Instituto de Ingeniería del Agua y Medio Ambiente

UNIVERSIDAD POLITECNICA DE VALENCIA

Progressive development of a hydrologic and inorganic nitrogen conceptual model to improve the understanding of small Mediterranean catchments behaviour

Chiara Medici

WP5 Workshops Aberdeen , 5th April 2011

Research Framework

❑ Mediterranean forested ecosystems

- **Alternate dry and humid conditions** that have great influence on the catchment hydrological response and soil microbial activity (pulse dynamic)
- The **'transfer of results'** from temperate-humid systems generally fails (Bonell, 1993)

❑ Investigative models

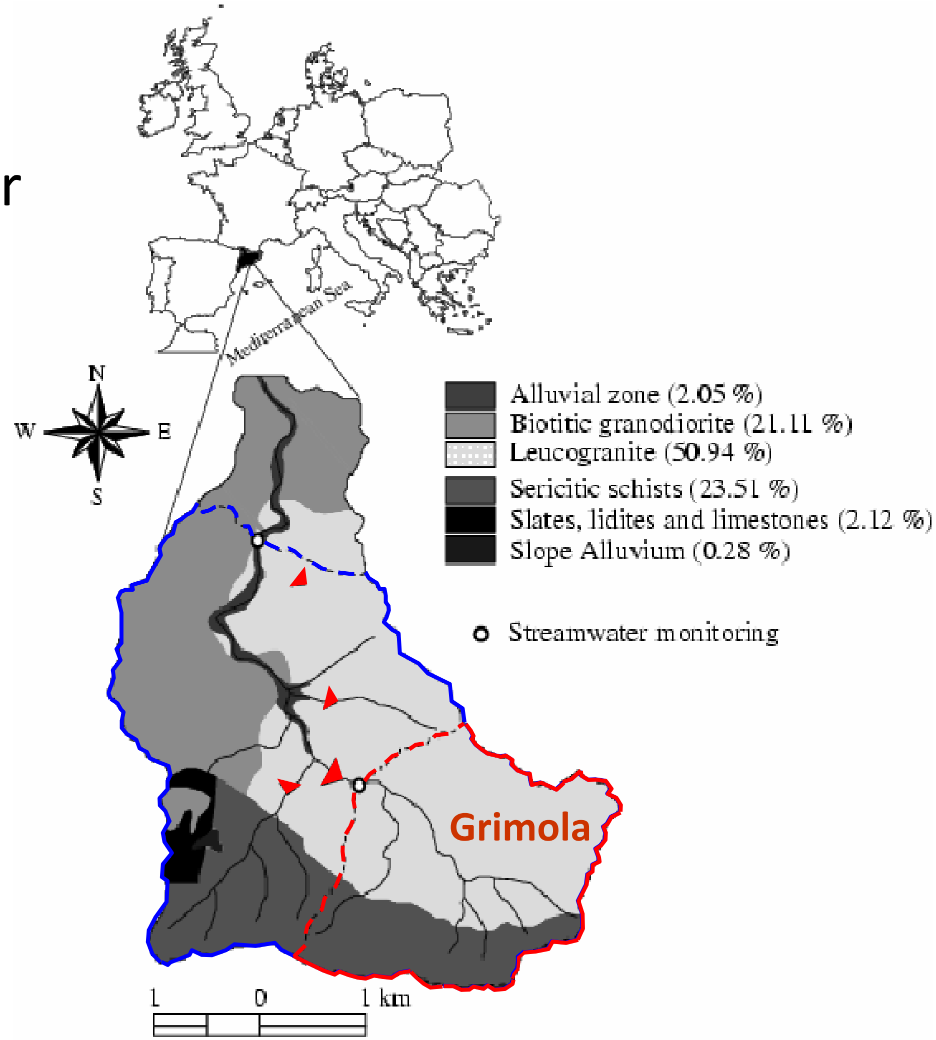
- Model applications are part of a **learning process**
  - About the *models* themselves
  - About the *environmental system*

Research Objective

- ❑ **Improve the understanding of Mediterranean systems**
  - ➢ Identifying the **key** hydrological and biogeochemical **processes**
  - ➢ Quantifying their **relative importance**
  - ➢ Understanding **hydrological and nitrogen interactions** through sensitivity analysis
- ❑ **Progressive perceptual understanding approach** (Piñol et al. 1997; Beven, 2001)
  - ➢ This study was started with a basic model then progressively modified in a thoughtful way to see if the model could be made more consistent with the perception of how the catchment worked
    - Fieldworks
    - Literature

The Fuirosos catchment

- ❑ Catchment area: 13 km^2
- ❑ Tributary of the Tordera river
- ❑ Mediterranean climate:
  - ➢ Mean annual Ppt: 750 mm
  - ➢ Mean annual PET: 975 mm
- ❑ Intermittent stream

