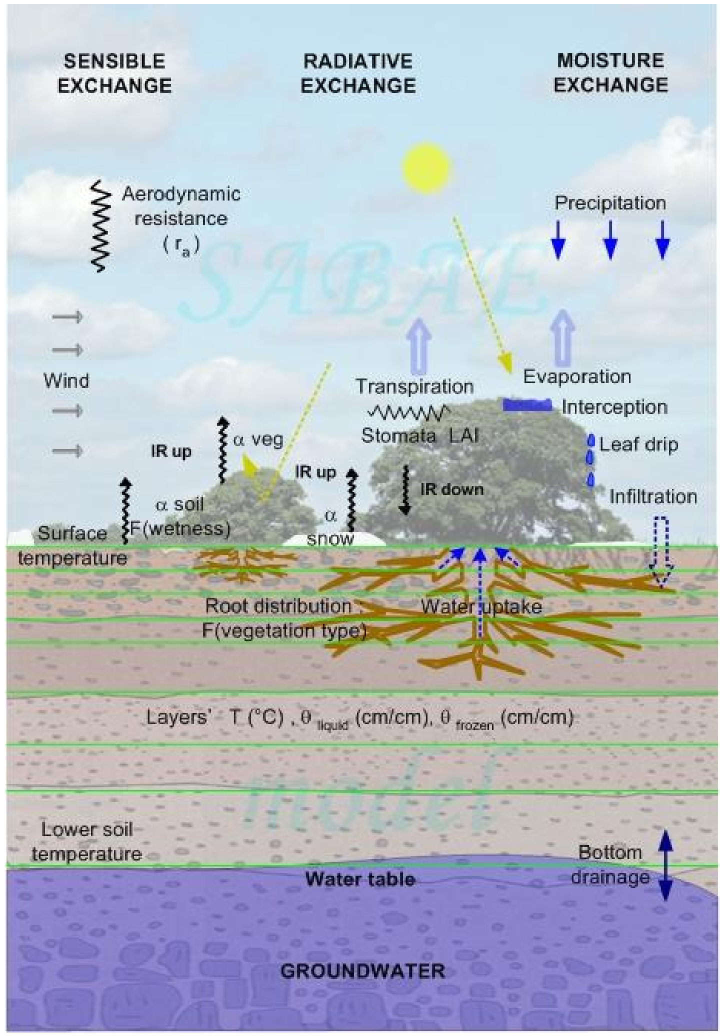
SABAE-HW – An enhancement of the water balance prediction in the Canadian Land Surface Scheme

Allan D. Woodbury [1] , Youssef Loukili [1] and Kenneth R. Snelgrove [2]

I - Problem Statement

1. Limitation of 3 soil layers in CLASS (10 cm, 25 cm, 375 cm)
2. Water balance numerical errors stemming from coarse grid
3. Only free-drainage provided at bottom (**410 cm)**
4. Fortran 77 programming impeding modern GCM couplings
5. Lack of inter-comparisons to other codes and solutions



II - Objectives

1. Improve the accuracy of water mass balance terms in CLASS
2. Efficient coupling with groundwater models
3. Suitable hydrologic modeling in actual field applications
4. Control and protection of regional groundwater resources
5. **Drought research, impacts and adaptations to climate forcing.**

[1] **University of Manitoba**
Winnipeg – Canada

[2] **Memorial University of Newfoundland**
Saint John's – Canada

Meteorological inputs required by CLASS and SABAE :

1. Incoming long wave and short wave solar radiation
2. Precipitation
3. Wind speed
4. Air temperature
5. Atmospheric pressure
6. Specific humidity , or relative humidity

Initializations of some prognostic variables

Soil characteristics

Vegetation parameters

Output from CLASS/ SABAE :

