Mathematical modeling of the process of water-soluble transport in soils

N Ravshanov¹, I Khurramov², S M Aminov³
¹ Tashkent University of Information Technologies, Tashkent, Uzbekistan
² Karshi State University, Karshi, Uzbekistan
³ Tashkent State Agrarian University, Tashkent, Uzbekistan
E-mail: ravshanzade-09@mail.ru

Abstract. A problem related to the actual problem of the process of water and salt transport in soil is solved in the paper; the review of scientific papers devoted to various aspects and mathematical support of the object under research is given. A mathematical model is proposed in the paper to carry out a complex study, taking into account: the colmatage of soil pores with finely dispersed particles with time; the changes in soil permeability coefficient, fluid loss and filtration coefficient; the changes in the initial porosity and settled mass porosity and an effective numerical algorithm based on the Samarsky-Fryazinov vector scheme with the second order approximation where the differential operators in equations are substituted by finite-difference ones. For the derivation of mathematical model of salt transport it is assumed in the paper that the pressure gradient in the canal is constant and equal to atmospheric pressure. The results of calculations on the proposed algorithms are presented in the form of graphs; a detailed analysis of these results is given. At the end of the paper, conclusions are drawn related to the analysis of numerical computer calculations. It is established that with scarce irrigation, the maximum absorption of water and the accumulated salt transport occurs in the upper layers of soil. Numerical calculations have established that changes in the rate of water transport in soil depend on: porosity, soil permeability, filtration coefficient, composition and structure of soil, and the porosity of settled mass. The process of salinity has reached equilibrium after the use in irrigation of salt water for several years.

1. Introduction

Analysis of the study of the process of water-salt transport in soils has shown that irrigation with waters with mineralization up to 15 g/l can yield crops of agricultural cultures over several years. Relatively good nature of the meliorative state of lands irrigated by mineralized waters for 2-3 years is a temporary aspect. Long-term irrigation leads in many cases to severe consequences, manifested not so much in the form of toxic action of salts, as in the form of abrupt changes in physical-chemical properties of soils, increase in alkalinity and deterioration of aqua-physical properties of soils as a result of shale-forming and degradation of aqua-physical properties of soil. Hence, the study and the implementation of management decisions on the process of water-salt transport in soil is an urgent problem, aimed to preserve the state of soils for the cultivation of agricultural products.

It should be noted that the main source for irrigation of agricultural crops in Central Asia, Transcaucasia is drainage and wastewaters. The volume of drainage and waste waters in irrigation systems in Central Asia, Transcaucasia and other regions reaches up to 30% of the...
water intake; mainly these waters are of increased mineralization; as a result, the mineralization of the Syr Darya and the Amu Darya rivers has already reached 2 g/l. The increase in the areas of irrigated land is accompanied by the involvement of new additional masses of readily soluble salts in soil-forming and geochemical processes and by further increase in water mineralization of the main rivers.

Though, on the one hand, the negative effects of the use of mineralized waters for irrigation of soil are known, on the other hand, the use of these waters is inevitable. Consequently, in the current situation, the forecasting of physical-chemical properties of soils as a result of irrigation by mineralized waters acquires a paramount importance and the first place is occupied by forecasting the soil state. According to the types of land salinization determined by the mineralization of groundwater and saline soils, four cases are distinguished:

- soils and groundwater are salinized;
- only soils are salinized;
- only groundwater is salinized;
- soils and groundwater are fresh.

One of the most effective tools for forecasting and monitoring the soil state is a mathematical tool: a model-numerical algorithm and software that can be used to carry out a computer-aided computational experiment (CE) with given basic hydro-chemical and hydrodynamic parameters of soil.

Mathematical model (MM) of the process of salts washing out from irrigated fields is described by complex systems of differential equations. The model is simplified in those cases when the process of salt transport into soil is considered without adsorption. At one-component process of salt transport with adsorption, the equations of diffusion and mass transfer are identical to the equations considered in [1]. If bear in mind that the cultivated fields are fertilized with various types of mineral substances, the washed out salts are also heterogeneous in their chemical structure. Consequently, when constructing MM of salt transport in soils, it is necessary to take into account the multicomponent nature of ion transport.