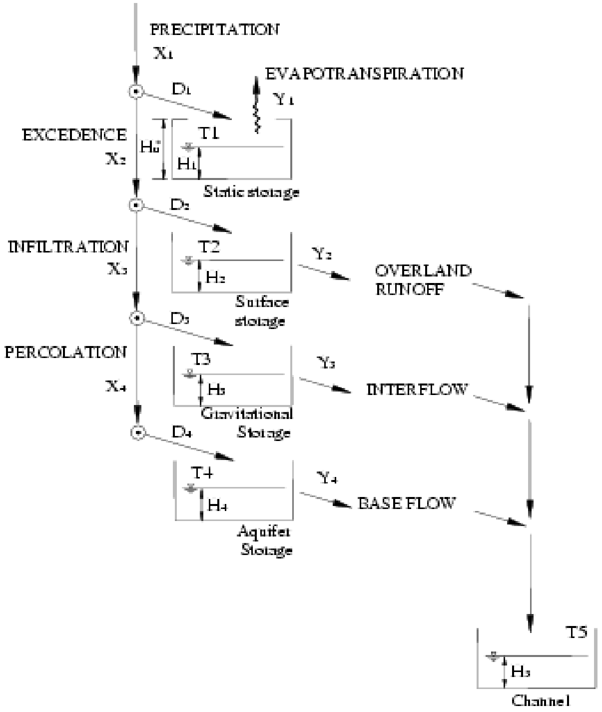


Hydrological modelling

Hydrological model evolution: *lumped*

6 parameters

LU3 model



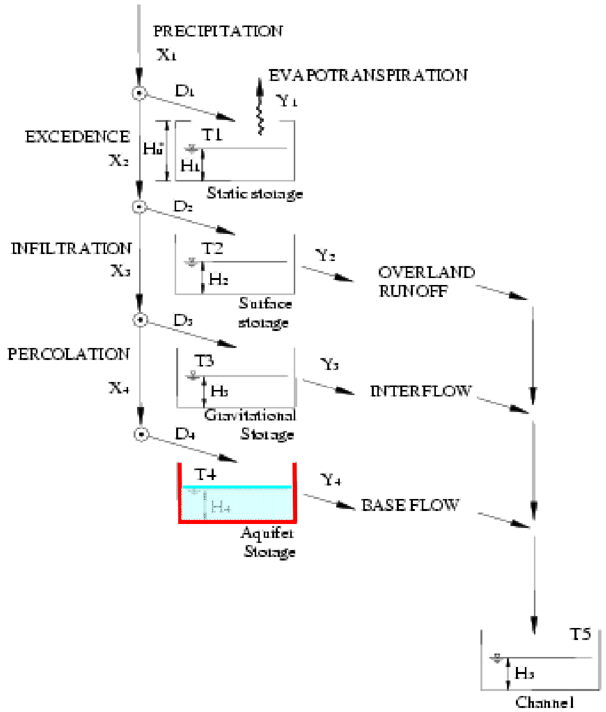
Hydrological model evolution: *lumped*

Threshold mechanism for the recharge to the deeper aquifer

Transpiration from both aquifers

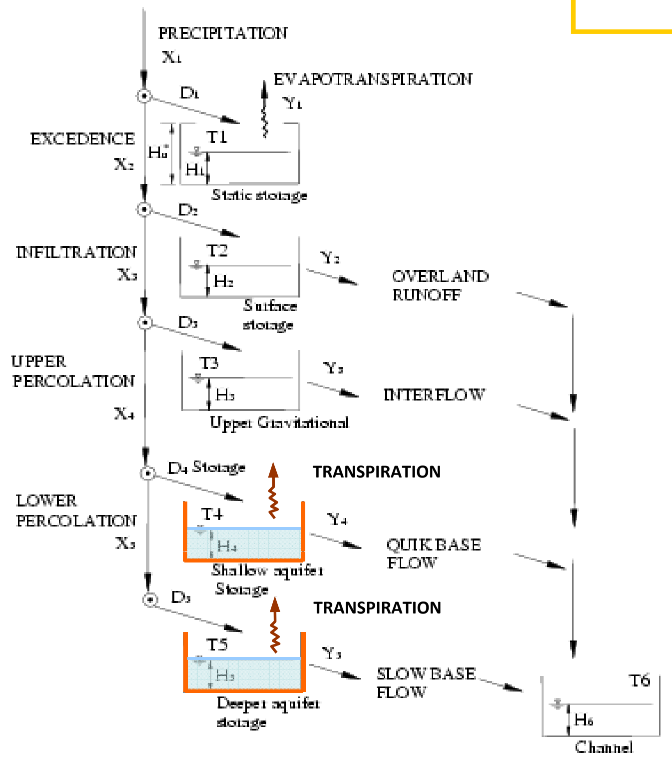
6 parameters

LU3 model



9 parameters

LU4 model



Hydrological model: *semi-distributed*

9 parameters 30 parameters

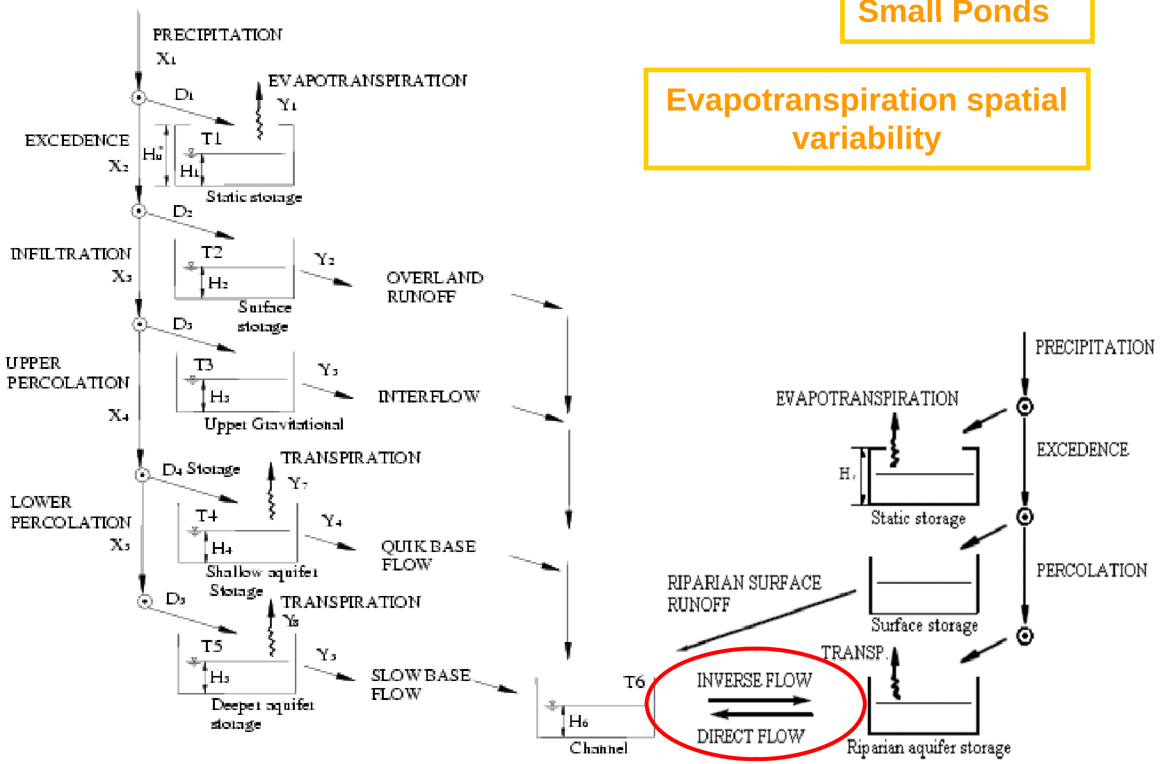
LU4 model

SD4-R model

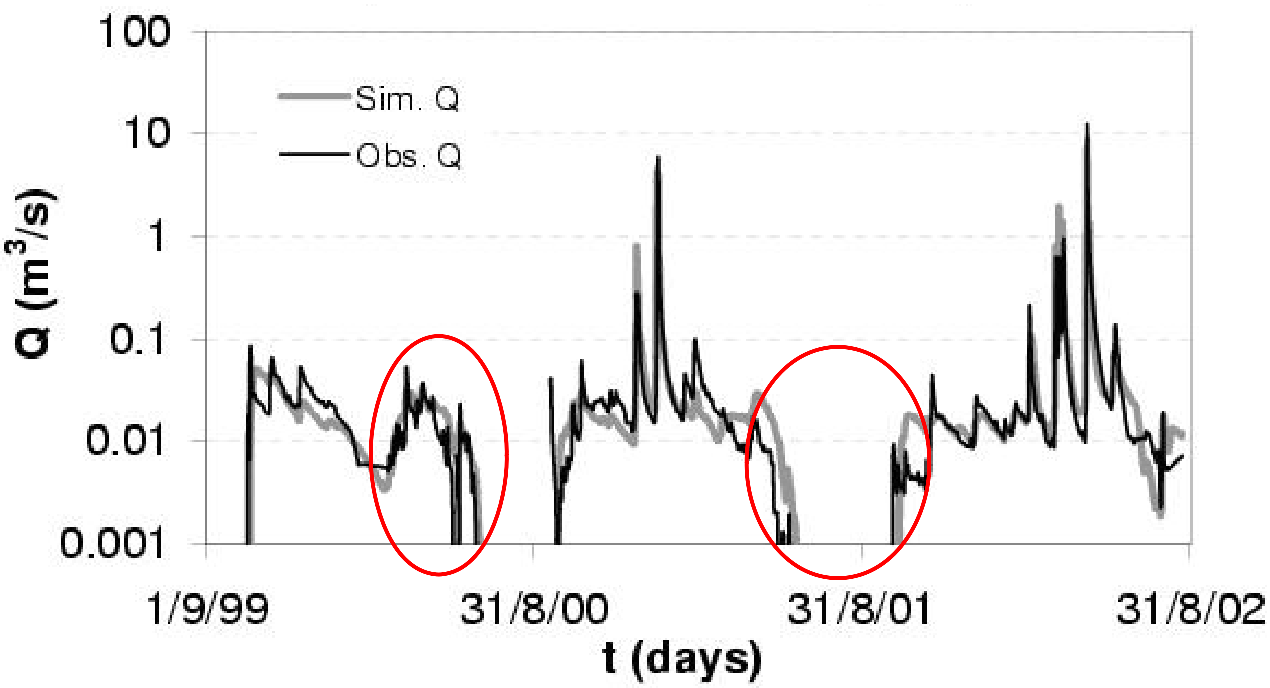
Riparian Zone

Small Ponds

Evapotranspiration spatial variability



SD4-R semi-distributed model



- Nash & Sutcliffe index 0.78
- Volume error -1.0%
- Number of days Q ≤ 0.001 m^3s^{-1} 212 (against 220)
- Max. Sim. discharge peak 8.6 m^3s^{-1} (against 10.9 m^3s^{-1})

