2nd International LIFE REWAT Summer School

Digital water management and water-related agroecosystem services: geostatistics, hydroinformatics and groundwater flow numerical modelling

September 9th—20th, 2019
Scuola Superiore Sant'Anna
Pisa, Italy

2nd FREEWAT International Workshop

Smart ICT tools for water resource management: the experience of the SMAQua project

Giovanna De Filippis

Scuola Superiore Sant'Anna, Italy
g.defilippis@santannapisa.it

FREEWAT
Free and Open Source Software Tools for Water Resource Management
EU HORIZON 2020 Project

SMAQua
SMart ICT tools per l'utilizzo efficiente dell'AcQua

SMAQua: smart ICT tools for efficient water use

- Increasing water demand
- Need for tools and methodologies for sustainable management of water
- Capitalization of FREEWAT's results

What?

Contribute to improving the *protection of water quality*

How?

Development and application of *innovative software tools* for the analysis of spatial data (GIS, numerical modelling)

Project partners

Scuola Superiore Sant'Anna Pisa

Regione Toscana

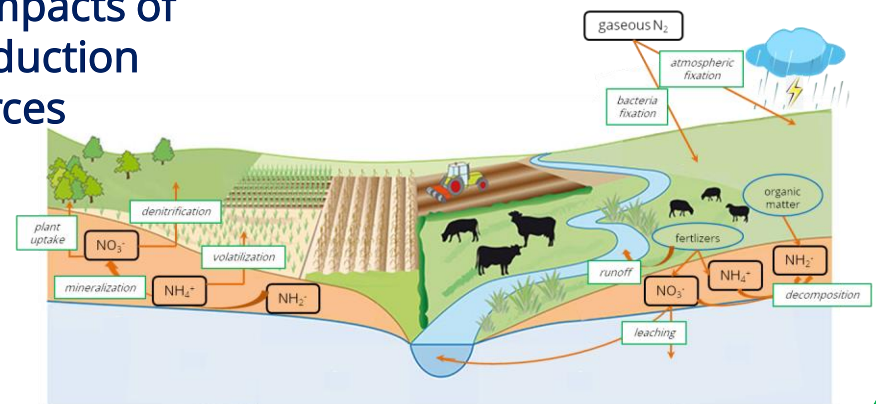
ASA Azienda Servizi Ambientali SpA

ERM

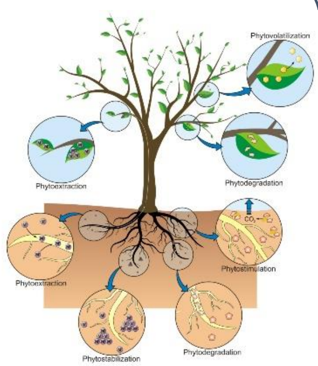
Project duration: 2018-2020

Specific objectives of the SMAQua project

Mitigating the impacts of agricultural production on water resources



Improving reclamation operations in contaminated areas



Reducing consumption in the management and distribution of drinking water

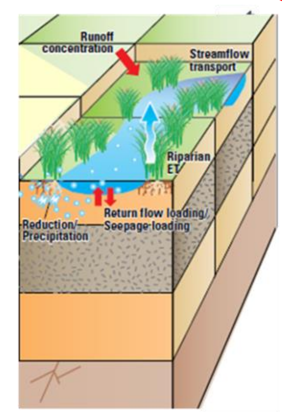
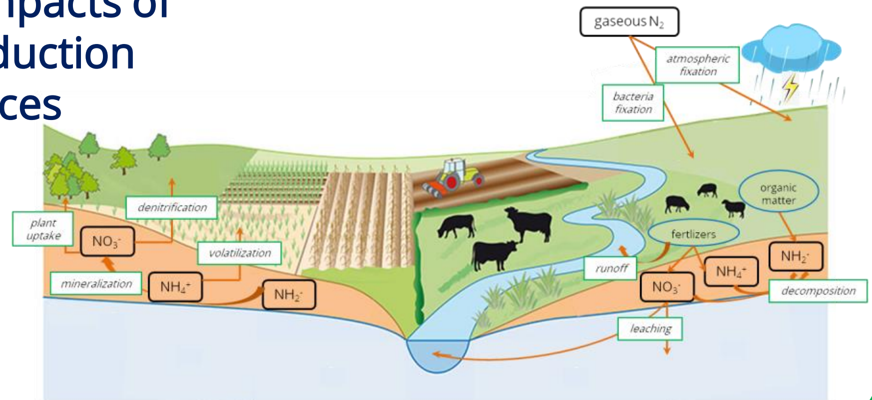


Figure from: Bedekar, V., Morway, E. D., Langevin, C. D., & Tonkin, M. J. (2016). MT3D-USGS version 1: A US Geological Survey release of MT3DMS updated with new and expanded transport capabilities for use with MODFLOW (No. 6-A53). US Geological Survey.

