OPTIMIZATION OF TURBULENT VISCOSITY COEFFICIENTS IN MODEL OF VERTICAL CIRCULATION IN DENSITY STRATIFIED RESERVOIR

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1. INTRODUCTION

In the literature the stratified flows are defined as the flows with density stratification. Depending on the source of water density difference following stratification is defined: thermal stratification, mechanical stratification due to the presence of solid particles and chemical stratification due to the dissolved chemical substances. Depending on the vertical distribution of density, Harleman [2] defines three stratified flows: two layered flow with distinctly formed interface between layers, multilayer flow and flow with continuous gradient of density. The stratified flow pattern is mainly controlled by vertical density changes. The value of water density itself influences the flow insignificantly.

The dimensionless parameter $A$, which is defined by the relationship (12), is the basic parameter deciding upon the solution of stratified flow. This parameter includes the intensity of density stratification and flow conditions. In the natural environment it can oscillate between 0 (no stratification) and around $10^6$. In the model of vertical stratification it is very difficult to specify the eddy viscosity coefficient correctly. Having the practical application of calculation results in mind, in this paper one put forward the optimisation procedure of flow solution through the reservoir under circumstances of vertical stratification, defining the real values of $K_x$ and $K_y$ coefficients.

Typical example of stratified flows are two layered flows at the river outlet to the sea The conditions of fresh and salt water mixing and the range of the salt water wedge, which penetrates upwards the river, depend mainly on the river flow, sea level, wind velocity and direction [7]. The basic factor controlling salt water wedge extent is the water density difference: salty and fresh.

The lower section of the Odra River (Fig. 1) is an example of the river mouth, where a salt water wedge occurs. The processes of waters’ mixing and exchanging are intensify, due to the
existence of deep fairway from Świnoujście to Szczecin. The researches carried out by the Maritime Institute Szczecin Branch [8] and IBW PAN [3] show, that after the strong stormy surges, salt water flows rapidly from the sea into the Szczecin Lagoon - the water salinity in deeper parts of the fairway is recorded at the level corresponding to the water salinity in the Pomeranian Bay, i.e. 5 ÷ 7 ‰. The range of salt water wedge reaches up to the Police cross-section (50 km away from the Baltic Sea), however the water of 1.5 ‰ salinity were observed even in the Odra River in Szczecin (while the average salinity in the Odra River is equal to 0.05 ÷ 0.08 ‰). However, even if there is not sea surge, there exist water of big salinity at the lower layers of the Świna River and Szczecin-Świnoujście fairway.
2. MATHEMATICAL MODEL OF PHENOMENON

The flow in the reservoirs under circumstances of vertical stratification of water density is analysed in this model. The following assumptions and simplifications were made to describe the phenomenon mathematically [4], [5]:

- the steady motion in the wide reservoir with $H$ depth,
- the flow is treated as the flat one in the reservoir’s vertical cross-section,
the abscissa \((x)\) covers the reservoir’s bottom line and is directed opposite to the main flow direction, the \(y\)-axis \((y)\) covers the vertical reservoir’s wall in the area of outflow and is directed upwards,
in the reservoir there is a water density gradient – the density varies from the \(\rho_2\) value at the water surface up to the \(\rho_1\) value at the bottom,
the waves’ influence and Coriolis’ force influence are neglected in the calculations.

In general case (Fig. 2) the inflow to the reservoir can take place with several orifices located one above the other or with the whole depth of the river. The location of the subsequent orifice is defined by its edges coordinates: \(y_1^{(m)}\) and \(y_2^{(m)}\). The outflow from the reservoir can take place with several orifices or with the whole depth. Similarly we have the location of the edges given by coordinates: \(y_1^{(n)}\) and \(y_2^{(n)}\). And the appropriate flow through the orifice is equal to \(q_m'\) and \(q_n'\).

\[
q_m' = y_2' - y_1' \quad \text{and} \quad q_n' = y_2^{(n)} - y_1^{(n)}
\]

**Fig. 2.** General scheme of reservoirs’ flow
Two-dimensional equation of eddy viscosity motion was applied [4], [5]:

\[
\frac{dV_x}{dt} = X - \frac{1}{\rho} \frac{\partial P}{\partial x} + \frac{\partial}{\partial x} \left( K_x \frac{\partial V_x}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_y \frac{\partial V_x}{\partial y} \right)
\]

