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# SIMULATION OF THE IRRIGATION FOR FURROW FOR THE MODEL SASIS: SENSIBILITY TO THE FACTORS OF SPACE CONSIDERATION AND STORM

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**ABSTRACT** Surface irrigation systems are the most commonly used in Brazil and the in the world, mainly due to the low energy requirements and its operations easiness; however, these systems present low levels of performance, usually, as a consequence of inadequate design and management. Thus, the objective of this research was to develop a tool capable of optimization the continuous flow furrow irrigation performance, making successive simulations of the advance phase and respective prognostics of the performance parameters of the irrigation systems. The proposed model denominated SASIS, "Software Applied to Simulation of the Surface Irrigation", and had its validation tested for different field conditions. Determined variables introduced in the model SASIS influence the results of the simulation of the irrigation for furrow with continuous flow was somewhat affected in an isolated form, the simulation, while in others the effect is conjugated as is the case of the factors of space consideration ($\phi$) and time ($\theta$), among the factors of space consideration ($\phi$) used in the interval from 0.51 to 0.71 and time ($\phi$) in the interval from 0.51 to 0.61 the software SASIS recommends values near of 0.60 for those two factors. The model presents effective mechanisms in the accomplishment of countless simulations, in a discharge strip understood between the minimum and the maximum allowable values, aiming to determine the relationship between discharge and water application efficiency, deep percolation and runoff rates, and consequently to optimize the performance of the furrow irrigation systems with continuous flow.

**Key words**: Furrow Irrigation, simulation, optimization

**INTRODUCTION** The method of surface irrigation is considered the oldest form of artificial application of water in the soil in order to meet the water requirements of crops; it is the most widely used method of the world, especially in the Asian and African continents, and even in the USA and in the most developed countries of Europe. In Brazil, despite the lack of accurate, it covers the largest irrigated area because, undoubtedly, of its pioneering during the deployment of large public irrigation projects, particularly in the Northeast.

Although the surface irrigation is the most widely used one of the world, it is considered low efficiency in water application, especially the furrow irrigation system, in which the ones of open furrow are responsible for the lower levels of efficiency. The low efficiency in the surface irrigation systems is due mainly to the lack of a careful scaling and to the practice of improper management of irrigation. According to Rezende et al. (1988), reduced levels of performance in furrow irrigation systems can be attributed to the incorrect scaling on the operation and unsatisfactory management.

The furrow irrigation presents different field and operating variables of the system which influence its performance, like flow and time of water application, dimensions, steepness and roughness of the surface soil, geometry of the furrow and caracteristics of water infiltration in the soil; the values of variables like steepness, roughness, geometry of the furrow and average of infiltration correspond to specific conditions of field, for which the designer must define flow, time of water application, length, row spacing and water depth. A good furrow irrigation project must consider these variables and the interaction among them (Wu & Liang, 1970; Reddy & Clyma, 1981).

The surface irrigation systems present the potential of applicating water to crops with efficiency of 70% to 80% (Merriam & Keller, 1978); actually, some automated systems have favored efficiency about 90% (Fischback & Somerhalder, 1971); but most irrigation projects of the world have worked with efficiency of application about 40% to 50% or with values even lower (Bos & Nugteren, 1974; Clyma et al., 1975; Kruse & Heermann, 1977).

The surface irrigation process takes place in four phases: advance, storage, depletion and recession, in which the first one starts when the water is adduced and ends when the advancing front reaches the end of the furrow or covers the entire portion of a range or board, starting the storage phase, in which water level in the surface soil rises, ending when the flow is canceled. That time, the depletion phase starts and ends when the water disappears in any portion along the furrow or range, what generally happens in the headboard. Then it is the recession phase, when water level starts demoting, and which ends when all the water disappear on the surface soil. In furrow irrigation, Walker (2001) considers the storage and depletion as only one phase, i.e. the event of furrow irrigation is divided into three phases: advance, storage/depletion and recession.