The dynamics of adsorption of multicomponent mixtures under isothermal conditions in the mode of parallel motion of sorption fronts was theoretically considered for the first time in [1–4]. The distribution scheme of two adsorbents along the length of the adsorbent bed for a certain fixed moment of time is given in [3].

The solution of the more complicated problem of the isothermal dynamics of the sorption of mixtures, unrelated to the assumptions on parallel transfer of sorption fronts, was obtained in [4]. For the case of two-component mixtures, the equation system consisted of two balance equations and two equations of sorption kinetics. As the balance equation, the Benton-Merker equations were used. In this paper, a system of equations with corresponding boundary conditions is solved by a numerical method.

However, in melioration, the rate of water transport into soil does not remain constant and it is a function of \(x\) and \(t\). In addition, the washing out waters always contain the finest suspended particles, capable to colmatage the pores in soil. As a consequence, soil resistance grows and with time water transport can stop and the flooding of the fields may occur.

It is necessary to emphasize that monitoring and predicting the salt regime of soils largely depend on the degree of determination of the main parameters of the process of salt transport and diffusion in layered porous media.

For detailed and complex study of the process of salt transfer in porous media, it is important to develop an adequate mathematical models that describe the main properties of the studied object.

It can be noted here that qualitative and quantitative changes in salt content in the investigated area (in multilayer porous media) under conditions of stationary water-salt regime
can be predicted using the analytical methods, and the prediction of stratification and secondary salinization of the aeration zone of soils as a result of long-term irrigation and raising of groundwater level with time present a practical interest.

Direct and inverse problems of salt transport model were solved in [2] under conditions of stationary water-salt regime of soil; it was noted that the main parameters describing the transport of dissolved salts into soil were the convective diffusion coefficients, which were determined from the data of special field and laboratory experiments; otherwise their finding was reduced to the solution of the inverse problem of mathematical physics, in which, according to a known solution of the boundary value problem, it was required to find the parameters of MM of the object as a whole.

A computational technique for solving multidimensional filtration and water transport problems in anisotropic layered soil was developed in [3]. It is characterized by a uniform counting in the aeration and full saturation zone, using an effective alternating-triangular method for solving grid equations systems; the estimates of accelerating parameters for difference analogues of typical problems of water transport in soils were obtained during horizontal drainage and vertical wells operation.

Article [4] presents MM and programs for calculating the multicomponent salt, nutrient and trace element compositions of pore solutions, solid and absorbed soil phases with account of absorption of chemical ingredients by the root system of plants. It gives a quantitative indicator of the danger of soil alkalinization when irrigating with mineralized water, taking into account sorption selective properties of soils and chemical composition of irrigation water. For the first time, data on the electrochemical behavior of metals-trace elements in aqueous solutions of different chemical composition were obtained.

Paper [5] is devoted to MM of the process of water transport in soil with account of intra-soil irrigation; it provides a substantiation of the choice of mathematical apparatus of the object under consideration for one-jet intra-soil moisturizers with account of water absorption by plant roots.

In [6, 7], the main approaches to MM of water-transport process for various irrigation methods are considered; known models of water transport in soils are analyzed taking into account the mass forces and occurring nonlinear effects which can be used for intra-soil irrigation. In the article, the main parameters of the object are taken into account in modeling the process: the groundwater level, coefficient of water loss, diameter of the capillaries, relative volume of the capillaries, etc. Integral differential equations that take into account the fractal structure of soil are used to numerically solve the problem of modeling the salt regime for fertigation in soil of the fractal structure. In this case, the mathematical apparatus of fractional differentiation and an index of fractal dimension, determined by the Hurst method, as well as the Euler gamma function and the Mittag-Leffler functions, were used.

In [8], the authors have proposed a transport model for pollutants transport through mineral barriers in the presence of chemical and water gradients. The model includes separate flows of fluid and chemicals, and considers the related flows and nonlinear diffusion. The resulting transport equations are solved by asymptotic expansion, based on the method of multiple time scaling. The steady state profile is calculated analytically.

