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Assessing nitrogen dynamics in a small Mediterranean forested catchment, Fuirosos (Catalonia)

By:

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Introduction

- Mediterranean ecosystems
  - Mediterranean catchments are characterized by a **complex hydrological behaviour** that presents high inter and intra-annual variability (Gallart et al., 2002)
  - **Altering dry** and **humid conditions** that have great influence on the catchment hydrological response (Medici et al., 2008) and soil microbial activity (Birch 1964, Austin et al., 2004, Reynolds et al., 2004)
  - Rainfall inputs to a dry soil represent **pulses** that trigger a cascade of biogeochemical and biological transformations (Schiwinning et al., 2004)

Introduction

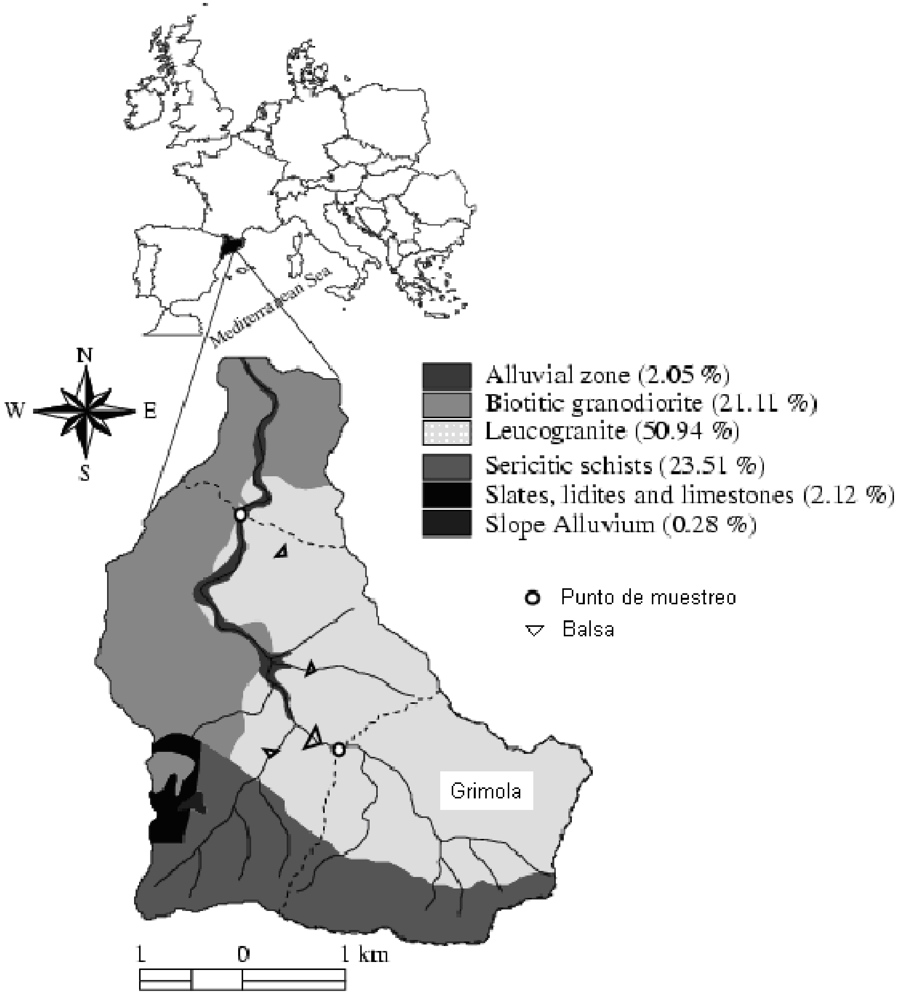
- Mathematical models have been developed to describe the nitrogen dynamics in **cool temperate river-systems**, but further work is needed to understand and model the main processes controlling the nitrogen cycle in **Mediterranean and semi-arid ecosystems** since these systems are not well understood (Gelfand et al, 2008; Bernal et al., 2005, Avila et al., 1995; Wade et al., 2004).
- Models developed for temperate climates generally fail when applied to Mediterranean catchments, as for example the INCA-N model (Wade et al., 2002; Bernal et al., 2004).

Objective

- The aim of this study was to improve our understanding of the main processes that govern the inorganic nitrogen fate and losses of a small Mediterranean catchment (Fuirosos) by means of mathematical modelling.

Study site: Fuirosos catchment

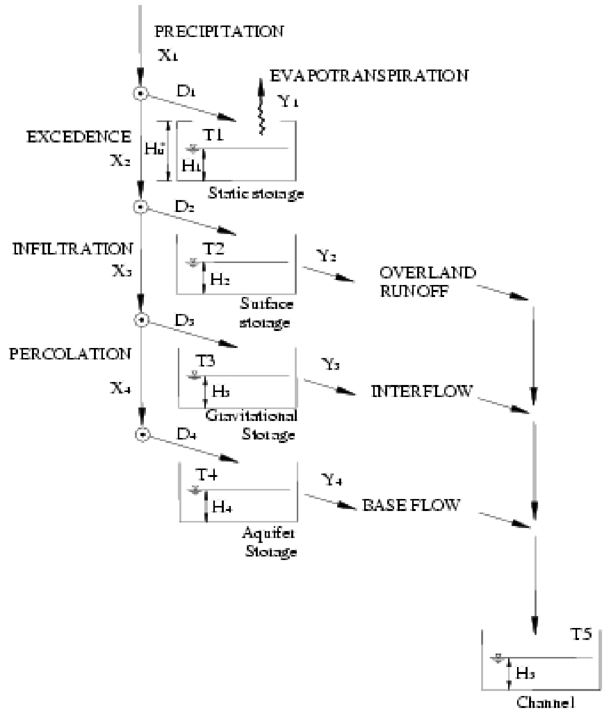
- Catchment area: 13 km^2
- Forest covers 90% of tot. area
- Lithology:
  - Granodiorite
  - Leucogranite
  - Schists
  - Well-developed riparian zone at the valley bottom
- Mediterranean climate:
  - Mean annual Ppt: 750 mm
  - Mean annual PET: 975 mm
- Intermittent stream



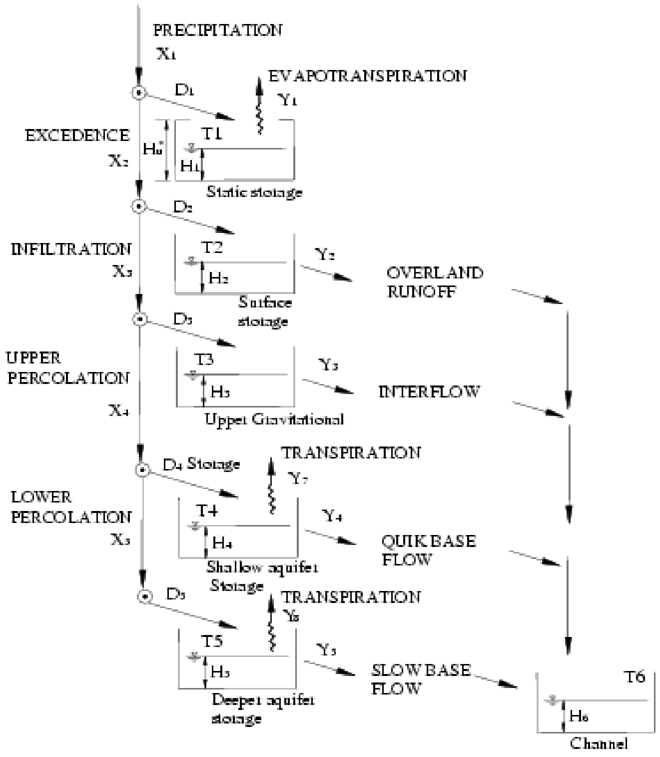
Hydrological model evolution

- Progressive perceptual modelling approach (Beven, 2000)