According to Azevedo (1992) and Azevedo & Walker (1993), the low application efficiency of the surface irrigation projects is due to an inappropriate scaling and management, which become complicated because of the spatial and time variation of the field parameters, especially the ones of water infiltration in soil. According to Souza (1992), the irrigation projects in Brazil are, in general, operated with low efficiency because the perspective used is the one in which the irrigation systems must be projected and constructed but, after the deployment, the management system is not considered, becoming, with rare exceptions, exclusively dependent on the sensitivity and experience irrigating.

The different simulation models of surface irrigation were developed in order to simulate an isolated irrigation event, assuming that there is not spatial variability in the field parameters (infiltration, roughness, steepness and sectional); in practice, the validityof this hypothesis has been verified considering that the simulations are very close to the field measurements of the phases, however, the time variability in these parameters are always taken into account, as for the evaluation of any irrigation event throughout the growing season, new measurements of field parameters are held.

With this research, we aimed to develop a mathematical computational model for simulation and optimization of furrow irrigation with continuous flow and, through the simulation of the advance phase, able to predict the performance of an irrigation event and select the great flow in the furrow irrigation with continuous flow, i.e. that one which maximizes the water application efficiency, balancing losses by percolation and runoff.

**MATERIAL AND METHODS** In the kinematic wave model used in this research, it is assumed that there is not variation of the height of flow with the distance, i.e., $\partial y / \partial x = 0$ neglecting completely the equation of motion, without what nothing can be said concerning to the dynamics of the shape of surface profile of flow, getting the equation of continuity indefinite in time $\partial A / \partial t$; to solve this problem, it is assumed the existence of a unique relationship which describes flow as function of the flow area; Then, it is substituted the equation of motion by the Manning Equation. The runoff, studied only cinematically, is similar to the propagation of a kinematic wave which collides, why these models are called kinematic waves. The designation of uniform runoff models is due to, obviously, the substatiation in a proper equation of uniform runoff.

Because this kind of model is not applicable to furrows when the steepness is too small, i.e., when the steepness tends to zero: actually its precision will decrease when $S_o$ approximates to zero. It was used Strelkoff & Katopodes's (1977) recomendations.

Therefore, the equations of the kinematic waves model used become:

Continuity equation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} + \frac{\partial Z}{\partial \tau} = 0 \qquad (1.0)$$

$$Q = \alpha\, A^m \quad (2.0) \qquad \text{(Manning Equation)}$$

Where: $\alpha = \frac{\sqrt{\rho_1\, S_O}}{n}$ (3.0) and $m = \frac{\rho_2}{2}$ (4.0)

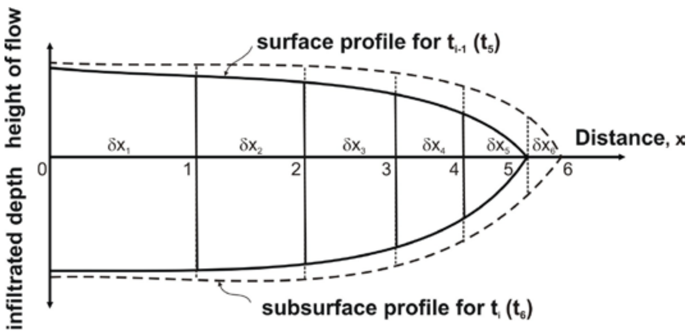
where: $A$ - cross-sectional of flow area, m$^2$; $t$ - time of occurence, second; $x$ - distance of water advance in field, m; $\tau$ - time of infiltration opportunity, second; $Z$ - infiltrated volume accumulated per unit length of furrow, m$^3$ m$^{-1}$; $Q$ - discharge flow, m$^3$ s$^{-1}$; $n$ – Manning roughness coefficient, m$^{-1/3}$ s; $S_o$ - steepness of field, m m$^{-1}$; and $\rho_1$ and $\rho_2$ are constant empirical adjusted to the field measurements of the geometry of the furrow; $\alpha$ and $m$ empirical constants.

