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SURCOS: A software tool to simulate irrigation and fertigation in isolated furrows and furrow networks

J. Burguete [a,c,*], A. Lacasta [b], P. García-Navarro [b]

[a] Soil and Water, EEAD/CSIC, P.O. Box 13034, 50080 Zaragoza, Spain
[b] Fluid Mechanics, LIFTEC, CSIC-Universidad de Zaragoza, María de Luna 3, 50018 Zaragoza, Spain
[c] BIFI: Instituto de Biocomputación y Física de Sistemas Complejos, Universidad de Zaragoza, Mariano Esquillor, Edificio I+D, 50009 Zaragoza, Spain

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ABSTRACT

A software tool useful for the numerical computation of surface irrigation and fertigation in furrows and furrow networks was developed. The model solves the complete one-dimensional St-Venant equations together with the transport equation of a passive solute. The flow equations and the solute advection are solved with a high resolution TVD explicit Eulerian scheme. The solute dispersion is solved with a centered implicit Eulerian scheme to avoid further restriction in the allowable time step. The computational speed of the model is high in isolated furrows. In cases of large furrow networks over extended irrigation times the model is slower but affordable computational speed is achieved. The computational model has been designed to be robust, intuitive and able to supply useful visual results. Both the executable and the source code, as well as the examples presented can be downloaded, edited and distributed under a BSD type license.

1. Introduction

Engineering studies of surface irrigation systems begin with an evaluation of current performance based on field-measured data in order to determine the applied amount of the irrigation water. The interest is in the distribution of infiltrated water along the field in order to evaluate whether water contributed to satisfy the irrigation requirement and how much was lost by deep percolation and runoff. The ultimate objective is to identify recommendations that result in acceptable levels of irrigation performance under the expected range of field conditions.

In the last decades computer based models were developed to support this analytical process. The most usual simulation engines, WinSRFR (Clemmens and Strelkoff, 1999) and SIRMOD (Walker, 2003), can be configured to model basins, borders, and furrows, all under the assumption of one-dimensional flow. This means that all flow characteristics vary only with distance along the field length and time, i.e. not across the field width. For borders and basins, the models are applicable to situations where the side-fall is negligible in comparison with the applied depth, infiltration and roughness are relatively uniform across the field width, and inflow is distributed. With furrows, simulations consider only a single furrow and, therefore, neighboring furrows are assumed identical. Any variation in properties from furrow to furrow must be modeled separately. Their simulation engines solve the one-dimensional unsteady open-channel flow equations coupled with empirical/semi-empirical equations describing infiltration and channel roughness. The governing equations represent the physical principles of conservation of mass and momentum. Given the relatively low velocities and Froude numbers that characterize surface-irrigation flows, their simulation engines often solve truncated forms of the momentum equation. The zero-inertia (force equilibrium) version assumes only pressure gradients, friction, and gravitational forces acting on the flow. Examples of recent applications of these models can be Bautista et al. (2009a,b) or Ebrahimiam and Liaghat (2011). Other irrigation models such as Mailapalli et al. (2009) or Soroush et al. (2013) have been reported but they do not offer an easy and user friendly software tool.

Water flow simulation in open channels and rivers has been a topic of interest recently and many numerical advances can be found. They include the presence of transcritical flow, bed slope changes, non-oscillatory high order calculations (Burguete and García-Navarro, 2001), unsteady boundary conditions (Burguete et al., 2006), solute transport (Burguete et al., 2007a) and dominant friction terms (Burguete et al., 2007b, 2008). In order to extend those developments to furrow irrigation simulation, specific models have been adapted to formulate friction, solute dispersion,

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* Corresponding author at: Soil and Water, EEAD/CSIC, P.O. Box 13034, 50080 Zaragoza, Spain. Tel.: +34 976716042.

E-mail addresses: jburguete@eead.csic.es (J. Burguete), alacasta@unizar.es (A. Lacasta), pigar@unizar.es (P. García-Navarro).

