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The impact of non-point source pollution on groundwater nitrate in shallow aquifer with SWAT applications -a review

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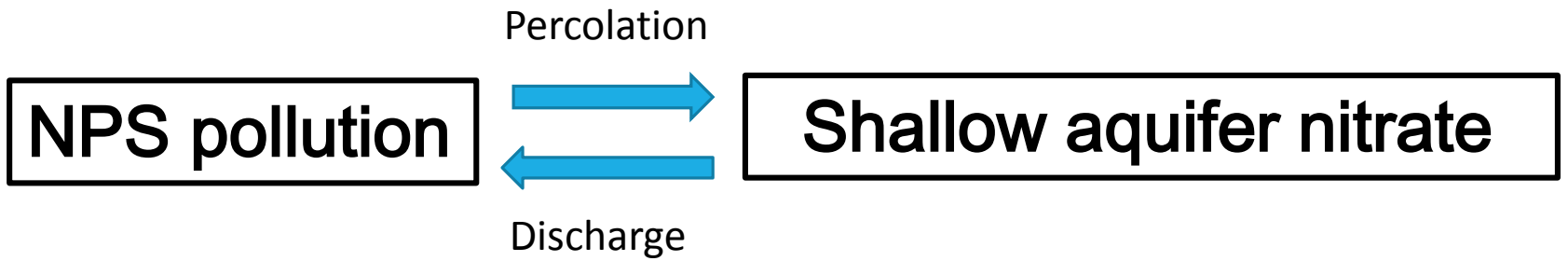
Outline of presentation

1. Background
2. Brief understanding of nitrate in shallow aquifer
3. Methodologies for baseflow nitrate loads estimation
4. SWAT Applications
5. Prospect

