 2007, 2008, 2009; Heinloo 2006).

MODEL SETUP

Introductory notes

The model is set up in the right-hand coordinate system (x, y, z) (with z directed upwards) for the area of a water body with a flat bottom. It is assumed that the suspension concentration is sufficiently small to not affect the constant water density. All considered fields are assumed to depend on the vertical coordinate only. In particular, for the average concentration of the suspension q and for the average velocity field $\boldsymbol{u}$ we shall assume that

$$q = q(z),$$

$$\boldsymbol{u} = (u_x(z), u_y(z), 0). \tag{1}$$

The medium turbulence driving the turbulent diffusion is specified according to the model of the Ekman bottom boundary layer, modified by the RAT theory.

The relation between the vertical distribution of the concentration of suspended sediments and the turbulence properties of the medium

Within the assumptions made in introductory notes the equation for the concentration of suspended sediments q is represented as

$$\boldsymbol{u}_g \cdot \nabla q = \nabla \cdot (\mathsf{K} \cdot \nabla q), \tag{2}$$

where $\boldsymbol{u}_g = (0, 0, -u_g)$ is the settling velocity of suspended sediments, $\nabla = (0, 0, \partial/\partial z)$ and K is the tensor of turbulent diffusion of suspended sediments. ($\mathsf{K} \cdot \nabla q = \boldsymbol{h} = -\langle q'\boldsymbol{v}'\rangle$, where $\boldsymbol{h}$ is the turbulent flux of suspended sediments, q' and $\boldsymbol{v}'$ denote the concentration fluctuation and the velocity fluctuation, respectively.)

The basic distinguishing feature of the current model consists in specification of flux $\boldsymbol{h}$ according to the RAT theory (Heinloo 2004). Let

$$\boldsymbol{R} = \frac{\partial \boldsymbol{e}}{\partial s}\left|\frac{\partial \boldsymbol{e}}{\partial s}\right|^{-2},$$

where $\boldsymbol{e} = \boldsymbol{v}'/v'$ and s is the length of the $\boldsymbol{v}'$ streamline curve, denote the curvature radius of the velocity fluctuation streamline. Using identity $\boldsymbol{v}' = \boldsymbol{R} \times \boldsymbol{\Omega}^*$ in which $\boldsymbol{\Omega}^* = \boldsymbol{v}' \times \boldsymbol{R}/R^2$, we have for $\boldsymbol{h}$:

$$\boldsymbol{h} = \boldsymbol{h}_0 + \boldsymbol{\Omega} \times \langle q'\boldsymbol{R}\rangle, \tag{3}$$

where $\boldsymbol{\Omega} = \langle \boldsymbol{\Omega}^* \rangle$ and $\boldsymbol{h}_0 = \langle \boldsymbol{\Omega}' \times (q'\boldsymbol{R})' \rangle$ ($\boldsymbol{\Omega}' = \boldsymbol{\Omega}^* - \boldsymbol{\Omega}$). The first and the second term on the right side of Eq. (3) describe the transport of the suspended sediment by the turbulence constituents not contributing and contributing to $\boldsymbol{\Omega}$, respectively. The quantity $\boldsymbol{\Omega}$, having the dimension of angular velocity, quantifies the average effect of orientation of eddy rotation. Within Kolmogorov's (Kolmogorov 1941) complement to Richardson's conception about cascading turbulence (Richardson 1922) $\boldsymbol{\Omega}$ is interpreted as a characteristic of the large-scale turbulence constituent interacting immediately with the average flow. Unlike this large-scale turbulence constituent, the turbulence constituent which does not contribute to $\boldsymbol{\Omega}$ is interpreted as the small-scale turbulence constituent. Proceeding from the latter interpretation, we shall assume for $\boldsymbol{h}_0$ that

$$\boldsymbol{h}_0 = k_0 \nabla q, \tag{4}$$

where k_0 is constant. The expression (Heinloo 2008)

$$\langle q'\boldsymbol{R}\rangle = k_1 \nabla q \times \boldsymbol{\Omega} + k_2 \nabla q, \tag{5}$$

where $k_1, k_2 > 0$ are constants, presents a vanishing for $\nabla q = 0$ approximation of $\langle q'\boldsymbol{R}\rangle$ linear on ∇q and $\boldsymbol{\Omega}$. Using Eqs (3)–(5), we shall have for K