(1)

\[
\frac{dV_y}{dt} = Y - \frac{1}{\rho} \frac{\partial P}{\partial y} + \frac{\partial}{\partial x} \left( K_x \frac{\partial V_y}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_y \frac{\partial V_y}{\partial y} \right)
\]

and the equation of flow continuity:

\[
\frac{1}{\rho} \frac{d\rho}{dt} + \frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} = 0
\]

(2)

After introducing into the modular equations:

- the stream function \( \Psi \): \( V_x = \frac{\partial \Psi}{\partial y} \) and \( V_y = -\frac{\partial \Psi}{\partial x} \)

(3)

- rotation function \( \Omega \):

\[
\Omega = \frac{\partial V_y}{\partial y} - \frac{\partial V_x}{\partial x}
\]

(4)

and after further transformations, the equation of stratified flow will have the following form [4]:

\[
\frac{d\Omega}{dt} = g \frac{\partial \rho}{\partial x} + \frac{\partial^2}{\partial y^2} \left[ \left( K_x + K_y \right) \frac{\partial^2 \Psi}{\partial x^2} + K_y \frac{\partial^2 \Psi}{\partial y^2} \right]
\]

(5)

Afterwards the following dimensionless parameters and co-ordinates were introduced:

- **dimensionless co-ordinates:**

  - \( \eta = \frac{y}{H} \) and \( \xi = \frac{x}{H} \sqrt{\frac{K_x}{K_x + K_y}} \)

  (6)

- **dimensionless functions:**

  - stream function:

    \[ \psi = \frac{\Psi}{q} \]

    (7)

  - components of flow velocity:

    \[ V_\xi = \frac{V_x}{V_0} = \frac{\partial \psi}{\partial \eta}, \quad V_\eta = \frac{V_y}{V_0} = -\frac{\partial \psi}{\partial \xi} \]

    where: \( V_0 = \frac{q}{H} \)

(8)

- **dimensionless parameters:**

  - Froud’s number:

    \[ Fr = \frac{q^2}{g H^3} \]

    (9)

  - Reynolds’ number:

    \[ Re = \frac{q}{\sqrt{(K_x + K_y) K_y}} \]

    (10)
Assuming the vertical density distribution according to the following relationship [4]:
\[
\rho = \rho_1 + \Delta \rho \ \psi
\]
and introducing the dimensionless \( A \) parameter that is equal to:
\[
A = \frac{\Delta \rho}{\rho_1} \frac{Re}{Fr} = \frac{\Delta \rho}{\rho_1} \frac{g H^3}{q} \frac{1}{\sqrt{K_e (K_e + K_r)}}
\]
the motion equation (5) has finally the following form:
\[
A \cdot \frac{\partial \psi}{\partial \zeta} + \frac{\partial^2 \left( \nabla^2 \psi \right)}{\partial \eta^2} = 0
\]

The basic equation of the stratified flow (Eq. 13) can be solved using Fourier series. The solution needs to specify boundary conditions for stream function and density. The resulting flow pattern allows to distinguish the dividing streamlines between circulation regions.

There are following parameters of solution that decide upon the shape of stream line for the assumed geometrical dimensions of the reservoir:
- dimensionless co-ordinates of reservoir’s outflow and inflow cross-section location,
- dimensionless parameter \( A \) – including the vertical gradient of water density and flow conditions,
- dimensionless co-ordinate \( \zeta \) describing the reservoir’s length,
- dimensionless wind dependent velocity \( V_1 \) at the water surface, coming from wind surface shear stress.

3. SALT WATER WEDGE PENETRATING UPSTREAM THE RIVER

The presented above model can be applied to the case of salt water wedge penetrating upstream at the river mouth [6], [7].