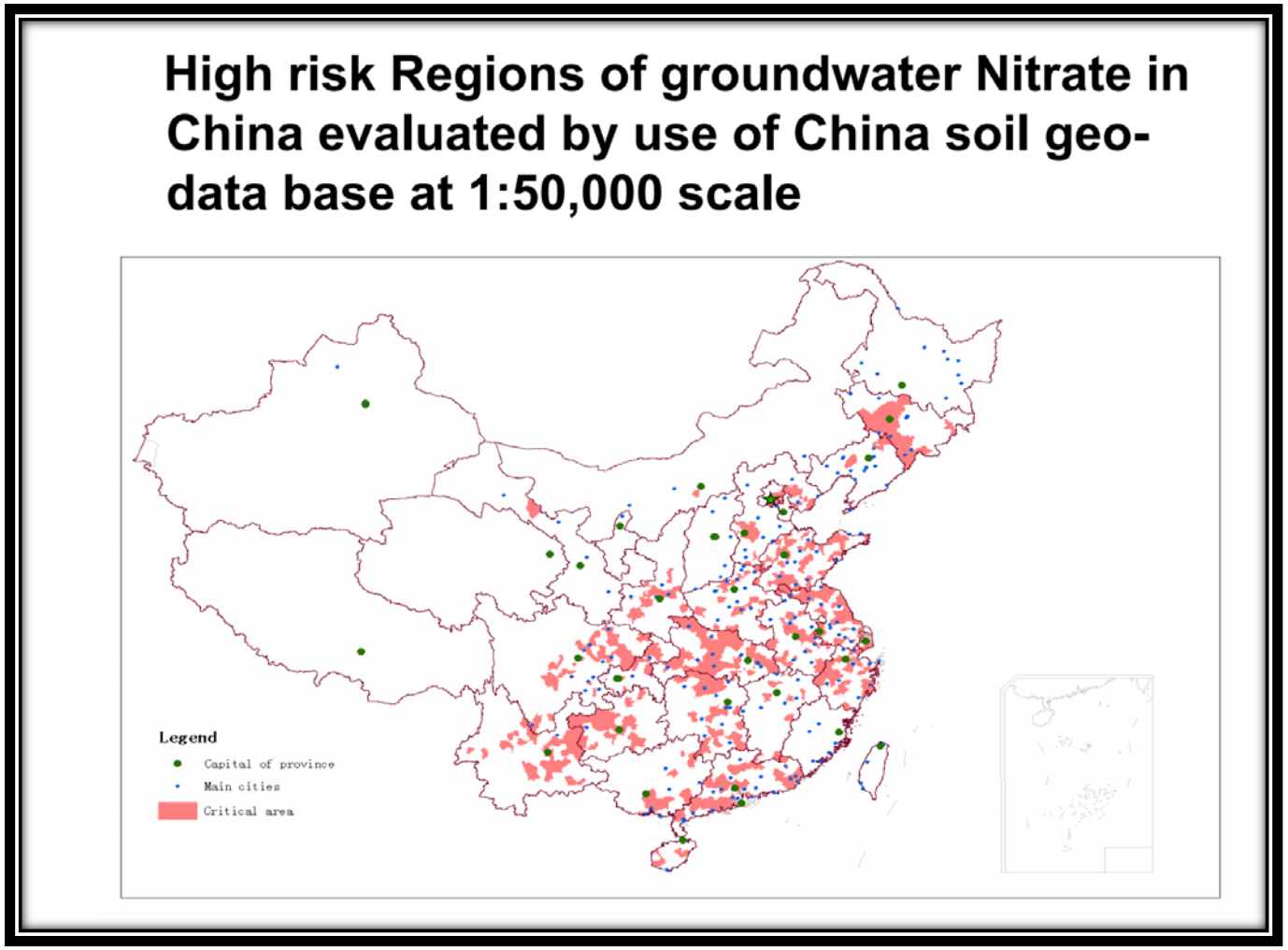
Background

- Agricultural activities: fertilization, irrigation and livestock
- Groundwater : one of the dominant hydrological pathways for nitrate migration toward streams



Groundwater nitrate pollution status

- America, 20% of shallow wells sampled in agricultural areas exceed the drinking water standard.(2011)
- China: 57% of all monitoring wells in 182 main metropolitan areas exceed 20 mg L-1(2013)
- US Environmental Protection Agency (USEPA) maximum contaminant level (MCL) of 10 mg/l.

