International Journal of Biological, Life and Agricultural Sciences
ISSN: 2415-6612
Vol:10, No:12, 2016

Soil Moisture Regulation in Irrigated Agriculture

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Abstract**—**Seepage capillary anomalies in the active layer of soil, related to the soil water movement, often cause variation of soil hydrophysical properties and become one of the main objectives of the hydroecology. It is necessary to mention that all existing equations for computing the seepage flow particularly from soil channels, through dams, bulkheads, and foundations of hydraulic engineering structures are preferable based on the linear seepage law. Regarding the existing beliefs, anomalous seepage is based on postulates according to which the fluid in free volume is characterized by resistance against shear deformation and is presented in the form of initial gradient. According to the above-mentioned information, we have determined: Equation to calculate seepage coefficient when the velocity of transition flow is equal to seepage flow velocity; by means of power function, equations for the calculation of average and maximum velocities of seepage flow have been derived; taking into consideration the fluid continuity condition, average velocity for calculation of average velocity in capillary tube has been received.

Keywords**—**Seepage, soil, velocity, water.

I. Introduction

In recent years, the World faces the water shortage problem. It is estimated that at present, about 1.5 billion of the world population is in the water shortage, while in 2050 this number is expected to reach 3.5 billion [1].

Currently, in spite of the fact that water resources may be enough in the whole country, still there is not the state producing agricultural products, which does not experience serious difficulties in terms of watering of the certain areas. Like many countries in the world, Georgia experiences particular difficulties in supplying water to the regions which are encompassed in the semi-arid areas, as the demand of water here is quite high, though its availability is considerable low.

As for the volume of water demand, among water management branches, agriculture sector is one of the major water-consumer, since about 70% of the existing water resources come to the irrigation water. Experts have estimated that the reduction of irrigation water consumption by 10% will save more water than that it is consumed by all water-users together [1].

According to many studies, among the irrigation technologies, the drip irrigation is the most reliable. Even in a case of using this method, water loss amounts about 30% if the irrigation mode is incorrectly selected [2], [5], [6], [9], [11].

Errors during the selection of watering regime parameters are mainly conditioned by ignorance or negligence of the inaccurate data of physical or mechanical properties of the soil, water and air modes data, seepage or other factors in the models illustrating soil moisture dynamics.

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Regarding the soil moisture issue, in the irrigation and drainage practices, the quantity of soil humidity is characterized by two indicators: the soil moisture and moisture capacity. In some cases, humidity is expressed in percentages or in units depending on different types of moisture capacity. Namely, full water saturation or marginal field water saturation is expressed in percentages. Obviously, this feature will be a relative term. In practice, for the determination of the moisture content, a variety of physical and electromagnetic methods are used. The forms of water in the soil are determined by its aggregate condition, degree of dispersion, and interaction with solid and air parts of the soil as mentioned above.

The two forms of the soil moisture are distinguished: linked water (gravitational forces do not participate in movement of linked water) and free water, which moves impacted by the gravitational as well as other forces. The definition of the different forms of the water in the soil in this way is conditional and enables to qualitatively estimate the impact of different factors on soil moisture. Chemically linked water is part of minerals molecules of soils. Constitutional water may be separated from the soil by overheating at high temperature, which is accompanied by the decomposition of minerals. Constitutional moisture's largest number (3-5% of the soil dry weight) is in clay minerals [3]-[5]. It is obvious that this category of water depends on the quality of fragmentation of the soil solid component degree, so on dispersion and colloid bulk quantities. Often, its number is determined by the correlated skeleton's specific surface.

Between maximum horoscopy and maximum molecular water capacity, resistant moisture fades. By reducing the moisture, the plant cannot rebuild vitality by the next humidity. There is also initial stage of the moisture level when plants start to fade, which can be eliminated if water supply/ irrigation is restarted/renewed. The plant fading begins when the water absorption by root system is less than transpiration. Different plant roots have different absorption abilities, so the declining power of critical humidity varies.

In natural conditions, a variety of soils which covers with the different seepage rates causes the intensity of the water outflow, and therefore, stipulates the changes of the distribution diagram of vertical distribution of velocity.

It should be noted that the issue of vertical distribution of velocity at any intensity of water seepage outflow has not been determined yet due to the absence of a convincing mathematical model of this quite difficult event. Specifically, this factor may explain the main focus of researchers on the creation of seepage equations and its laboratory and natural researches. [1]

In a porous environment, particularly in the soil-ground field, a number of scientific articles are dedicated to study the seepages regularities; however, just a few works are related to the interrelations between seepage and channel flows, their joint impact on the allowable (not-washable) velocity magnitude.

Based on analysis of experimental data, in a case of a negative seepage, i.e. in the event of outflow, it is observed that the bottom velocities and their gradient raise in the bottom layer in opposition to the preliminary assumptions [6].