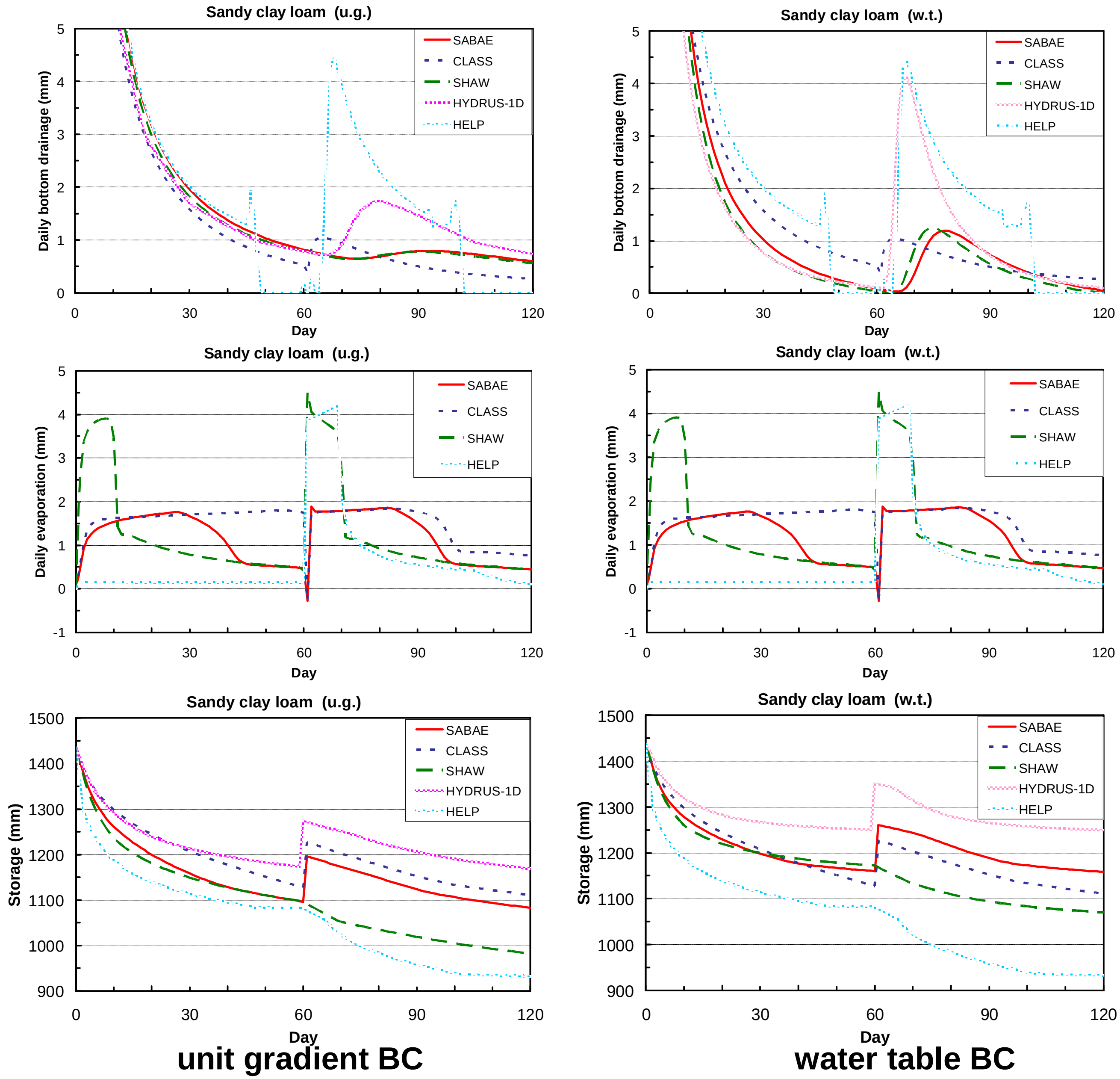
1. Surface, canopy, snow and soil layer temperatures
2. Liquid and frozen water contents
3. Surface heat flux
4. Net absorbed short and long wave radiations
5. Sensible and latent heat fluxes
6. Water evaporation, pond and bottom drainage
7. Snow accumulation and snow melt

Extensions: SABAE

- Grid extension: heat and moisture equations
- Efficient GMRES(3) system resolution
- Variety of boundary conditions
- Complete update to Fortran 90/95
- Comprehensive input and output data files
- Modifiable hydrological database

Benchmarking and Inter-comparisons

- **SHAW**
  - **S**imultaneous **H**eat **a**nd **W**ater [Flerchinger and Saxton, 1989]. Simulates heat, water and solute transfer through 1-D system
- **HYDRUS-1D**
  - Agricultural Research Service U.S. Department of Agriculture [Vogel et al., 1996; Simunek et al., 1998]
- **HELP3**
  - **H**ydrologic **E**valuation of **L**andfill **P**erformance [Schroeder and Gibson [1982] [1994] designing barrier-type solid waste landfill covers
- **CLASS version (2.5)**