For spatial numerical solution of the equations of the kinematic waves model, it was used, in this research, the Eulerian integration procedure with first order approximation by Walker & Humpherys (1983) and Wallender (1986), which results in two algebraic equations more stable and easier to be dissolved in microcomputers. Conceptually, the approximation considers the surface and subsurface profile of water throughout the wetted area during sequential stages of calculation. The Figure 1 illustrates the surface and subsurface profiles of flow in the times $t_{i-1}$ and $t_i$, identifying the cells which compse them. During each stage of calculation the water flow advances an incremental distance, $\delta x$; e.g., during the first interval (first stage of calculation), extends to a distance $\delta x_1$; in the second interval, to a distance $\delta x_2$, and so. It can be generalized to the distance of the advancing front, $x_i$, in the time $t_i$, as it follows:

$$x_i = \sum_{k=1}^{i} \delta x_k \qquad (5.0)$$

where $\delta x_k$ is the k[th] increment of space, defined by the advance during the interval, when i = k, where k is the number of time increment.

A typical cell of the profile is illustrated in the Figure 2, displaying profiles in the stages of calculation $t_{i-1}$ and $t_i$. Notes J, M, L and R are introduced in each cell in order to identify the variables which describe flow conditions related to time and space. Thus, the variables subscripted by J or M reffer to the flow conditions in time $t_{i-1}$ and borders left (upstream) and right (downstream) of the cell, respectively. Similarly, L and R are subscripted borders left and right og the cell in time $t_i$. Combining the cells of all time incremets there will be a grid calculation in the line ($x,t$), in which the advance and recession trajectories may be drawn. It is observed, in this line, that during the advance phase the cells are rectangular, but the ones of the advancing front, which are triangular because there is not flow borders downstream of this cells, in times $t_i$ e $t_{i-1}$. During the storage and depletion phases, all cells are rectangular; and during the recession, the cell end upstream is triangular for the same reasons of flow behavior in the advancing front, but the other cells are rectangular. The width of each cell is determined by the distance of the advancing front during each stage of calculation $\delta t$, which becomes, then, one of the unknowns of the problem, once it was considered $\delta t$ constant. This is called a spatial solution of the Saint-Venant equations because $\delta x$ is an unknown, while the value of $\delta t$ is defined by the user model.




SOURCE : WALKER & SKOGERBOE (1987)

Figure 1. Schema of progression of superficial flow and infiltration for the constant interval.

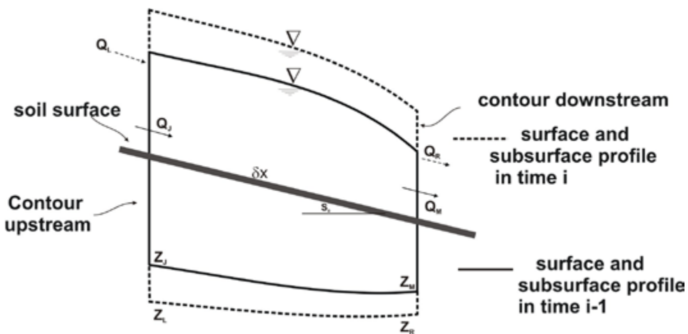


Figure 2. Deformed cell of flow (Walker & Skorgeboe, 1987)

The integrated form of the equation of continuity in relation to distance and time results in:

$$
\begin{aligned}
&\frac{1}{2}\left[\left(Q_{x+\delta x,\,t} - Q_{x,\,t}\right)_{t+\delta t} + \left(Q_{x+\delta x,t} - Q_{x,\,t}\right)_{t}\right]\delta t + \\
&\frac{1}{2}\left[\left(A_{x,\,t+\delta t} - A_{x,t}\right)_{x+\delta x} + \left(A_{x,t+\delta t} - A_{x,t}\right)_{x}\right]\delta x + \\
&\frac{1}{2}\left[\left(Z_{x,t+\delta t} - Z_{x,t}\right)_{x+\delta x} + \left(Z_{x,t+\delta t} - Z_{x,t}\right)_{x}\right]\delta x = 0
\end{aligned}
\qquad (6.0)
$$

Since during the advance phase the flow decreases throughout the distance for the effect of the rate of water infiltration in soil, falling to zero in the advancing front, the non-linearity of the profile, both surface and subsurface, becomes quite marked, making the factor ½ not appropriated to consider the flow conditions; thus, an appropriate consideration must be from ½ to 1. Then, the factors $\theta$ and $\phi$ are created to consider the non-linearity of the profile, respectively, related to time and space. These factors are extremely important only during the advance phase because after this phase there is tendency to establish stable conditions of flow. The consideration must be superior in time $t+\delta t$ as during the advance phase the non-linearity increases with time, getting maximum when the water reaches the end of the area (zero flow conditions); besides, also there must be superior in the input section because the height of flow varies soon in this section, once it is on it where flow is being applied.

