Comparing steady and non-steady state subsurface drainage using calculations with relevant models

Abstract
The results of model developed for steady state subsurface drainage calculating the level of the water table using the traditional Darcy equation as well as the energy balance of groundwater flow are compared with those of a model developed for non-steady state subsurface drainage, based on the non-linear reservoir concept, calculating the fluctuations of the water-table, while the characteristics of the drainage system and the soil conditions are the same.
The average water level in the non-steady state using the non-linear reservoir approach corresponds, after an initial period, well with the steady state energy balance approach.

Contents

1. Introduction

The RainOff model [Ref. 1] uses the non-linear reservoir concept to simulate rainfall-runoff relations in watersheds [Ref. 2] as well as the recharge – water level - discharge relations for subsurface drainage systems.

The EnDrain model [Ref. 3] uses both the classical Darcy equation as well as the energy balance of groundwater flow to obtain the steady state shape of of the water table between two parallel subsurface drains (ditches or pipes, [Ref. 4]). Input data are the recharge, the drain depth, the drain spacing, the drain dimensions, the hydraulic conductivity of the soil above and below drain level, and the depth of the impermeable layer, see the following figure.

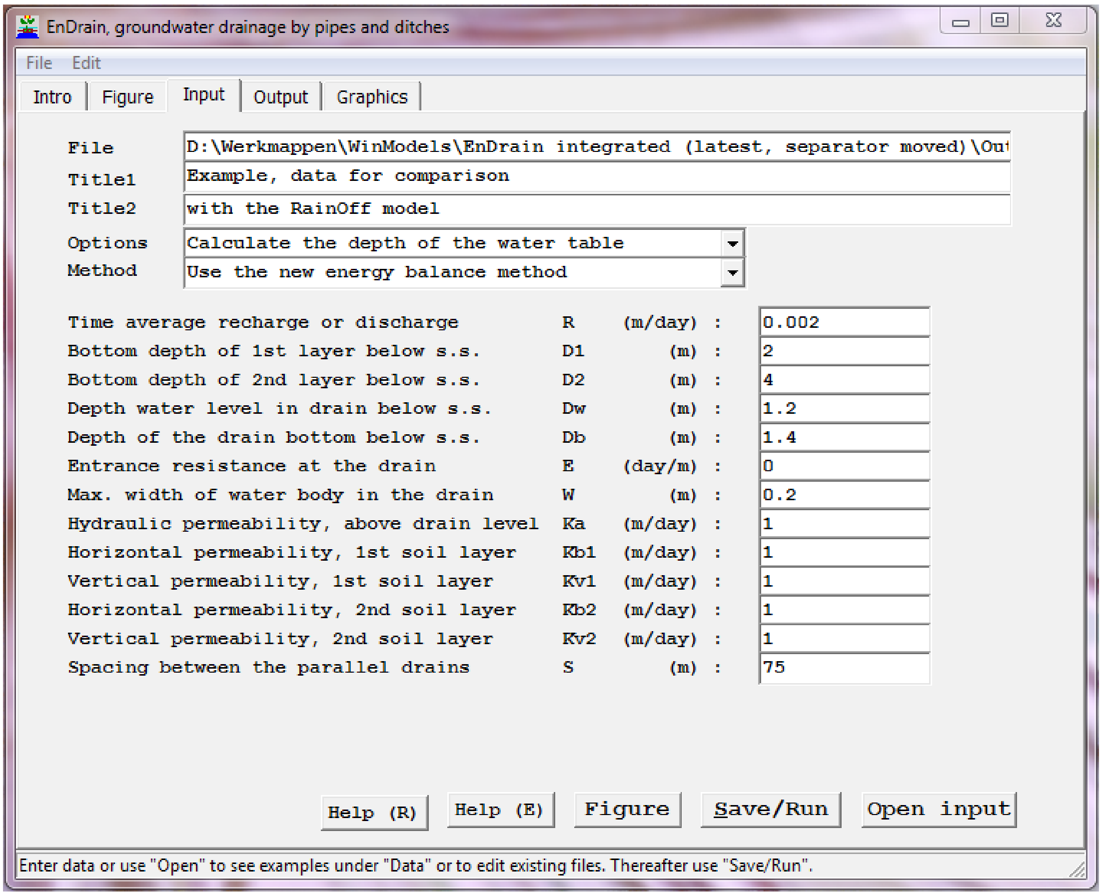

Figure 1.