Water mass balance terms for infiltration in sandy clay loam

Source: Loukili et al. (2006)

Summary to Date

- Soil column grid extension tested in SABAE
- Inter-comparisons with CLASS, SHAW, HYDRUS-1D, HELP
- Generally, SABAE and SHAW have comparable moisture and bottom drainage results
- CLASS overestimation of evaporation is confirmed
- Bottom drainage : underestimation by CLASS and overestimated by HELP
- *Next Phase: coupled 1-D vertical mass and energy transport with 2, 3-D groundwater*

References: coupled 1-D vertical mass and energy transport with 2, 3-D groundwater

- Bergamaschi, L., and Putti, M., (1999). *Mixed finite elements and Newton-type linearizations for the solution of Richards equation*. In: International Journal for Numerical Methods in Engineering 45:1025-1046.
- Celia, M.A., Bouloutas, E.T., and Zarba, R.L., (1990). *A General mass-conservative numerical solution for the unsaturated flow equation*. In: Water Resources Research 26:1483-1496.
- Fathing, M. W., Kees, C. E., and Miller, C. T., (2003). *Mixed finite element methods and higher order temporal approximations for variably saturated groundwater flow.* In: Water Resources Research 26: 373-394.
- Guarracino, L., and Quintana, F., (2004). *A third-order accurate time scheme for variably saturated groundwater flow modeling*. In: Communications in Numerical Methods in Engineering 20: 379- 89.
- Kavetski, D., Binning, P., and Sloan, S.W., (2002). *Noniterative time stepping schemes with adaptive truncation error control for the solution of Richards equation*. In: Water Resources Research 38: 1211-1220.
- Mansell, R.S., Liwang Ma., Ahuja, L.R., and Bloom, S.A., (2002). *Adaptive Grid Refinement in Numerical Models for Water Flow and Chemical Transport in Soil: A Review*. In: Vadose Zone Journal 1: 222-238.
- Miller, C.T., Abhishek, C., and Farthing, M.W., (2006). *A spatially and temporally adaptive solution of Richards equation*. In: Advances in Water Resources 29: 525-545.
- Williams, G.A., and Miller, C.T., (1999). *An evaluation of temporally adaptive transformation approaches for solving Richards equation*. In: Advances in Water Resources 22 831-840.
- Vakirevich et al. (1998), A quasi three-dimensional model for flow and transport in unsaturated and saturated zones: 1. Implementation of the quasi two-dimensional case, *Adv. Wat. Res*. 21(8), 679-689.
- Pikul et al., (1974), A numerical model based on coupled one-dimensional Richards and Boussinesq equations, Wat Resources Res., 10(2), 295-302.