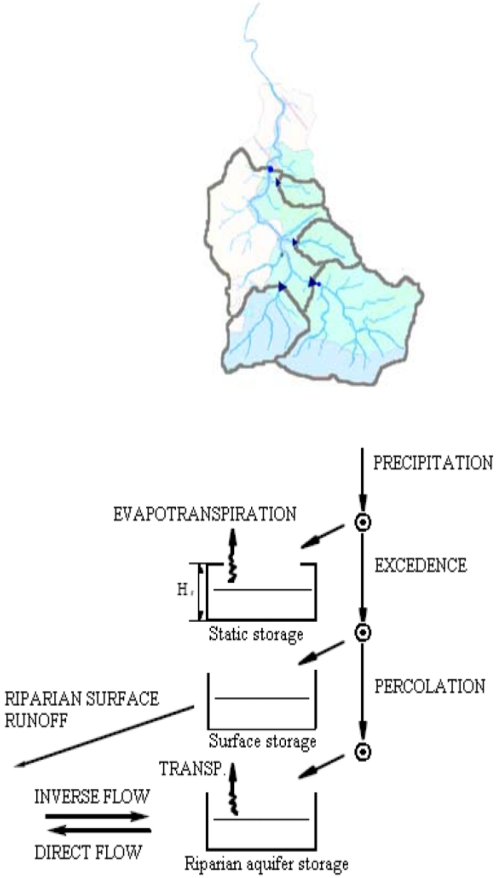
LU3 model



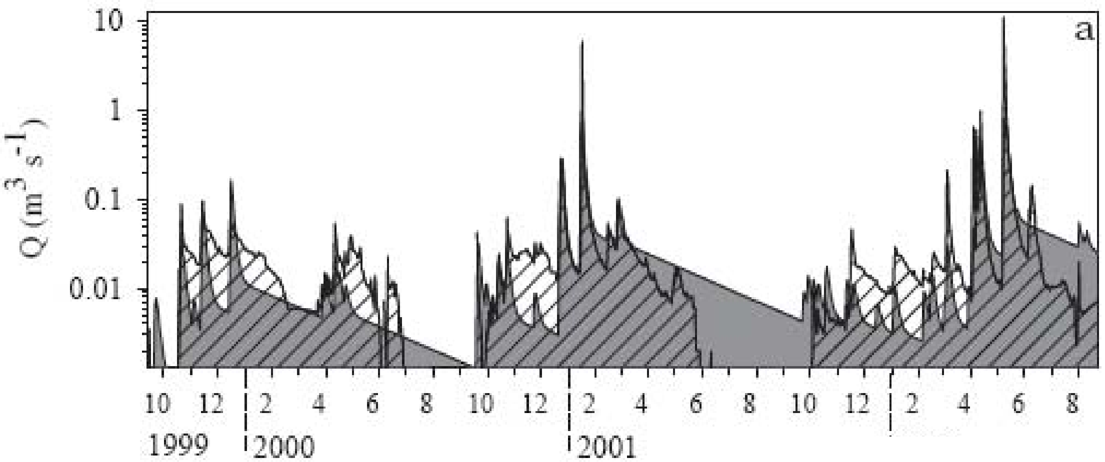
LU4 model



SD4-R model



Calibration results with SD4-R model



INCA model

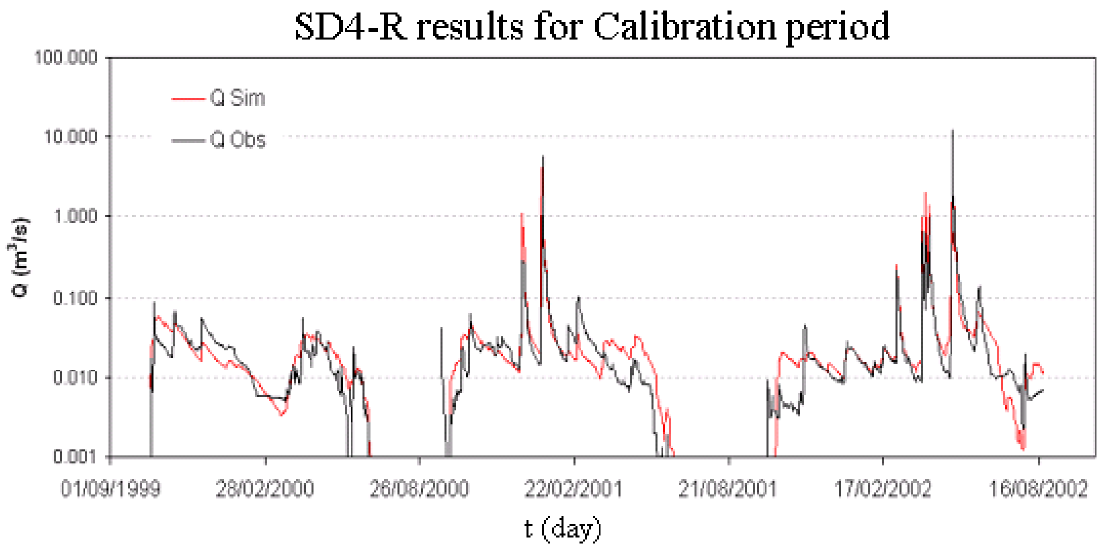
(Wade et al., 2002, Hydrol. Earth Syst. Sci., 6, 559-582)

(Picture after Bernal et al., 2004)

SD4-R model

(Medici et al., 2008, Hydrol. Processes)

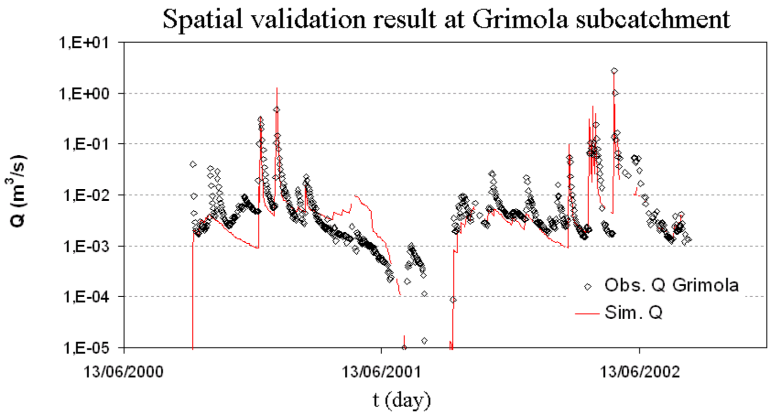
Nash index: 0.78
Volumen Err < 5%
Obs Q_{max} : 10.9 m^3/s
Sim Q_{max} : 8.6 m^3/s
(daily time step!!)



Validation results with SD4-R model

- Nash index: 0.4 (0.8 without including February 2003)