$$\mathsf{K} = k_0 \hat{\boldsymbol{I}} + k_1[\Omega^2 \hat{\boldsymbol{I}} - \boldsymbol{\Omega}\boldsymbol{\Omega}] + k_2 \hat{\boldsymbol{E}} \cdot \boldsymbol{\Omega}, \tag{6}$$

where $\hat{\boldsymbol{I}}$ and $\hat{\boldsymbol{E}}$ are the unit and the Levi-Civita tensors and $\Omega = |\boldsymbol{\Omega}|$. It follows from $\boldsymbol{h} = \mathsf{K} \cdot \nabla q$ and Eq. (6) that for q depending on the vertical coordinate only the vertical component of $\boldsymbol{\Omega}$ does not influence the vertical diffusion process, therefore we shall assume further that

$$\boldsymbol{\Omega} = (\Omega_x(z), \Omega_y(z), 0),$$

due to which Eq. (2) simplifies to

$$-u_g \frac{\partial q}{\partial z} = \frac{\partial}{\partial z}\left((k_0 + k_1\Omega^2)\frac{\partial q}{\partial z}\right). \tag{7}$$

Further discussion is restricted to the constant settling velocity u_g and to k_0 negligibly small compared with $k_1\Omega^2$. For the boundary conditions of Eq. (7), specified as

$$q = q_0 \text{ at } z = 0,$$

and

$$q \to 0 \text{ for } z >> H,$$

where H is the characteristic thickness of the layer containing suspended sediments, from (7) we shall have

$$q = q_0 \exp\left(-\frac{u_g}{k_1} \int_0^z \frac{dz}{\Omega^2} \right). \tag{8}$$

Equation (8) relates the vertical distribution of q to the particular specification of the dependence $\Omega = \Omega(z)$ and u_g / k_1.

Determination of the Ω-field

To determine $\boldsymbol{\Omega}$, we shall assume, in addition to the assumptions adopted in introductory notes, that $|\boldsymbol{\Omega}| >> \omega^0 = |\boldsymbol{\omega}^0|$, where $\boldsymbol{\omega}^0$ is the normal projection of the angular velocity of the Earth's rotation. The equations of the RAT theory (Heinloo 2004), corresponding to the model conditions adopted in introductory notes and to $\boldsymbol{\Omega}$ specified above, are represented as

$$-\nabla_h p + (\mu + \gamma)\Delta \boldsymbol{u} + 2\gamma \nabla_z \times \boldsymbol{\Omega} + 2\rho \boldsymbol{u} \times \boldsymbol{\omega}^0 = 0, \tag{9}$$

$$\theta \Delta \boldsymbol{\Omega} - 4(\gamma + \kappa)\boldsymbol{\Omega} + 2\gamma \nabla_z \times \boldsymbol{u} = 0. \tag{10}$$

Equation (9) differs from the corresponding equation in Heinloo (2004) by an additional (Coriolis) term. In Eqs (9) and (10): $\nabla_h = (\partial/\partial x, \partial/\partial y, 0)$; $\nabla_z = (0,0,\partial/\partial z)$; $\nabla = \partial^2/\partial z^2$; μ is the coefficient of turbulence shear viscosity; γ is the coefficient of turbulence rotational viscosity; κ is the coefficient quantifying the suppression of the average effect of prevailing orientation of eddy rotation by the cascading process; θ/J is the diffusion coefficient of the angular momentum $J\boldsymbol{\Omega}$, where J is the effective moment of inertia the square root of which determines the characteristic spatial scale of eddies contributing to $\boldsymbol{\Omega}$. Above the Ekman layer Eq. (10) vanishes and Eq. (9) reduces to the geostrophic balance condition $2\rho \boldsymbol{U} \times \boldsymbol{\omega}^0 = \nabla_h p$, where $\boldsymbol{U}$ is the geostrophic velocity.

We shall specify the boundary conditions for $\boldsymbol{u}$ and $\boldsymbol{\Omega}$ as follows:
for $z >> H_{\mathrm{E}}$

$$\boldsymbol{u} \to \boldsymbol{U} \text{ and } \boldsymbol{\Omega} \to 0, \tag{11}$$

for $z = 0$

$$\left.\frac{\partial \boldsymbol{u}}{\partial z}\right|_{z=0} = \boldsymbol{\tau}_0 / \mu \text{ and } \boldsymbol{\Omega}\big|_{z=0} = \frac{1}{2}\nabla \times \boldsymbol{u}. \tag{12}$$

Equation (12) states that the stress at $z = 0$ is determined by the turbulent shear stress only.