Replacing, in the Equation 6.0, ½ by $\theta$, $(1-\theta)$, $\phi$, $(1-\phi)$ and writing the flow variables in terms of the notes of a computational cell, there is:

The Equation 6.0 may, then, be represented in terms of the notes, in the Figure 2, as follows:

$$
\begin{aligned}
&\left[\theta\left(Q_R - Q_L\right) + \left(1-\theta\right)\left(Q_M - Q_J\right)\right]\delta t + \\
&\left[\phi\left(A_L - A_J\right) + \left(1-\phi\right)\left(A_R - A_M\right)\right]\delta x + \\
&\left[\phi\left(Z_L - Z_J\right) + \left(1-\phi\right)\left(Z_R - Z_M\right)\right]\delta x = 0
\end{aligned}
\qquad (7.0)
$$

where θ and ϕ coefficients of time and space consideration, respectively, whose values vary from ½ and 1; in general, it has taken values equal to 0.65 and 0.51 for θ and ϕ, respectively. In his software SIRMOD III, Walker (2001) uses 0.60 for both; the same value used in this research.

The numerical solution is obtained by solving the Equation 7.0 for each cell in the computational mesh starting horizontally from left to right, in each stage of calculation. The only unknowns in each cell are $Q_R$ e $A_R$; however, once $Q$ is explicitly being calculated on Manning equation (Equation 2.0), it is not considered an unknown; the same case is applied to $Z$ (infiltration) which is being calculated on Kostiakov-Lewis equation. What is done is to replace the equations of $Q$ and $Z$ by the Equation 7.0 and, then, it gets only one unknown ($A_R$).

Replacing the Equation 2.0 by the Equation 7.0 and dividing it by $\theta\alpha/\delta t$, there will be the following equation nonlinear in $A_R$:

$$A_R^m + \left(\frac{1-\phi}{\theta\alpha}\right)\frac{\delta x}{\delta t}A_R - A_L^m + \left(\frac{1-\theta}{\theta}\right)\left(A_M^m - A_J^m\right) +$$
$$\frac{\phi}{\theta\alpha}\left(A_L + Z_L - A_J - Z_J\right)\frac{\delta x}{\delta t} + \left(\frac{1-\phi}{\theta\alpha}\right)\left(Z_R - A_M - Z_M\right)\frac{\delta x}{\delta t} = 0 \qquad (8.0)$$

Aiming to simplify the Equation 8.0, the constants and variables with values known from the previous stage of calculation in the coefficients $C_1$ e $C_2$ are isolated. Then, there is:

$$C_1 = \left(\frac{1-\phi}{\theta\alpha}\right)\frac{\delta x}{\delta t} \qquad (9.0)$$

and,

$$C_2 = -A_L^m - \left(\frac{1-\theta}{\theta}\right)A_J^{m+1} + \left(\frac{1-\theta}{\theta}\right)A_M^{m+1} +$$
$$\frac{\phi}{\alpha\theta}\left(A_L + Z_L - A_J - Z_J\right)\frac{\delta x}{\delta t} + \left(\frac{1-\phi}{\alpha\theta}\right)\left(Z_R - A_M - Z_M\right)\frac{\delta x}{\delta t} \qquad (10.0)$$

getting the equation

$$A_R^{m+1} + C_1 A_R + C_2 = 0 \qquad (11.0)$$

The Equation 11.0 is used for interior cells and for the first one after the first stage of calculation. Since the Equation 11.0 is solved implicitly (by Newton-Raphson's method) for each cell, separatedly, there is not, a matrix. This equation is used implicitly to determine $A_R$ and, after, it is determined explicitly $Q_R$, by Manning equation (Eq. 2.0).