In a case of a positive seepage, i.e. inflow, according to the common view, when transition of the particle into floating condition is more intense than in case of existence of seepage, the sand particles start to vibrate at a rather high washing-out velocity and make jumps at much shorter distances [6].

Experimental studies have shown that in case of sand soil with the particle size d = 0.25 mm and in the event of value of the velocity equal to 29 cm/s and positive seepage, the particles dropping intensity is increased by three times compared to the case when there is no seepage; i.e., it is believed that washing-out is increased by 300% at the expense of raising the bottom velocity and reduction of the particles stability [7].

In case of negative seepage, the particles dropping intensity shall be also reduced by three times, it seems that it can be explained by reducing the washing velocity and raising the quality of the stability of the particles.

It is accepted that the limited range of changes of the mechanical composition of soils and the flow depth are totally ignored though it significantly affects the volume of the washing velocity.

The studies are dedicated to the seepage effect on a vertical distribution of velocity providing an opinion about the influence of weighted seepage rate on the velocity distribution. As the studies have shown such impact in comparison to the main flow even in case of too insignificant expenditure of the seepage, the velocity range change is noticeable in the bottom layer; in case of seepage, the flow dynamic structure is changed [7].

Presence of the criteria for strict quantitative assessment of the processes can be explained by the physical and mechanical properties of soils, as well as the scarcity of the hydro-mechanical parameters range. It has been determined that in case of the upward seepage, the permissible average velocity is decreased, while in case of downward seepage it is increased [7].

The sphere of changes to the velocity on the vertical reviewed by all scientists is not coming out of the turbulent boundary layer, because all of the reporting schemes concern the volumes relevant to the ones expressed in the velocities at a roughness ledge altitude, so the results obtained a convincing justification.

Sub-surficial velocity depends on the main transit flow rates, but it is still significantly low although it is significantly higher than the bandwidth of the seepage. Seepage rate cannot be equated with the seepage losses, since it is expected that leakage of the seepage flow into the river flow is due to the difference between the pressure seepage gradient and hydraulic slopes.

The analysis of the theoretical and experimental studies conducted for identification of the interaction of main transit and seepage flows during the velocity range formation showed that any direction of the seepage leads to the change of the main flow dynamic structure, which is expressed in the particles' power impact as well as in the necessity of explaining the physical essence of the main and sub-surficial flows interaction [8].

According to the above-mentioned explanations, the consideration of the surface phenomena in the essence of process allows us, along with the study of moisture dynamics in the active layer of soil, to forecast the micro-bio-physical processes. This issue is even more gripping in multi-capillary porous clay soils which are represented by especial hydro-physical processes and a wide range of anomalies. Therefore, hydrological parameters, particularly water migration in soils pores, movement regularity, and moisture regulation, require the knowledge of a number of pattern changes of hydro-physical properties and determination of rheological index [9], [10].

The existing researches confirm that the regularity of seepage processes in the clay soils cannot be placed within the specific legal framework of Newtonian fluids and for the reflection of physical picture of a phenomenon. Usage of more general models is needed; namely, different models describing Darcy's linear law between filtration rate and hydraulic slope [8].

It should be noted that all existing equations for computation of seepage rate, particularly in canals, at dams, at the foundations of the hydraulic engineering structures, are predominantly based on the law of linear seepage. Regarding the recent beliefs, anomalous seepage is based on the postulate according to which the fluid in the free volume is characterized with the resistance towards the shear deformation in the form of initial gradient [11].

II. General Part

Based on the linear law of distribution of tangent tension in the perpendicular plane of flow motion direction, according to the equilibrium of resistance (friction) force acting on the lateral surface and pressure force acting on the partitions, the resistance force of an initial shift can be determined based on the similarity of ΔOA_1 B_1 and ΔOAB triangles:

$$\tau_0 = \gamma i r. \tag{1}$$

Using the power model for flow motion in capillary, we will receive:

$$\tau = \tau_0 + K\left(\frac{du}{dy}\right)^n. \tag{2}$$

According to the distribution of tangent tension on the vertical, we may write:

$$\gamma(R - y - r) = K\left(\frac{du}{dy}\right)^n. \tag{3}$$

By integrity of (3), distribution of velocity on the vertical in capillary will look like:

$$V_y = \left(\frac{\gamma i}{K}\right)^{\frac{1}{n}} \frac{n}{n+2}\left[(R-r)^{\frac{n+1}{n}} - (R-r-y)^{\frac{n+1}{n}}\right]. \quad (4)$$

when$y = R - r$, the maximum value of velocity will be:

$$V_{max} = \left(\frac{\gamma i}{K}\right)^{\frac{1}{n}} (R-r)^{\frac{n+1}{n}}. \quad (5)$$

relation of local and maximum velocities will be:

$$\frac{V_y}{V_{max}} = 1 - \left(1 - \frac{y}{R-r}\right)^{\frac{n+1}{n}}. \quad (6)$$

An average velocity in the capillary pipe is determined according to the continuity condition and looks like:

$$V_{evg} = \frac{n}{n+1}\left(\frac{\gamma i}{K}\right)^{\frac{1}{n}} (R-r)^{\frac{n+1}{n}}\left(1 - \frac{n}{2n+1}\frac{R-r}{R}\right), \quad (7)$$

where n is the indicator of motion index, γ is the volumetric weight of water, K is the consistency factor, and R is the radius of capillary pipe.