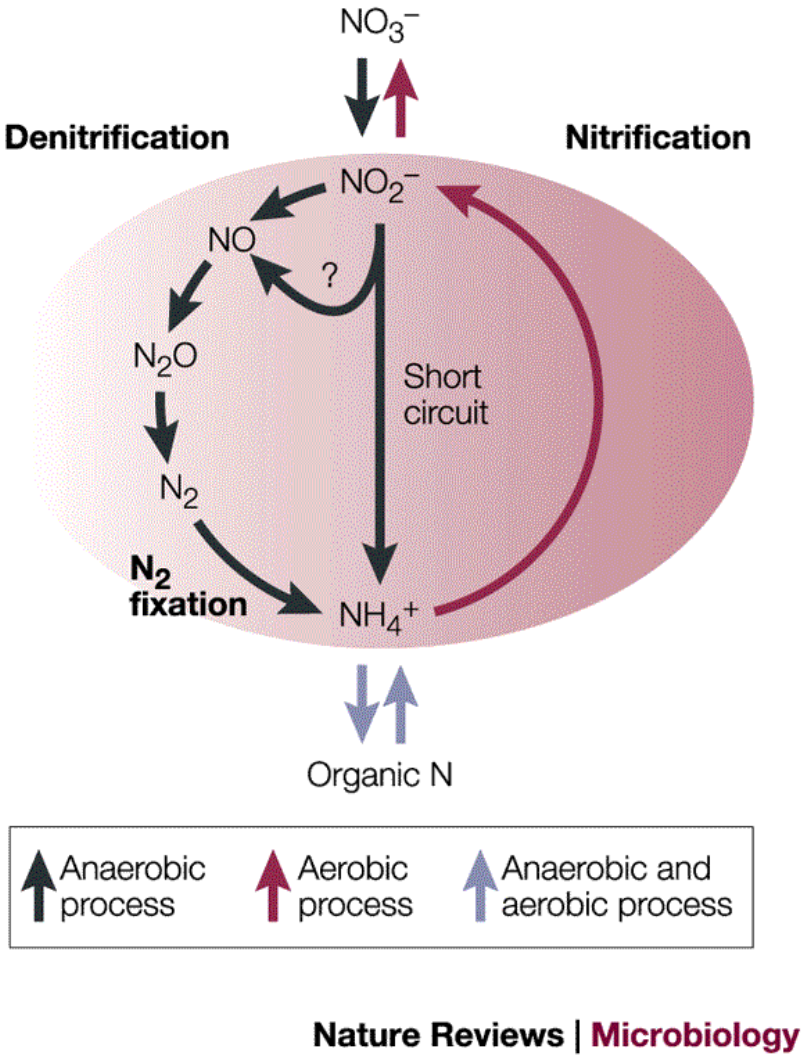


Zhang Wei-Li, Legacy soil data from China national soil survey, 2012

Groundwater nitrate pollution status

- Nitrate (NO3-), one of most ubiquitous NPS contaminants found in ground water, is receiving an increasing amount of attention because excess nitrate would not only lead to the problem of ecological security (e.g. bloom and red tide) easily (Lunau, et al., 2013)

- Increase the risk of birth defects (Johnson, et al., 2010) together with some diseases such as diarrhea of children (Gupta, et al., 2001), methaemoglobinaemia in infants (Fewtrell, 2004) and cancers (Ward, et al., 2010).



Main sources of nitrate loading in shallow aquifer

Agricultural activities, such as fertilization , irrigation （ Main Factor ）

- ✓ The relationship between the increase in groundwater nitrate levels and the high rate of N fertilizer application has been well confirmed in previous studies

Non-agricultural sources： sewerage leakage, contaminated landfills, waste of urban animal, house building, industry, and atmospheric deposition.

- ✓ Though wastewater treatment is very common in industrialized countries, irrigation using untreated or partly treated wastewater is still widespread in most developing countries (Norton-Brandão, et al., 2013), which leads to high risk of groundwater nitrate contamination

Main factors affecting nitrate in shallow aquifer

Natural Factors(e.g. soil type and composition, temperature, and precipitation)

- ✓ Compared with fine clay soils, sandy soils commonly have less retention of nitrate because of a lower cation exchange capacity, which attributes to the relatively low contents of silt and clay

Human Factors (e.g. cultivation) and town construction

- ✓ high-frequency irrigation is more likely to cause more serious nitrate leaching relative to low-frequency irrigation

Methodologies for baseflow nitrate loads estimation

Segment sampling and monitoring

- ✓ Divide discharge process into two baseflow and stormflow periods for loads estimation,Sub-watershed of Mahan tango Creek, USA. Zhu, et al. (2011)
- ✓ Samples taken during baseflow, elevated baseflow, and stormflow for analysis and loads estimation,USA. Pionke, et al. (1996)

Baseflow separation together with loads estimating program

- ✓ Using the USGS program ESTIMATOR based on baseflow set separated by HYSEP and recursive digital filter, in Raccoon River watershed, USA. Schilling and Zhang (2004)

Methodologies for baseflow nitrate loads estimation

Solute transport equations

- ✓ Determined by Solutes Flux theory based on groundwater field study, Mulgrave River Catchment, Australia. Rasiah, et al. (2013)

Differential method

- ✓ Estimated by subtracting the loads from upstream gauge from the total at downstream gauge, for baseflow period in Walnut Creek watershed, Southern Iowa, USA. Schilling and Wolter (2001)

Methodologies for baseflow nitrate loads estimation

- ✓ Quantitative research on shallow aquifer contribution to NPS nitrate pollution remains relatively rare.
- ✓ High-frequency monitoring data is needed
- ✓ Result highly relied on baseflow separation
- ✓ Model-based estimation maybe be more effective

Evaluate the impact of NPS pollution on groundwater nitrate in shallow aquifer with SWAT model

- ✓ Interaction between GW-SW combining with SWAT model
- ✓ Spatial distribution variation of nitrate in groundwater
- ✓ Estimate nitrate leaching to groundwater system ; export from baseflow