The symbols used in the above figure are clarified with a sketch of the properties of the drainage system in the next figure.

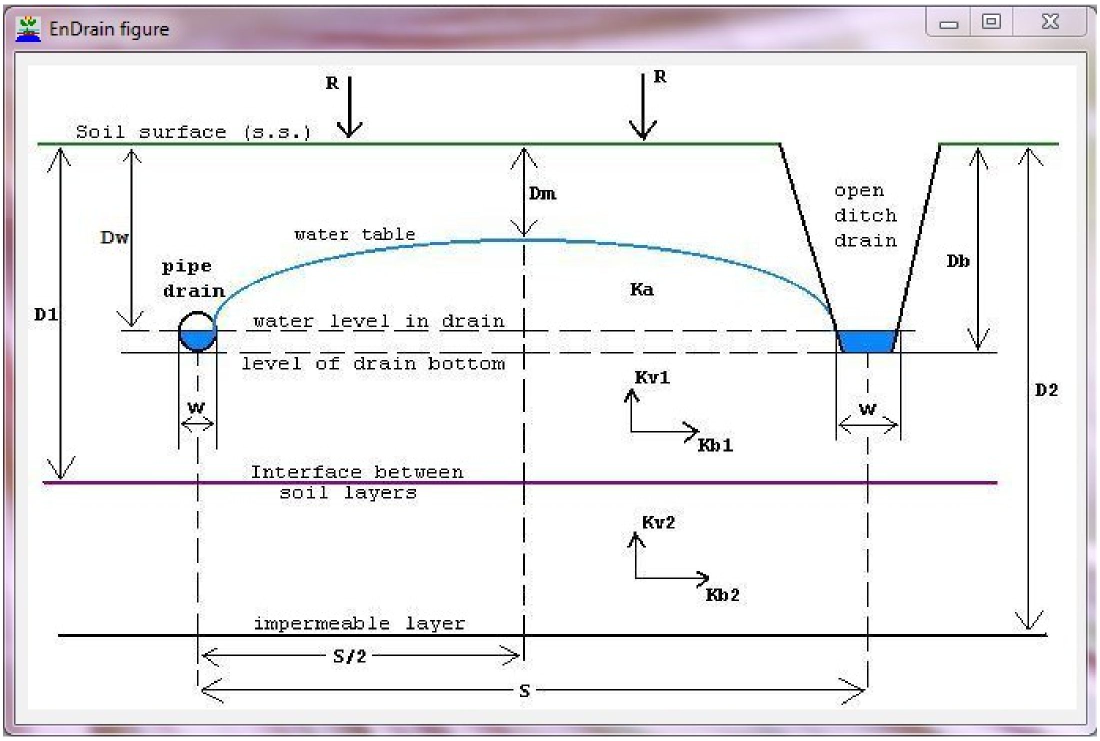

Figure 2.

The RainOff model uses the equations: $Q = A.H + B$ and $dH/dT = d\{(Q-B)/A\}/dT = (R - Q)/P$, where Q is the runoff or discharge, H is the water storage or hydraulic head, A and B are parameters depending on the dimensions of the drainage system, R is the recharge (rainfall minus change in water storage), and P is the drainable porosity of the soil. The calculation method for A and B is shown in the next figure. To compare the results of both models, the RainOff model needs regularly fluctuating recharges so that in the long run the fluctuations reach an equilibrium.