Extend 1-D columns to base of aquifer

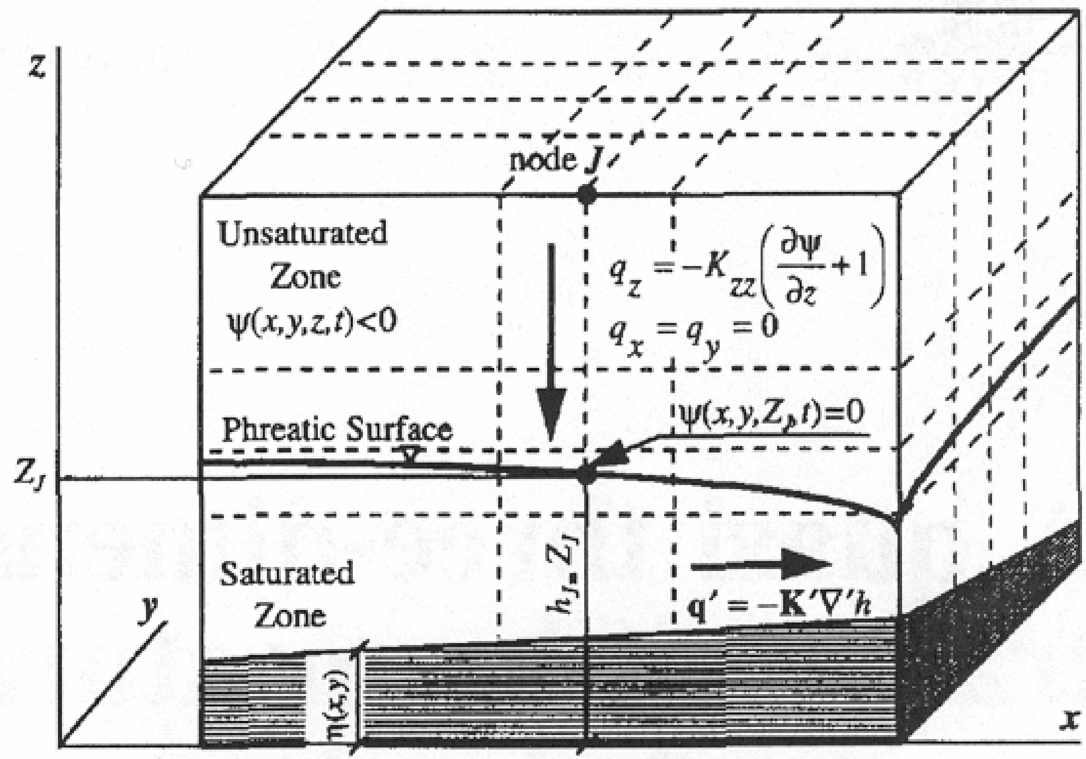


Fig. 1. Idealization of the modeled subsurface system with a section of the finite difference grid (dashed lines).

Source: Vakirevich et al. (1998), A quasi three-dimensional model for flow and transport in unsaturated and saturated zones: 1. Implementation of the quasi two-dimensional case, *Adv. Wat. Res*. 21(8), 679-689.

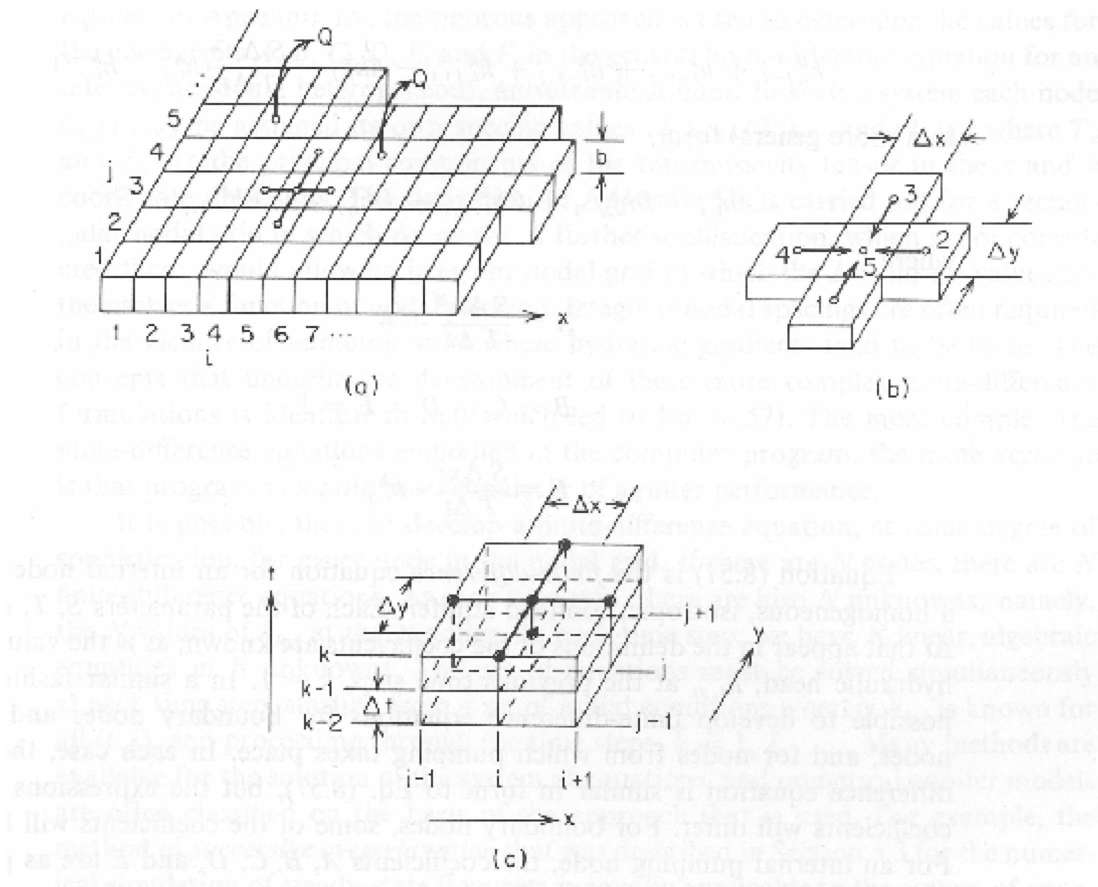


Figure 8.26 Discretization of a two-dimensional, horizontal, confined aquifer.

