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A Computational App for a Proper Evaluation of the Irrigation Effect Over the Aquifers

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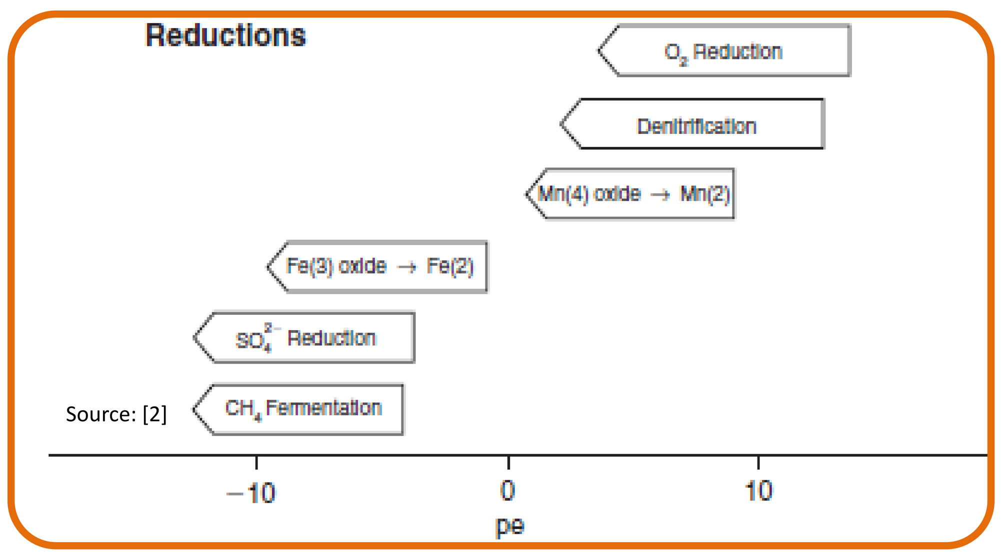
Motivation

A correct design and control of the irrigation cycles is very important for the correct and efficient grow of the crops. It is well known that a correct design of the irrigation cycles increases its efficiency and reduces the amount of water required. The irrigation cycles have effect over the quality and quantity of water. It becomes more relevant in these areas of the world where the amount of water is limited. Nowadays, several scientists are involved in different research whose objectives are focus on find alternative sources of water that can be used to the irrigation. One idea is to reuse human waste water [1]. This concept is based on the pollutant removal effect of the sun, the soil and the plants itself. However, it requires an important control of the polluted water evolution in the subsurface.

Numerical modelling is an important tool to help engineers and scientists to design structures, simulate experiments, etc. In the present context, it can be used as a proper design of irrigation structures. It serves also to evaluate the propagation of the pollutants or nutrients not absorbed by plants in the irrigation water through the subsurface.

We present an useful app designed in COMSOL® that simulates the effects of different irrigation cycles over the soil saturation. It also can simulate the evolution of certain pollutants dissolved or suspended in the water through the subsurface attending to its degradation. The application reproduces the groundwater flow field, the saturation and the movement of the pollutants or nutrients. The model is designed to evaluate the evolution of the dissolved elements involved in the organic matter degradation chain.

Chemical model



App Workflow

Inputs

Geometry

- Nº of irrigation zones
- Nº of materials
- Size of the domain
- Thickness of each materials
- Location of sampling points

Boundary conditions

- Hydraulic:
  - Hydraulic heads.
  - Irrigation function
  - Recharge function
- Transport: Inlet concentrations

Parameters

- Hydraulic parameters:
  - Permeability
  - Porosity
  - Van-Genuchten model
- Transport parameters:
  - Dispersivity
  - Effective diffusion
- Kinetic reaction constants

Model settings

- Spatial discretization:
  - 3 resolutions of the FEM
- Temporal discretization:
  - Time-step
  - Total time
- Solver settings:
  - Direct/sequential
  - relative tolerance

Computation

Variable saturated groundwater Flow: Richard's equation

$$\rho\left(\frac{C_m}{\rho g}+S_eS\right)\frac{\partial p}{\partial t}+\nabla\cdot\rho\left(-\frac{k_s}{\mu}k_r(\nabla p+\rho g\nabla D)\right)=Q_m$$

Transport of diluted species: Advection-dispersion-diffusion equation

$$\emptyset\frac{\partial c_i}{\partial t}+c_i\frac{\partial \emptyset}{\partial t}+u\cdot c_i=\nabla\cdot\left[(D_{D,i}+D_e)\nabla c_i\right]+R_i$$

Organic matter oxidation: 2nd order kinetic.

$$\frac{\partial CH_2O}{\partial t}=\frac{\partial O_2}{\partial t}+0.5\cdot\frac{\partial NO_3}{\partial t}+0.5\cdot\frac{\partial MnO_2}{\partial t}+0.25\cdot\frac{\partial Fe(OH)_3}{\partial t}+2\cdot\frac{\partial SO_4}{\partial t}$$