Specific objectives of the SMAQua project

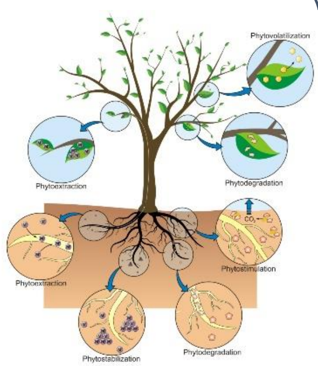
Mitigating the impacts of agricultural production on water resources

Simulation of the nitrogen cycle



Improving reclamation operations in contaminated areas

Setting-up phytoremediation strategies



Reducing consumption in the management and distribution of drinking water

Tools for simulation of mass exchange between surface- and ground-water

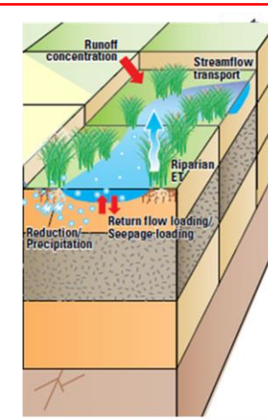
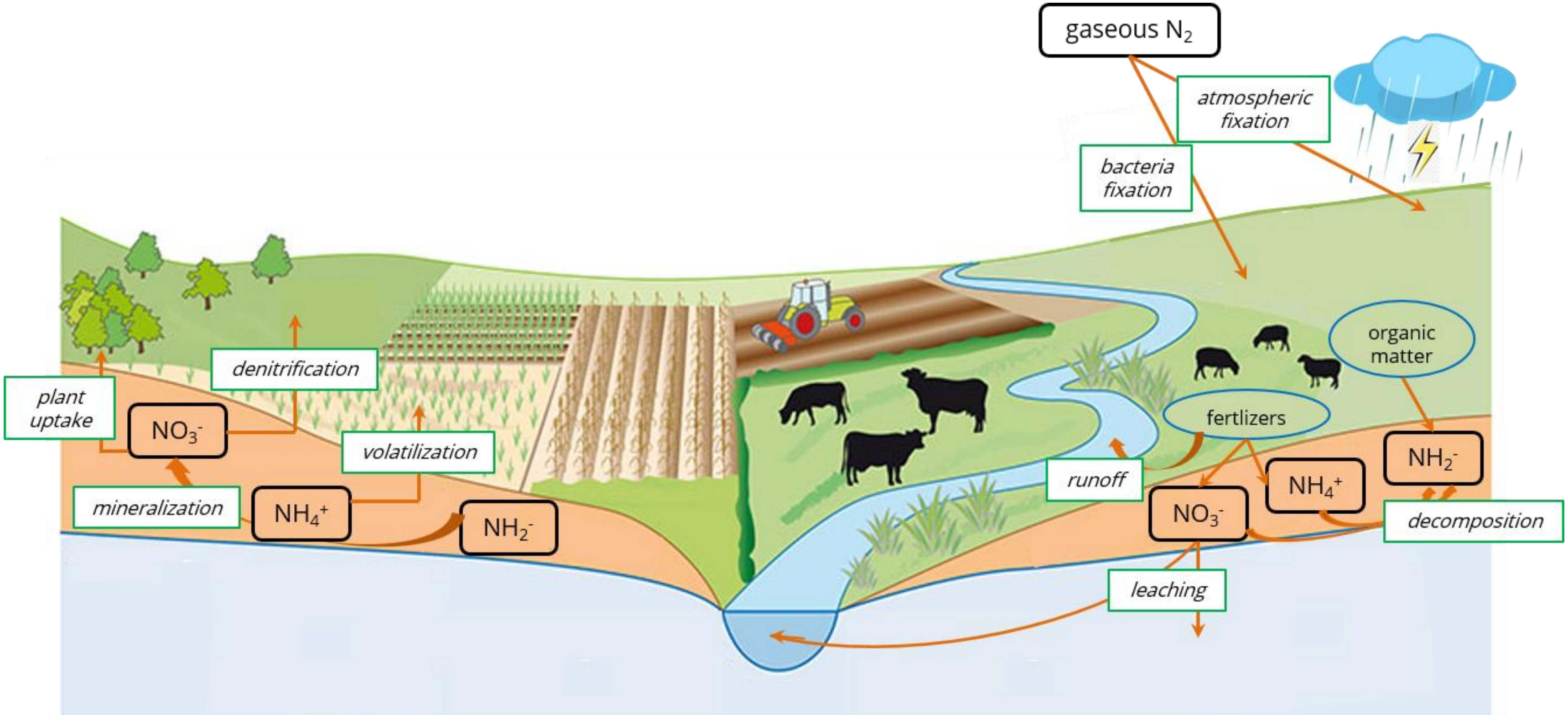