Classic 2-D Aquifer simulator by finite difference, source: Freeze and Cherry (1979)

Coupling Strategy

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial \psi}{\partial z} + K_{zz}\right) + I$$

- Mixed form of Richard's equation in each 1-D column

$$-K_{zz}\left(\frac{\partial \psi}{\partial z} + 1\right)\Bigg|_{z=h^+} = \nabla' \cdot [\mathbf{K}'(h-\eta) \cdot \nabla' h] + \mathbf{q}|_{\eta} \cdot \nabla(z-\eta) + \sum_l \mathrm{P_w}(x_l, y_l, t) \times \delta(x - x_l, y - y_l)$$

- Horizontal flux solved by 2-D aquifer equation (FD)

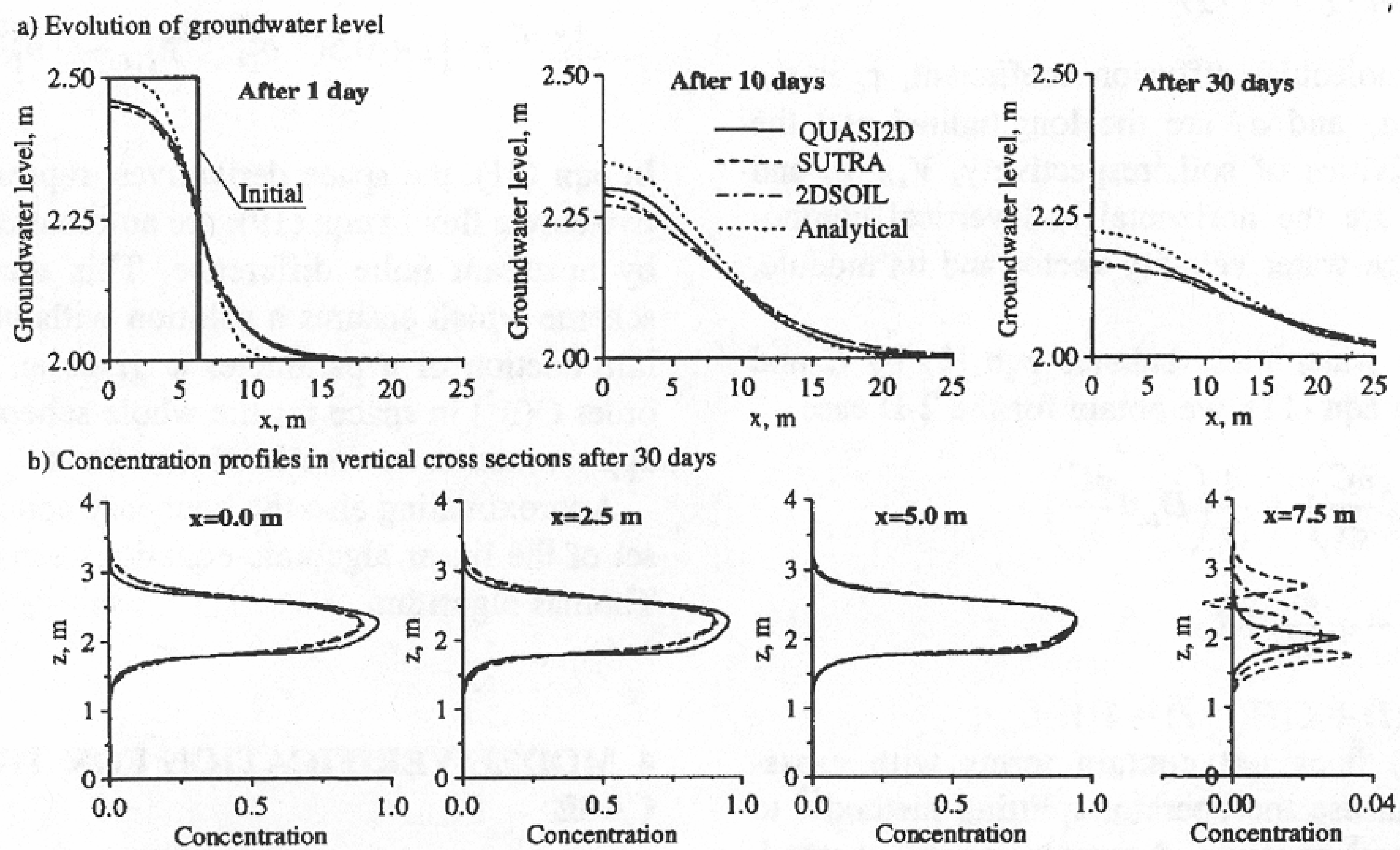


Fig. 2. Groundwater level (a) and concentration profiles (b) for the problem of 'stripe spread' (example 1).

Source: Vakirevich et al. (1998)