2. Experimentation

A calculator of RainOff to find the values of A and B is pictured in the next figure. The data used here are the same as those used in the EnDrain program (figure 1).

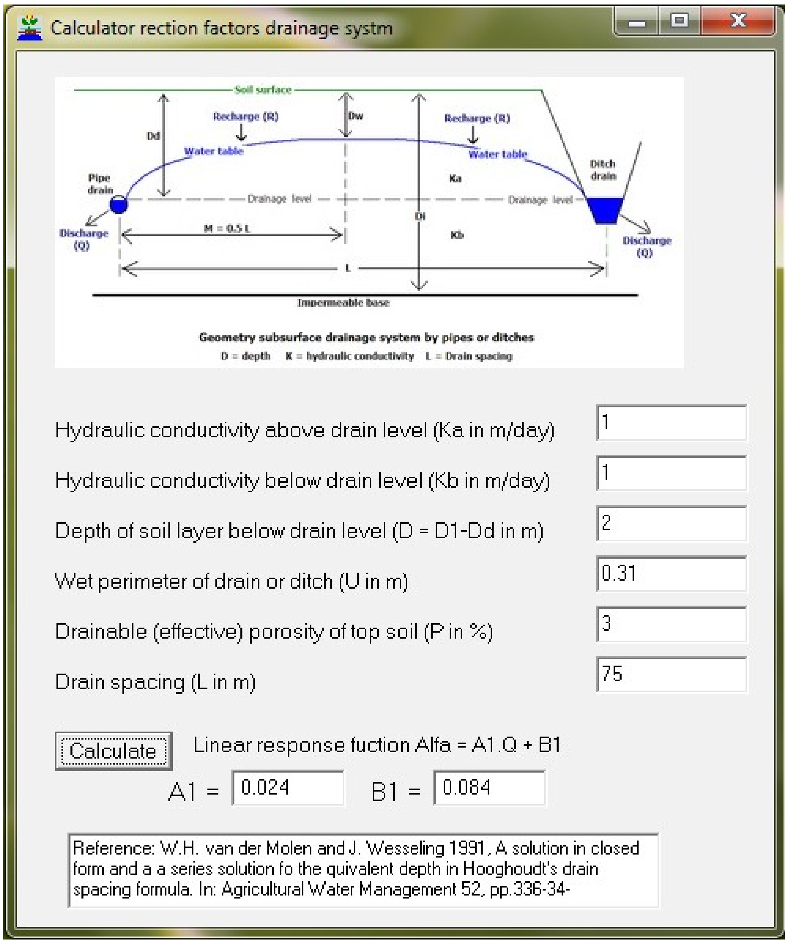

Figure 3.

The resulting A and B values are transferred to the input tab-sheet, as depicted in the next figure, where it is also shown how the calculator is activated.