- Volumen: 24%

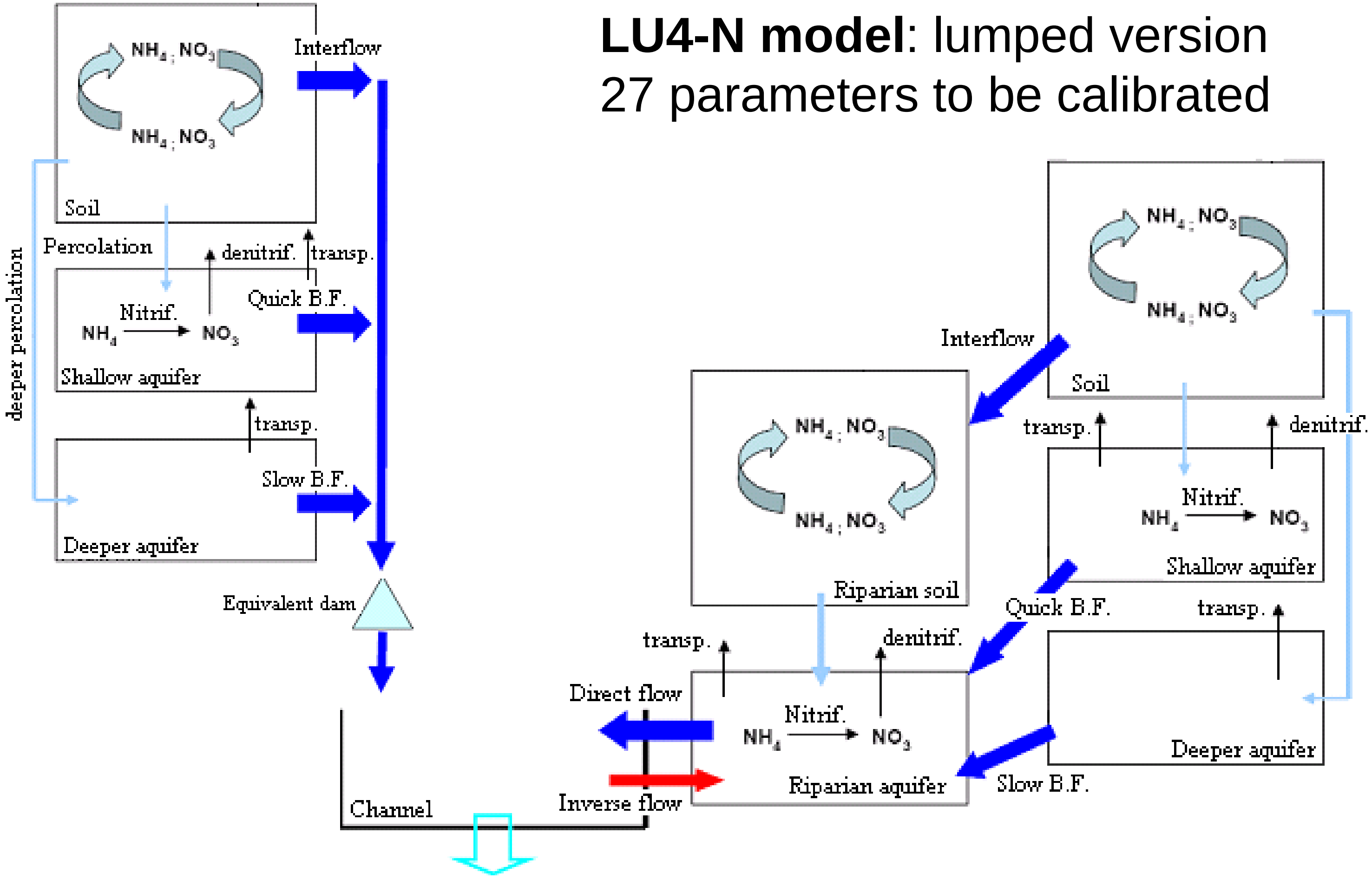


- Nash index: 0.7

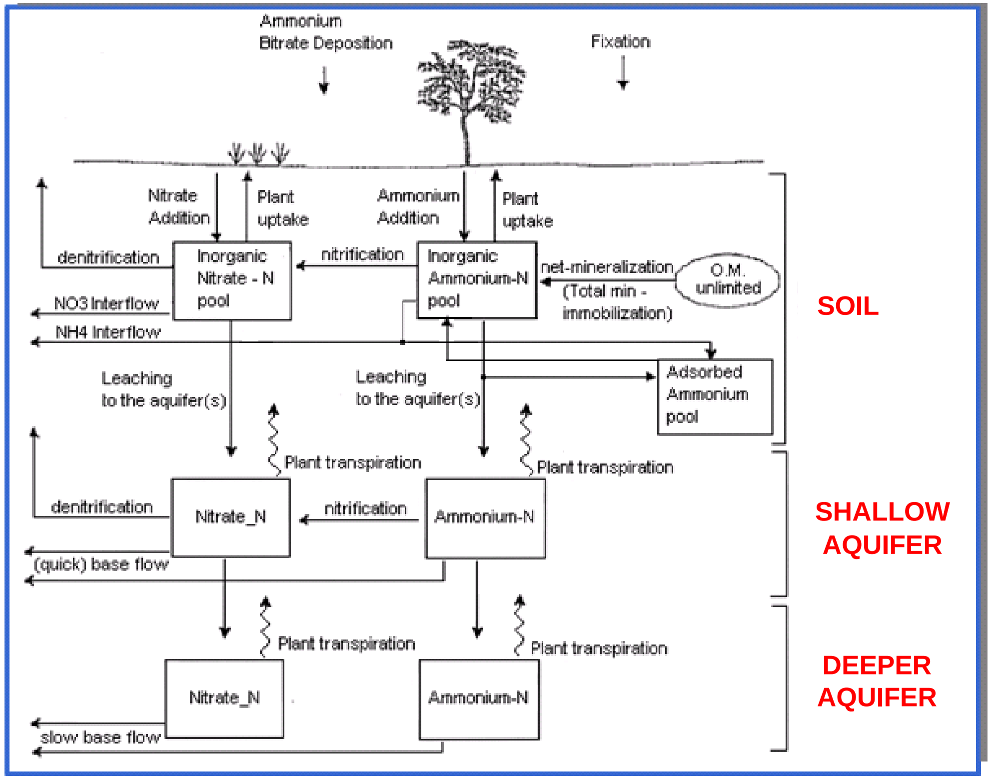
- Volumen Err. < 5%

Nitrogen model evolution

LU4-N model: lumped version
27 parameters to be calibrated



INCA-based Nitrogen Cycle



- The model provides a simplified conceptualization of nitrogen cycle in ***soil*** and ***shallow aquifer***.
- The model includes a ***soil moisture threshold*** for all the considered soil biological processes, expressed as a percentage of the maximum amount of water retained by upper soil capillary forces (H_u^*).

Soil moisture thresholds

- Mineralization:

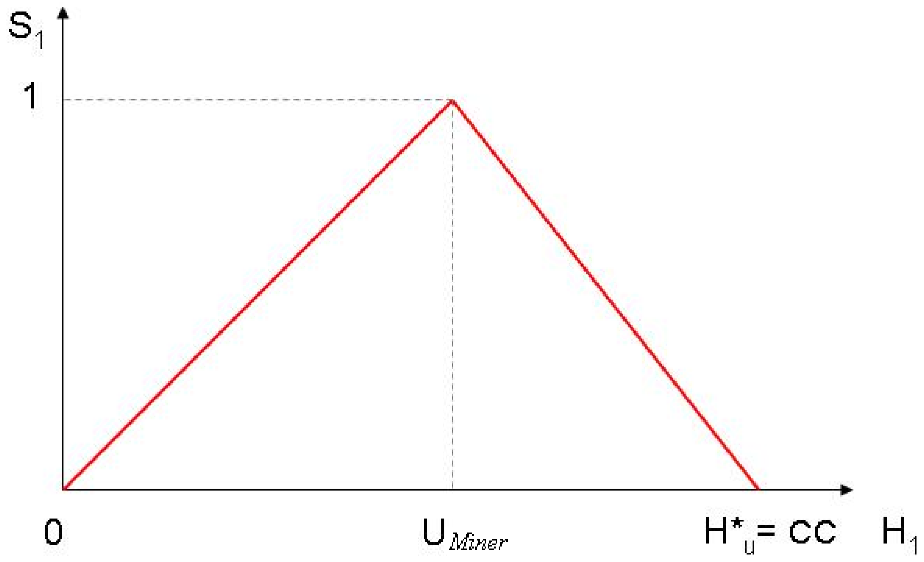
$$\left(M_{NH_4}\right)_{Mineral.} = K_{Miner} \cdot \boxed{S_{1\_Miner}} \cdot TF$$

  - M_{NH4} ammonium mineralized mass (kg ha^{-1} day^{-1})
  - S_1 is the soil moisture factor
  - K_{Min} is the mineralization constant rate (Kg ha^{-1} day^{-1})
  - TF is the temperature corrector factor (Whitehead et al., 1998)

Soil moisture thresholds

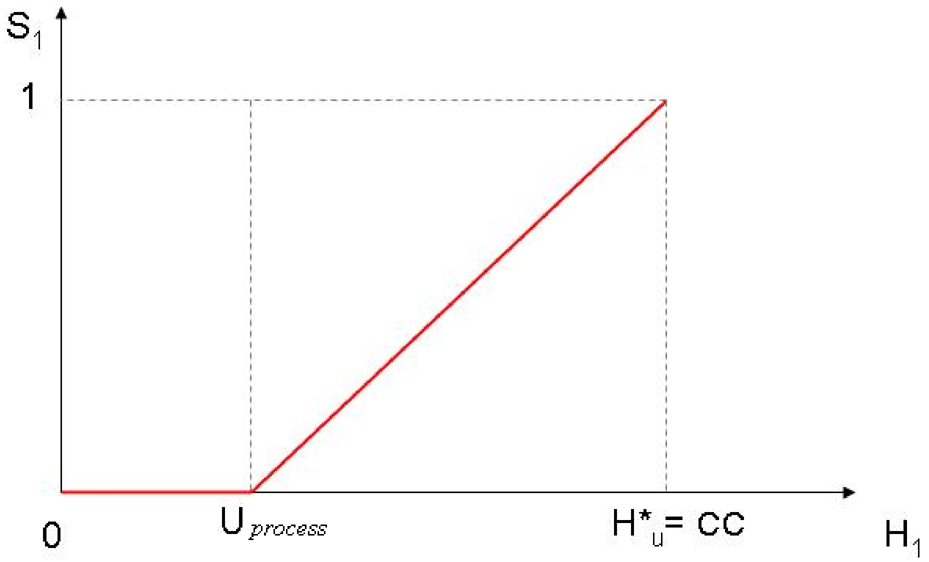
- Mineralization:
  - S_1 is the soil moisture factor
  - H_1 is the actual static storage water content (mm/day)
  - H_u^* is maximum amount of water retained by upper soil capillary forces (mm)
  - U_{Miner} is the soil moisture threshold for mineralization (%), expressed as a percentage of Hu* (mm)

$$\left(M_{NH_4}\right)_{Mineral.} = K_{Miner} \cdot \boxed{S_{1\_Miner}} \cdot TF$$

