Richards model for simulations of water infiltration in agricultural soil using DuMu^x

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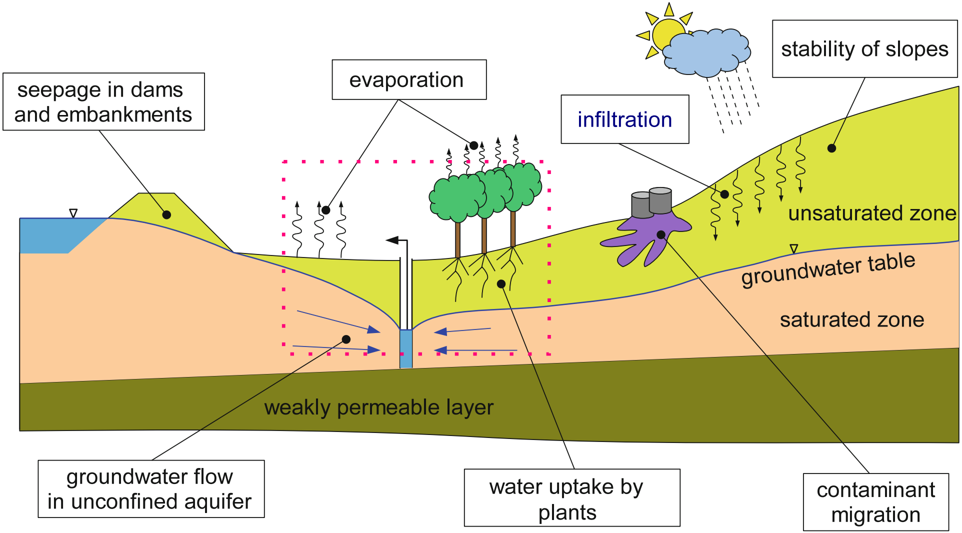
Ecological footprint of the water cycle on agriculture



Presentation of water infiltration problem

- Urban planning, together with population growth over the years, so food demand increased and exploit more natural resources for agricultural activities, however eagerness to meet this demand we have neglected the good management of natural resources and the stability of the surrounding ecosystems. [3]
- Currently in agriculture, one of the most frequent problems with the greatest environmental impact generated by poor crop management is the inefficient use of water resources, by implementing inefficient irrigation systems when trying to meet the water demand generated by plants. It is also one of the most important points addressed in environmental issues and is not only of concern because of the waste of water but also because of the damage and losses that can be caused in the physicochemical properties of the soil.

Presentation of water infiltration problem

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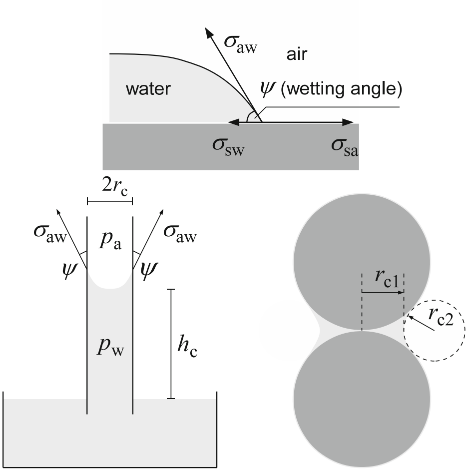
$\boxed{\text{What is the capillarity water soil?}}$

Capillarity

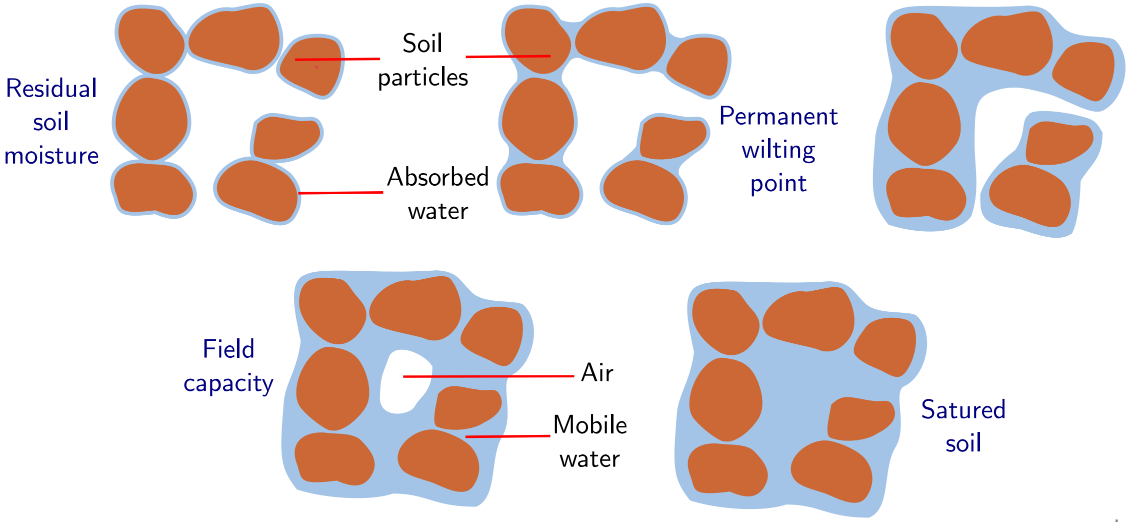
$$\Delta p = p_a - p_w = \sigma_{aw}\left(\frac{1}{r_{c1}} + \frac{1}{r_{c2}}\right) = \frac{2\sigma_{aw}\cos\psi}{r_c}$$