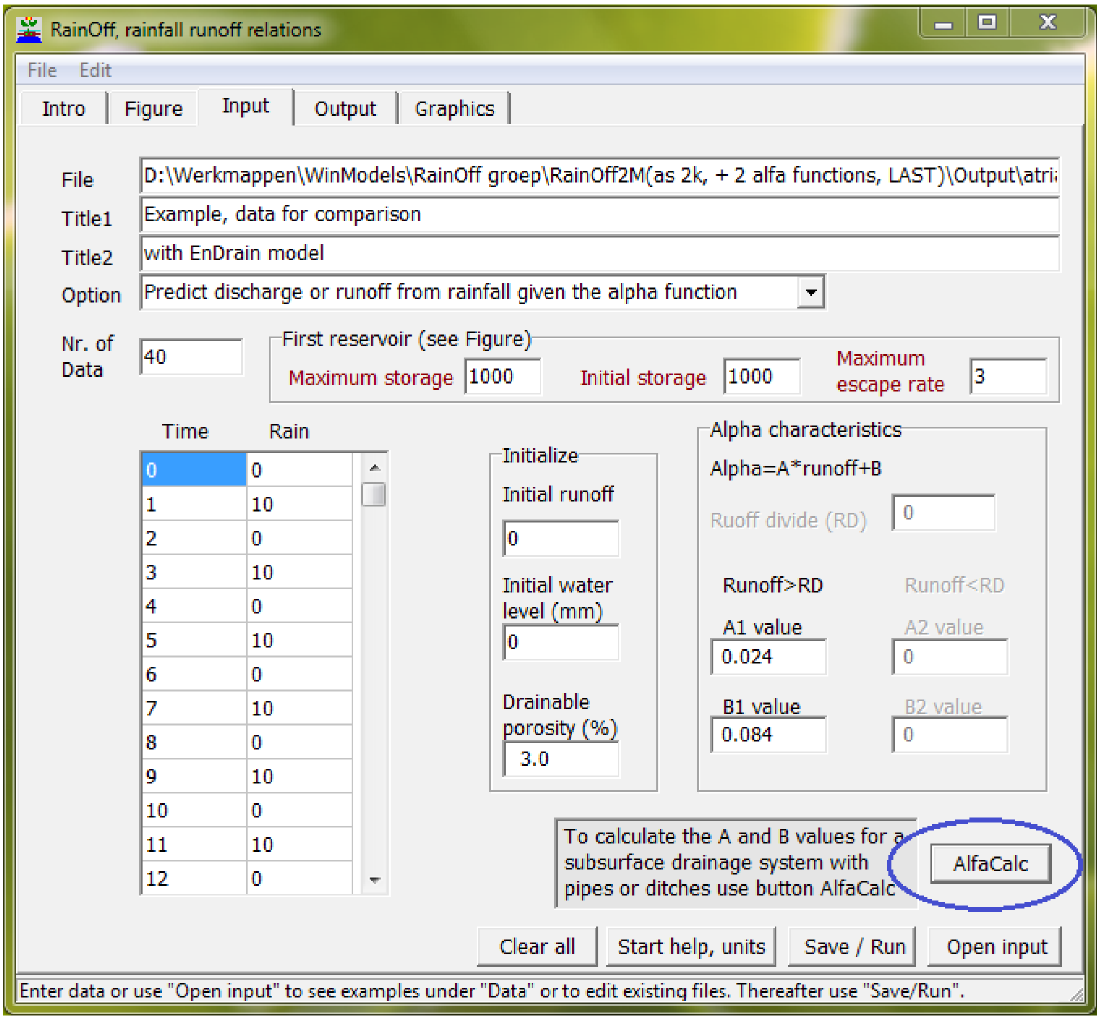

Figure 4.

In the above illustration it can be seen that the rainfall is 0 and 10 mm every other day, giving a recharge of 5 mm/day on average. Subtracting the escape rate (representing in this case the evaporation), being 3 mm/day, results in a net average recharge of 5 – 3 = 2 mm/day, the same as used in the EnDrain program (figure 1).

The results of the EnDrain software are demonstrated in the following picture. It presents the shape of the water-table over the distance from the drain to midway between the drains, using the classical Darcy equation and the energy balance of the groundwater flow respectively.