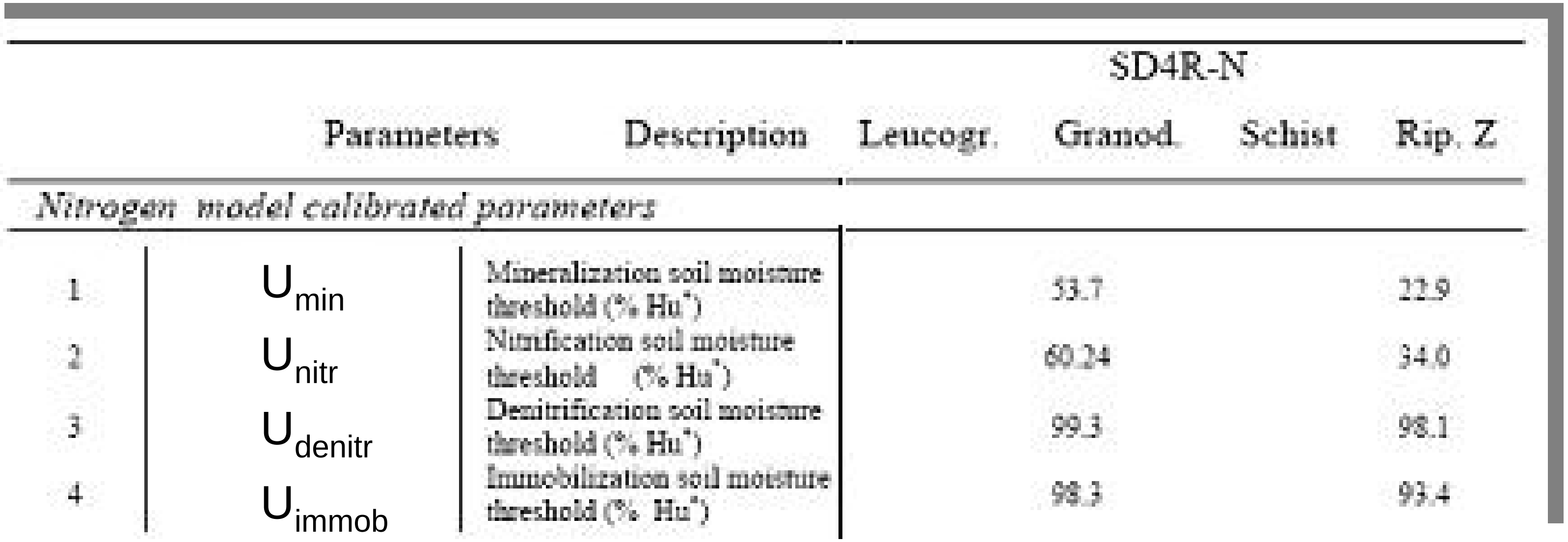


Soil moisture thresholds

- Other soil processes:
  - Nitrification
  - Denitrification
  - Immobilization
  - Plant uptake

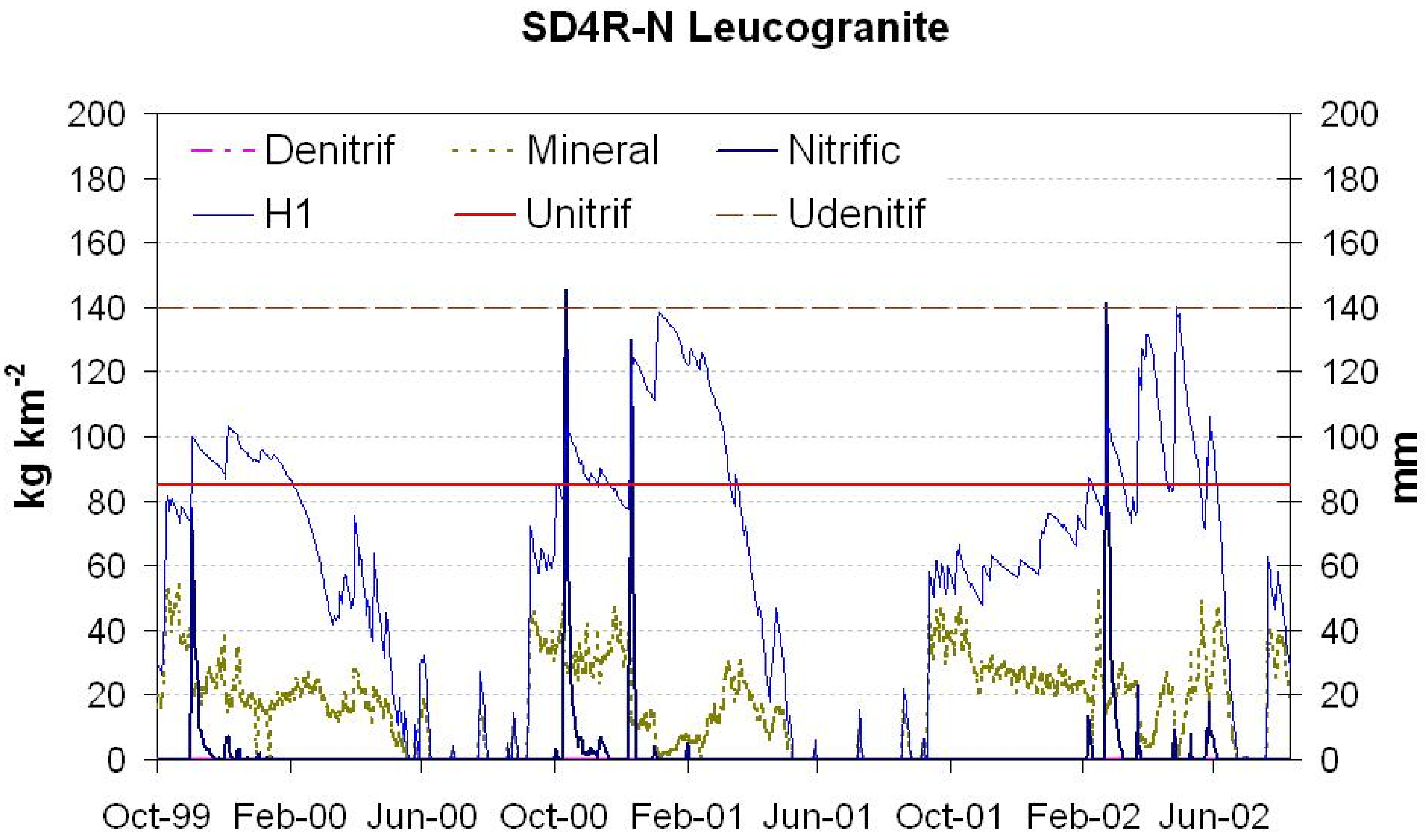


SD4-R-N biological thresholds

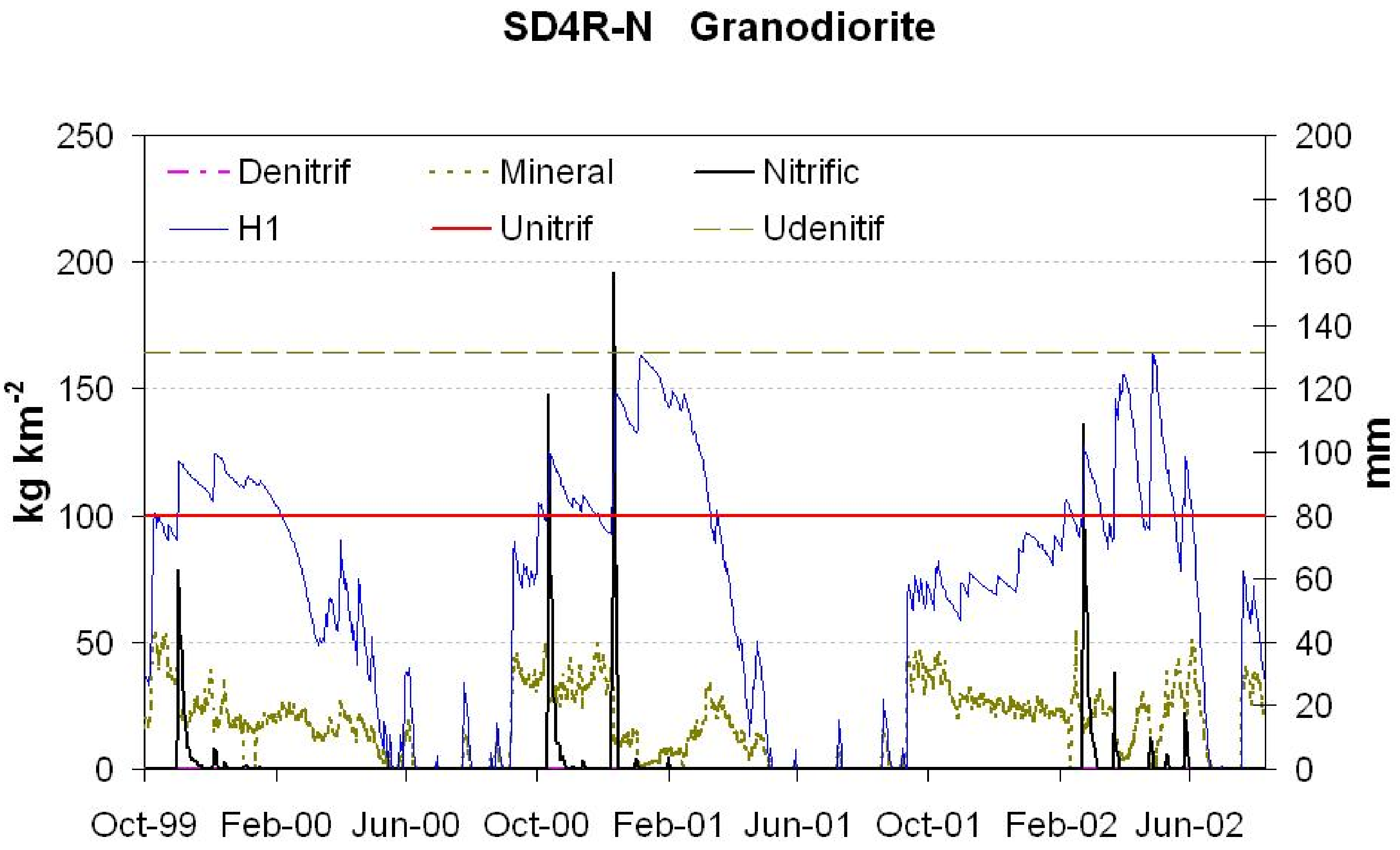


	Parameters	Description	SD4R-N			
			Leucogr.	Granod.	Schist	Rip. Z
Nitrogen model calibrated parameters						
1	U_{min}	Mineralization soil moisture threshold (% Hu^*)		53.7		22.9
2	U_{nitr}	Nitrification soil moisture threshold (% Hu^*)		60.24		34.0
3	U_{denitr}	Denitrification soil moisture threshold (% Hu^*)		99.3		98.1
4	U_{immob}	Immobilization soil moisture threshold (% Hu^*)		98.3		93.4