The boundary conditions in this case are as follows (Fig. 3):
- for \( \eta = 0 \) : \( \psi = 0, \quad V \eta = -\frac{\partial \psi}{\partial \zeta} = 0, \quad \rho (\zeta, 0) = \rho_1, \)
- for \( \eta = 1 \) : \( \psi = -1, \quad V \eta = -\frac{\partial \psi}{\partial \zeta} = 0, \quad \rho (\zeta, 1) = \rho_2, \)
- for \( \zeta \to \infty \) : \( \psi(\zeta, \eta) = \psi_{1\infty}(\eta), \quad V \zeta = V_{1\infty}(\eta), \)
- for $\xi \to -\infty$:
  \[
  \psi(\xi, \eta) = \psi_{2\infty}(\eta), \quad V_\xi = V_{2\infty}(\eta).
  \]

**Fig. 3.** The assumed boundary conditions (distribution of the stream line)

In the evaluations – on the basis of the former research [4], [5], [6] – the parabolic distribution of horizontal velocity’s component in the vertical direction was assumed in the cross-sections: inflow ($\xi \to \infty$) and outflow ($\xi \to -\infty$) obtaining the stream function $\psi_{1\infty}(\eta), \psi_{2\infty}(\eta)$ as well as longitudinal velocity components $V_{1\infty}(\eta), V_{2\infty}(\eta)$ according to the following formulae:

- **stream functions:**
  \[
  \psi_{1\infty}(\eta) = (2 + V_1)\eta^3 - (3 + V_1)\eta^2
  \]
  \[
  \psi_{2\infty}(\eta) = \begin{cases} 
  \frac{(2 + V_1)(1 - \eta_0)}{1 - \eta_0} \left(\eta - \eta_0\right)^3 - \left(3 + V_1(1 - \eta_0)\right)\left(\eta - \eta_0\right)^2 & \text{for } \eta_0 \leq \eta \leq 1 \\
  0 & \text{for } 0 \leq \eta \leq \eta_0
  \end{cases}
  \]

- **horizontal components of flow velocity:**
  \[
  V_{1\infty}(\eta) = 3(2 + V_1)\eta^2 - 2(3 + V_1)\eta
  \]
  \[
  V_{2\infty}(\eta) = \begin{cases} 
  \frac{3}{1 - \eta_0}(2 + V_1(1 - \eta_0))\left(\eta - \eta_0\right)^2 - \frac{2}{1 - \eta_0}(3 + V_1(1 - \eta_0))\left(\eta - \eta_0\right) & \text{for } \eta_0 \leq \eta \leq 1 \\
  0 & \text{for } 0 \leq \eta \leq \eta_0
  \end{cases}
  \]

where:

$V_1$ – wind-dependent, dimensionless velocity at the water surface in the outflow (when no wind, the velocity $V_1 = -1.5$),

$\bar{V}_1$ – dimensionless velocity at the water surface in the outflow.
The equation of stratified flow in the river mouth area with the assumed boundary conditions were solved by the method of Fourier’s series achieving the following forms of stream function [6], [7]:

\[ \psi_1(\xi, \eta) = \psi_{1,0}(\eta) + \sum_{n=1}^{\infty} \left\{ a_{1n} \cdot \exp\left( d_{1n} (\xi - \xi_0) \right) \cdot \sin (\pi \eta) \right\} \quad \text{for } \xi \geq \xi_0 \]  
\[ \psi_2(\xi, \eta) = \psi_{2,0}(\eta) + \sum_{n=1}^{\infty} \left\{ a_{2n} \cdot \exp\left( d_{2n} (\xi - \xi_0) \right) \cdot \sin (\pi \eta) \right\} \quad \text{for } \xi < \xi_0 \]  

Dimensionless components of horizontal velocity:

\[ V_{\xi}(\xi, \eta) = V_{1,0}(\eta) + \sum_{n=1}^{\infty} \left\{ \pi na_{1n} \cdot \exp\left( d_{1n} (\xi - \xi_0) \right) \cdot \cos (\pi n \eta) \right\} \quad \text{for } \xi \geq \xi_0 \]  
\[ V_{\xi}(\xi, \eta) = V_{2,0}(\eta) + \sum_{n=1}^{\infty} \left\{ \pi na_{2n} \cdot \exp\left( d_{2n} (\xi - \xi_0) \right) \cdot \cos (\pi n \eta) \right\} \quad \text{for } \xi < \xi_0 \]  

and dimensionless components of vertical velocity:

\[ V_{\eta}(\xi, \eta) = -\sum_{n=1}^{\infty} \left\{ d_{1n} a_{1n} \cdot \exp\left( d_{1n} (\xi - \xi_0) \right) \cdot \sin (\pi n \eta) \right\} \quad \text{for } \xi \geq \xi_0 \]  
\[ V_{\eta}(\xi, \eta) = -\sum_{n=1}^{\infty} \left\{ d_{2n} a_{2n} \cdot \exp\left( d_{2n} (\xi - \xi_0) \right) \cdot \sin (\pi n \eta) \right\} \quad \text{for } \xi < \xi_0 \]  