SWAT – An Overview

- **Spatial Scale: watershed or river basin**

- **Data Organization: subbasins or hydrologic response units (HRU's)**

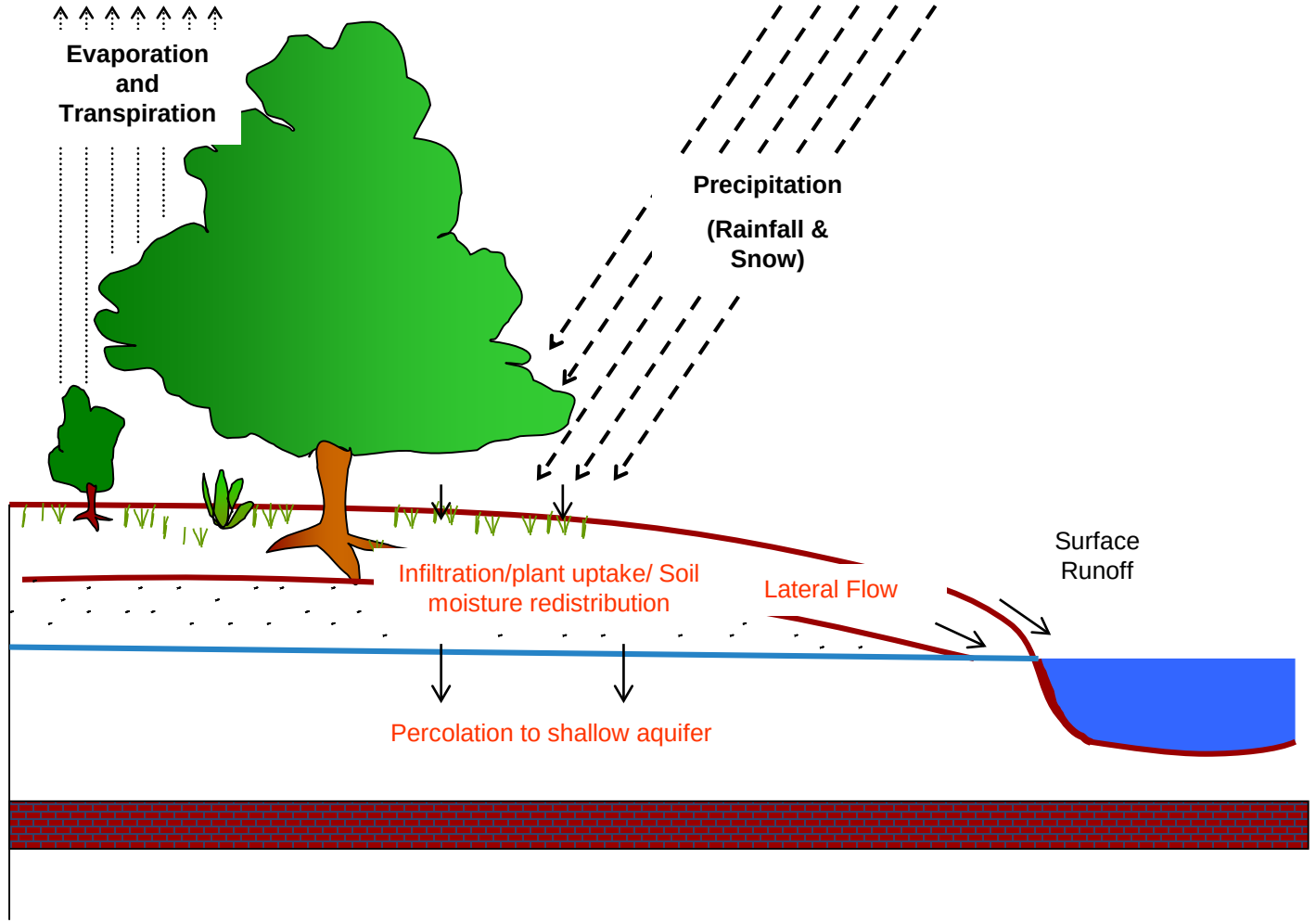
- **Time scale: Continuous time model (long term yield model) based on a daily scale, Not for a single event**

- **Data Inputs: weather, soil properties, topography, vegetation, and land management practice From the BASINS databases**

SWAT – An Overview

SWAT soil water routing feature consists of four main pathways:

- soil evaporation
- plant uptake and transpiration
- lateral flow
- percolation.