E.g. $$\frac{\partial O_2}{\partial t}=-k_{O_2}\cdot[O_2][CH_2O]$$

Post-process

Plots

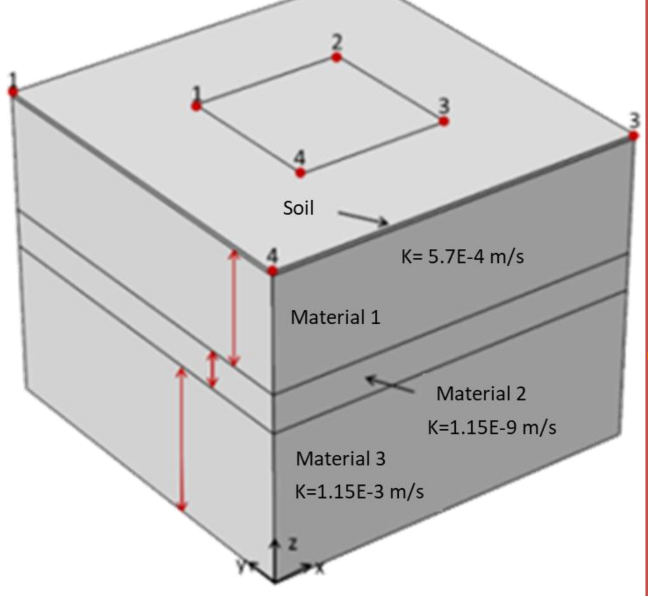
- Hydraulic:
  - 2D & 3D plots showing the saturation, the hydraulic head, flow velocity and the flow direction for the different times.
- Transport:
  - 2D&3D plots showing the spatial distribution of each species for the different times.

Tables

- Results at the observation points
  - Hydraulic head and effective saturation
  - Concentration of chemical species