In the cross-section \( \xi = \xi_0 \) that is separating the river from sea the following conditions are, of course, fulfilled:

\[ \psi_1(\xi_0, \eta) = \psi_2(\xi_0, \eta), \quad V_{\xi}(\xi_0, \eta) = V_{\eta}(\xi_0, \eta) \] and \[ V_{1,0}(\xi_0, \eta) = V_{2,0}(\xi_0, \eta). \]  

Coefficients \( a_{1n}, a_{2n}, d_{1n}, d_{2n} \) for the assumed boundary conditions that appear in the formulae (16a, b), (17a, b) i (18a, b) are in paper [6].

There are following parameters of solution that decide upon the stream line shape in the river mouth area and the range of salt wedge:

- dimensionless \( \eta_0 \) co-ordinates specifying the wedge height in the river-sea border cross-section,
- parameter \( A \) – including the vertical gradient of water density and river flow,
- dimensionless, wind-dependent velocity \( V_1 \) at the water surface.
The detailed analysis, how the individual parameters of the solution influence the shape and range of salt wedge in the river, was put forward in the previous papers [6] and [7]. For instance, Fig. 4 illustrates the wind influence on the range of salt wedge ($A=1000$, $\eta_0=0.45$).

**Fig. 4. Wind influence upon the range of salt wedge**

In practical cases the most important is the horizontal wedge extend. It can be estimated from Eq. 17a:

$$V_{1e}(\xi = \xi_k, \eta = 0) = 0$$  \hspace{1cm} (19)

where: \( \xi_k \) - range of salt water wedge.

In the case of rectangular velocity distribution at inflow, horizontal wedge extent is given as follows [6]:

$$\xi_k = \frac{A}{\pi^4} \ln \left[ \frac{\pi a_1(1)}{-V_{1e}(0)} \right]$$  \hspace{1cm} (20)
Fig. 5 shows how the horizontal range of salt wedge penetrating upwards the river changes in dependence on its height $\eta_0$ in the river-sea bordering cross-section ($\zeta = \zeta_0$) and the parameter $A$ that includes the vertical changes of water density as well as flow intensity (the calculations were carried out for the windless conditions – $V_1 = -1.5$).

The wind acting upon the surface of the flowing water is the factor, which significantly influences on the shape and range of the salt wedge penetrating upwards the river. The Fig. 6 illustrates graphically the relationship between the direction and velocity of the wind, which is represented by the dimensionless surface velocity $V_1$, and the horizontal range of salt wedge $\zeta_k$.
4. ANALYSIS OF EDDY VISCOSITY COEFFICIENTS

Practical calculations of the circulations in density stratified reservoir needs to specify the eddy viscosity coefficients $K_x$ and $K_y$ to calculate further parameters $A$ and $\xi_1$ which are basic for the flow pattern.

Introducing the Boussinesq’s hypothesis into the equations of turbulent motion and defining the shear stress $\tau_x(y)$ according to the Prandtl’s formula concerning the mixing way, we obtain as follows:

$$\tau_x(y) = \rho K_x(y) \frac{dV_x}{dy}$$  \hspace{1cm} (21)

However, it can also be assumed, that vertical turbulent stresses $\tau_x(y)$ get changed linearly – from the $\tau_d$ value at the bottom to the $\tau_w$ value at the water surface:

$$\tau_x(y) = \tau_d - \frac{y}{H} \left( \tau_d + \tau_w \right)$$  \hspace{1cm} (22)

If the wind influence upon the flowing water ($\tau_w = 0$) is neglected, the following will be obtained:

$$\tau_x(y) = \tau_d \left( 1 - \frac{y}{H} \right)$$  \hspace{1cm} (23)

The comparison of (21) and (23) relationships enables specifying the relation between the $K_x$, $K_y$ eddy viscosity coefficients and river water flow conditions. In further analysis it is very convenient to assume that the $K_y$ viscosity coefficient is – as in the flow model – constant and proportional to the elemental $q$ flow according to the formula:

$$K_y(y) = K_y = \kappa \cdot q$$  \hspace{1cm} (24)