The authors consider the chemical concentration gradients and porous water pressure gradients only, while electrical and temperature gradients are absent. In addition, second-order terms in electro-osmotic conductivity in diagonal coefficients are neglected. The off-diagonal coefficients are related by the Onsager symmetry relationships.

In [9], the agro-hydrological model of SWAP (Soil-Water-Atmosphere-Plant) was calibrated and its adequacy was confirmed (with field experiments) for modeling the process of water-salt transport in the arid region of China. The simulation results show a lower water content in soil, but a higher salt concentration with scarce irrigation. The SWAP model was also used to predict
the long-term deficit of saltwater irrigation. The process of salinity has reached equilibrium after the use of salt water for several years.

In [10], a study was carried out based on a model of salt transport that describes in detail the corresponding processes on soil surface; computing experiments were carried out to detect the effect of irrigation water on the salinization of soil in the rice growing zone.

Modeling of the process of water transport in the unsaturated zone is carried out by the authors using the scheme of interaction between the atmosphere and the landscape surface of the area (ALSIS). In particular, they consider a one-dimensional isothermal Darcian flow in a variable-unsaturated solid porous medium and assume that the fluid is incompressible, and the air phase plays an insignificant role in water flow.

In [11], the authors consider a site with detailed geological, chemical and hydraulic characteristics over about 16-meter depth of the aquifer consisting of unconsolidated alluvial deposits in the eastern San Joaquin Valley, California. The authors have carried out simple calculations of the mass balance and compared it to six conceptually different two- and three-dimensional numerical models of the vadose zone, which were realized to represent different degrees of hierarchical details of the heterogeneity. Despite the widely differing structure and heterogeneity of the unsaturated flow, all models led to a narrow range of nitrate accumulation assessment in the deep vadose zone, taking into account regular measures for water-nitrogen fertilizing. It was found that the value of nitrate volume obtained as a result of numerical calculations is approximately six to eight times greater than the actual value measured in the field on the site.

This study emphasizes that physical heterogeneity of deep vadose zones can have a limited impact on the transfer of conservative contaminants that are repeatedly applied to soil surface. The results of the study also raise questions about the understanding of the chemical state of nitrates in the vadose zone; and the assumption of the existence of a significant stationary domain of water in the deep vadose zone, which is not explained by the heterogeneity of the parameters of the Richard equation; this is necessary to take into account in modeling the nitrate transport under conditions of cyclic infiltration with convective flow with predominance of gravity.

In [12], MM of the object of investigation has been proposed, where the generalized Richards equation was used to model water transport in unsaturated soils.

The authors have solved this equation numerically and adjusted this solution for horizontal water transport. The classical Richards equation predicts a decrease in diffusion of soil water at the same water content as infiltration, whereas the generalized Richards equation well describes all observations with a single diffusion function. The validity of the generalized Richards equation indicates the presence of memory effects in the phenomena of soil water transport and can explain the scale dependence and variability of the hydraulic conductivity of soil encountered by researchers who applied the classical Richards equation.

Hydrodynamic and hydraulic models of water flow in wetlands are proposed in [13], they allow describing the processes of filtration and surface runoff with varying degrees of detail and accuracy. In the paper, the issues of modeling the quality of ground- and surface waters are considered based on the models of salt transport by interacting filtration and canal flows.

In [14, 15], the study was carried out within the framework of various mathematical models describing a cyclic self-sustaining ion exchange process and identifying the simplest and the most adequate to experiment model and solving the inverse problem for determining the kinetic coefficients of the sorption process.

A detailed analysis of the above-mentioned studies has shown that under a complex study of the process of water-salt transport in soils, in the derivation of MM of the object it is necessary to take into account the main essential parameters: the colmatage of soil pores with finely dispersed particles with time; changes in soil permeability coefficient, water loss and filtration
coefficient; changes in initial porosity and the porosity of the settled mass.