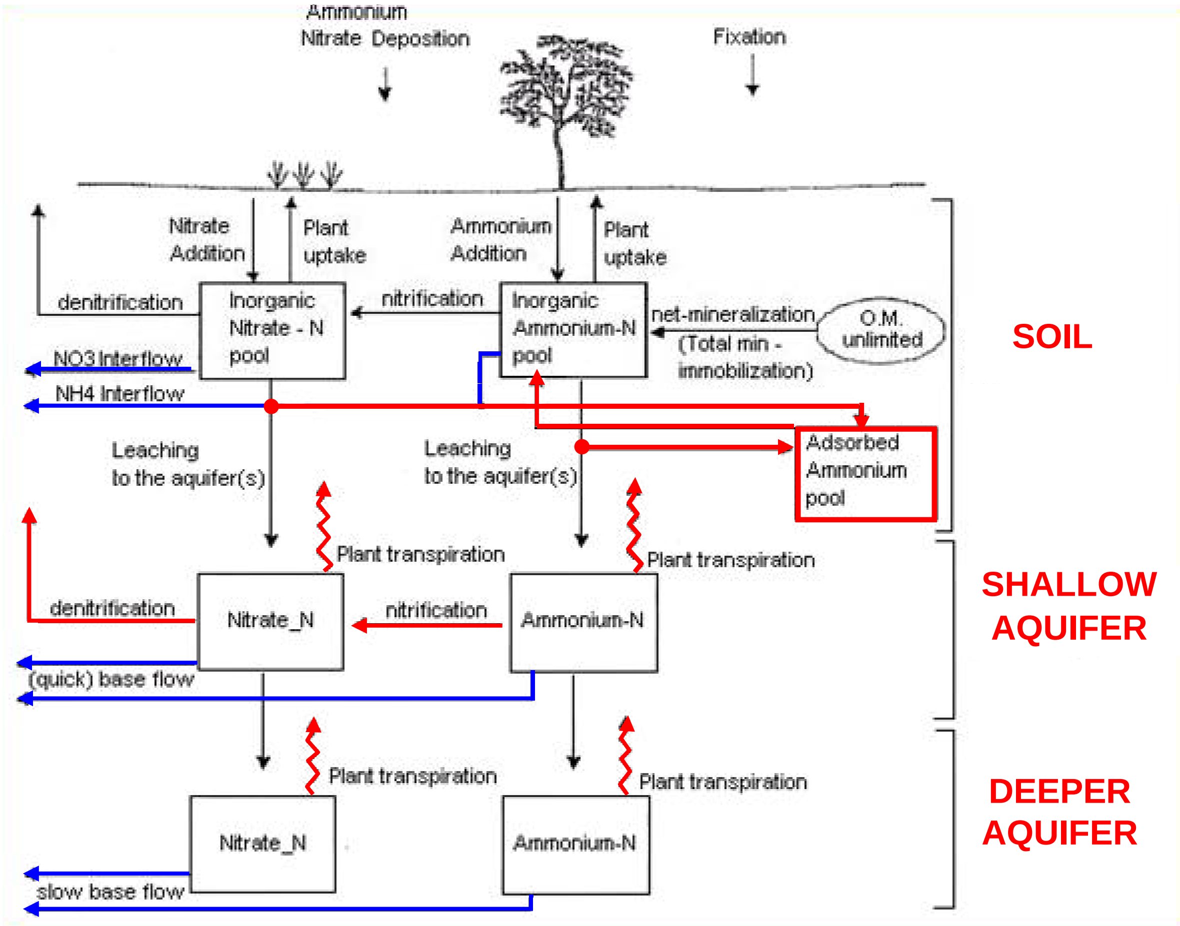
Inorganic nitrogen modelling

Inorganic nitrogen modelling

- In the second part of the work the previous **4-responses models** were **extended** to include processes representing the inorganic nitrogen cycle **to simulate the nitrate and ammonium concentration** observed in the Fuirosos stream

  - The INCA-N model was used as a basis for the equation implemented, but **additional mechanisms** were added to take into account **specific aspects** of this Mediterranean **catchment** (since the INCA-N conceptualization, initially adopted, did not give good results at Fuirosos)

INCA-based Nitrogen cycle

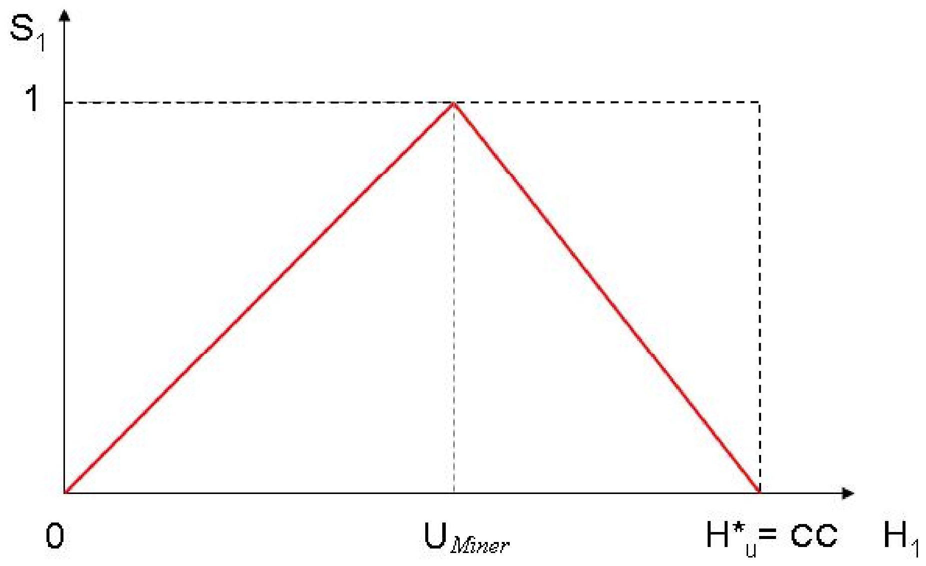


(Modified from Whitehead et al. 1998)

Soil moisture thresholds

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

- Mineralisation:
  - 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 mineralisation (%), expressed as a percentage of H_u^* (mm)