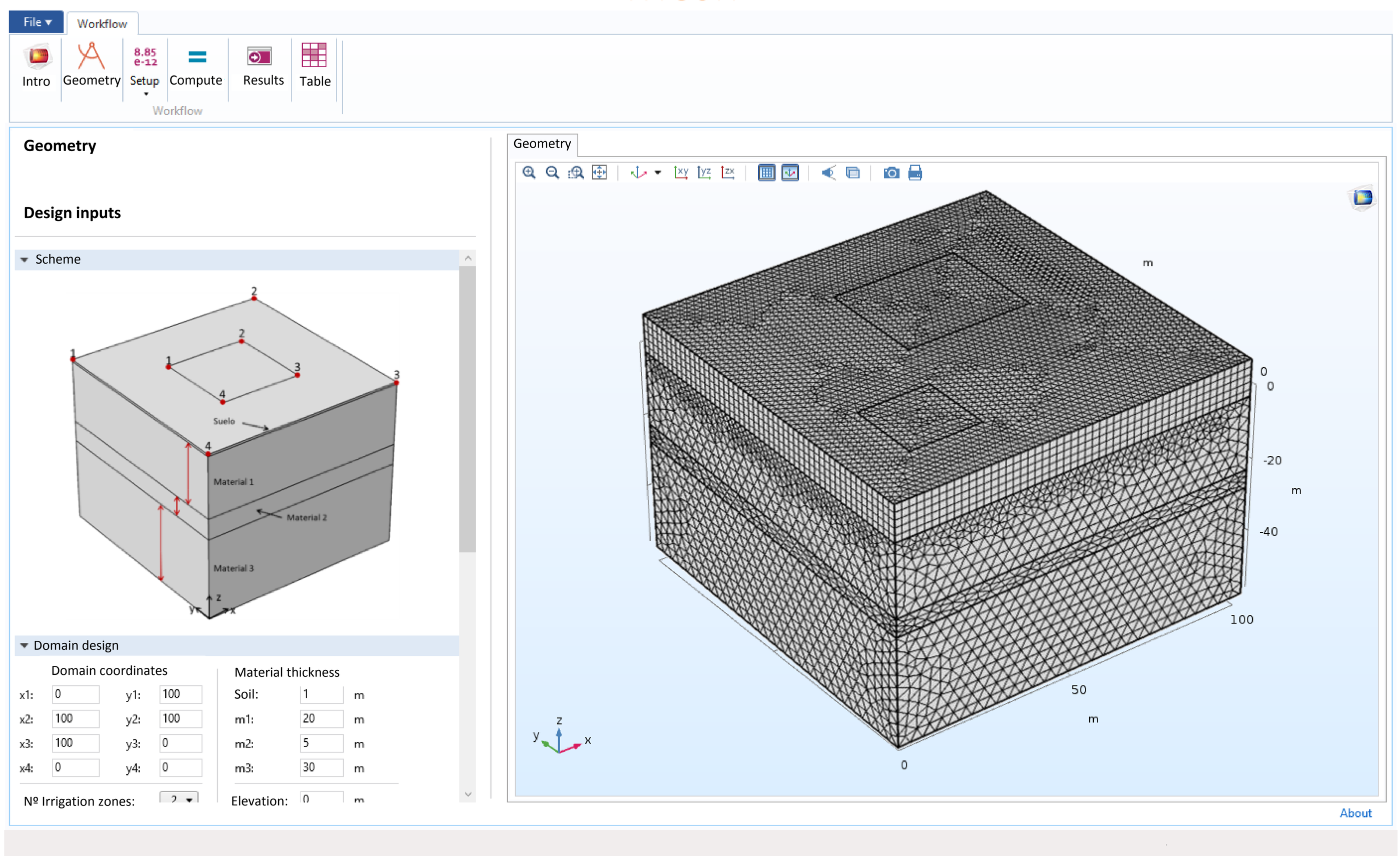
Application example

Geometry



This example consider two permeable materials separated by an small aquitard. Two irrigation zones

Mesh



Finite element grid formed by tetrahedra and prisms

Boundary conditions

Regional flow streams from north (85 m) to south (82 m).

Aquifer is characterized by a bicarbonated water with a low mineralization whereas one of the irrigation waters is characterized by a high content in DOM, SO4 and Cl.

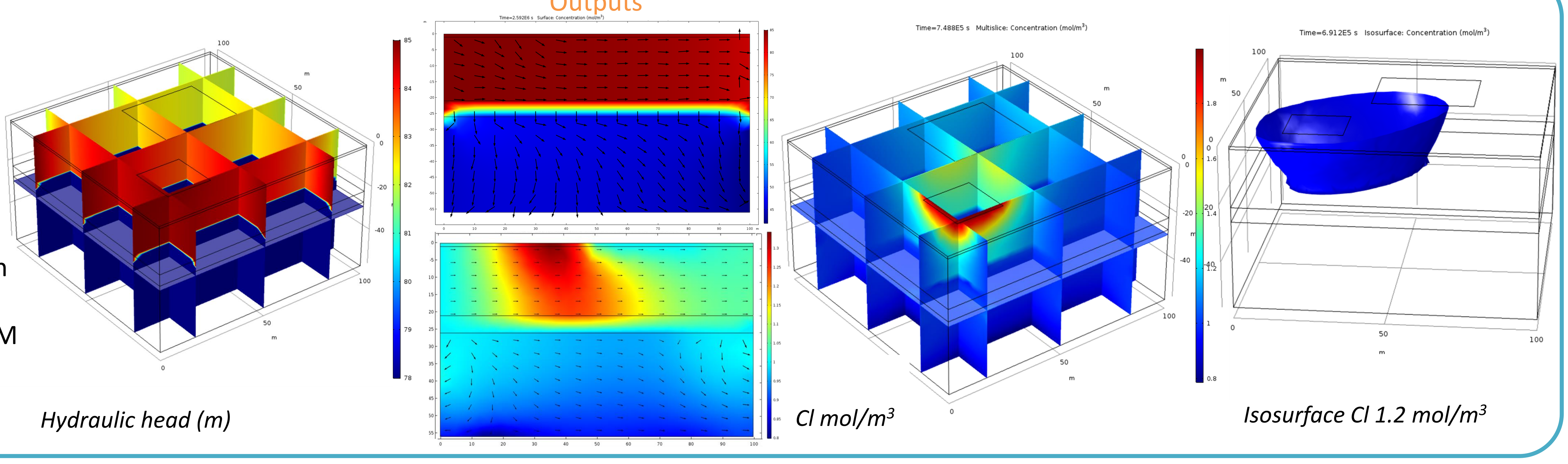
Computation settings

Groundwater flow is solved first in a transient simulation for a total time of 10 days with 100 linear time-steps.

Second, the computed flow field is used for a transport simulation with the same time discretization and the same duration.

Outputs

The irrigation is imposed over the small crop. It modifies locally the groundwater flow that now flow from SE to NW. The reclaimed water used to irrigate the crop infiltrates in the upper aquifer although they don't reach the depth aquifer due the presence of an aquitard that isolate both aquifers. Regarding to the DOM it is degraded in the aquifer thanks to anoxic conditions.



Hydraulic head (m) — *Cl mol/m³* — *Isosurface Cl 1.2 mol/m³*

Concluding remarks

The possibility of generated custom apps with COMSOL® allow the user to generate general models such as the one presented here that can be applied for different cases.

References

[1] Hussain I.; L. Raschid; M. A. Hanjra; F. Marikar; W. van der Hoek. 2002. Wastewater use in agriculture: Review of impacts and methodological issues in valuing impacts. Working Paper 37. Colombo, Sri Lanka: International Water Management Institute.

[2] Appelo, C.A.J y Postma.D, 2014. Geochemistry, groundwater and pollution. 2nd edition.