Figure from: Bedekar, V., Morway, E. D., Langevin, C. D., & Tonkin, M. J. (2016). MT3D-USGS version 1: A US Geological Survey release of MT3DMS updated with new and expanded transport capabilities for use with MODFLOW (No. 6-A53). US Geological Survey.

Simulation of the nitrogen cycle

Physical, chemical and biological processes involving nitrogen within an agroecosystem



Change of N storage in soil =
Σ (fixation+fertilizers+organic matter+point sources+production processes) –
Σ (runoff+sink terms+decomposition processes)

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Modelling approach

Objective

- Modelling the nitrogen cycle in the unsaturated zone, in order to determine the mass of NO_3^- leaching towards the water table

Methodology

- Simulating all the processes above, in order to determine the mass of NO_3^- within the soil which is available for leaching
- Joining the nitrogen cycle model and the flow model through the unsaturated zone, in order to determine the mass of NO_3^- leaching towards the water table

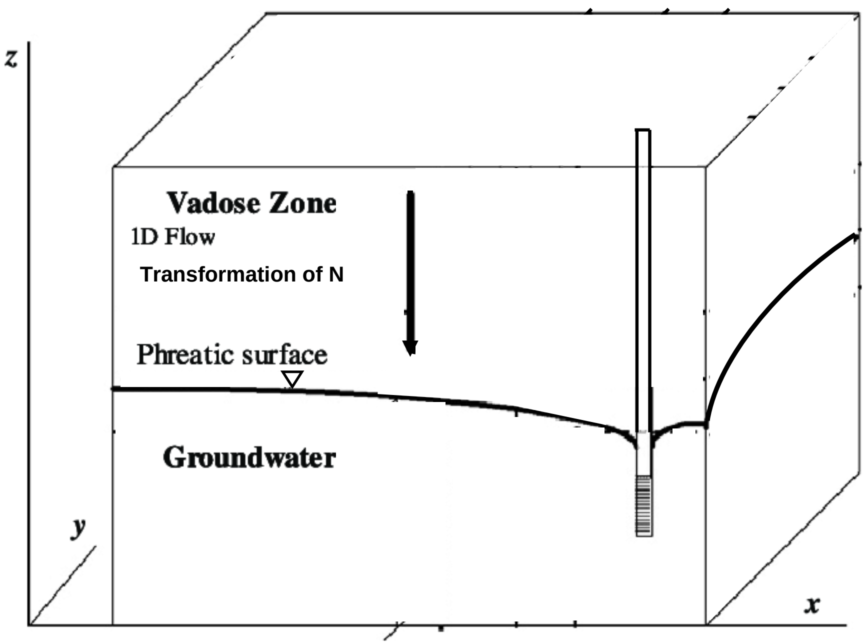
Expected results

- Concentration of NO_3^- at the water table
- This is going to be treated as a mass source in the advective-dispersive solute transport process within the saturated zone

The most widespread modelling approaches

Conceptualization of most models aimed at simulating the nitrogen cycle:

- physically-based and lumped codes

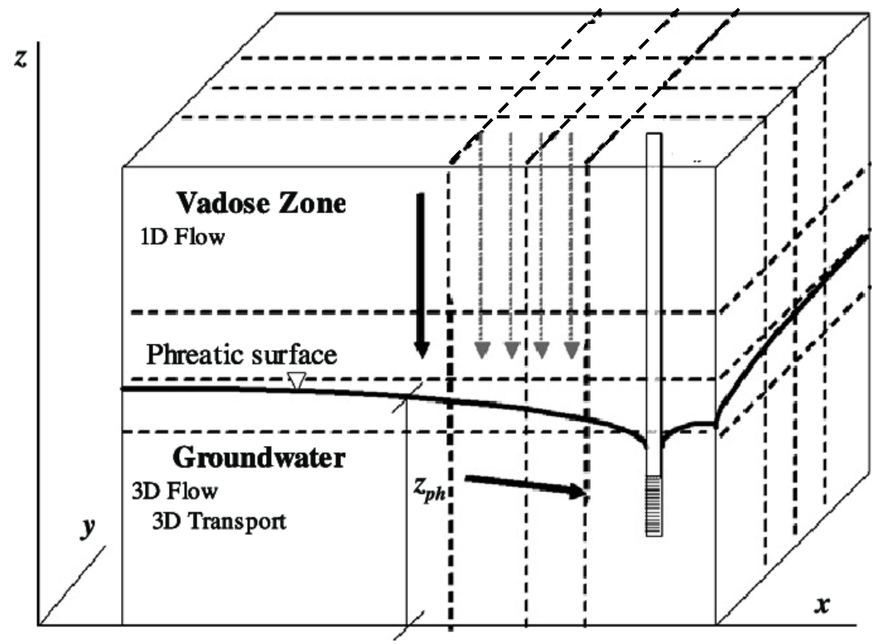


Ex. flow in SWAT (*Neitsch et al., 2009*):

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

Conceptualization of flow and transport models (FREEWAT approach (*Rossetto et al., 2018*)):

- physically-based and spatially-distributed codes (use of regular grids)

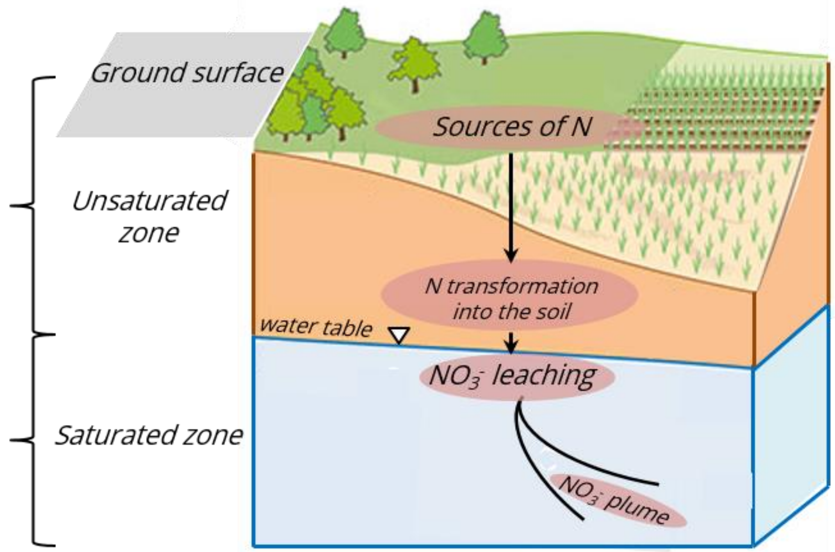


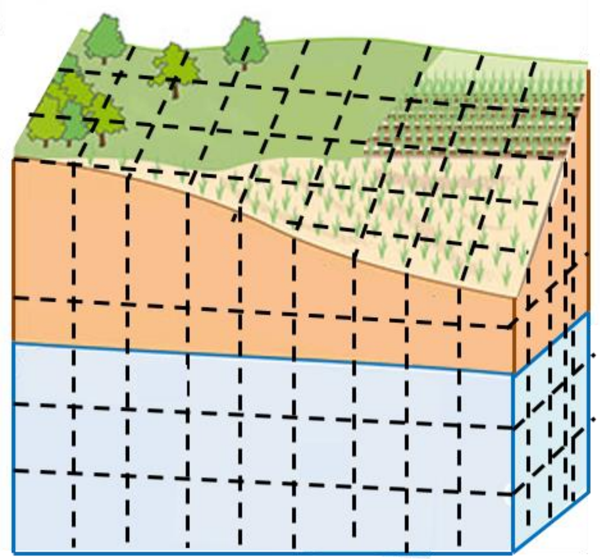
Ex. flow in MODFLOW (*Harbaugh, 2005*):

$$\frac{\partial}{\partial x}\left(bK_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(bK_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(bK_z \frac{\partial h}{\partial z}\right) = S_s \frac{\partial h}{\partial t} + \sum W(x,y,z,t)$$

$$\frac{\partial \theta}{\partial t} + \frac{\partial K(\theta)}{\partial z} + i = 0$$