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Nomenclature

α	Volume of water infiltrated per unit length of furrow
Δ	Time increment
δ	Spatial increment
δw_k	First order upwind coefficients
ϵ	Dimensionless parameter of aerodynamical resistance
θ	Parameter controlling the degree of implicitness of the source term
Λ	Flow Jacobian eigenvalues diagonal matrix
λ^k	Flow Jacobian eigenvalues
ν	Artificial viscosity coefficient
ϕ	Mass of solute infiltrated per unit length of the furrow
$\Psi_k^{\pm}$	High order TVD coefficients
ψ	High order TVD flux limiter function
A	Wetted cross sectional area
a	Kostiakov model exponent
B	Cross section top width
B_0	Furrow base width
b	Fitting exponent of the vertical profile of flow velocity
CFL	Dimensionless Courant–Friedrichs–Lewy number
c	Velocity of the infinitesimal waves
$\vec{D}$	Solute dispersion vector
d	Characteristic length of the bed roughness irregularities
EF	Fertilizer efficiency
EW	Water efficiency
$\vec{F}$	Flux vector
$G_k^{\pm}$	First order upwind coefficients
g	Gravity constant
H	Furrow depth
h	Water depth
h_{min}	Depth threshold value to allow water discharge
I	Infiltration rate
$\vec{I}$	Infiltration vector
I_1	Pressure force integral
I_c	Saturated infiltration long-term rate
$\mathbf{J}$	Jacobian matrix of the flow
K	Kostiakov model constant
K_l	Longitudinal solute dispersion coefficient

L	Furrow length
$L_k^{\pm}$	High order TVD coefficients
l	Longitudinal coordinate
$M_{junction}$	Total mass of solute at the junction cells
m_i	Solid mass deposed at ith cell
N	Number of cells discretizing a furrow
$o_k^{\pm}$	First order upwind coefficients
P	Cross-sectional wetted perimeter
$\mathbf{P}$	Flow Jacobian diagonalizer matrix
Q	Discharge
Q_{in}	Inflow discharge
R	Water retention capacity of the soil
$R_k^{\pm}$	High order TVD coefficients
r	Friction factor
$\vec{r}_{in}$	Inflow point location vector
S	Fertilizer instantaneous solubility
S_0	Longitudinal bottom slope
$\vec{S}^c$	Source term vector
S_f	Longitudinal friction slope
s	Cross sectional average solute concentration
t	Time
t_f	Final application time
t_i	Initial application time
t_s	Final irrigation time required to complete infiltration
$\vec{U}$	Vector of conserved variables
UF_{25}	Fertilizer low quarter uniformity
UW_{25}	Water low quarter uniformity
u	Cross sectional average velocity
$V_{junction}$	Total volume of water at the junction cells
W	Distance between furrows
y	Transversal coordinate
Z	Tangent of the angle between the furrow walls and the vertical direction
z	Vertical coordinate
z_b	Bed level
z_s	Surface water level

infiltration and junctions in furrows and furrow networks (Burguete et al., 2009a,b).

The objective of the present work is the development of a software tool to simulate the complete water flow dynamics and solute transport in furrows and furrow networks with a basis on the exhaustive verification and validation performed in Burguete et al. (2009a,b). The software *SURCOS* has been designed to incorporate the cited modeling improvements in a user friendly, reliable, robust and efficient tool.

First, the governing equations used are outlined in order to state the notation. Second, the numerical scheme used in the simulation engine is detailed to enable an easy reproduction of the model. Then, the main components of the software interface are presented. Finally, some examples of use are included to illustrate the performance.

The model and the examples presented in this work are distributed (Burguete et al., 2013a,b) as free software under a Berkeley Software Distribution (BSD) type license with available and editable source code.

2. Physical model

2.1. Shallow-water model

The one-dimensional system formed by the cross sectional averaged liquid and solute mass conservation, momentum balance in main stream direction, infiltration and solute transport in prismatic open channels can be expressed in conservative form as (Burguete et al., 2009a):

$$\frac{\partial \vec{U}}{\partial t} + \frac{\partial \vec{F}}{\partial l} = \vec{I} + \vec{S}^c + \frac{\partial \vec{D}}{\partial l}, \tag{1}$$

where $\vec{U}$ is the vector of conserved variables, t is the time, $\vec{F}$ the flux vector, l the longitudinal coordinate, $\vec{I}$ the infiltration vector, $\vec{S}^c$ the source term vector, and $\vec{D}$ stands for solute dispersion:

$$\vec{U} = \begin{pmatrix} A \\ Q \\ As \end{pmatrix}, \quad \vec{F} = \begin{pmatrix} Q \\ gI_1 + \frac{Q^2}{A} \\ Qs \end{pmatrix}, \quad \vec{S}^c = \begin{pmatrix} 0 \\ gA(S_0 - S_f) \\ 0 \end{pmatrix},$$
$$\vec{I} = \begin{pmatrix} -PI \\ 0 \\ -PIs \end{pmatrix}, \quad \vec{D} = \begin{pmatrix} 0 \\ 0 \\ K_l A \frac{\partial s}{\partial l} \end{pmatrix}, \tag{2}$$

with A the wetted cross sectional area, Q the discharge, s the cross sectional average solute concentration, g the gravity acceleration, S_0 the longitudinal bottom slope, S_f the longitudinal friction slope, K_l the longitudinal solute dispersion coefficient, I the infiltration rate, P the cross-sectional wetted perimeter and I_1 represents pressure forces.