Equation of water infiltration was obtained on equation:

$$Z = k\tau^a + f_o\tau \qquad (12.0)$$

where: $Z$ - accumulated infiltration, $m^3\ m^{-1}\ min^{-1}$; $\tau$ - time of infiltration opportunity, min; $k$ - constant of Kostiakov-Lewis equation of infiltration, $m^3\ min^{-a}\ m^{-1}$; $a$ - empirical coefficients of Kostiakov-Lewis equation of infiltration; $f_o$ - basic infiltration rate in $m^3\ m^{-1}\ min^{-1}$

The maximum nonerosive flow was obtained through the following equation:

$$Q_{máx} = \left[ \left( \frac{V_{máx}^{\rho_2}\, n^2}{3600\, S_0\, \rho_1} \right) \right]^{\frac{1}{\rho_2 - 2}} \qquad (13.0)$$

where: $Q_{máx}$ - max nonerosive flow, $m^3\ min^{-1}$; $V_{máx}$ - max nonerosive speed, $m\ min^{-1}$; $n$ - Manning coefficient, $m^{-1/3}$ s; $\rho_1$ e $\rho_2$ - coefficients which express the geometry of the furrow, dimensionless; $S_o$ - steepness of the furrow, $m\ m^{-1}$

The infiltrated volume was determined by using the trapezoidal rule by the equation:

$$V_z = \frac{L}{2n}\left[Z_o + \left(2Z_1 + 2Z_2 + \ldots + 2Z_{n-1}\right) + Z_n\right] \qquad (14.0)$$

where: $L$ - length of the area, $Z_i$ – accumulated infiltration to point i, $m^3\ m^{-1}$; n - number of segments in which the furrow is subdivided

The accumulated infiltration in each segment of the furrow is given by:

$$Z_i = k\left[t_r - (t_a)_i\right]^a + f_o\left[t_r - (t_a)_i\right] \qquad (15.0)$$

where: $k$ - Kostiakov-Lewis equation constants, $m^3\ min^{-a}\ m^{-1}$, $a$ - Kostiakov-Lewis equation empirical constants, $f_o$ – basic infiltration rate, $m^3\ m^{-1}\ min^{-1}$, $t_r$ - time of recession, min, $(t_a)_i$ - time of advance for ai$^{th}$ station, min

The recession phase is marked by disappearance of water from surface soil. According to some authors, the recession occurs as soon as the water application ends. In this work, the depletion and recession phases were neglected, considering that the cutting time, $t_{com}$, replaces $t_r$ in the Equation 15.0.

**RESULTS AND DISCUSSION** Certain variables introduced in the model SASIS influenced in the results of the simulation of the furrow irrigation with continuous flow, some of which affect, in isolation, the simulation while in others the effect is combined, i.e., the effect of one depends on the effect of the other; later, the fact of having, perhaps, a combined effect between the space ($\phi$) and time ($\theta$) consideration factor will be highlighted. An appropriate choice of the consideration factors of the integration of the deformable cells advance contributes to a better simulation of the advancing curve, favoring a more precise prognosis of the performance of irrigation. In order to evaluate the simulation of the software in relation to space ($\phi$) and time ($\theta$) considertation factors, we have worked with field data used by Azevedo (1992), AMALGACQ having laid all the other parameters and varied both space (ϕ), in the interval from 0.51 to 0.71, and time (θ), in the interval from 0.51 to 0.61, consideration factors. In the Table 4.6 it is observed that for set of values of ϕ and θ of (0.53 and 0.57; 0.57 and 0.59; 0.59 and 0.59; 0.65 and 0.61; and 0.60 and 0.60) occurred variations in the advance time which varied from 14 to 22% in relation to the average advance time in field; therefore, it is noticed the existance of various combinations of values of these factors able to simulate the advance phase with acceptable variations to the prognosis of the advance time; it is also verified ranges of combinations of these factors which do not permit simulations in the advance phase, what certainly is due to linearity of the advance curve for these field data (AMALGACQ); concerning to the efficiency of the application and storage and to the infiltrated volume, it was found to be directly affected by the space and time consideration factors, and also variations in the efficiency of application and storage of 10.4 and 12.7% and in the infiltrated volume 5.89 $m^3$; the lowest value (58.5%) estimated for the efficiency of application was for combination of the factors of space and time consideration parameters, of 0.51 and 0.57 respectively, while the highest value (58.9) was for combination 0.69 and 0.51; for the efficiency and storage, the lowest value estimated (87.1%) was for combinations (0.51 and 0.57), while the maximum value (100%) was obtained for several pairs of combinations; regarding the infiltrated volume, the highest value (39.12 $m^3$) was estimated when the combination 0.69 e 0.51 was used for space (ϕ) and time (θ) consideration, respectively, while the lowest value estimated for the infiltrated volume (33.3 $m^3$) was when it was used 0.51 for space (ϕ) and 0.57 for time (θ) consideration. Therefore, it was observed, somewhat, that the more rigorous in choosing factors ϕ and θ the better the result of the simulation. SIRMOD simulated, for these field data (AMALGACQ), advance time 67.3 min., estimated an efficiency of water application and storage of 67.2 and 100% respectively, beyond an infiltrated volume of 41.43 $m^3$ for the value of ϕ of 0.51 and θ of 0.60. It is, then, concluded, in Table 1, that there are several combinations of consideration factors in the Saint-Venant equation, which are able to improve the simulation of the advance phase with the model SASIS. Walker (2001) uses, in SIRMOD III, 0.60 for both and, according to him, other models use values from 0.51 to 0.55. Software SASIS recommends values close to 0.60 for both. According to Carvalho (1994), space and time consideration factors, ϕ and θ, are used in the integration, because of the nonlinearity of the continuity equation. Based on the values presented in Table 1, it is verified that there is a low variation in the efficiencies of application, storage and infiltrated volume with the growth of the consideration factor; the opposite is true with the advance time, i.e., it decreases whenever the consideration factor increases.