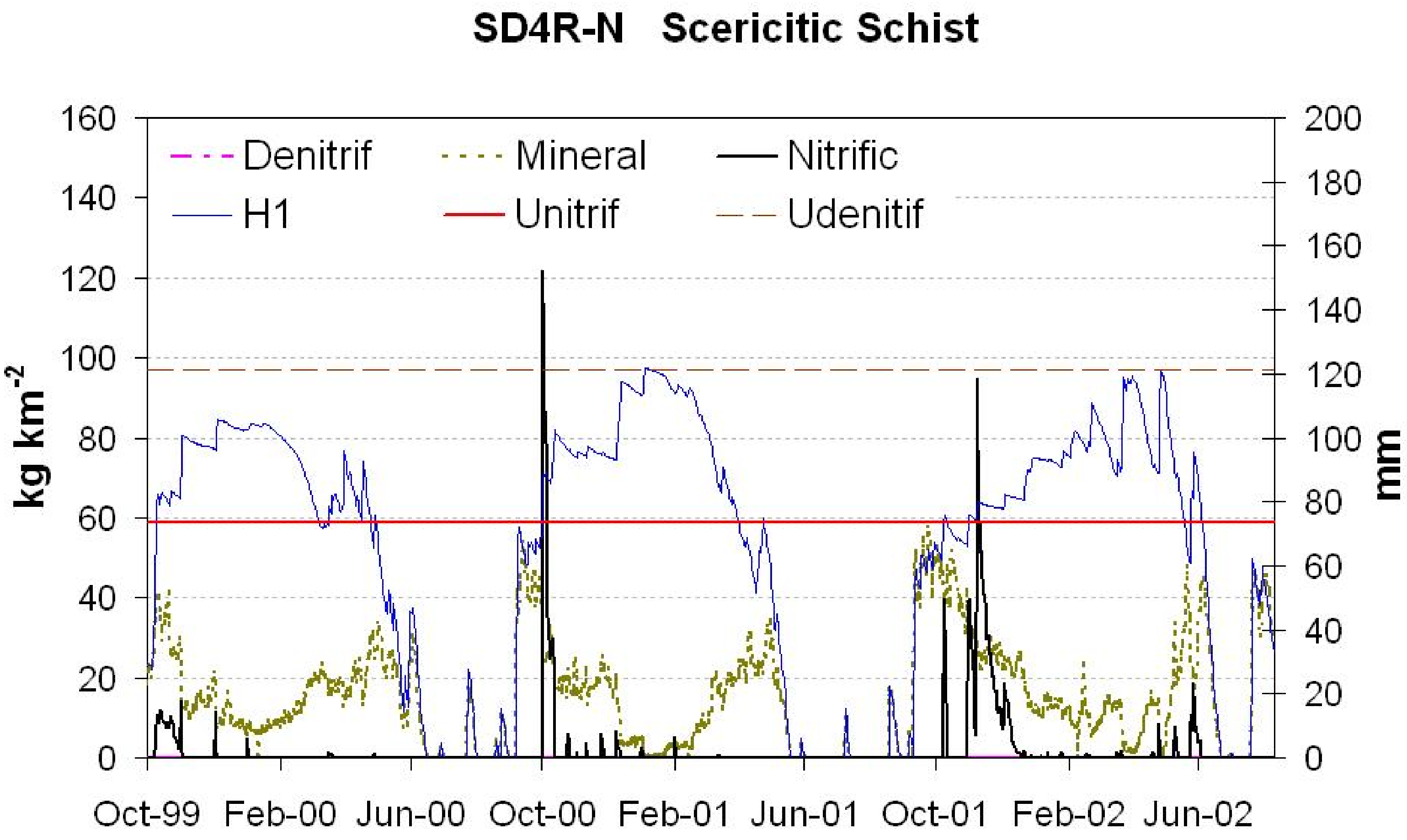
Soil moisture effect



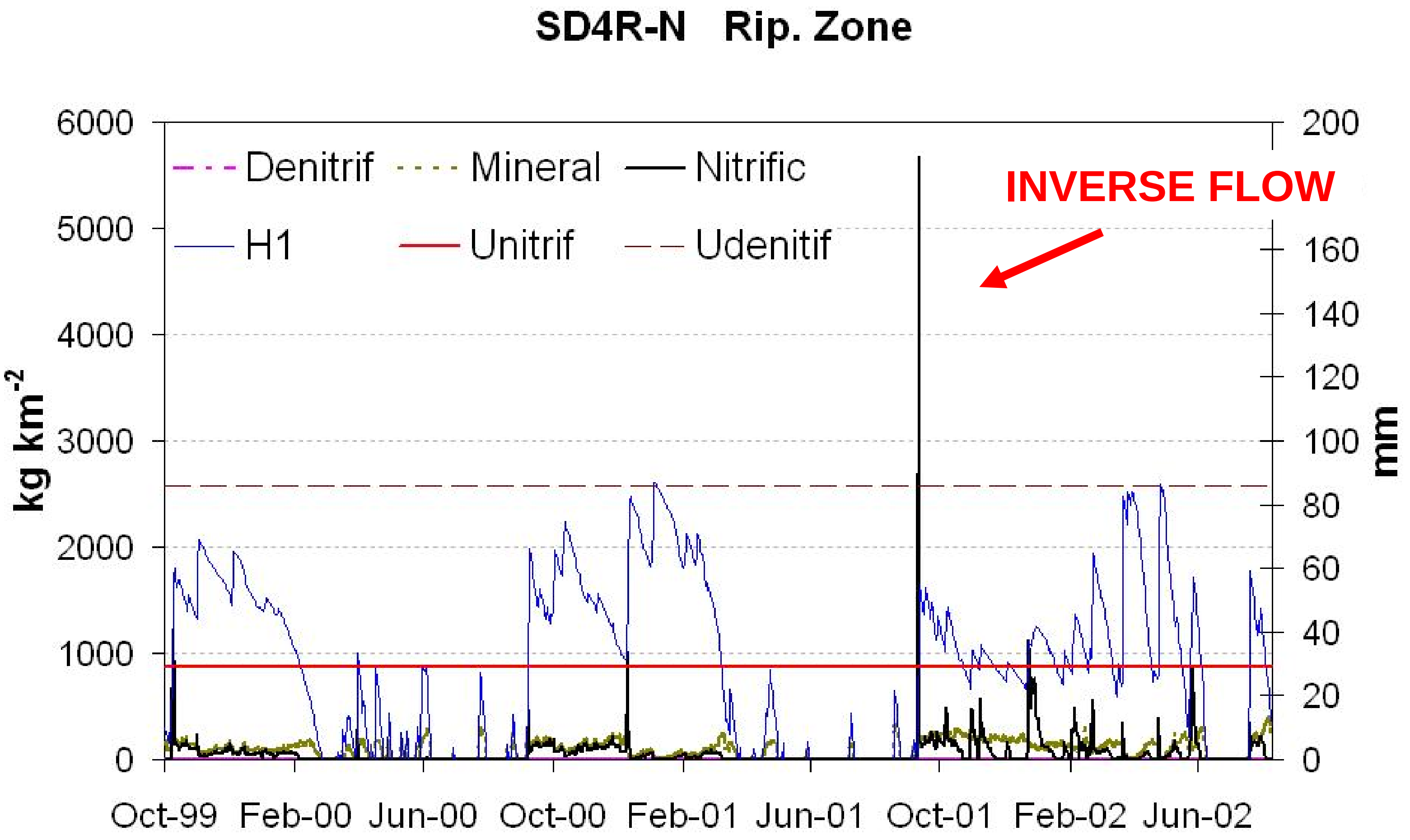
Soil moisture effect



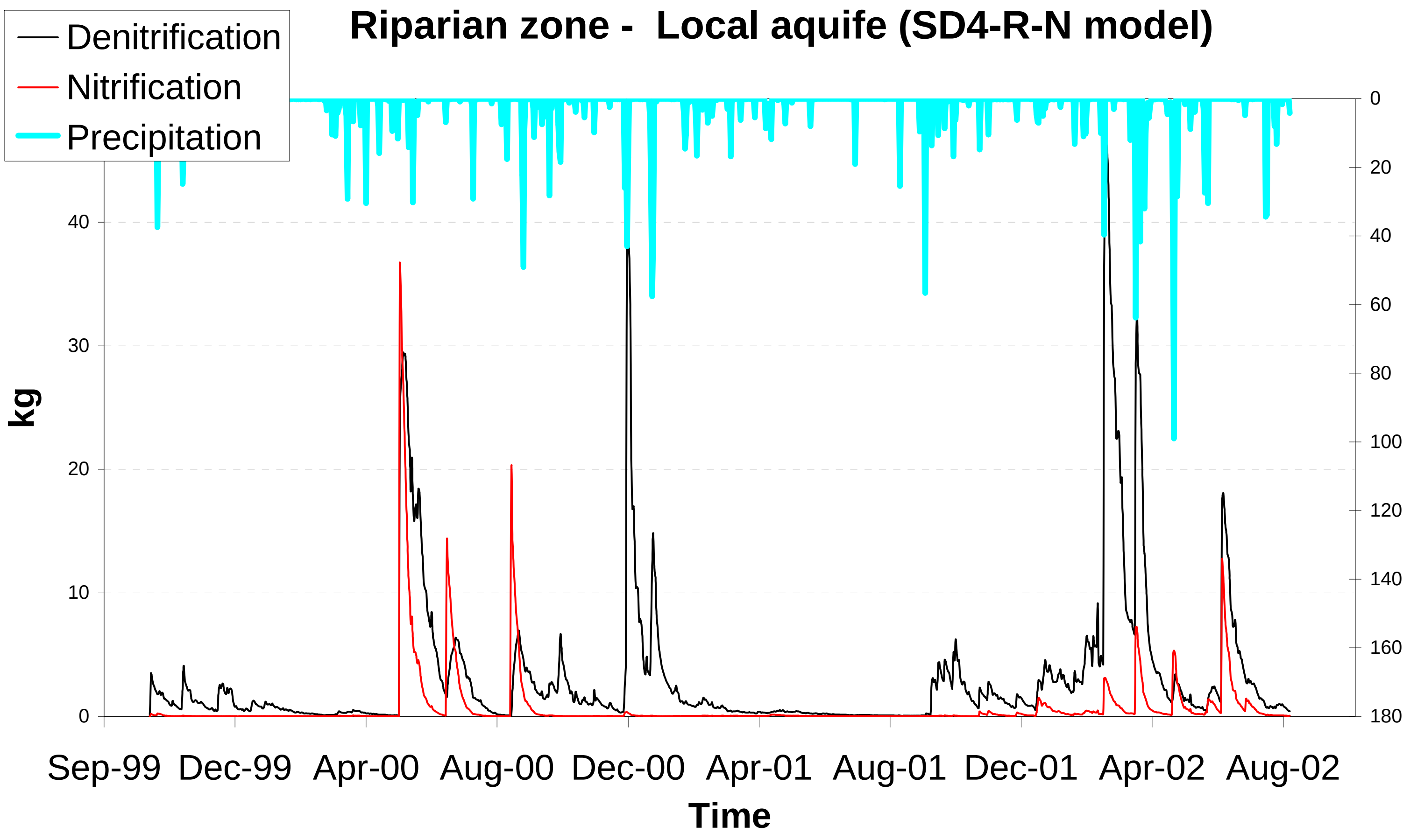
Soil moisture effect



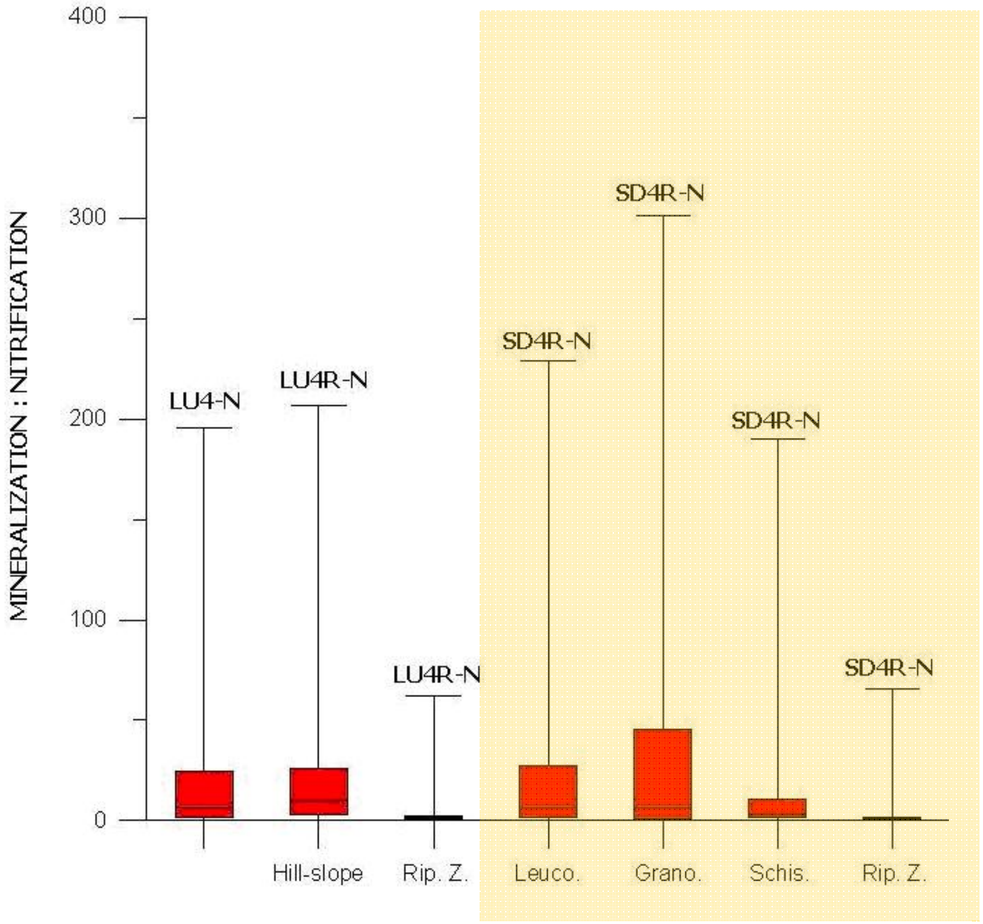
Soil moisture effect



Riparian local aquifer N-cycle



M:N relationship