Using notations $\tilde{u} = u_x + iu_y$, $\tilde{\Omega} = \Omega_x + i\Omega_y$ and $\tilde{\nabla} = \partial/\partial x + i\partial/\partial y$ instead of $\boldsymbol{u}$, $\boldsymbol{\Omega}$ and ∇_h (i is the imaginary unit), we can rewrite Eqs (9) and (10) as

$$(\mu + \gamma)\tilde{u}'' + 2\gamma i \tilde{\Omega}' - i\rho f(\tilde{u} - \tilde{U}) = 0, \tag{13}$$

$$\theta \tilde{\Omega}'' - 4(\gamma + \kappa)\tilde{\Omega} + 2i\gamma \tilde{u}' = 0, \tag{14}$$

where $f = 2\omega^0 > 0$ is the Coriolis parameter and $\tilde{U} = -i\tilde{\nabla}p/\rho f$. In Eqs (13) and (14) and hereafter the prime denotes derivative with respect to the vertical coordinate z. The solution of Eqs (13) and (14) for constant μ, γ, κ, θ and ρ satisfying conditions (11) read as

$$\tilde{u} = \tilde{U} + C_1 \exp(\lambda_1 z) + C_2 \exp(\lambda_2 z), \tag{15}$$

$$\tilde{\Omega} = a_1 C_1 \exp(\lambda_1 z) + a_2 C_2 \exp(\lambda_2 z), \tag{16}$$

where λ_1 and λ_2 are the roots of the biquadratic equation

$$\lambda^4 - \left(\frac{1}{\ell^2} + \frac{i}{\ell_1^2} \right)\lambda^2 + \frac{i}{\ell^2 \ell_2^2} = 0 \tag{17}$$

with negative real parts. In (16) and (17)

$$a_1 = \frac{2i\gamma\lambda_1}{4(\gamma+\kappa) - \theta\lambda_1^2}, \quad a_2 = \frac{2i\gamma\lambda_2}{4(\gamma+\kappa) - \theta\lambda_2^2} \tag{18}$$

and

$$\frac{1}{\ell^2} = \frac{4\mu_{ef}(\gamma+\kappa)}{\theta(\mu+\gamma)}, \ \frac{1}{\ell_1^2} = \frac{\rho f}{\mu+\gamma} < \frac{1}{\ell_2^2} = \frac{\rho f}{\mu_{ef}},$$

where $\mu_{ef} = \mu + \gamma\kappa/(\gamma+\kappa)$.

Boundary conditions in Eq. (12), written in terms of $\tilde{u}$ and $\tilde{\Omega}$ as $\tilde{u}'(0) = \tilde{\tau}_0/\mu$ and $\tilde{\Omega}(0) = i/2\tilde{u}'|_{z=0}$, determine C_1 and C_2 in Eqs (15) and (16) as

$$C_1 = -\frac{\tilde{\tau}_0}{\mu}\frac{b_2}{b_1\lambda_2 - b_2\lambda_1}, \quad C_2 = \frac{\tilde{\tau}_0}{\mu}\frac{b_1}{b_1\lambda_2 - b_2\lambda_1}, \qquad (19)$$

where

$$b_1 = a_1 - \frac{i}{2}\lambda_1, \quad b_2 = a_2 - \frac{i}{2}\lambda_2. \qquad (20)$$

Using Eq. (19), we have from Eqs (15) and (16)

$$\tilde{u} = \tilde{U}\left[1 - \frac{\tilde{\tau}_0}{\tilde{U}\mu}\frac{1}{b_1\lambda_2 - b_2\lambda_1}(b_2\exp(\lambda_1 z) - b_1\exp(\lambda_2 z))\right] \qquad (21)$$

and

$$\tilde{\Omega} = \frac{\tilde{\tau}_0}{\mu}\frac{1}{b_1\lambda_2 - b_2\lambda_1}[-a_1 b_2\exp(\lambda_1 z) + a_2 b_1\exp(\lambda_2 z)]. \qquad (22)$$

Equations (21) and (22) represent the solution for the Ekman bottom boundary layer, generalized by the RAT theory. Equation (8) together with Eq. (22) determines $q = q(z)$.

