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Modelling the Evaporation Flux from Shallow Sandy Aquifers

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Abstract A mathematical model based on Richard's equation and the soil hydraulic properties was developed in order to understand the influence of the soil depth to the water table on the maximum potential evaporative flux through the unsaturated zone. The model was applied on shallow aquifers using different types of sandy soils with hydraulic properties available from literature. Simple equations are presented to estimate the maximum evaporation from shallow sandy water table aquifers.

Keywords: Evaporation, vadoze zone, shallow water table

1. Introduction

Static moisture distribution above a water table is frequently referred to as the characteristic curve for the soil and commonly described in the literature using Brooks-Corey model (Corey 1986). This equilibrium distribution is altered at the upper surface in the case of evaporation resulting in altering the capillary pressure and causing upward flow. Qualitative moisture distribution for both equilibrium and upward flow are shown in figure 1. Evaporation through the unsaturated zone is very difficult to quantify and researchers have used two methods to quantify the rate of evaporation from water tables. The first method is based on modelling the moisture migration through the unsaturated zone and solving appropriate differential equations subjected to proper boundary conditions. Experimental procedures to estimate evaporation were conducted for the same purpose using usually special equipment like the one presented by Watanabe and Tsutsui (1994). Both procedures are difficult and not reliable to be applied to real field problems and therefore there is a need to come up with a method by which rough estimation of evaporation rate from shallow aquifers which is the objective of this research. The objective will be achieved through using typical soil hydraulic parameters for different types of soils in a flow model in the vadoze zone subject to boundary conditions represented by the capillary pressure at the water table as well as the ground surface.

2. Model Development

The case to be examined is shown in figure 2 and in order to estimate the evaporation rate through the unsaturated soil above a stationary water table (q) one needs to solve the governing equation given below (Corey, 1986)

$$\frac{d\,h_c}{dz} = 1 + \frac{q}{K_w}$$

Where:
h_c = capillary pressure
z = the height above the water table
K_w = the wetting fluid hydraulic conductivity
The boundary conditions to be imposed are the capillary pressure at the bottom (i.e. water table) and the capillary pressure at the ground surface.

The hydraulic conductivity is variable depending on the degree of saturation. Brooks-Corey model will be used in this study.

$$K_w = K_s\left(\frac{h_d}{h_c}\right)^{2+3\lambda}$$

Where:
K_s Saturated hydraulic conductivity
h_d displacement pressure head
λ pore siz distribution index
The specific values for these parameters depends on the type of soil and these parameters have to be known before the governing equation is solved. Reported hydraulic characteristics for four types of sand were used in this study based on the soil conservation service textural classifications, which are sand, sandy clay, sandy clay loam and sandy loam, with the objective of developing a simple relation between the potential maximum evaporation rates from shallow aquifers.

3. Results

To estimate the maximum potential evaporation from shallow sandy aquifers four types of sand were selected to represent sandy soils. According to the Soil Conservation Service textural classifications and published data Carsel and Parrish (1988) estimated, using multiple regression equations, the retention parameters for different types of soils including : sand; sandy clay; sandy clay loam and sandy loam. Table 1 lists the relevant hydraulic parameters for the four sand types which were used in the mathematical model.

The differential equation, subjected to two boundary conditions: at the water table and the top surface, was solved numerically for each of the sand types. Seven to six values for the possible evaporation rate were used in order to generate figure 3 which shows the relation between the depth to the water table and the maximum evaporation potential for the different types of sand.

The semi-log plot shown in figure 3 suggest close to linear decrease in the potential evaporation as the depth to the water table increases for all types of sand modelled. The best fit equations yields the following simple equations.

For

$$q = 1.315e^{-0.015d}$$

$$q = 0.798e^{-0.0203d}$$

$$q = 0.777e^{-0.0363d}$$

$$q = 1.222e^{-0.126d}$$

4. Conclusion

A simple equation to calculate the potential evaporation from shallow aquifers, which considers the effect of the various hydraulic parameters of the sand, was developed. The basic model used in this study involved the used of the Brooks-Corey model in Richard's equation and numerically obtaining solutions for various combinations of sand type and depth to the water table.