Inter-comparisons

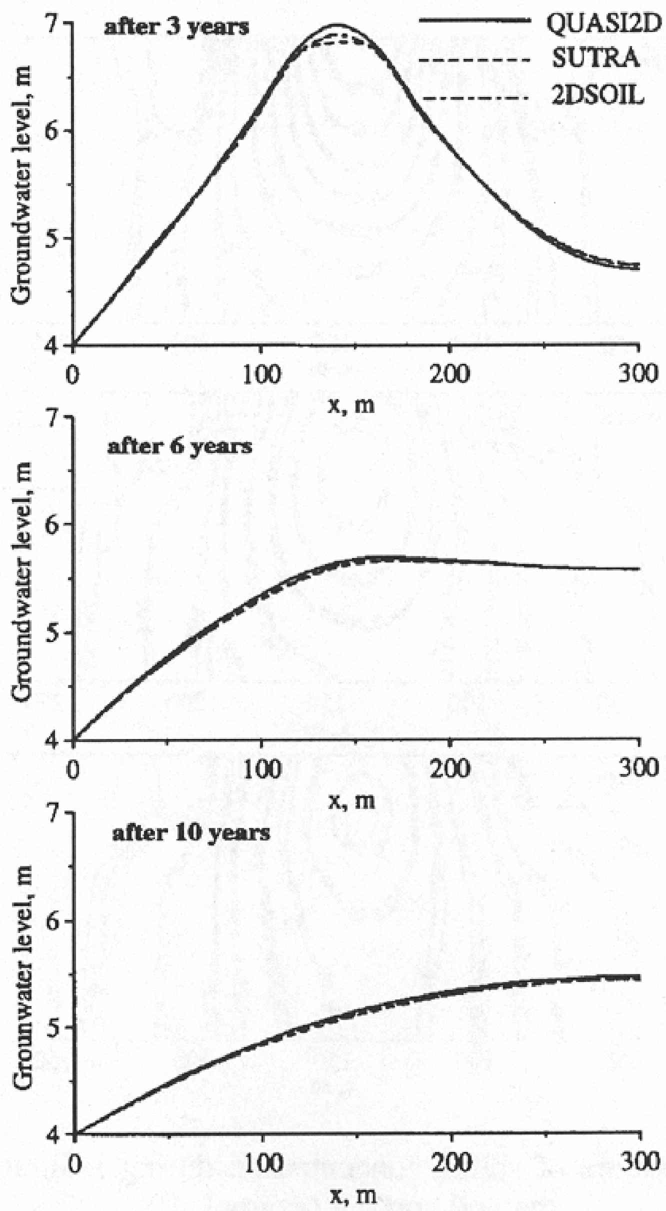


Fig. 3. Groundwater level during infiltration from the soil surface (example 2).

Source: Vakirevich et al. (1998)

Team and Milestones

- Dr. Youssef Loukili, Research Associate
- Smrita Joshi, Ph.D. student

Team and Milestones

- Submission to *Vadoze Zone J*., March, 2007 *(Loukili, Woodbury, Snelgrove)*
- Programming linked 1-D vertical, 2-D horizontal groundwater: May 2007 *(Joshi)*
- Field experiments & hypothesis testing: September 2007 *(Hayashi, Loukili, Joshi)*
- GMS-MODFLOW of ADA (3-D aquifer): September 2007 *(Joshi)*
- Altering SABAE: September 2007 *(Loukili)*
- Stand-alone SABAE runs (*Hanesiak, Bhuiyan* NARCCAP of ADA), Fall 2007 *(Loukili)*