APPROXIMATE FORMULA FOR $q = q(z)$

Consider the situation described by Eqs (8) and (22) for ℓ restricted to $\ell \ll \ell_1, \ell_2$. In particular this inequality has been found holding for turbulent flows in plane channels, round tubes and between rotating cylinders (Heinloo 1999, 2004), where instead of ℓ_1 and ℓ_2 the characteristic transverse length scale of the flow region had been used. For $\ell \ll \ell_1, \ell_2$, Eq. (17) simplifies to

$$(\lambda\ell)^4 - (\lambda\ell)^2 + i\varepsilon^2 = 0,$$

where $\varepsilon = \ell/\ell_2$, from which we have

$$\lambda_1 = -\frac{1}{\ell}, \quad \lambda_2 = -\frac{1+i}{\ell_2\sqrt{2}}. \qquad (23)$$

Equation (23) determines the flow in the Ekman bottom boundary layer through two characteristic lengths: ℓ, characterizing the turbulent diffusion, and $\ell_2 \equiv H_E$, determining the thickness of the Ekman bottom boundary layer for the turbulence viscosity identified with μ_{ef}. Using Eq. (23), we have for a_1, a_2, b_1 and b_2 in Eqs (18) and (20)

$$a_1 = -i\frac{\mu+\gamma}{\gamma}\frac{1}{2\ell}, \quad a_2 = (1-i)\frac{\gamma}{(\gamma+\kappa)}\frac{1}{2\sqrt{2}\ell_2},$$

$$b_1 = -\frac{i}{2}\frac{1}{\ell}\frac{\mu}{\gamma}, \quad b_2 = -\frac{1-i}{2\sqrt{2}\ell_2}\frac{\kappa}{\gamma+\kappa}$$

and, consequently,

$$\tilde{u} = \tilde{U} - \left(\frac{\mu_{ef} - \mu}{\mu\mu_{ef}}\ell\exp\left(-\frac{z}{\ell}\right)\right.$$

$$\left.+\frac{1}{\mu_{ef}}\ell_2\exp\left(-\frac{z}{\ell_2}\right)\exp\left(i\left(\frac{z}{\ell_2} - \frac{\pi}{4}\right)\right)\right)\tilde{\tau}_0, \qquad (24)$$

$$\tilde{\Omega} = \frac{i}{2\mu}\left(\frac{\kappa(\mu+\gamma)}{(\gamma+\kappa)\mu_{ef}}\exp\left(-\frac{z}{\ell}\right)\right.$$

$$\left.+\frac{\mu\gamma}{(\gamma+\kappa)\mu_{ef}}\exp\left(-\frac{z}{\ell_2}\right)\exp\left(i\frac{z}{\ell_2}\right)\right)\tilde{\tau}_0. \qquad (25)$$

For restriction $\mu \ll \gamma$, justified by the Richardson–Kolmogorov turbulence conception about the cascading nature of turbulence, and for γ of the order of κ, Eq. (25) simplifies to

$$\tilde{\Omega} = \frac{i}{2\mu}\exp\left(-\frac{z}{\ell}\right)\tilde{\tau}_0. \qquad (26)$$

From Eq. (26) it follows for $\Omega = |\tilde{\Omega}|$ that

$$\Omega = \frac{\tau_0}{2\mu}\exp\left(-\frac{z}{\ell}\right),$$

where $\tau_0 = |\tilde{\tau}_0|$ and, according to Eq. (8),

$$q = q_0\exp\left[D\ell\left(1 - \exp\frac{2z}{\ell}\right)\right]. \qquad (27)$$

In Eq. (27)

$$D = \frac{2u_g}{k_1}\frac{\mu^2}{\tau_0^2}.$$

Equation (27) determines $q = q(z)$ as depending on q_0 and on two parameters D and ℓ.