It is seen that in Table 1 the situations which best approximated of the value measured in field were for ϕ and θ equal to 0.57 and 0.59 respectively, and ϕ and θ equal to 0.60 and 0.61 respectively; it is observed that the simulation is more affected when values of θ inferior to 0.55 and values of ϕ superior to 0,60 are considered, where simulation os more affected by space consideration factor than by time consideration factor affirming, therefore, the values used for ϕ and θ (0.60 and 0.60) by Walker (2001) in SIRMOD III and, here, by software SASIS.

Analising the effect of space ϕ and time θ consideration factor in the infiltrated volume it is possible to observe varying behavior for the simulation of this value, while volume oscillates with the growth of ϕ and θ. This oscillation confirms the variation which occurs in the efficiency of water application with the growth of the values of ϕ and θ. Table 1 indicates that the lowest value simulated for the infiltrated volume (33.23 $m^3$) was equal to 0.51 for ϕ and to 0.57 for θ, while the highest value (39,12 $m^3$) was equal to 0.69 for ϕ and to 0.51 for θ, occurring, then, a variation of 17.7% in the infiltrated volume. It is observed that the lowest values estimated for the infiltrated volume occur when the values of θ close to 0.60 and ϕ close to 0.51 are considered, while the highest values estimated for the infiltrated volume ask for values of ϕ superior to 0.60 and θ between 0.51 and 0.61 to be considered.

## CONCLUSIONS

1. The simulations of the advance phase by the model SASIS presented discrepancies in the advance time at the end of the area, inferior to the ones identified by the model SIRMOD, which did not compromised the prognosis of the balance of water volume, profile of water infiltration or the parameters of the performance of furrow irrigation system with continuous flow.

2. The analysis of the sensitivity of simulation of the advance phase in the irrigation identified ranges of combinations between space and time consideration factors of the surface and subsurface profile of flow, which resulted in acceptable discrepancies between simulated and measured advance time, noting, more,

3. SASIS presented effective mechanisms in the implementation of a number of simulations, in a range of flow between the minimum and the maximum allowed, aiming to determine the relation between flow and efficiency of water application, percolation and runoff rates and, consequently, to optimize the performance of furrow irrigation system with continuous flow.