Assuming this, the vertical distribution of water velocities can be described as follows:

$$V_x(y) = \frac{1}{\rho K_y} \int \tau_x(y) \, dy$$  \hspace{1cm} (25)

including relationship (21):

$$V_x(y) = \frac{\tau_d}{\rho \kappa q} \int \left( 1 - \frac{y}{H} \right) \, dy = \frac{\tau_d}{\rho \kappa q} \left( y - \frac{y^2}{2H} \right)$$  \hspace{1cm} (26)

Integrating the velocity $V_x(y)$ by depth we obtain the elemental flow intensity $q$:

$$q = \frac{H}{3} \int_0^y V_x(y) \, dy = \frac{1}{3} H^2 \frac{\tau_d}{\rho \kappa q}$$  \hspace{1cm} (27)
hence: 
\[ \tau_d = 3 \frac{\rho \kappa q^2}{H^2} \]  
(28)

Bottom shear stress \( \tau_d \) can be described – according to the Du Boys’ formula – also as:
\[ \tau_d = \gamma HI \]  
(29)

where: \( \gamma \) - volumetric weight of water \([\text{kg/m}^3]\),
\( I \) - hydraulic slope – according to Chezy formula equal to:
\[ I = \frac{q^2}{c^2 H^3} \]  
(30)

Comparison of relationships (28) and (29) allows calculating the \( \kappa \) coefficient as:
\[ \kappa = \frac{1}{3} \frac{g}{c^2} \]  
(31)

Including further:
\[ \left( \frac{u_d}{V_{sr}} \right)^2 = \left( \frac{\sqrt{g HI}}{c \sqrt{H I}} \right)^2 = \frac{g}{c^2} \]  
(32)

we obtain finally:
\[ K_y = \frac{1}{3} \left( \frac{u_d}{V_{sr}} \right)^2 \cdot q \]  
(33)

The eddy viscosity coefficient in the horizontal \( K_x \) direction can be defined – with a good approximation and on the grounds of the former researches [1] – according to the below relationship:
\[ K_x = \left( \frac{u_d}{V_{sr}} \right)^{\chi} \cdot q \]  
(34)

where: \( \chi \) - numerical coefficient, dependent on reservoir’s geometrical parameters.

The previous numerical evaluations and analysis of the obtained results show that the \( \chi \) coefficient in the (34) formula takes values within the range 0.5 ÷ 1.0. The influence of \( \chi \) parameter’s assumption on the model solution was put forward in the paper [9].
5. Optimization procedure

The optimization of eddy viscosity coefficients is complicated and needs to apply iteration procedure. The algorithm is given below.

The procedure goes as follows:

1. the initial values: $\Delta \rho / \rho_1$, $H$, $B$, $q$, location of reservoir’s outflow and inflow cross-sections (coordinates: $y_1^{(m)}$, $y_2^{(m)}$, $y_1^{(n)}$, $y_2^{(n)}$) as given,
2. for the beginning we assume in the Eq. 34 coefficient $\chi = \text{const}$,
3. we fix the value $K_y$ to start calculations,
4. we assume value $K_x$ (for example $K_x = 100 K_y$) to start algorithm and we calculate the flow pattern,
5. next step is to define:
   - dimensionless $A$ parameter according to (12),
   - dimensionless reservoir’s length [4]:
     \[ \xi_1 = \frac{B}{H} \sqrt{\frac{K_y}{K_x + K_y}} \]  (35)
   - interface between transit flow and circulating $\eta_{tr}(\xi)$ from the condition:
     \[ \psi_{tr}(\xi, \eta_{tr}) = 0 \]  (36)
   - transit stream’s depth:
     \[ H_{tr}(\xi) = (1 - \eta_{tr}(\xi)) \cdot H \]  (37)
   - average velocity of transit stream:
     \[ V_{tr}(\xi) = V_0 \int_{\eta_{tr}}^{1} V_{\xi} \, d\eta \quad \text{gdzie: } V_0 = \frac{q}{H} \]  (38)
   - shear velocity of transit flow at the interface:
     \[ u_{\xi}(\xi) = \sqrt{K_y \frac{dV_x}{dy}} \]  (39)
6. base upon this we can calculate new eddy viscosity coefficient $K_x$ according to the (34),
   new value $A$ according to (13) and the dimensionless reservoir’s length $\xi_1$ from (35),
7. the iteration goes so far until we achieve given accuracy:
   \[ |A_{i+1} - A_i| < \text{eps}_A \quad (i \text{ – number of iteration}). \]
5.1. Exemplary calculations

The suggested iteration allows achieving some solutions for both the assumed parameters: elemental flow intensity $q$, reservoir’s geometrical dimensions $H$, $B$, $\eta_1$, $\eta_2$ and the given density gradient $\Delta \rho/\rho_1$.