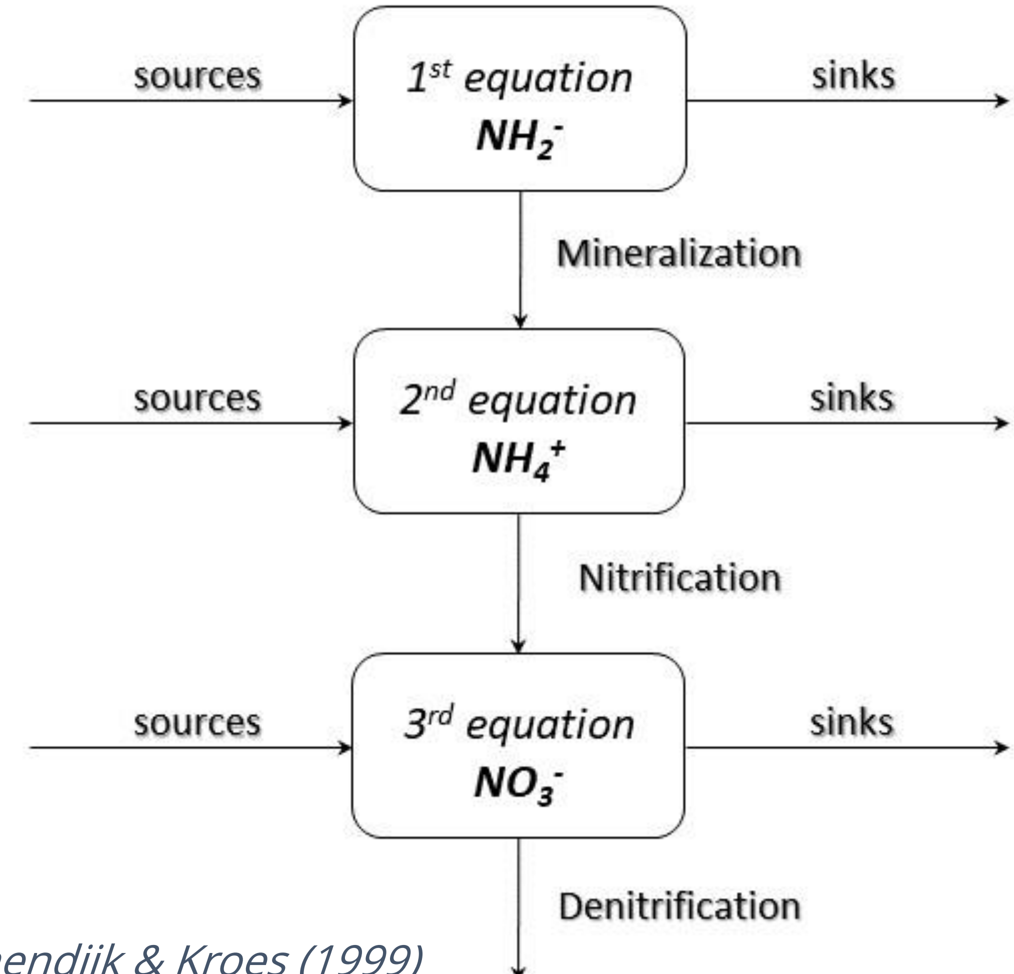
Modelling approach





Approach to be adopted at each grid cell!

ANIMO – Agricultural Nutrient Model



Modified after Groenendijk & Kroes (1999)

Overview of the modelling approach

Flow through the unsaturated zone

Vertical flow through the unsaturated zone (UZF MODFLOW package)

Nitrogen cycle

Transformation processes in the soil for each N pool (ANIMO model + EPIC approach for NO_3^- crop uptake)

Agricultural water management

Supply and demand components of irrigated crops (Farm Process)

Above Ground Biomass (Crop Growth Module)

Flow and Transport in the saturated zone

NO_3^- concentration simulated at the water table is treated as a mass source to the saturated zone (MT3DMS code)

Advantage of the coupling approach:
most of the inputs/outputs from the flow through the unsaturated zone and from the Agricultural water management components are used in the nitrogen cycle part (relatively frugal, poorly parameterized approach)