$$\sigma_{aw}\cos\psi = \sigma_{Sa} - \sigma_{Sw}, \quad h_c = \frac{1.5\times10^{-5}}{r_c}$$

- σ_{aw} is the surface tension of the air-water interface.
- σ_{Sa} is the surface tension of the solid-air interface.
- σ_{Sw} is the surface tension of the solid-water interface.
- ψ is the wetting angle.



Soil water content



Mathematical Model of Infiltration

Richards equation 1D

Derived the conservation of mass, the one-dimensional continuity equation of infiltration is given as

$$\frac{\partial \theta}{\partial t} + \nabla \cdot \vec{q} = 0. \tag{1}$$

By Darcy's law, q_z represents

$$q_z = -K\frac{\partial H}{\partial z} = -K\frac{\partial (h-z)}{\partial z} = K\left(1 - \frac{\partial h}{\partial z}\right). \tag{2}$$

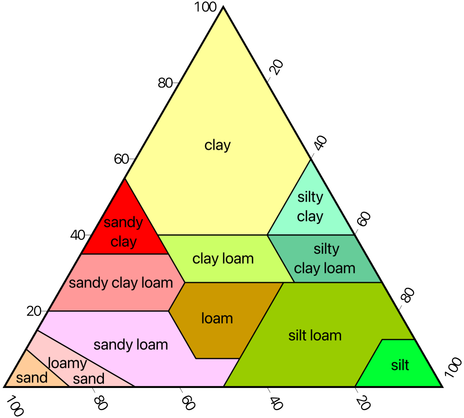
Joining the equations (1) and (2) we obtain the mixed Richards formulation

$$\frac{\partial \theta}{\partial t} + \frac{\partial}{\partial z}\left[K\left(1 - \frac{\partial h}{\partial z}\right)\right] = 0.$$

where

- θ is the soil water content $\left(m^3/m^{-3}\right)$.
- z is the soil depth
- $\vec{q}$ is the water infiltration rate (m/s).
- K is hydraulic conductivity.
- H is the total water potential in axis z.
- h is the preassure head.

The soil and his features



Listado: Spatial parameters `soil.params`.

```
Densidad Aparente: 1,36 gr/cm3
Densidad real: 2,54 gr/cm3
Humedad a diferentes tensiones:
Saturacion: 65,89
0,1 bar: 58,20
cc: 40,25
1 bar: 39,43
3 bares: 36,95
5 bar: 34,48
10 bar: 28,30
P.M.P: 22,12
Textura:
Arenas: 30,76
Limos: 26
Arcillas: 43,04
Clase textural: Arcilloso
Porosidad: 46,46%
Conductividad Hidraulica: 2,83 mm/Hora
```

Software simulator for Porous Media Problems

DUNE for Multi-{Phase, Component, Scale, Physics, ...} flow and transport in porous media (DuMu^x)

- DuMu^x is a multipurpose open-source simulator under the GNU Lesser General Public License 3 .
- DUNE is available on macOS, Debian , Ubuntu , openSUSE , Arch Linux and FreeBSD .
  DUNE Release 2.9.0 is planned for end of October 2022.
- Porous-Medium Flow, Non-Isothermal, Free Flow, Geomechanics, Pore-Network models. Multidomain, multi-component, multi-phase. Parallel, Grid Adaptivity.
  Release 3.6.0 is planned for October 7, 2022.

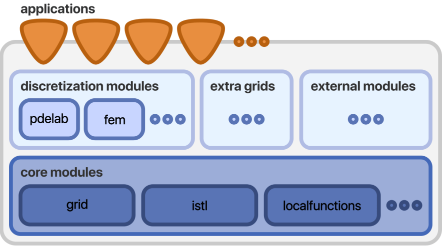


Figure: Taken from `https://dune-project.org`.