2. Problem Statement
To derive MM of the object under research, taking into account the above factors, it is assumed that soil is homogeneous: the ground waters, the canals, the water bodies adjacent to the region under consideration, are assumed so far away that their influence can be neglected. Then MM of the process of water transport with soil pore colmatage can be written using equation [16]:

\[
\frac{\partial W}{\partial t} + W \frac{\partial W}{\partial x} = -\frac{\alpha}{\rho} \frac{\partial P_k}{\partial x} + \frac{\mu}{\rho} \frac{\partial^2 W}{\partial x^2} - \frac{\alpha}{\rho} P_n - \frac{\mu W}{p k_0 (1 - \delta)^2};
\]

(1)

\[
\frac{\partial \theta_m}{\partial t} + \frac{\partial W \theta}{\partial x} = \frac{\partial \omega}{\partial x};
\]

(2)

\[
\frac{\partial \delta}{\partial t} = \lambda (\theta - \gamma \delta);
\]

(3)

\[
\frac{\partial m P_n}{\partial t} = \frac{\partial}{\partial x} \left( k_f \frac{\partial P_n}{\partial x} \right);
\]

(4)

\[
\frac{\partial m c}{\partial t} + \frac{\partial W c}{\partial x} = D \frac{\partial^2 c}{\partial x^2};
\]

(5)

\[k = k_0 (1 - \sqrt{\delta})^3, m = m_1 + \delta (m_0 - m_1)\]

(6)

with initial and boundary conditions

\[W = W_0, \theta = \varphi (x), \delta = 0, P_n = P_{n,0}, C = C_0 \text{ at } t = 0,\]

(7)

\[W = W_0, \theta = \theta_0, k_f \frac{\partial P_n}{\partial x} = \frac{\mu W_0 \lambda}{k_0} \text{ at } x = 0,\]

(8)

\[\frac{\partial W}{\partial x} = 0, \frac{\partial P_n}{\partial x} = P_e (c - s) \text{ at } x = \infty.\]

(9)

Here \(W\) is the velocity of water in soil; \(\theta\) - a concentration of suspended matter; \(\delta\) - a concentration of suspended matter in the pores; \(P_k\) - a pressure in the canal; \(P_n\) - a soil pressure; \(\rho, \mu\) - density and viscosity of the suspension; \(m, k\) - porosity and permeability of soil; \(k_f\) - a coefficient of filtration; \(m_1, m_0\) - initial porosity and porosity of the settled mass; \(C\) - a concentration of salt; \(D\) - a diffusion coefficient; \(\alpha\) - coefficient of water transport; \(W_0, P_0, \theta_0\) - initial velocity of pressure and concentration of suspended matter; \(\omega\) - artificial viscosity, represented as a quadratic viscosity \(\omega = \mu_0 \left( \frac{\partial \theta}{\partial x} \right)^2\) or \(\omega = -0.5 \mu_0 |\theta_x| (\theta_x - |\theta_x|)\).

The coefficient of "viscosity" is chosen equal to \(\mu_0 = (1 \div 2) h^2\) (\(h\) - is an integration step).

Assume that the pressure gradient in the canal is constant and equal to atmospheric pressure, i.e. \(- \frac{\partial P_k}{\partial x} = P_{atm}\). In cases where the pressure gradient is variable (this may be the case, for example, for the problem of intra-soil irrigation when water is fed through perforated pipelines directly to the roots of crops, saving a large amount of water due to evaporation, which is very essential in the hot climate of Central Asia), it is expressed by the formula

\[- \frac{\partial P_k}{\partial x} = \frac{\mu}{k} W.\]

(10)
3. Solving Method

From the statement of the problem (1)-(9) it is difficult to obtain an analytical solution. For numerical integration, dimensionless variables are introduced by the formulas:

\[
\begin{align*}
W &= \frac{W}{W_0}, \quad \bar{\theta} = \frac{\theta}{\theta_0}, \quad \bar{\delta} = \frac{\delta}{\theta_0}, \quad \bar{P} = \frac{P_n}{P_0}, \\
\bar{x} &= \frac{x}{x + H}, \quad \bar{k} = \frac{k}{k_0}, \quad \bar{n} = \frac{n}{\alpha}, \quad \bar{\tau} = \frac{H}{W_0}.
\end{align*}
\]