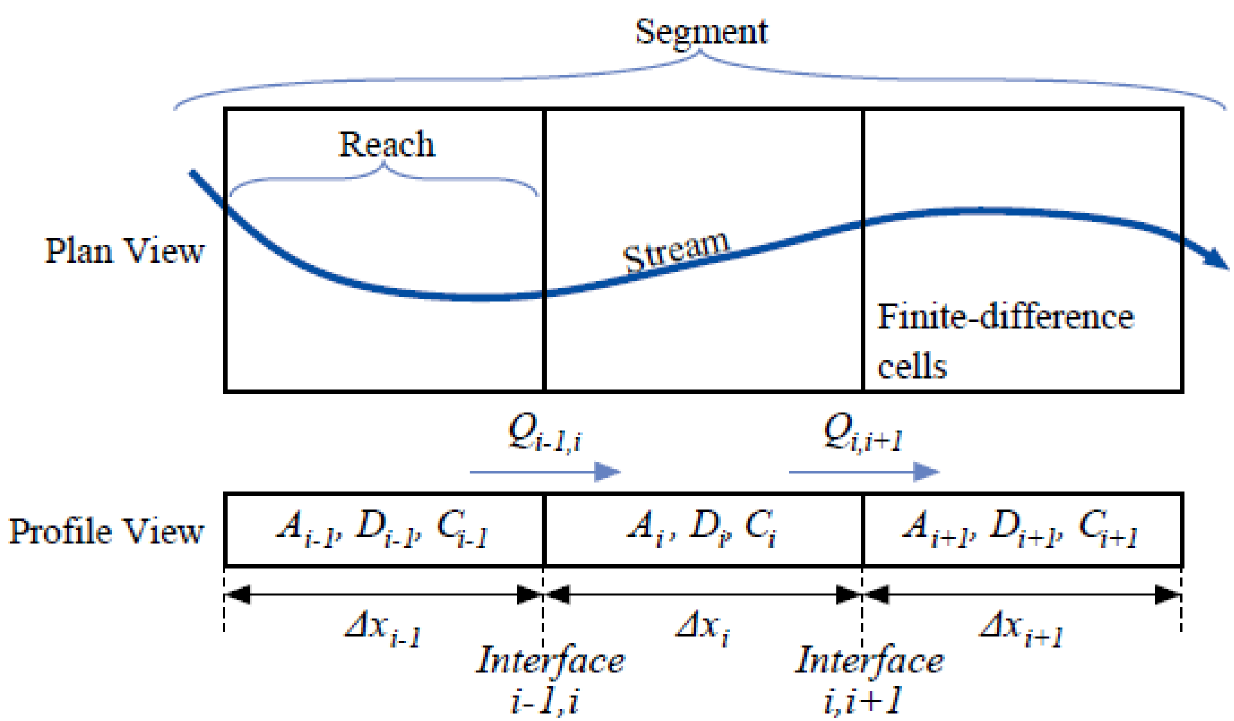
Mass exchange between surface- and ground-water

Integration of two MT3D-USGS packages:

- SFT (Streamflow Transport) -> 1D surface-water network transport accounting for groundwater interaction and stream/lake/unsaturated zone connections
- LKT (Lake Transport) -> lake concentration based on simulated inputs and outputs (for example, groundwater exchange, stream inflow/outflow, precipitation, evaporation)

Streamflow Transport (SFT) Package

$$\frac{A\Delta x\Delta C}{\Delta t} = \Delta\left(QC\right) + DA\frac{\Delta C}{\Delta x} + Q_s C_s$$



Limitation: 1D process!

Source: Bedekar, V., Morway, E. D., Langevin, C. D., & Tonkin, M. J. (2016). MT3D-USGS version 1: A US Geological Survey release of MT3DMS updated with new and expanded transport capabilities for use with MODFLOW (No. 6-A53). US Geological Survey.

Lake Transport (LKT) Package

$$\sum Q_{So_i}(\Delta t)C_{So_i} - \sum Q_{Si_i}(\Delta t)C_{Si_i} = V_l^n C_l^n - V_l^{n-1}C_l^{n-1}$$

$$C_l^n = \frac{\left(\sum_{j=1}^{NTrib}(Q_{Trib}C_{Trib})_j - \sum_{k=1}^{NDiv}(Q_{Div}C_{Div})_k + Q_pC_p - Q_eC_e + Q_rC_r - \sum_{m=1}^{NWithDrw}(Q_WC_W)_m + \sum_{i,j,k\epsilon l}(Q_{GW}C_{GW})_{i,j,k} - Q_{Seep}C_{Seep}\right)\Delta t}{V_l^n} + \frac{V_l^{n-1}C_l^{n-1}}{V_l^n}$$

Limitation: istantaneous mix!

Source: Bedekar, V., Morway, E. D., Langevin, C. D., & Tonkin, M. J. (2016). MT3D-USGS version 1: A US Geological Survey release of MT3DMS updated with new and expanded transport capabilities for use with MODFLOW (No. 6-A53). US Geological Survey.