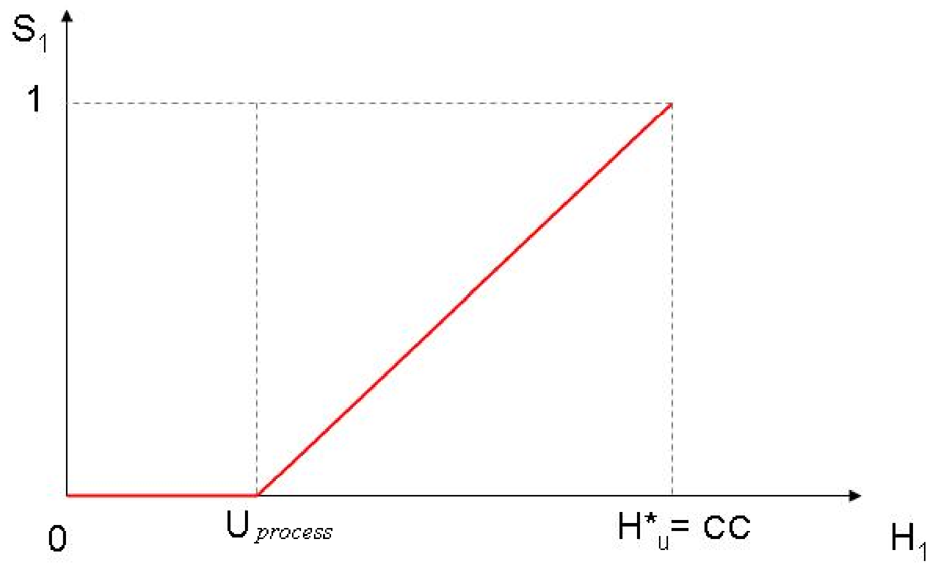


H_1: Soil water content

- This is consistent with Bernal et al., (2003, 2005) and McIntyre et al., (2009)

Soil moisture thresholds

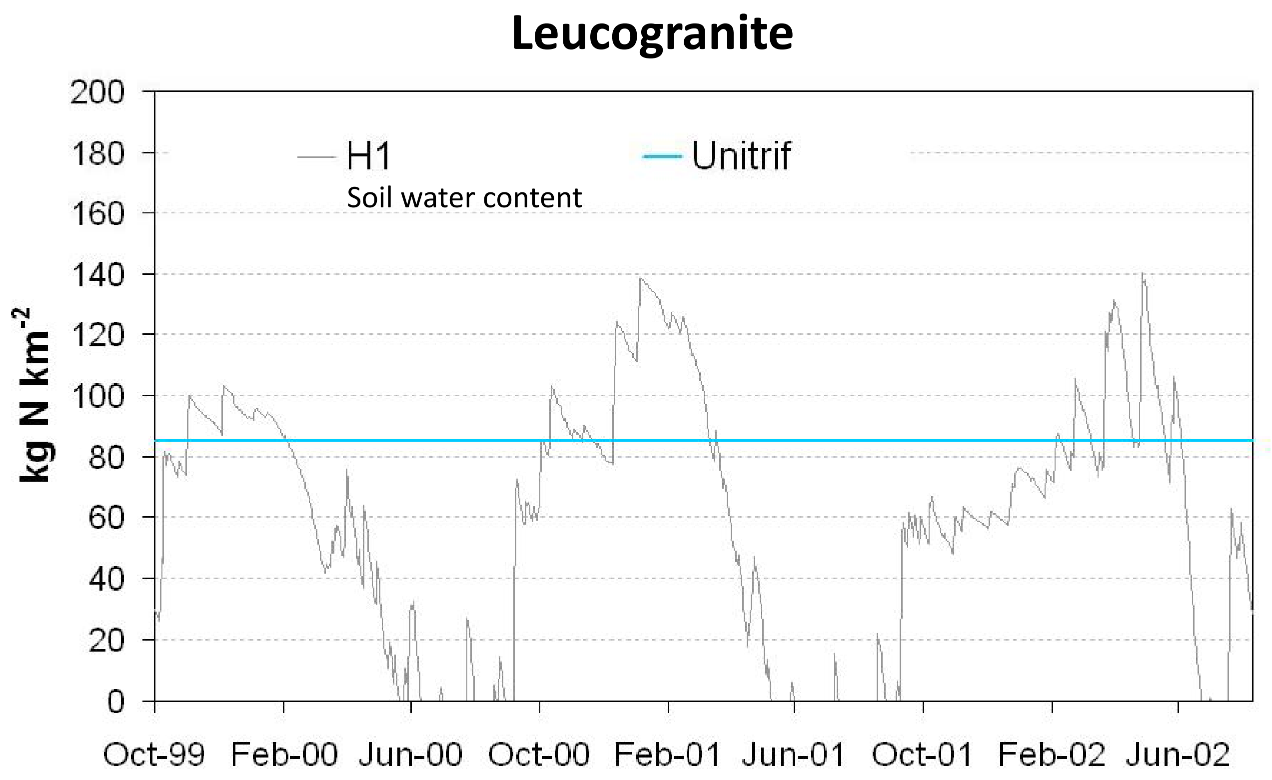
- Other soil processes: a **minimum soil moisture content** is needed for the process to be activated
  - Nitrification
  - Denitrification
  - Immobilization
  - Plant uptake



H_1: Soil water content

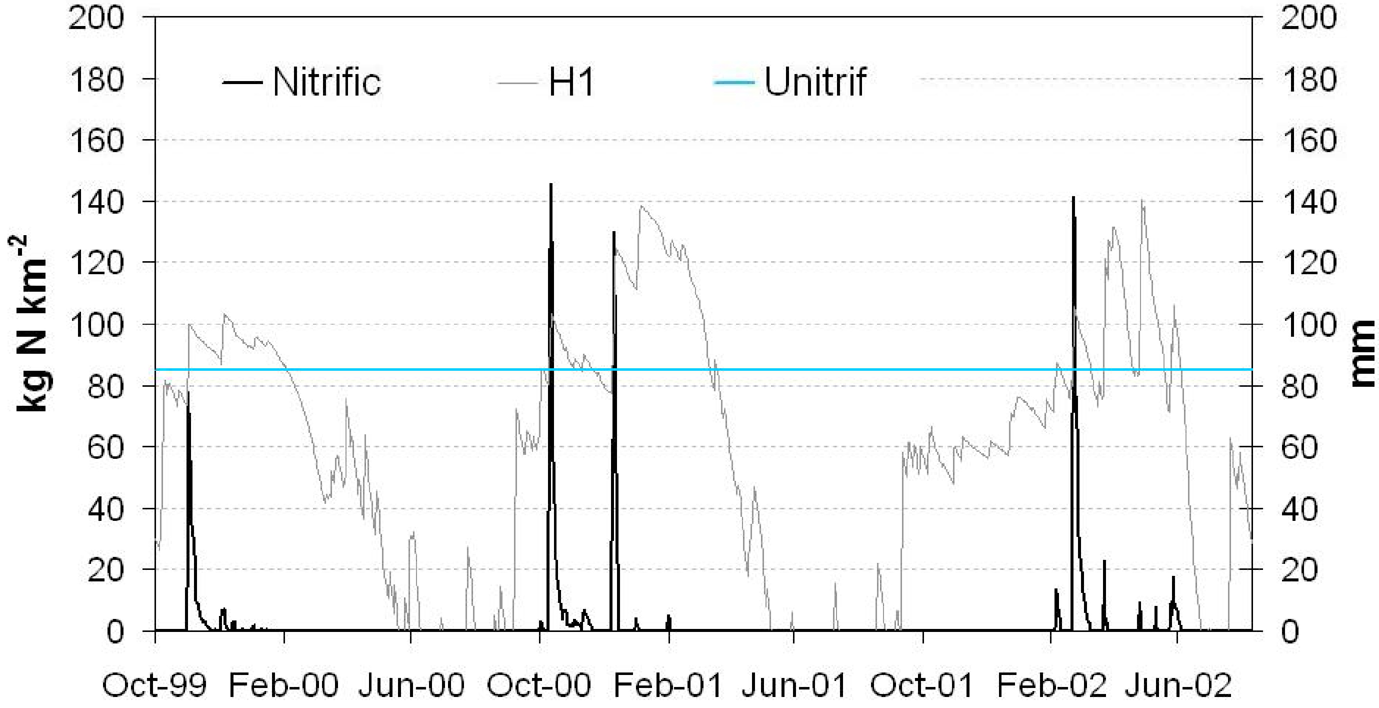
- This is consistent with Mummey et al., (1994) and Schwinning et al., (2004)