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Table 1. Sensitivity analysis of simulation by model SASIS in relation to the variation of space (ϕ) and time (θ) consideration factors, for the Field data AMALGACQ (Advance time = 232 min)

| ϕ \ θ | 0,51 | | | | 0,53 | | | | 0,55 | | | | 0,57 | | | | 0,59 | | | | 0,61 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TL | Ea | Er | Vz | TL | Ea | Er | Vz | TL | Ea | Er | Vz | TL | Ea | Er | Vz | TL | Ea | Er | Vz | TL | Ea | Er | Vz |
| 0,51 | 115 | 63,7 | 94,9 | 36,21 | 130 | 62,7 | 93,4 | 35,61 | 160 | 62,7 | 93,3 | 35,54 | 290 | 58,5 | 87,1 | 33,23 | | | | | | | | |
| 0,53 | 110 | 63,4 | 94,3 | 36,04 | 125 | 63,8 | 95,0 | 36,20 | 145 | 62,2 | 92,6 | 35,28 | 195 | 60,4 | 89,0 | 34,28 | | | | | | | | |
| 0,55 | 110 | 66,4 | 98,9 | 37,70 | 120 | 64,3 | 95,7 | 36,50 | 140 | 64,4 | 95,9 | 36,5 | 170 | 61,4 | 91,4 | 34,80 | | | | | | | | |
| 0,57 | 105 | 65,2 | 97,0 | 37,06 | 115 | 64,2 | 95,6 | 36,49 | 130 | 63,5 | 94,5 | 36,0 | 155 | 62,1 | 92,4 | 35,19 | 265 | 58,9 | 87,7 | 33,42 | | | | |
| 0,59 | 105 | 67,9 | 100 | 38,54 | 110 | 63,3 | 94,7 | 36,17 | 125 | 64,3 | 95,7 | 36,46 | 145 | 62,9 | 93,4 | 35,64 | 190 | 60,4 | 90,0 | 34,27 | | | | |
| 0,60 | 100 | 64,6 | 96,2 | 36,78 | 110 | 65,0 | 96,8 | 36,94 | 120 | 62,9 | 93,7 | 35,74 | 140 | 62,8 | 93,5 | 35,62 | 180 | 61,5 | 91,6 | 34,87 | | | | |
| 0,61 | 100 | 65,8 | 98,0 | 37,43 | 110 | 66,4 | 98,9 | 37,70 | 120 | 64,5 | 96,0 | 36,60 | 135 | 62,5 | 93,0 | 35,44 | 170 | 61,9 | 92,1 | 35,08 | | | | |
| 0,63 | 100 | 68,1 | 100 | 38,70 | 105 | 64,9 | 96,7 | 36,91 | 115 | 64,2 | 95,5 | 36,44 | 130 | 63,5 | 94,6 | 36,03 | 155 | 62,2 | 92,7 | 35,29 | | | | |
| 0,65 | 95 | 65,2 | 97,0 | 37,13 | 105 | 67,4 | 100 | 38,24 | 115 | 67,0 | 99,8 | 38,00 | 125 | 64,0 | 95,3 | 36,30 | 145 | 62,7 | 93,3 | 35,55 | 190 | 60,2 | 89,6 | 34,13 |
| 0,67 | 95 | 67,5 | 99,8 | 38,16 | 100 | 65,0 | 96,8 | 36,99 | 110 | 65,7 | 97,9 | 37,24 | 120 | 63,9 | 95,2 | 36,28 | 140 | 64,2 | 95,6 | 36,37 | 170 | 61,5 | 91,6 | 34,88 |
| 0,69 | 95 | 68,9 | 100 | 39,12 | 100 | 67,0 | 99,7 | 38,07 | 105 | 64,0 | 95,3 | 36,39 | 115 | 63,3 | 94,3 | 35,99 | 130 | 62,5 | 93,0 | 35,46 | 155 | 61,6 | 91,6 | 34,91 |
| 0,71 | 90 | 64,7 | 96,3 | 36,93 | 100 | 68,9 | 100 | 39,10 | 105 | 66,1 | 98,4 | 37,53 | 115 | 65,7 | 97,8 | 37,26 | 125 | 62,9 | 93,7 | 35,72 | 150 | 63,3 | 94,3 | 35,88 |

TL: advance time at the end of the area, min; Ea: efficiency of application, %; Er: efficiency of storage, %; and Vz: infiltrated volume, $m^3$