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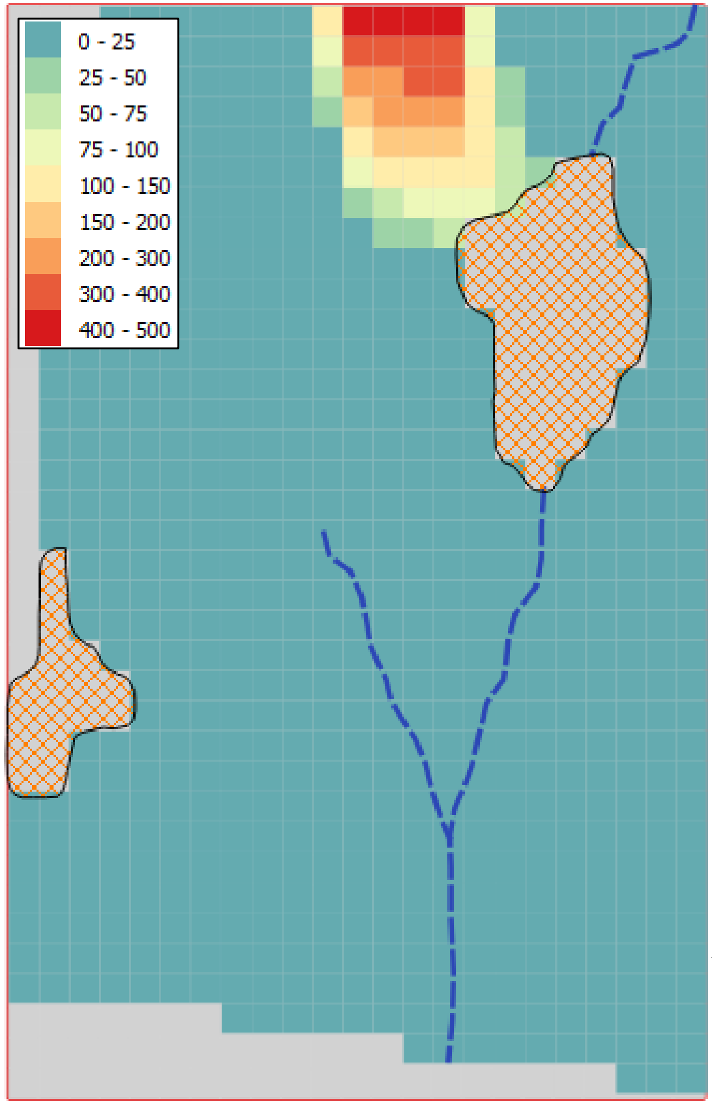
An application



Width of the study area: ≈ 130 km^2

Homogeneous sand-and-gravel aquifer

8 model layers (thickness ≈ 5 m)