SWAT Applications on groundwater nitrate review

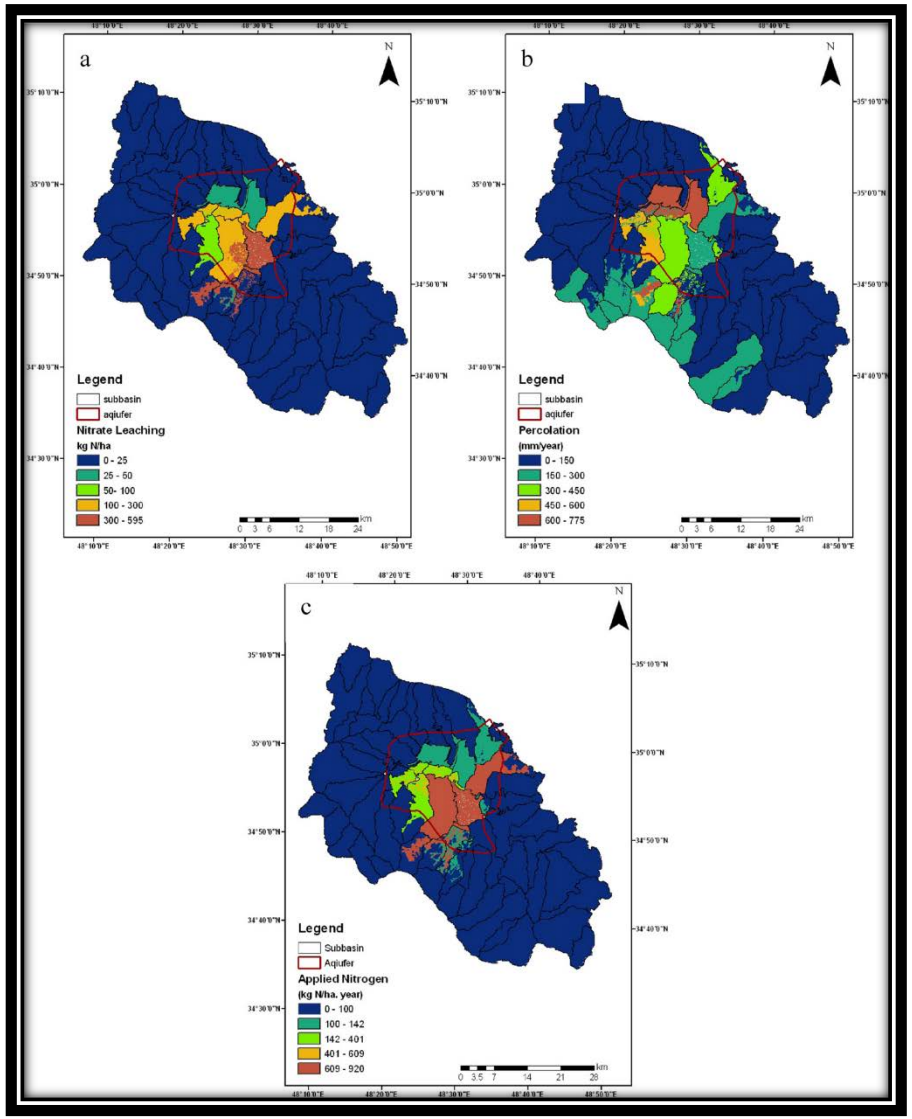
Mainly focus on：

- Investigate the temporal and spatial variability of nitrate leaching
- Groundwater nitrate vulnerability assessment
- Couple model simulation：SWAT-MODFLOW-MT3DMS；
  SWAT-MODFLOW-RT3D

SWAT Applications on groundwater nitrate review

- employed SWAT to model the amount and dynamics of nitrate leaching from a typical crop rotation in this watershed.

- Spatial variations in nitrate leaching found to agree with measured nitrate concentrations in groundwater