Then, at \(-\frac{\partial P_k}{\partial x} = P_{atm} = \text{const}\), we get:

\[
\frac{\partial W}{\partial t} + (1-x)^2 \left[ W + \frac{2(1-x)}{Re} \right] \frac{\partial W}{\partial x} = -Eu \left( \frac{\partial P_k}{\partial x} - P_n \right) \alpha + \frac{(1-x)^4}{Re} \frac{\partial^2 W}{\partial x^2} - \frac{1}{k_0(1-\delta)^2};
\]

\[
\frac{\partial \theta}{\partial t} + (1-x)^2 \frac{\partial W \theta}{\partial x} = \mu_1 (1-x)^2 \frac{\partial \omega}{\partial x};
\]

\[
\frac{\partial \delta}{\partial t} = \lambda_0 (\theta - \gamma \delta);
\]

\[
\frac{\partial mP_n}{\partial t} + \frac{k_f W_0 H}{W_0} = (1-x)^2 \frac{\partial}{\partial x} \left[ k(x, t) (1-x)^2 \frac{\partial P_n}{\partial x} \right];
\]

\[
\frac{\partial mc}{\partial t} + (1-x)^2 \left[ \frac{\partial Wc}{\partial x} + \frac{2(1-x)}{Pe} \frac{\partial c}{\partial x} \right] = \frac{(1-x)^4}{Pe} \frac{\partial^2 c}{\partial x^2};
\]

\[
W = 1, \theta = \varphi(x), \delta = 0, c = 1, P_n = 1 \text{ at } t = 0;
\]

\[
W = 1, \theta = 1, \frac{\partial c}{\partial x} = \frac{P_r(c - s)}{Pe(c - s)};
\]

\[
\frac{k_f}{\partial x} = \frac{1}{k_0(1-\delta)^2};
\]

\[
\frac{\partial W}{\partial x} = 0, \frac{\partial c}{\partial x} = 0, \frac{\partial P}{\partial x} = 0, (x = 1),
\]

where \(\omega = (1-x)^2 \left[ (1-x)^2 \frac{\partial \theta}{\partial x}, \mu_1 = \frac{\nu_0}{\nu W_0} \right] \), \(\theta = \frac{\rho W_0}{\rho W_a} \) is the Reynolds number; \(Eu = \frac{P_r}{\rho W_0} \) - the Euler number; \(Pe = \frac{\rho W_0}{\nu} \) - the Peclet number.

Hereinafter, for simplicity, the dashes over dimensionless variables will be omitted.

To solve problem (12)-(19), the vector scheme is applied and we obtain [18]:

\[
\begin{align*}
\frac{\partial u}{\partial t} + (1-x)^2 \left[ u + \frac{2(1-x)}{Re} \right] \frac{\partial v}{\partial x} &= -\alpha Eu \left( \frac{\partial P_k}{\partial x} - P_n \right) + \frac{(1-x)^4}{Re} \frac{\partial^2 u}{\partial x^2} - \frac{u}{k_0(1-\delta)^2}; \\
\frac{\partial v}{\partial t} + (1-x)^2 \left[ v + \frac{2(1-x)}{Re} \right] \frac{\partial u}{\partial x} &= -\alpha Eu \left( \frac{\partial P_k}{\partial x} - P_n \right) + \frac{(1-x)^4}{Re} \frac{\partial^2 v}{\partial x^2} - \frac{v}{k_0(1-\delta)^2}; \\
\frac{\partial \theta_1}{\partial t} + (1-x)^2 \frac{\partial u \theta_2}{\partial x} &= -\mu_1 (1-x)^2 \frac{\partial \omega y}{\partial x}; \\
\frac{\partial \theta_2}{\partial t} + (1-x)^2 \frac{\partial v \theta_1}{\partial x} &= -\mu_1 (1-x)^2 \frac{\partial \omega z}{\partial x}; \\
\frac{\partial \delta_1}{\partial t} &= \lambda_0 (\theta_1 - \gamma \delta_1); \\
\frac{\partial \delta_2}{\partial t} &= \lambda_0 (\theta_2 - \gamma \delta_2);
\end{align*}
\]
\[
\begin{align*}
\frac{\partial n_{m1}}{\partial t} + \left[ \frac{\partial n}{\partial x} + \frac{2(1-x)^4}{Pe} \frac{\partial N}{\partial x} \right] (1-x)^2 &= \frac{(1-x)^4}{Pe} \frac{\partial^2 n}{\partial x^2}; \\
\frac{\partial n_{m2}}{\partial t} + \left[ \frac{\partial n}{\partial x} + \frac{2(1-x)^4}{Pe} \frac{\partial n}{\partial x} \right] (1-x)^2 &= \frac{(1-x)^4}{Pe} \frac{\partial^2 N}{\partial x^2}; \\
U &= v = 1, y = z = \varphi(x), \delta_1 = \delta_2 = 0, n = N = 1, (t = 0), \\
u &= v = 1, \theta_1 = \theta_2 = 1, \frac{\partial n}{\partial x} = Pe(n-s), \frac{\partial N}{\partial x} = Pe(N-s), (x = 0), \\
\theta_1 &= (1-\delta_1)^2, \theta_2 = (1-\delta_2)^2, \frac{\partial n}{\partial x} = \frac{\partial N}{\partial x} = 0, (x = 1),
\end{align*}
\]