2 lakes and 4 streams connected to model layer 1

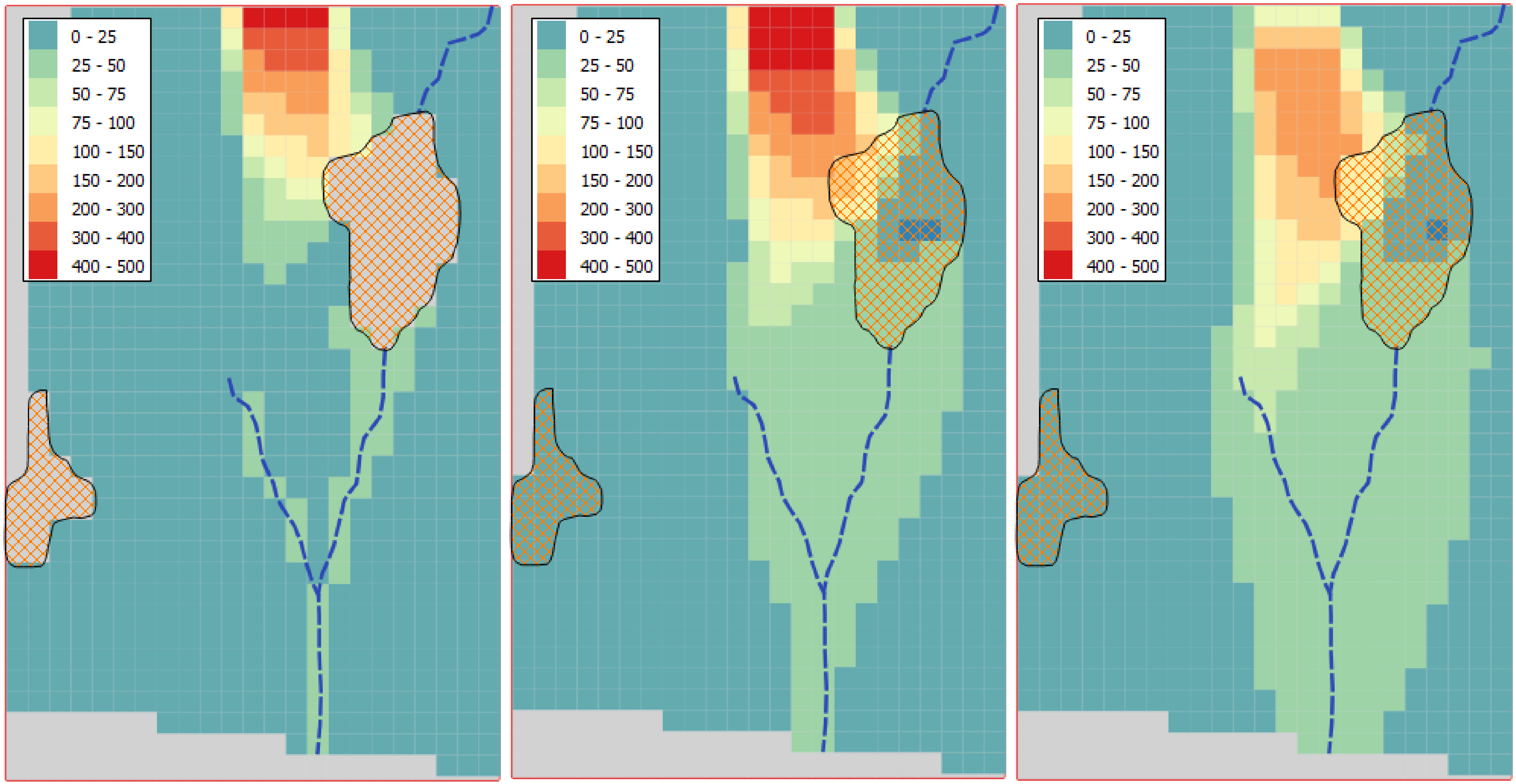
Steady-state model 25 years long

Gw flow from north to south

◀ *Boron concentration (µg/L) in model layer 1 after 4 years*

Source: Bedekar, V., Morway, E. D., Langevin, C. D., & Tonkin, M. J. (2016). MT3D-USGS version 1: A US Geological Survey release of MT3DMS updated with new and expanded transport capabilities for use with MODFLOW (No. 6-A53). US Geological Survey.

An application



Boron concentration (µg/L) in model layers 1, 3 and 5 after 25 years

References

Bedekar, V., Morway, E. D., Langevin, C. D., Tonkin, M. (2016). *MT3D-USGS version 1: A U.S. Geological Survey release of MT3DMS updated with new and expanded transport capabilities for use with MODFLOW*, U.S. Geological Survey Techniques and Methods 6-A53, 69 p.

Groenendijk, P., & Kroes, J. G. (1999). *Modelling the nitrogen and phosphorus leaching to groundwater and surface water with ANIMO 3.5* (No. 144). Winand Staring Centre.

Sharpley, A. N. (1990). *EPIC-erosion/productivity impact calculator: 1, Model Documentation*. USDA Techn. Bull. 1759, 235.

LIFE REWAT project partners

- CONSORZIO BONIFICA 5 TOSCANA COSTA
- SCUOLA SUPERIORE SANT'ANNA PISA
- ASA AZIENDA SERVIZI AMBIENTALI SpA
- REGIONE TOSCANA

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- COMUNE DI CAMPIGLIA MARITTIMA

Patronage

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- ORDINE DEI GEOLOGI DELLA TOSCANA
- Early Career Hydrogeologists' Network ECHN-Italy
- ACQUE SOTTERRANEE Italian Journal of Groundwater
- GIT

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ANIMO – Agricultural Nutrient Model

Nitrogen compound	*Conservation*	*Vertical transport*	*Lateral outflow*	*Crop uptake*	*Decomposition*	*Production*
NH_2^-	$\frac{\partial(\theta(t)c_{NH2}(t))}{\partial t}$	$= -\frac{\partial J_{s,NH2}(t,z)}{\partial z}$	$-R_{x,NH2}(t)$		$-R_{d,NH2}(t)$	$+R_{p,NH2}(t)$
NH_4^+	$\frac{\partial(\theta(t)c_{NH4}(t))}{\partial t} + \rho_d \frac{\partial X_{e,NH4}(t)}{\partial t}$	$= -\frac{\partial J_{s,NH4}(t,z)}{\partial z}$	$-R_{x,NH4}(t)$	$-R_{u,NH4}(t)$	$-R_{d,NH4}(t)$	$+R_{p,NH4}(t)$
NO_3^-	$\frac{\partial(\theta(t)c_{NO3}(t))}{\partial t}$	$= -\frac{\partial J_{s,NO3}(t,z)}{\partial z}$	$-R_{x,NO3}(t)$	$-R_{u,NO3}(t)$	$-R_{d,NO3}(t)$	$+R_{p,NO3}(t)$

These are equations to be solved one by one, in the order presented above, cell by cell, stress period by stress period

- Decomposition processes of each pool are included, along with source terms, in the production terms of the pool below.
- The crop uptake process is based on the EPIC model (Sharpley, 1990).