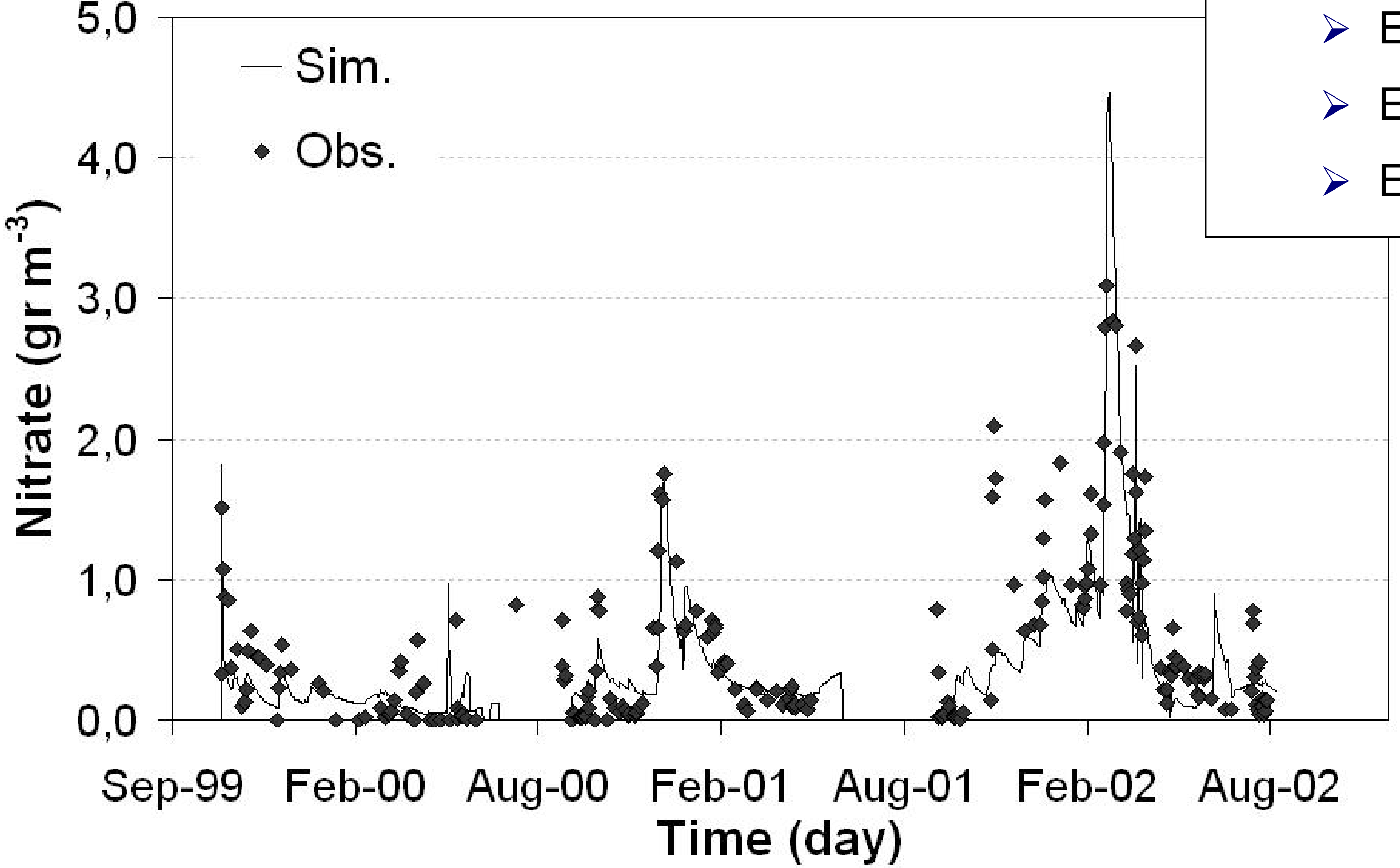


- Due to the threshold mechanism, the annual average M:N ratio is approximately 8:1, which is consistent with the ratio (10:1) founded in other Mediterranean areas (e.g., Serrasolses et al., 1999). This was explained considering the soil moisture limitation effect on nitrification.