where

\[
\omega_y = (1-x)^2 \left\{ (1-x)^2 \left[ \frac{\partial^2 \theta_1}{\partial x^2} \right] + \omega_2 = (1-x)^2 \right\} \left\{ (1-x)^2 \right\} \frac{\partial^2 \theta_2}{\partial x^2}.
\]

The numerical algorithm for solving the problem (20)-(25), the calculation of the running coefficients and the elements of the transition matrix are described in detail in [17, 18]:

\[
\begin{align*}
a_i u_{i+1} - b_i u_{i-1} + c_i u_i - d_i v_i + \ell_i v_{i-1} &= -f_i; \\
a_i ' u_{i+1} - b_i ' u_{i-1} + c_i ' u_i - d_i ' v_i + \ell_i ' v_{i-1} &= -f_i ';
\end{align*}
\]

The solution (26) is sought in the form

\[
\begin{align*}
u_i &= A_i u_{i+1} + B u_{i+1} + c_i \\
v_{i+1} &= A_i ' u_{i+1} + B u_{i+1} + c_i '
\end{align*}
\]

When perform in computer-aided numerical calculations, the necessary number of iterations is determined from condition

\[
\frac{|u_{i}^{(s)} - u_{i}^{(s-1)}|}{|u_{i}^{(s)}|} < \varepsilon, \quad |v_{i}^{(s)} - v_{i}^{(s-1)}| < \varepsilon, \quad \varepsilon > 0.
\]

4. Discussion

The results of calculations based on the proposed algorithms are shown in Figs. 1–11. The computing experiments are carried out with the initial data taken from [19].

As seen from the curves in Figs. 1 and 6, a sharp drop in the rate of water transport is observed mainly in the upper layers of soil, and at \( x \geq 0.7 \) it decreases moderately along the layer thickness. From the analysis of numerical computer calculations, it can be seen that changes in the rate of water transport mainly depend on: firstly, soil porosity and permeability; secondly, the filtration coefficient, which depends on soil composition and structure; thirdly, the porosity of the settled mass.

Analysis of the numerical calculations carried out on a computer (Fig. 2) has shown that at the initial stages of the process of water and salt transport, the concentration of suspended matter in the upper layers of soil (at \( 0 \leq x \leq 0.85 \)) has a maximal value, and at \( x \geq 0.86 \) the concentration of suspended matter in soil decreases sharply along the thickness; with time of the water and salt transport process, the concentration of suspension along the layer thickness decreases linearly (Fig. 8).

As seen from the curves in Figs. 3 and 9, the concentration of suspended matter in soil pores reaches maximum value in the upper layers of soil. At \( 0.1 \leq x \leq 0.76 \) the concentration of suspended matter in the pores does not change in thickness, at \( x \geq 0.86 \) it decreases sharply along the thickness, and in the lower soil layer it remains constant. Analysis of computer numerical calculations has shown that an increase in sedimentation rate of suspended matter in soil pores depends on concentration of suspended particles in the solution.
As seen from the curves in Figs. 1, 6, a sharp drop in the rate of water transport is observed mainly in the upper layers of soil, and at $x \ge 0.7$ it decreases moderately along the layer thickness. From the analysis of numerical computer calculations, it can be seen that changes in the rate of water transport mainly depend on: firstly, soil porosity and permeability; secondly, the filtration coefficient, which depends on soil composition and structure; thirdly, the porosity of the settled mass.