3. Results

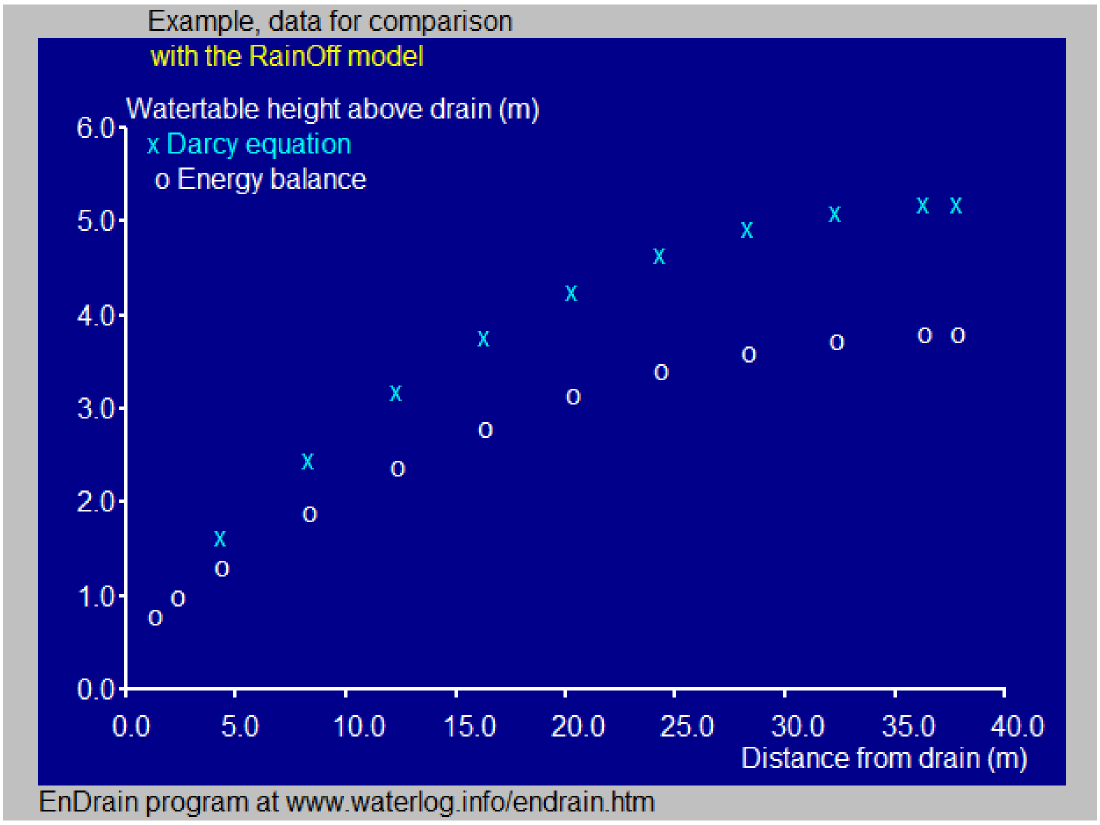

Figure 5.

The elevation of the water table midway between the drains above drain level is 0.38 and 0.52 m for the Darcy and energy balance respectively. The energy balance takes into account the energy supplied by the downward percolating water to the water table, whereas the Darcy equation does not. Reason why the water table is deeper in the case of the energy balance.

The results of the RainOff model are shown in the next illustration. It depicts the fluctuations of the water-table midway between the drains in the course of the time. The green line corresponds with the average water level in time towards the end of the calculation period.