Soil moisture simulated effect (SD4-R-N)



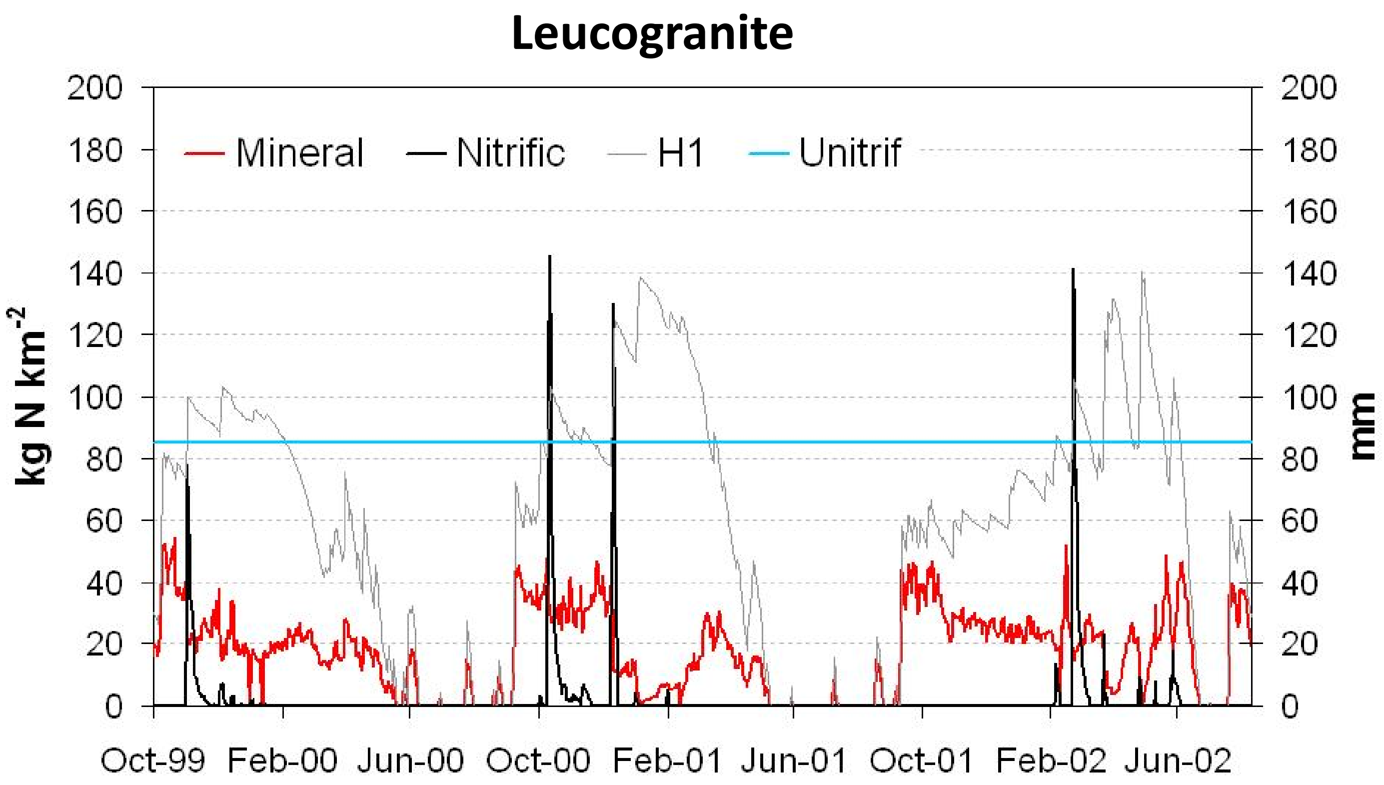
Soil moisture simulated effect (SD4-R-N)

Leucogranite



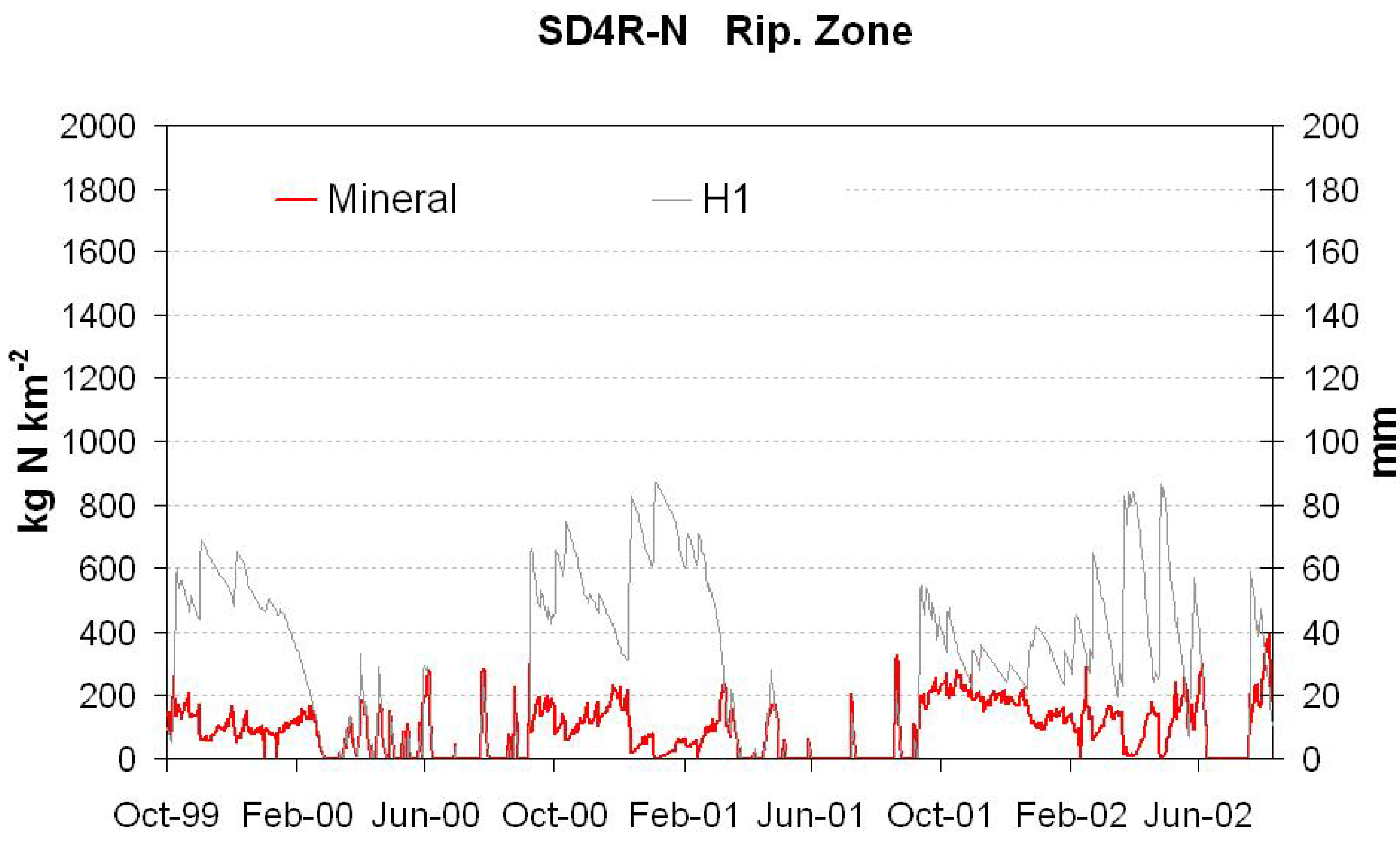
The **nitrification pulse dynamic** reproduced, in terms of average annual loads, a **M**ineralisation:**N**itrification (**M:N)** ratio of **8:1**, which is consistent with 10:1 obtained by Serrasolses et al (1999)