As an example of the optimization the results for the median cross section ($\xi = \xi_1/2$) are given in Fig. 8. The plot is given in term $K_y/q$ to make it more general.

Fig. 7. Reservoir’s geometrical parameters and boundary conditions

The following source data were assumed in the calculations:

- reservoir’s geometrical parameters: $H = 10$ m, $B = 40$ m, $\eta_{11} = 0.5$, $\eta_{12} = 1.0$, $\eta_{21} = 0.7$, $\eta_{22} = 1.0$,

- density stratification in reservoir: $\Delta \rho/\rho_1 = 0.001$,

- elemental flow through the reservoir: $q = (0.5 \div 6.0)$ m$^2$/s,

- eddy viscosity coefficients: $K_y = (10^{-4} \div 10^{-2}) \cdot q.$
Fig. 8. The results of calculations of stratified flow \((H = 10\text{m}, B = 40\text{m})\)
From the obtained results we have following conclusions:
- the increase of $K_y$ involves increase of $K_x$,
- the increase of flow rate $q$ lowers the value $A$,
- the dimensionless length of reservoir $\zeta_1$, does not depend on the flow rate $q$,
- the increase of flow rate $q$ causes the increase of mean velocity $V_{sr}$ and shear velocity $u_d$ but the ratio $u_d/V_{sr}$ practically does not depend on the flow $q$,
- the changes of the depth of transit flow depending on the flow $q$ is given in the Fig. 9.

![Fig. 9. The plot $q$ against transit flow depth $H_{str}$ ($H = 10m$, $B = 40m$)](image)

The flow pattern depends on geometry of the reservoir, especially on ratio $B/H$. The dependence of parameter $A$ and $K_y/q$ for various reservoir length ($B = 20, 40, 80, 160$ i $320$ m) is given in Fig. 10 and Fig. 11.

![Fig. 10. The dependence of parameter $A$ against $B$ ($H = 10$ m, $q = 2$ m$^2$/s)](image)
The proceeded calculations allows to define following relationship between eddy viscosity coefficients $K_x$ and $K_y$:

$$\frac{K_x}{q} = a \left( \frac{K_y}{q} \right)^b$$  \hspace{1cm} (40)

The following source data were assumed in the calculations:

- reservoir’s depth: $H = 10$ m,
- dimensionless co-ordinates describing the reservoir’s outflow and inflow cross-section location: $\eta_{11} = 0.5$, $\eta_{12} = 1.0$, $\eta_{21} = 0.7$, $\eta_{22} = 1.0$,
- density stratification in reservoir: $\Delta \rho / \rho_1 = 0.001$.

The coefficients “$a$” and “$b$” estimated statistically are given in Fig. 12 and Fig. 13.
And now if we take \( K_y \) according Chezy formula (33) and the above relationship \( K_x = f (K_y) \) we can calculate the appropriate parameters \( A \) and \( \xi \), which define the flow pattern. From this calculation it comes also that the coefficient \( \chi \) in the Eq. 34 varies from 0.5 – 0.85.

6. CONCLUSIONS
The paper presents the mathematical model of vertical circulation in a density stratified reservoir. The model can be applied to the case of salt water wedge penetrating upstream the river mouth. It allows to calculate the horizontal wedge extent and the whole flow pattern.

In the model of vertical stratification it is very difficult to specify the eddy viscosity coefficient correctly so that they could precisely reflect the flow conditions in the reservoir. Having the practical application of calculation results in mind, in this paper one put forward the optimisation procedure of flow solution through the reservoir under circumstances of vertical stratification, defining the real values of \( K_x \) and \( K_y \) coefficients.

The described optimization of eddy viscosity coefficients gives practical tool for engineering calculations concerning selective withdrawal problems and the salt water wedge penetration.
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