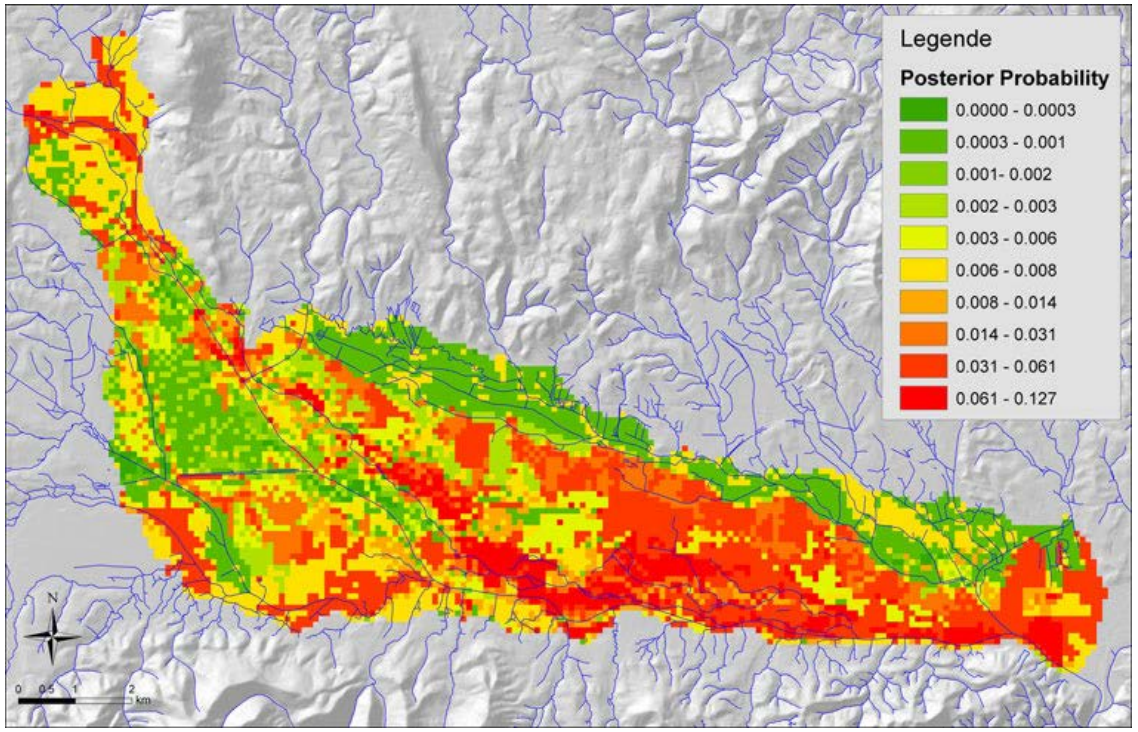


Simulated annual nitrate leaching, percolation and applied nitrogen at HRU level.

Samira Akhavana et al.,2010

SWAT Applications on groundwater nitrate review

- process-based models reflecting relative groundwater nitrate vulnerability
- three process-based models generalized output layers of groundwater recharge (GROWA), nitrate leached from the soil profile (SWAT) and groundwater flow velocity (FEFLOW)



Posterior probability map of groundwater nitrate pollution in Lower Savinja Valley,
Jozˇe Uhan et al.,2011