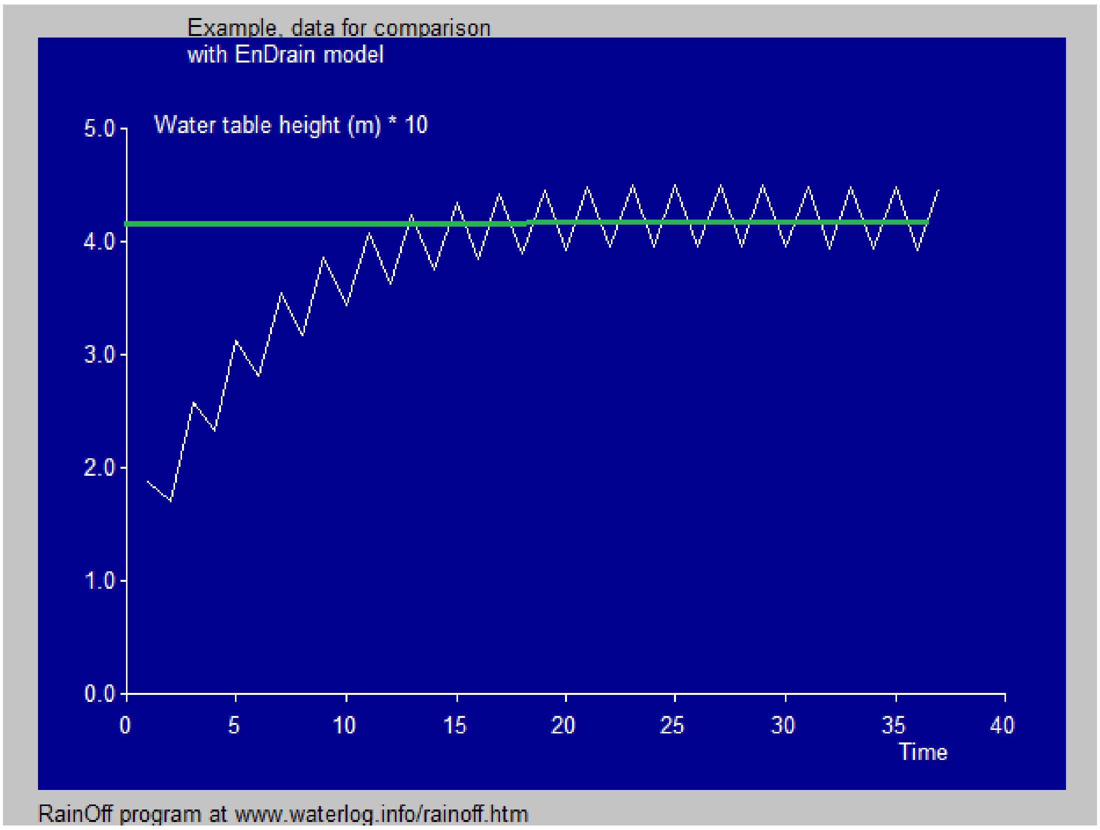

Figure 6.

The level of the green line is at 0.41 m, which corresponds well with the level found with EnDrain in the case of the energy balance (0.38), while the Darcy option gives a much higher value (0.52). The reason is that the non-steady state model adds the percolation water to the water-table, so that it rises attaining a higher energy level, thus taking the energy balance also into account. The model based on the Darcy equation does not do that and therefor misses an energy component so that the water-level gets higher.

4. Conclusions

The EnDrain software for steady state drainage gives good results when the full energy balance of groundwater flow is used. It shows the shape of the steady state water-table in the region from the drain to midway between the drains and represents the average shape of the fluctuations in time.

The RainOff model gives for non-steady state drainage gives good results as it automatically includes the proper energy balance. It shows the fluctuation of the water-table in time at the point midway between the drains. When the rainfall-recharge pattern is not too irregular, the model shows a stabilization in the long run. The stabilized fluctuations give, on average, the same value as the one calculated with EnDrain with the full energy balance.

5. References

[Ref. 1] RainOff, free software for the calculation of rainfall-runoff relations in watersheds and non steady groundwater flow to subsurface drains. Download from: https://www.waterlog.info/rainoff.htm

[Ref. 2] RAINFALL-RUNOFF RELATIONS OF A SMALL VALLEY ASSESSED WITH A NON-LINEAR RESERVOIR MODEL. In: International Journal of Environmental Science, 2018. On Line: https://www.iaras.org/iaras/filedownloads/ijes/2019/008-0002(2019).pdf

[Ref. 3] EnDrain, free software for the calculations of subsurface drainage (hydraulic conductivity, hydraulic head, drain spacing, level of the water table). Download from: https://www.waterlog.info/endrain.htm

[Ref. 4] THE ENERGY BALANCE OF GROUNDWATER FLOW APPLIED TO SUBSURFACE DRAINAGE IN ANISOTROPIC SOILS BY PIPES OR DITCHES WITH ENTRANCE RESISTANCE. Download from: https://www.waterlog.info/pdf/enerart0.pdf