If u_g is relatively large or τ_0 sufficiently small so that $D\ell > 1$, then according to Eq. (27), we have $\partial^2 q/\partial z^2 > 0$ for all z and $|\partial q/\partial z|$ decreases monotonously with z increasing. This situation is typical of coarse-grained sediments like sand. For $D\ell < 1$ the entire suspension layer can be divided into two layers, one with $\partial^2 q/\partial z^2 < 0$ (located immediately next to the boundary) and the other with $\partial^2 q/\partial z^2 > 0$, separated by an inflection point at $z = -0.5\ell \ln(D\ell)$. There is a concentration jump (lutocline) in the concentration distribution for $D\ell << 1$, explaining the lutocline as emerging for a relatively large bottom shear τ_0 and/or small settling velocity u_g, typical of fine-grained sediments like clay or mud. Figures 1 and 2 illustrate the presence of the indicated two types of vertical distributions of sediment concentrations in terms of q/q_0 and q/Q, where $Q = \int_0^\infty q dz$, as functions of $\zeta = z/\ell$ for fixed ℓ and for different values of $D\ell$. For fixed D the lutocline appears steeper for smaller ℓ (Fig. 3). In Fig. 4 a modelled vertical distribution of

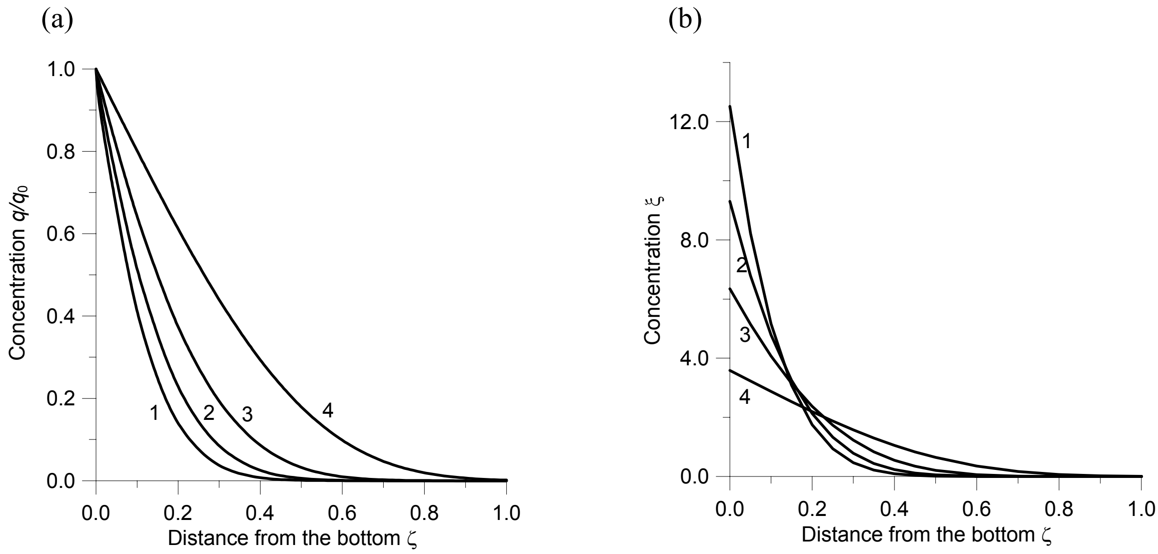

Fig. 1. Modelled distributions of q/q_0 (a) and $\xi = \ell q/Q$ (b) as functions of $\zeta = z/\ell$ calculated according to Eq. (27). The calculations are performed for $\ell = 1$ m and for $D\ell = 4$ (curve 1), $D\ell = 3$ (curve 2), $D\ell = 2$ (curve 3) and $D\ell = 1$ (curve 4).