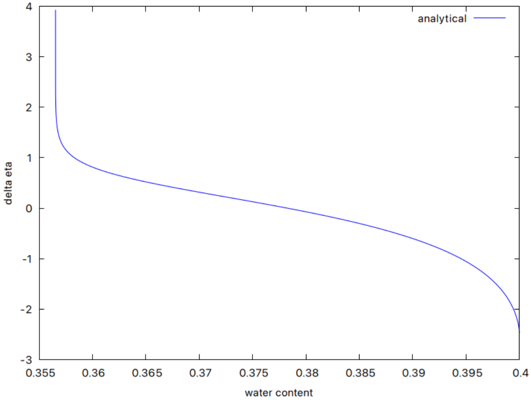
Figure: Binaries are available in arch4edu repository. (Jingbei Li, Carlos Aznarán, 2022.)

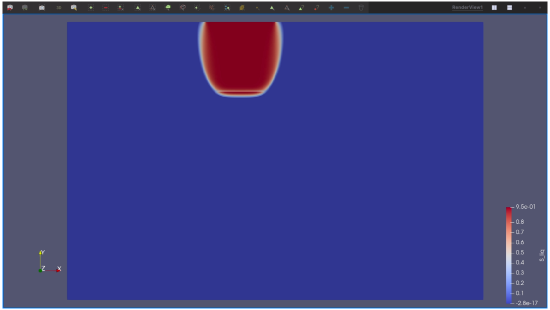
Spatial parameters file

```cpp
template<class GridGeometry, class Scalar>
class RichardsLensSpatialParams
: public FVPorousMediumFlowSpatialParamsMP<GridGeometry, Scalar, RichardsLensSpatialParams<GridGeometry, Scalar>>
{
    using ThisType = RichardsLensSpatialParams<GridGeometry, Scalar>;
    using ParentType = FVPorousMediumFlowSpatialParamsMP<GridGeometry, Scalar, ThisType>;
    using GridView = typename GridGeometry::GridView;
    using FVElementGeometry = typename GridGeometry::LocalView;
    using SubControlVolume = typename FVElementGeometry::SubControlVolume;
    using Element = typename GridView::template Codim<0>::Entity;
    using GlobalPosition = typename Element::Geometry::GlobalCoordinate;

    enum { dimWorld = GridView::dimensionworld };

    using PcKrSwCurve = FluidMatrix::VanGenuchtenDefault<Scalar>;

public:
    using PermeabilityType = Scalar;

    RichardsLensSpatialParams(std::shared_ptr<const GridGeometry> gridGeometry)
    : ParentType(gridGeometry)
    , pcKrSwCurveLens_("SpatialParams.Lens")
    , pcKrSwCurveOuterDomain_("SpatialParams.OuterDomain")
    {
        lensLowerLeft_ = {1.0, 2.0};
        lensUpperRight_ = {4.0, 3.0};
        lensK_ = 1e-12;
        outerK_ = 5e-12;
    }
```

```cpp
private:
    bool isInLens_(const GlobalPosition &globalPos) const
    {
        for (int i = 0; i < dimWorld; ++i)
            if (globalPos[i] < lensLowerLeft_[i] - eps_ ||
globalPos[i] > lensUpperRight_[i] + eps_)
                return false;

            return true;
    }

    static constexpr Scalar eps_ = 1e-6;

    GlobalPosition lensLowerLeft_;
    GlobalPosition lensUpperRight_;

    Scalar lensK_;
    Scalar outerK_;
    const PcKrSwCurve pcKrSwCurveLens_;
    const PcKrSwCurve pcKrSwCurveOuterDomain_;
};
```

Results


analytical
delta eta
water content
4
3
2
1
0
-1
-2
-3
0.355
0.36
0.365
0.37
0.375
0.38
0.385
0.39
0.395
0.4


RenderView1
9.5e-01
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-2.8e-17
S_liq
Y
Z
X

Referencias

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Oliver Sander. *The Distributed and Unified Numerics Environment (DUNE)*. Apr. 12, 2016. URL: http://congress.cimne.com/icme2016/admin/files/filepaper/p72.pdf (visited on 07/12/2021).

Acknowledgment

Thank you so much!

Laboratorio de Análisis Ambiental
Sede Palmira, Colombia.

Slides available on:

`https://cpp-review-dune.github.io/flow-test-dumux/slides.pdf`

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