Soil moisture simulated effect (SD4-R-N)



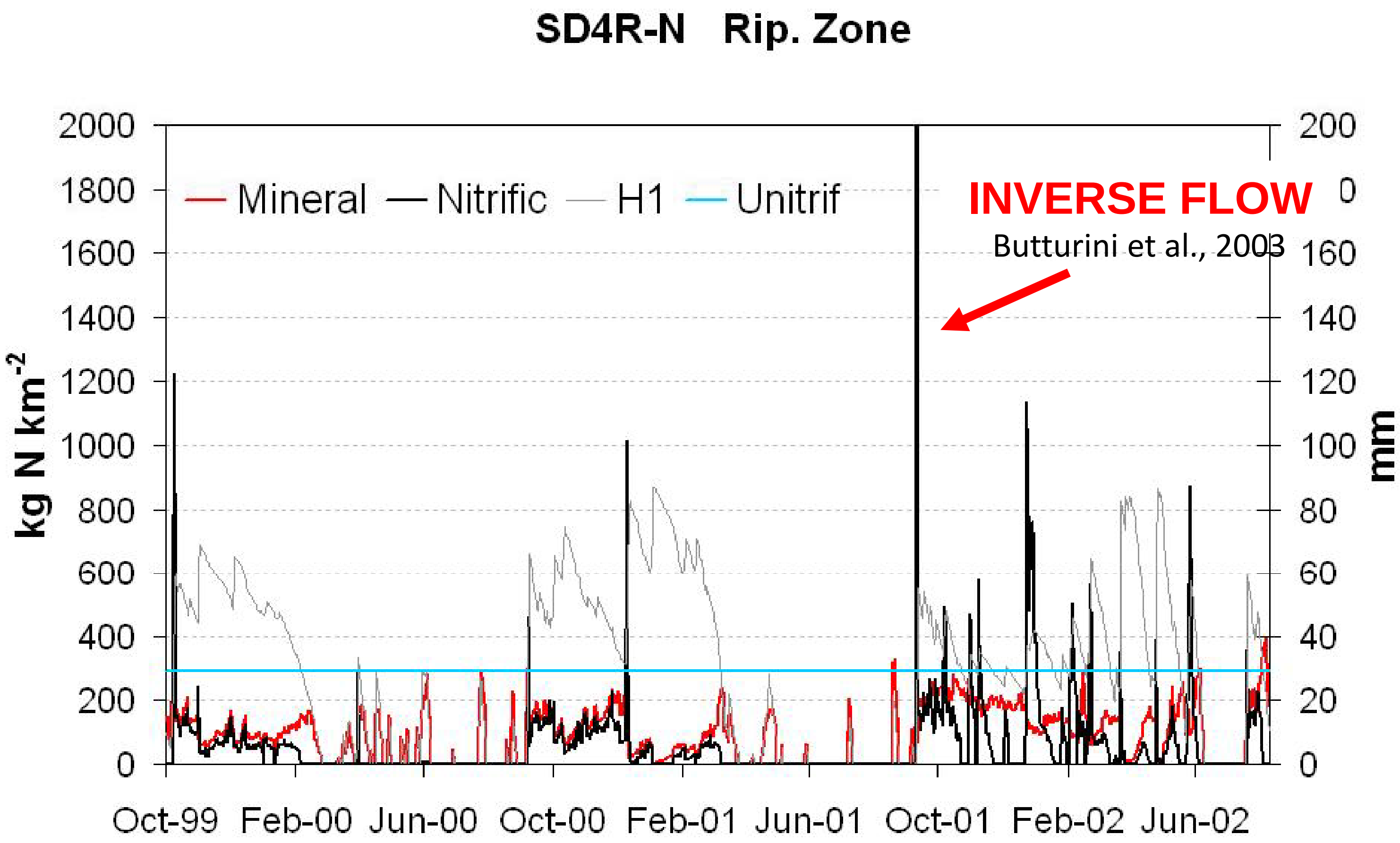
Simulated **mineralisation** is **higher** immediately **after the summer drought period**. This is consistent with McIntyre et al. 2009 that observed higher mineralisation rates under moderate soil moisture conditions

Soil moisture simulated effect (SD4-R-N)



Higher mineralisation rates in the riparian area then in the rest of the catchment

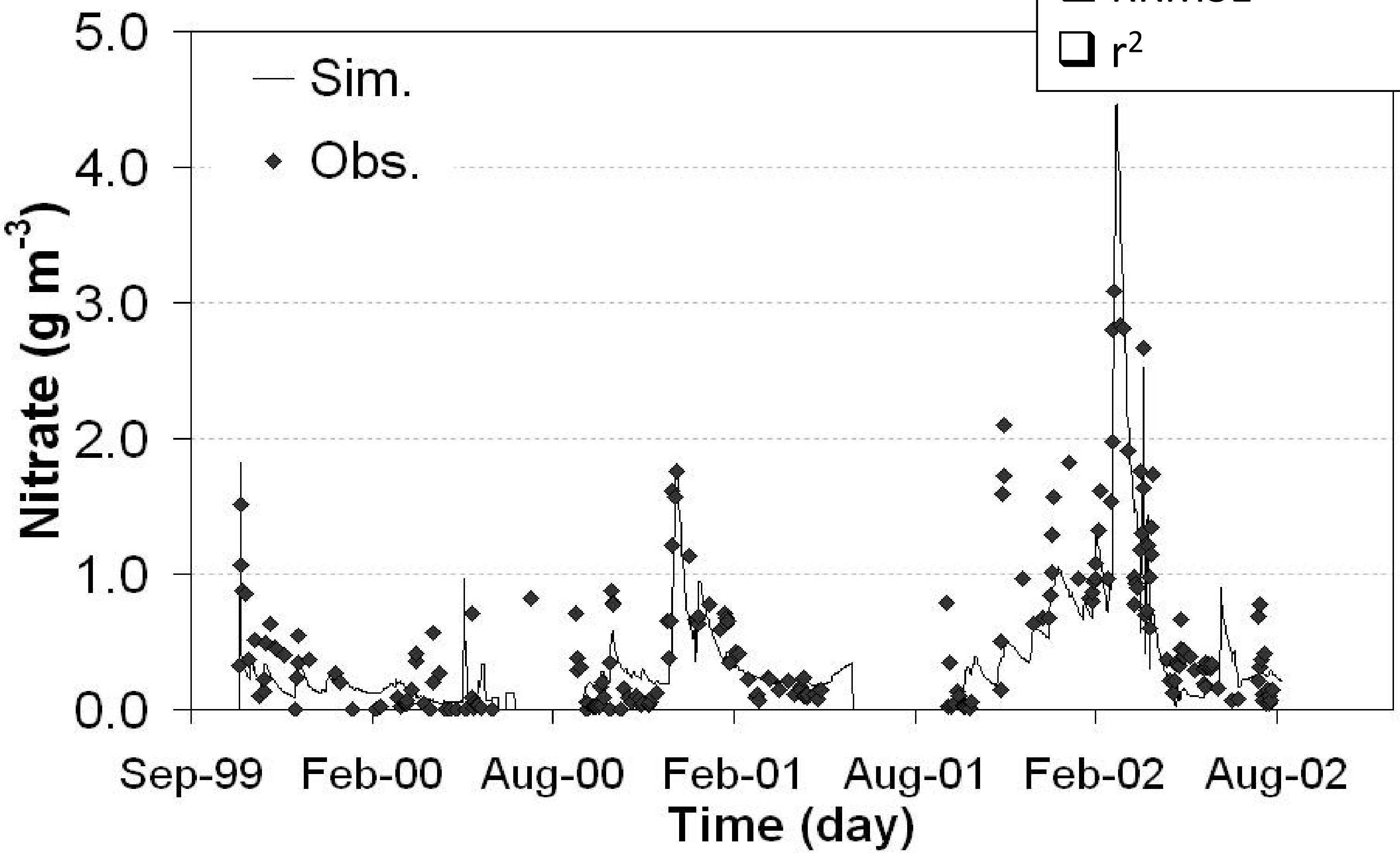
Soil moisture simulated effect (SD4-R-N)