Analysis of the numerical calculations carried out on a computer (Fig. 2) has shown that at the initial stages of the process of water and salt transport, the concentration of suspended matter in the upper layers of soil ($0 \le x \le 0.85$) has a maximal value, and at $0.86 \le x$ the concentration of suspended matter in soil decreases sharply along the thickness; with time of the water and salt transport process, the concentration of suspension along the layer thickness decreases linearly (Fig. 8).

**Figure 1.** Changes in the rate of water transport along the layer thickness at $t = \tau = 1, \alpha = 0.954406$

**Figure 2.** Changes in concentration of suspended matter along the layer thickness at $t = \tau = 1, \alpha = 0.954406$
As seen from the curves in Figs. 3, 9, the concentration of suspended matter in soil pores reaches maximum value in the upper layers of soil. At $0.1 \leq x \leq 0.76$ the concentration of suspended matter in the pores does not change in thickness, at $x \geq 0.86$ it decreases sharply along the thickness, and in the lower soil layer it remains constant. Analysis of computer numerical calculations has shown that an increase in sedimentation rate of suspended matter in soil pores depends on concentration of suspended particles in the solution.

As seen from the curve in Fig. 4, the soil pressure decreases linearly along the thickness to a certain value, and then it grows back in thickness in the initial stages of the process of water and mass transport. The minimum value of pressure in soil corresponds to $x = 0.80 - 0.85$. Analysis of the numerical calculations has shown that with time the process of water and salt transport in soils along the layer thickness increases linearly at $0 \leq x \leq 0.87$ (Fig. 10); the pressure increase in soil is accelerated at $x \geq 0.88$. Numerical calculations on computers have shown that the growth of pressure in soil moves with time in the direction to the upper layers of soil.
As follows from the curves in Figs. 5 and 11, the salt concentration in soil is maximally accumulated in the upper layers of soil (at $0 \leq x \leq 0.15$), and at $x \geq 0.2$ it decreases sharply along the thickness, and at it equals to zero. Such dynamics is also observed at time $\tau = 7, \alpha = 0.114121$. Comparison of numerical calculations at has shown that with the expiration of time of salt transport, the concentration of salts increases with time by an order of magnitude (Figs. 5 and 11).
Figure 7. Changes in concentration of suspended matter along the layer thickness at $\tau = 7, \alpha = 01.114121$.

Figure 8. Change in concentration of suspended matter in soil pores along the layer thickness at $\tau = 7, \alpha = 01.114121$. 

Figure 9. Changes in soil porosity along the layer thickness at $\tau = 7, \alpha = 0.114121$

Figure 10. Changes in pressure inside soil along the layer thickness at $\tau = 7, \alpha = 0.114121$
As seen from the results of numerical calculations, soil porosity at \( x = 0 \) to \( x = 0.2 \) sharply increases, while at \( 0.2 \leq x \leq 0.85 \) it remains constant, and at \( x \geq 0.9 \) it again grows along the layer thickness (Fig. 9). Analysis of numerical calculations has shown that the concentration of suspended matter and the velocity of the settled mass in soil pores play an important role in the change of soil porosity.

5. Conclusions
By numerical calculations it has been stated that changes in the rate of water transport into soil depend on: porosity, soil permeability, filtration coefficient, composition and structure of the soil, and porosity of the settled mass.

Analysis of numerical calculations has shown that the growth of the sedimentation rate of suspended particles in soil pores depends on the concentration of suspended matter in the solution.

Numerical calculations have established that, with scarce irrigation, the maximum absorption of water and the accumulated salt layer are observed in the upper layers of soil. The process of salinity has reached equilibrium after the use of salt water for several years.

A comparison of numerical calculations at \( \tau = 1 \) and \( \tau = 7 \) has shown that with the expiration of salt transport time, the concentration of salts in soil increases with time by an order of magnitude.

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