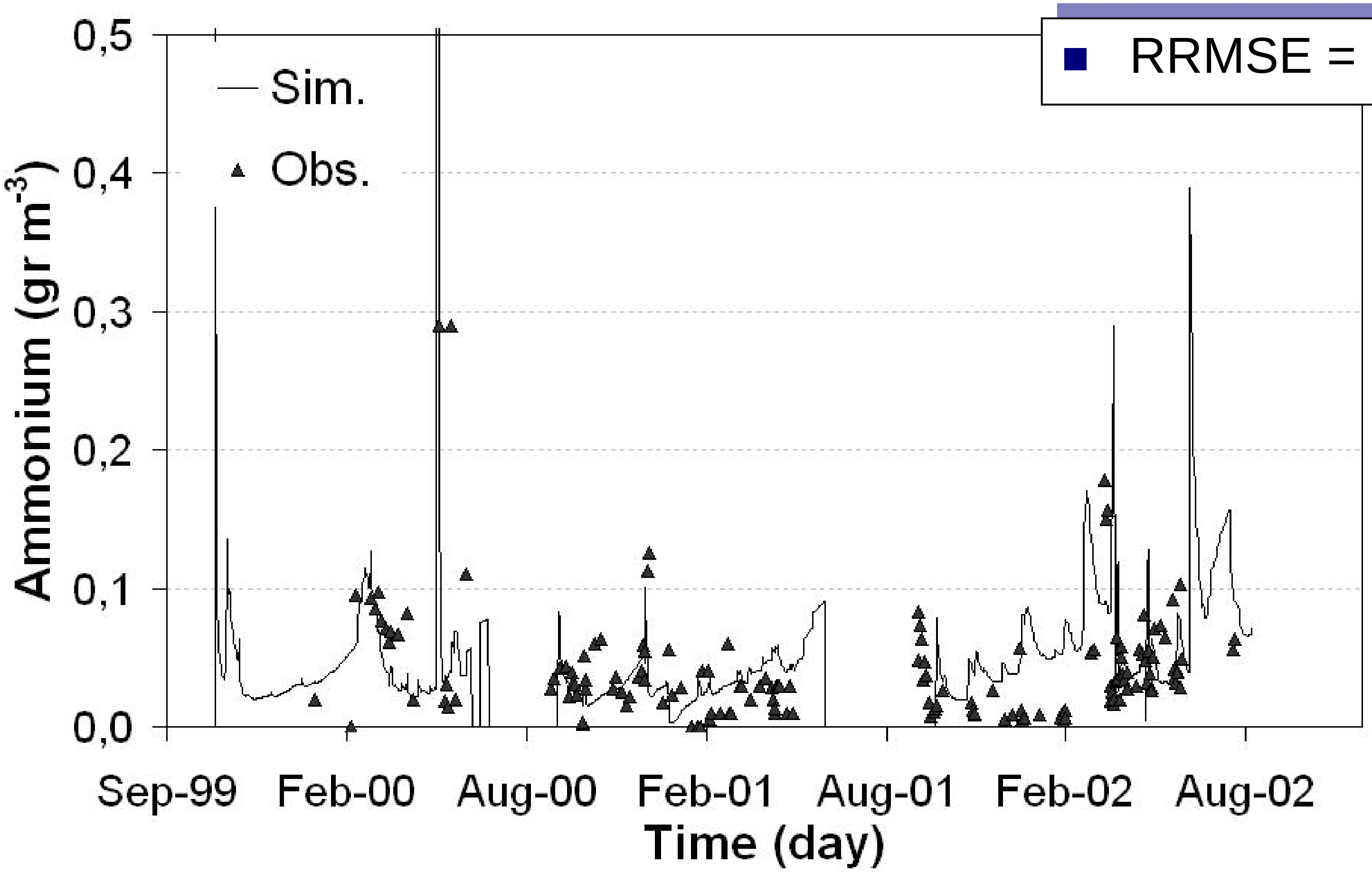
- Interestingly, when considering the riparian zone alone, the simulated M:N ratio decreases to almost 1:1