Equation (7) by its content is different from all other similar equations and particularly from those equations that are received for clay suspensions. Analysis of (7) reveals that one of the difficulties here is to define the index of motion and it requires an introduction of special researches.

In order to solve the problem, according to the velocity profile and based on assumptions, if we describe the distribution in the gradient layer using parabola equation, then we will get:

$$Y = \alpha V_{y.}^2. \quad (8)$$

The area of velocity profile will be looked like:

$$S = V_{max}\left(1 - \frac{R-r}{3R}\right). \quad (9)$$

If we equalize (7) and (9), for the distribution parabola on the vertical velocity, the index will be looked like $n = 1$, i.e. when the n is equal to 1, the non-Newton liquid motion model transforms into the Shvedov-Bingham viscous-plastic model. Taking into consideration the value of n, the correlation V_{evg}/V_{max} in the equations of average and maximum velocities will be equal to:

$$\frac{V_{avg}}{V_{max}} = 1 - 0.33\frac{R-r}{R}. \quad (10)$$

If we consider the value of n in the design model of power function of velocity, accordingly the values of average and maximum velocities will be equal to:

$$V_{avg} = \frac{1}{2}\frac{\gamma i}{\mu}R^2\left(1 - \frac{r}{R}\right)^2\left(1 - \frac{1}{3}\frac{R-r}{R}\right). \quad (11)$$

$$V_{max} = \frac{1}{2}\frac{\gamma i}{\mu}(R-r)^2\left(1 - \frac{r}{R}\right)^2. \quad (12)$$

In a case of x quantity of water tubes located in the orthogonal plane of axis of cylindrical sample, the total water flow rate will be:

$$Q = V_{avg}\pi(R-r)^2 x. \quad (13)$$

If we insert (9) into (1), we will get:

$$Q = \frac{\pi\gamma i}{2\mu}R^2\left(1 - \frac{r}{R}\right)^2\left(1 - \frac{1}{3}\frac{R-r}{R}\right). \quad (14)$$

when the velocity in the capillary tube is equal to seepage velocity, i.e.:

$$V_F = \frac{\gamma i R^2}{2\mu} = KI. \quad (15)$$

In a case of x quantity of tubes:

$$Q = V_F\pi R^2 x\left(1 - \frac{r}{R}\right)^4\left[1 - \frac{1}{3}\frac{R-r}{R}\right]. \quad (16)$$

If we will consider, that by using the presented ideal model the seepage velocity will yield:

$$V_F = K(I - I_0). \quad (17)$$

then, the water flow rate will be:

$$Q = K(I - I_0)\omega. \quad (18)$$

When the water velocity is equal to the seepage velocity, the equation for the computation of seepage coefficient will be determined:

$$K = \frac{\gamma R^2}{2\mu}\left(1 - \frac{r}{R}\right)^4\left(1 - \frac{1}{3}\frac{R-r}{R}\right). \quad (19)$$

when r=0, (19) will get the following form:

$$K = 0.08\frac{\rho g r^2}{\mu}. \quad (20)$$

when $r = R$, then $K = 0$.

Because the water flow rate for x tube looks like:

$$Q = V_F\pi R^2 x\left(1 - \frac{r}{R}\right)\left(1 - \frac{1}{3}\frac{R-r}{R}\right). \quad (21)$$

If we equalize (18) and (21), the ratio between the initial gradient and the velocity gradient will be equal to:

$$\frac{I_0}{I} = 1 - n\left(1 - \frac{r}{R}\right)^2\left(1 - \frac{1}{3}\frac{R-r}{R}\right). \quad (22)$$

Equation (22) clearly shows that the ratio of the initial gradient to the total gradient is a porosity function, and when it increases, the ratio decreases.

III. Conclusion

According to the above-mentioned results, we have obtained:

- an equation for the computation of seepage coefficient, when the velocity of transition flow is equal to the seepage velocity;
- equations for the computation of average and maximum flow velocities using the power function;
- an equation for computation of average velocity in the capillary tube, taking into consideration the fluid continuity equation.

This work was supported by Shota Rustaveli National Science Foundation (SRNSF) [grant number RNSF/DO 82/10-170/14].

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