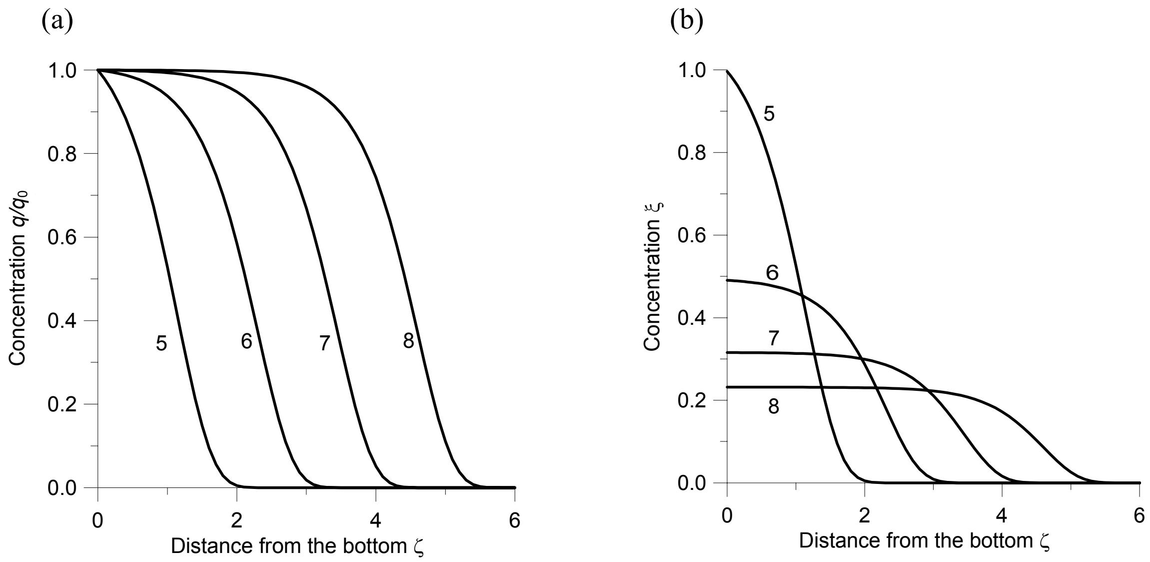

Fig. 2. Modelled distributions of q/q_0 (a) and $\xi = \ell q/Q$ (b) as functions of $\zeta = z/\ell$ calculated according to Eq. (27). The calculations are performed for $\ell = 1$ m and for $D\ell = 10^{-1}$ (curve 5), $D\ell = 10^{-2}$ (curve 6), $D\ell = 10^{-3}$ (curve 7) and $D\ell = 10^{-4}$ (curve 8).

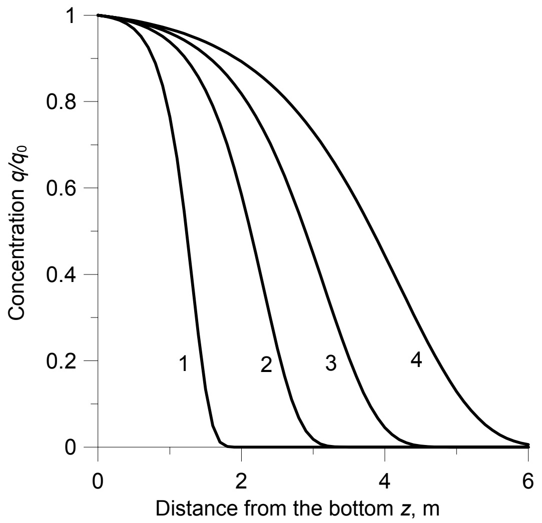

Fig. 3. Modelled distributions of q/q_0 as functions of z calculated according to Eq. (27). The calculations are performed for $D = 10^{-5}\ \mathrm{m}^{-1}$ and for $\ell = 0.5$ m (curve 1), $\ell = 1$ m (curve 2), $\ell = 1.5$ m (curve 3) and $\ell = 2.2$ m (curve 4).

normalized suspension concentration q/Q is compared with the laboratory data from Coleman (1986) for two series of 20 (Fig. 4a) and 10 (Fig. 4b) individual flume flow runs, each run injected with a different amount of suspended matter. The suspension was formed of sand particles with the diameter of 0.105 and 0.210 mm in the first (20 runs) and the second (10 runs) series, respectively. Due to missing lutocline data suitable for testing Eq. (27), we just refer to the qualitative resemblance of the distributions depicted in Fig. 2 with the similar observed and/or modelled distributions published in Kirby & Parker (1983), E & Hopfinger (1989), Noh & Fernando (1991) and Michallett & Mory (2004).

CONCLUSIONS

A stationary model of the vertical distribution of the concentration of suspended sediments in a turbulent boundary flow over a flat bottom is presented. The distinguishing feature of the suggested model consists in considering the concentration distribution formed by the large-scale turbulence, which, according to the applied theory of rotationally anisotropic turbulence (the RAT theory), is considered having a prevailing orientation of eddy rotation. The model results in an analytic expression covering both observed types of the vertical distribution of concentration – with and without the presence of the lutocline. The generation of turbulence driving the vertical mixing of suspended sediment is considered within the Ekman bottom boundary layer model generalized by the RAT theory.