Nitrate calibration

- Global E = 0.68
  - E_{1year} = 0.49
  - E_{2year} = 0.57
  - E_{3year} = 0.66

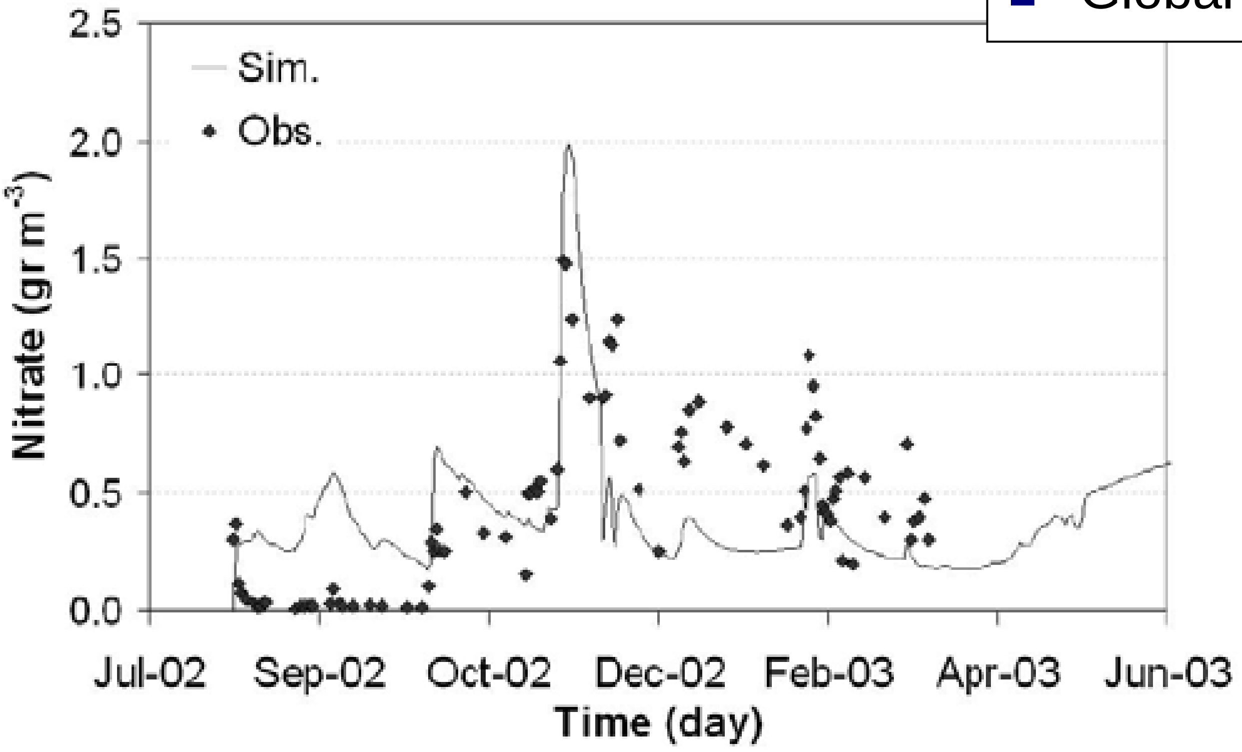


Ammonium calibration



- RRMSE = 0.9

Temporal Validation for nitrate

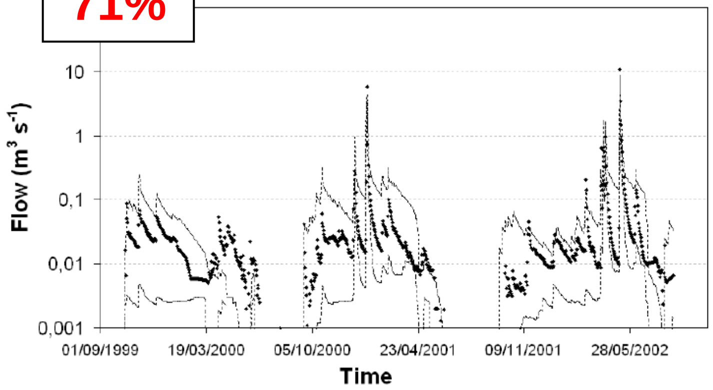


- Global E = 0.3

5% & 95% GLUE bounds for discharge

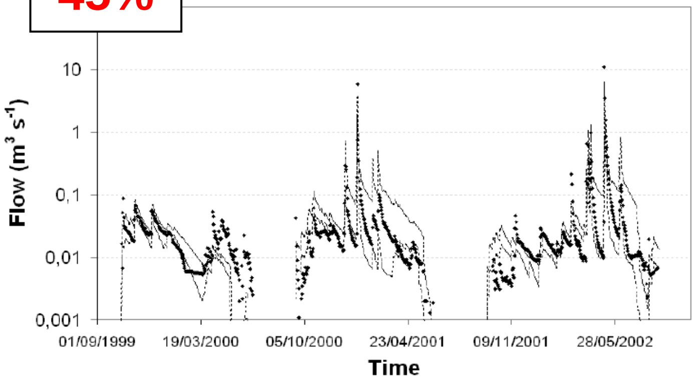
71%

LU4-N model - $E_{tot}(Q)$



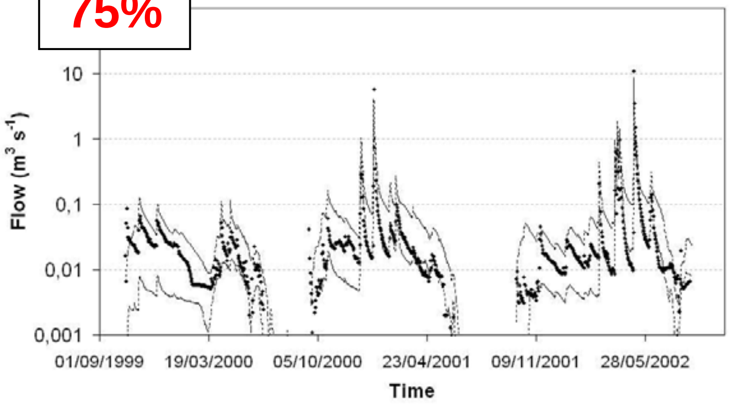
45%

LU4-N model - $E^*_{123}(Q)$



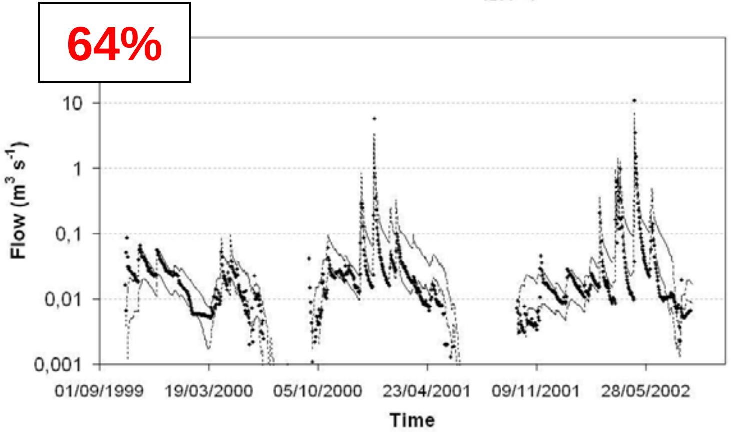
SD4-R-N model - $E_{tot}(Q)$

75%

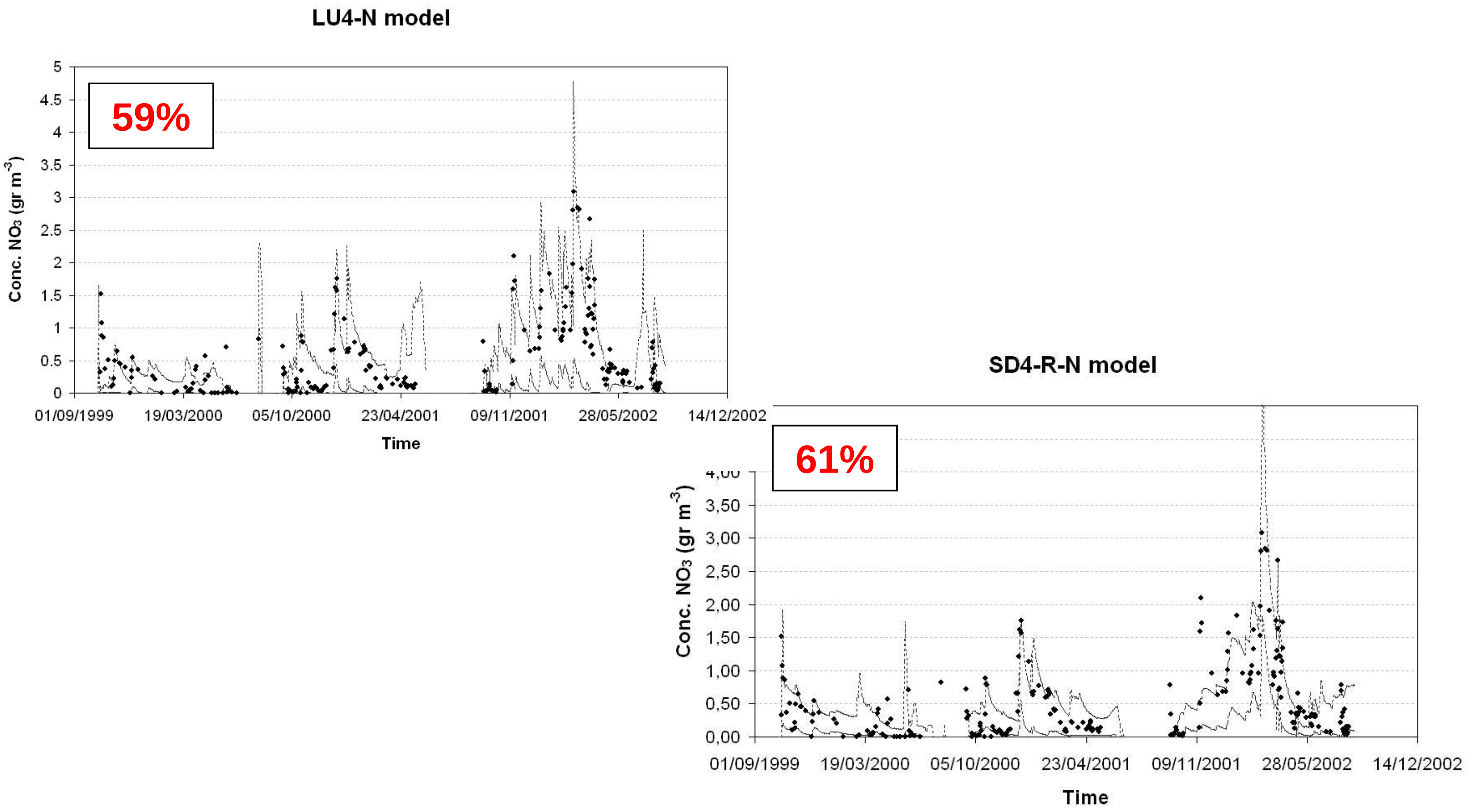


SD4-R-N model - $E^*_{123}(Q)$

64%



5% & 95% GLUE bounds for nitrate



Conclusions

- The results suggested that all the soil nitrogen processes were highly influenced by the rain episodes and that soil microbial processes occurred in ‘pulses’ stimulated by soil moisture increasing after rain.
- The model simulations highlighted the riparian zone as a possible source of nitrate, especially after the summer drought period (inverse flow), but it can also act as an important sink of nitrate due to denitrification, in particular during the wettest period of the year.
  - The riparian zone was indeed a key element to simulate the catchment nitrate behaviour.

Conclusions

- In the riparian zone the mechanism of mineralization-nitrification can be essentially different from the rest of the catchment due to the specific moisture condition and different organic matter that can be found there.
    - Higher mineralization rate in the riparian area than in the rest of the catchment.
    - Nitrification seems to occur more continuously in the riparian soil than in the catchment hillslope,

Conclusions

- Mineralization seems to be highest immediately after the summer drought period, which is relted with the so called ‘Birch effect’ (Birch 1959, 1960, and 1964)
- The results obtained highlighted the nitrification and denitrification processes in the unsaturated weathered granite, below the soil organic horizon, as important processes. In particular, concerning the riparian zone.
- Further work is needed to develop better simulations of ammonium storage and transport in the catchment and the link between organic-N and ammonium.

Conclusions

- For discharge, the number of behavioural outputs decreases with model complexity (which indicates less model degrees of freedom despite the increased number of parameters), but the portion of observed data included within GLUE bounds gets larger, suggesting increasing models ability to reproduce observed data.
- The number of behavioural outputs for nitrate increases with model complexity.
  - In the case of SD4-R-N model, the larger number of behavioural outputs obtained for nitrate can be explained with the improved discharge simulation.

Conclusions

- Nitrate near-optimum parameters sets generally provided acceptable discharge simulations. On the contrary, discharge best parameters sets did not guarantee acceptable nitrate simulations.
- A simultaneous calibration of all the most sensitive models parameters was revealed as the best calibration strategy (as suggested also by McIntyre et al. 2005).

Thank you for your attention!!

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