Nitrification follows much more closely the pattern of mineralisation

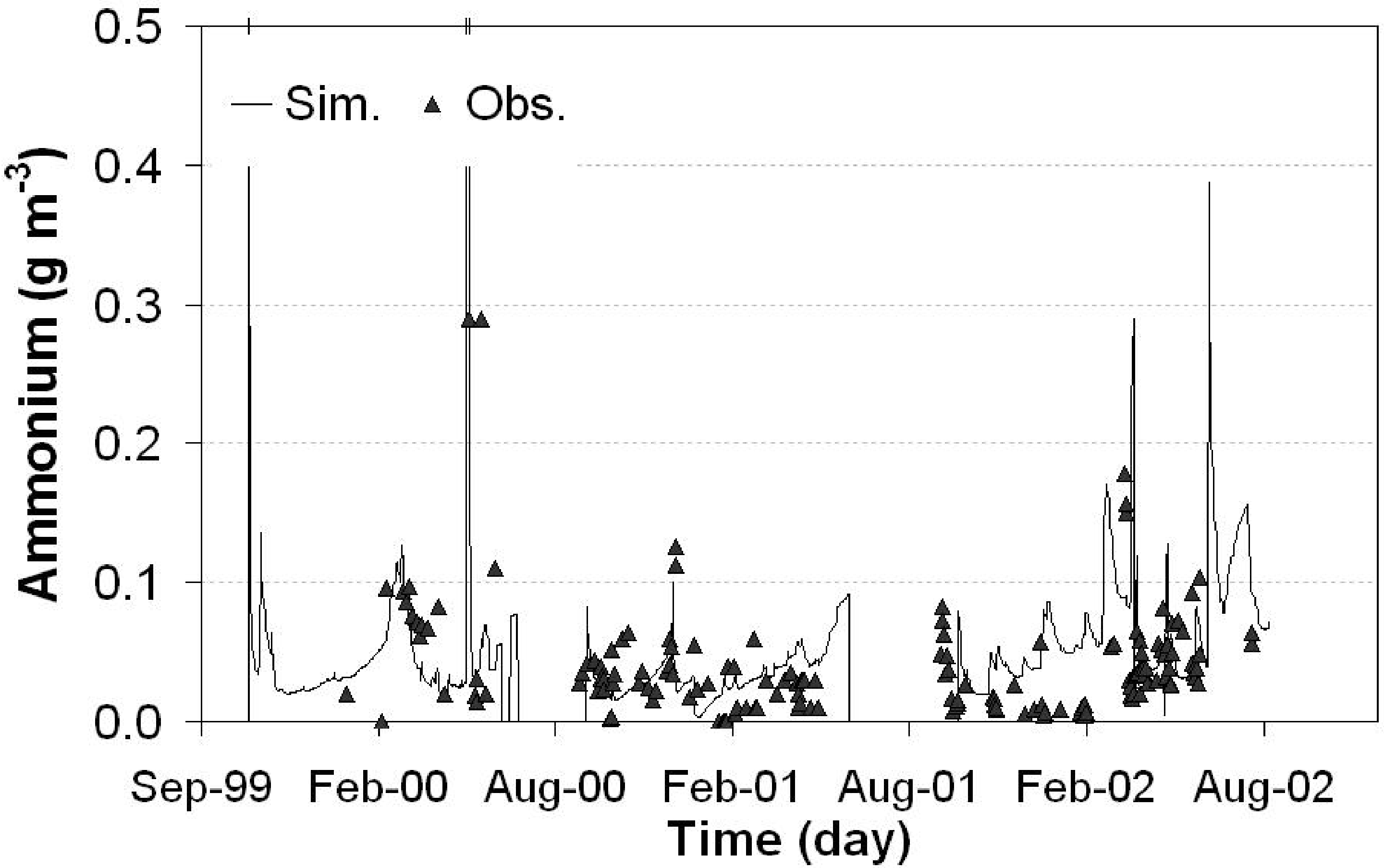
SD4-R-N model nitrate calibration results