Coupled model application

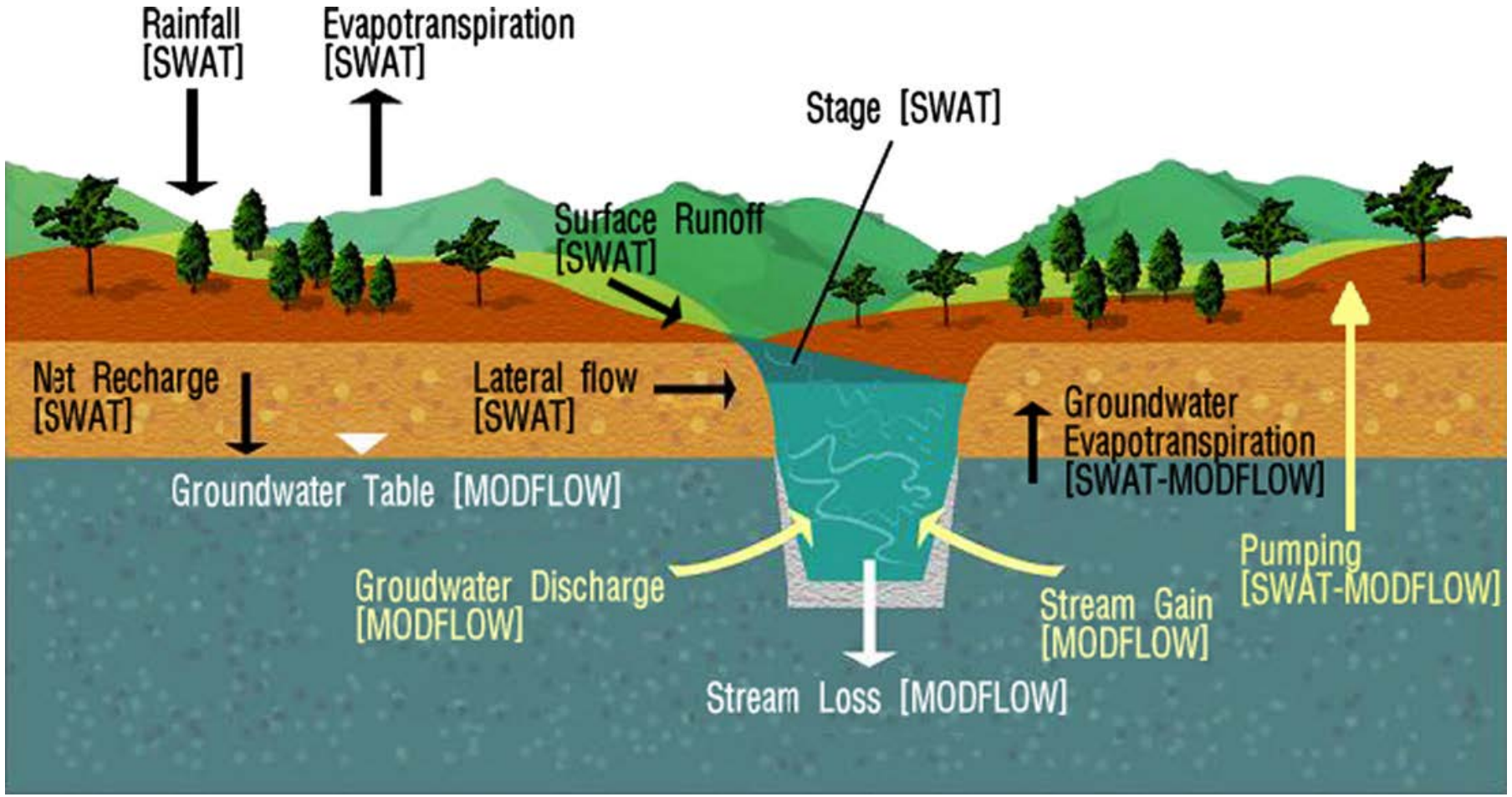
- ✓ While SWAT has its own module for groundwater components (Arnold et al., 1993), the model itself is lumped and therefore distributed parameters such as hydraulic conductivity distribution could not be represented.
- ✓ The conventional groundwater flow analysis performed by MODFLOW often overlooks the accuracy of the recharge rates that are required to be calculated into the model. Consequently, there is considerable uncertainty in the simulated groundwater flow results.

Coupled model application

- ✓ Sophocleous et al. (1997, 1999) have previously presented an interface between SWAT and the MODFLOW called SWATMOD, which is capable of simulating the flow of surfacewater, groundwater, and stream–aquifer interactions on a continuous basis.

- ✓ Perkins and Sophocleous (1999) describe drought impact analyses using this system. This system was modified to become a two-way coupling system and was used by Sophocleous and Perkins (2000) to investigate irrigation effects on streamflow and groundwater levels in the lower Republican River watershed in north central Kansas.It was also used on streamflow and groundwater declines within the Rattlesnake Creek watershed.