For the model parameters ℓ and D, estimated from the observed data, the derived formula for the vertical distribution of the concentration of suspended sediments can be applied in circulation models for calculation of the water quality and for sediment transport. In these calculations the vertical distribution of the concentration of sediments is treated as quasi-stationary, and the horizontal distribution as quasi-homogeneous.

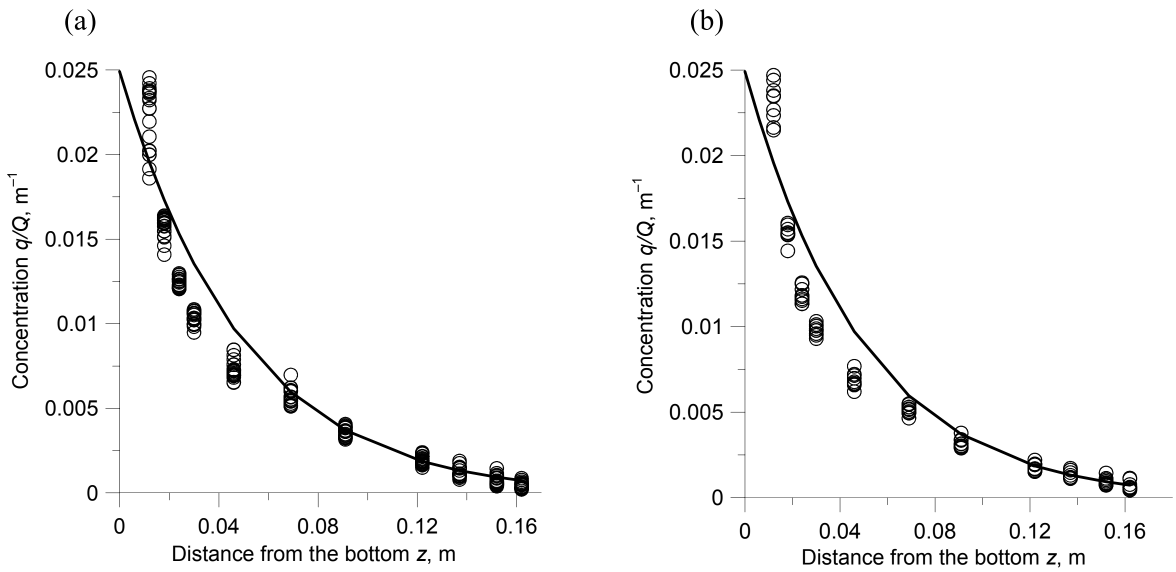

Fig. 4. Modelled dependences of q/Q on z (curves) compared with data (dots) of 20 runs from the first series (a) and of 10 runs from the second series (b) reported in Coleman (1986). The theoretical curves are calculated for $D = 10\ \mathrm{m}^{-1}$ and $\ell = 2$ m.

Acknowledgements. The authors thank Prof. E. Wolanski and Prof. A. J. Mehta for useful advice, Prof. R. Kirby for providing his works on the topic discussed, Prof. V. Zhurbas and anonymous referees for critical comments.

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Looduslikes veekogudes suspenseerunud setete vertikaalse jaotuse mudel

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On esitatud mudel setete hõljumi kontsentratsiooni vertikaalse jaotuse kirjeldamiseks looduslike veekogude põhjakihis. Mudel põhineb hõljumiosakeste settimise ja turbulentse segunemise tasakaalutingimusel. Mudeli eripära seisneb keskkonna turbulentsi ja sellest põhjustatud efektide käsitlemisel pöördeliselt mitteisotroopse turbulentsi teooria raames ning mudeli lõpptulemuse esitamises analüütilise avaldisena hõljumi kontsentratsiooni vertikaalse jaotuse arvutamiseks. On näidatud, et lõpptulemuse vormilisele lihtsusele vaatamata kirjeldab tuletatud avaldis hõljumi vertikaalset jaotust nii lutokliini olemasolu kui selle puudumise korral. Mudelarvutusi lutokliini puudumise juhul on võrreldud laboratoorse katse andmetega.