Table 1. Title of the table

Type	h_d, cm	K, cm/s	λ
Sand	6.9	8.22 x 10^{-3}	1.68
Sandy clay	37	3.36 x 10^{-5}	0.23
Sandy clay loam	17	3.59 x 10^{-4}	0.48
Sandy loam	13	1.27 x 10^{-3}	0.89

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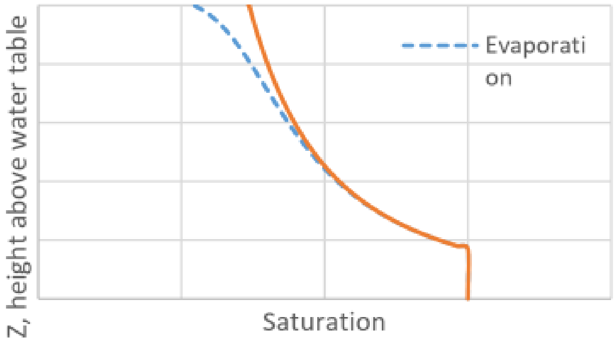

Figure 1. Moisture distribution profile

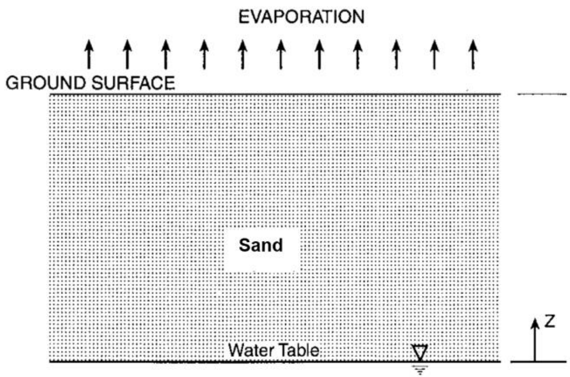

Figure 2. Conceptual model

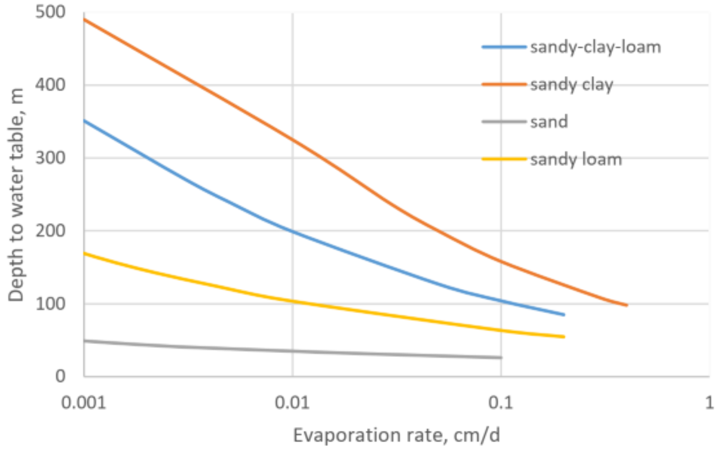

Figure 3. Potential evaporation flux versus depth

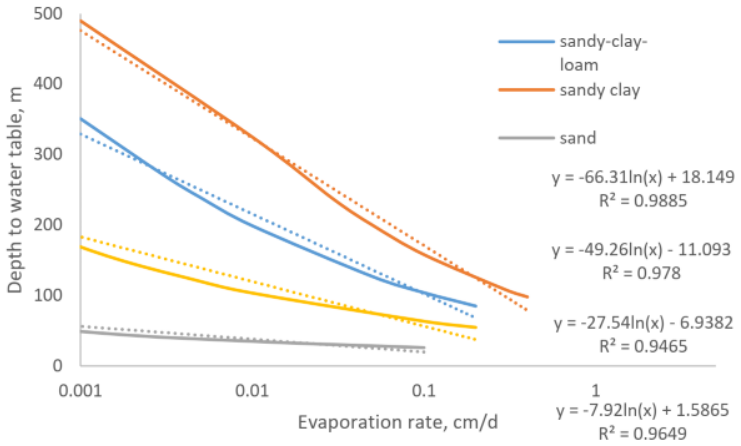

Figure 4. Best fit lines for potential evaporation vs depth

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