Coupled model application



Schematic diagram of combined surface water and groundwater model

SWAT-MODFLOW-MT3DMS

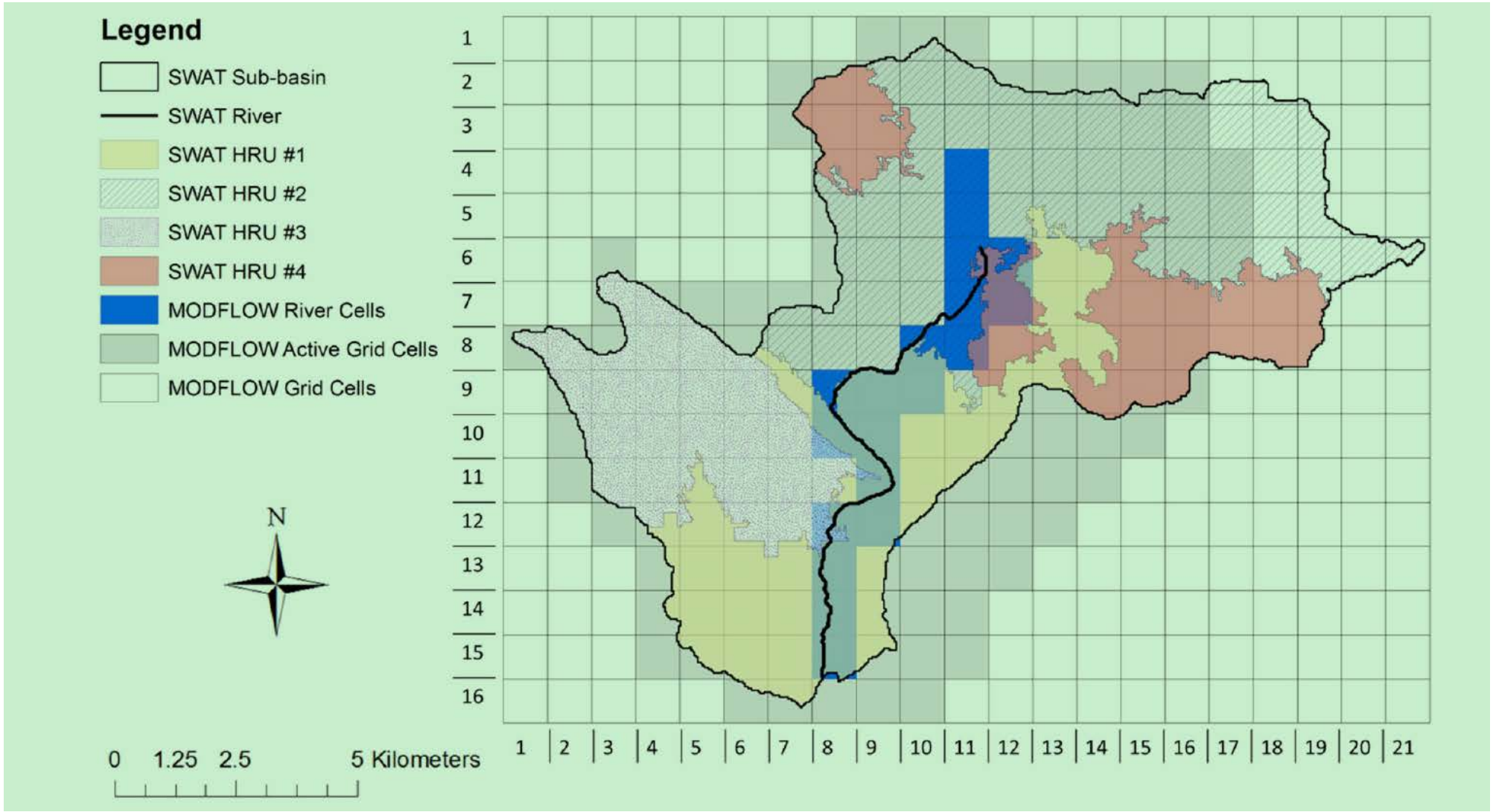
Conan et al. (2003) applied coupled modeling of SWAT with MODFLOW to the Coet-Dan watershed in Brittany, France.

- ✓ The integrated model consisted of SWAT for water and N fate in the unsaturated zone → **Simply coupled**
- ✓ MODFLOW as ground water flow using SWAT predicted recharge as time-variant input
- ✓ MT3DMS for assessing the fate of NO3 leached from the opsoil as predicted by SWAT

SWAT-MODFLOW-RT3D

Method：Link SWAT with physically-based, spatially-distributed groundwater models MODFLOW.

- ✓ As SWAT HRUs do not have a designated geographic location, HRUs are disaggregated in preprocessing GIS routines. Disaggregation splits apart an HRU into individual polygons that have a specific geographic location.
- ✓ The MODFLOW model is called as a subroutine within the SWAT modeling code. It replaces the original SWAT groundwater subroutines.
- ✓ the leakage between HRU and cell grid was build by swatmf_link.txt file.



Linking SWAT HRUs and MODFLOW grid cells, SWAT-MODFLOW Tutorial, 2015.

Prospect

- Improvement of coupling model in accuracy
- Uncertainty analysis
- BMPs application with SWAT-MODFLOW

Thank You