❑ Nash	0.68
❑ RRMSE	0.43
❑ r^2	0.69



Ammonium calibration results

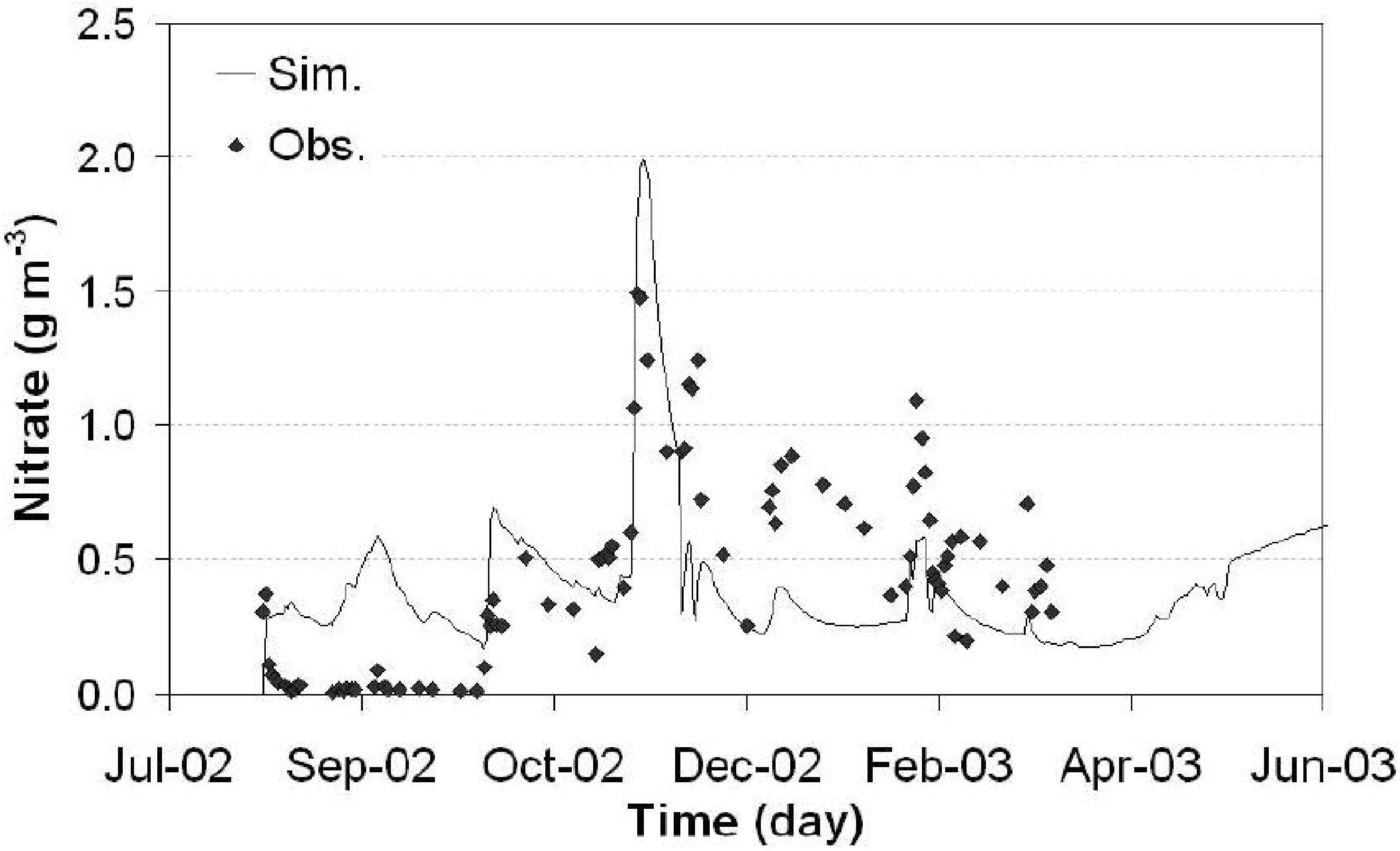
r = 0.23



r = Pearson correlation coeff.

Temporal validation for nitrate

Nash = 0.3



General Sensitivity Analysis

General Sensitivity Analysis

- To assess these issues a **General Sensitivity Analysis**, GSA (Hornberger and Spear, 1980) and the **Generalized Likelihood Uncertainty Estimation** methodology, GLUE (Beven and Binley, 1992), were applied to the three catchment scale nitrogen models of varying complexity developed in this work.
  - based on **100,000 Monte Carlo** (MC) simulations
  - The idea is to **randomly select** the model **parameters** from **uniform probability distributions** spanning specified ranges of each parameter to obtain a **sample of model simulations** from throughout the feasible parameter space

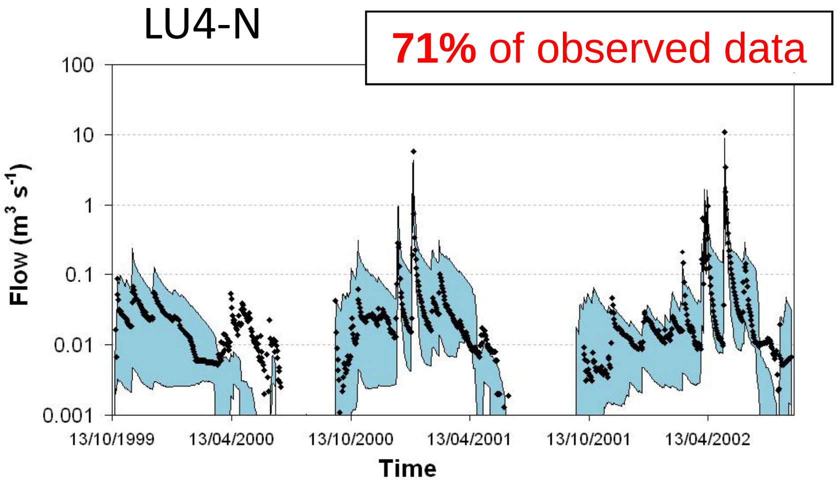
Objective functions adopted

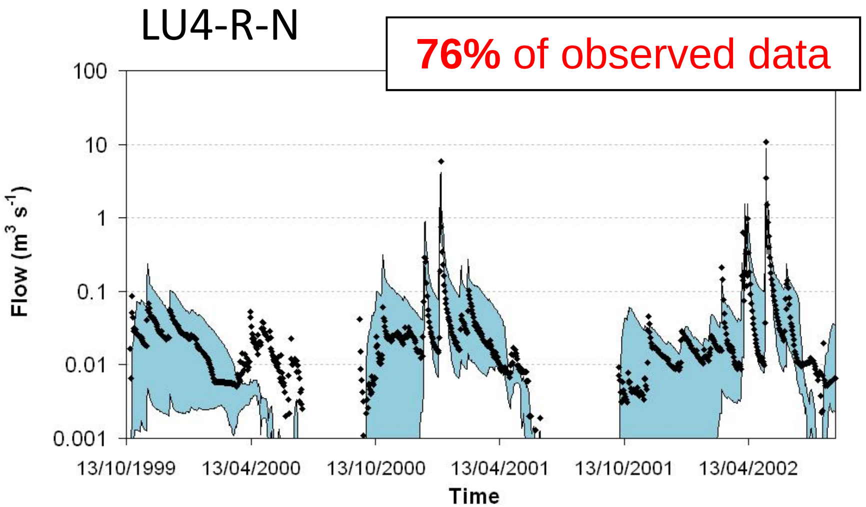
- Nash and Sutcliffe efficiency index (**E**)
  - $\mathbf{E_{TOT}}$ → efficiency index for the 3-year calibration period (1999 - 2002)
  - $\mathbf{E_{1yr}}$, $\mathbf{E_{2yr}}$ and $\mathbf{E_{3yr}}$ → efficiency indexes for each year individually
  - $\mathbf{E_{123}} = E_{1yr} + E_{2yr} + E_{3yr}$ (multi-objective approach)
- Relative Root Mean Squared Error (**RRMSE**), as defined by Franchello et al., (2004).

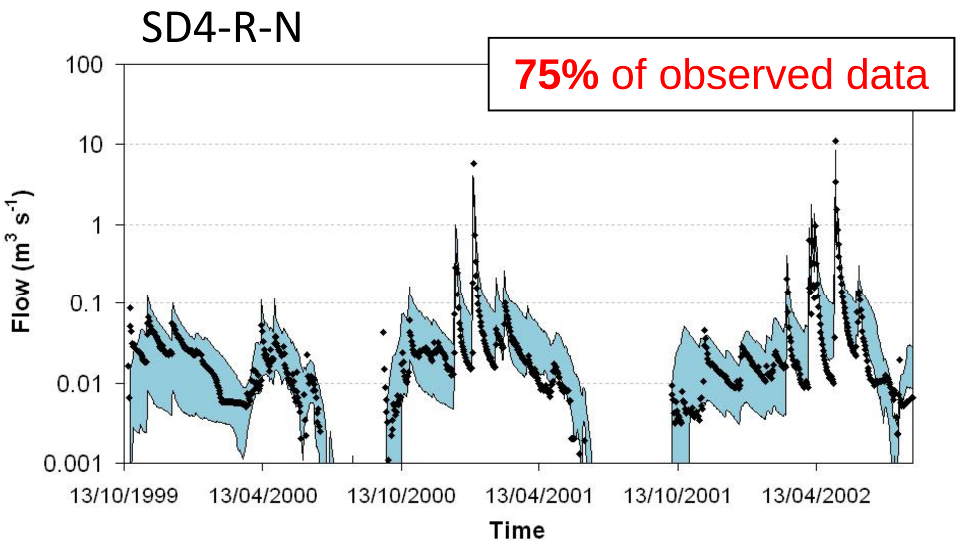
Behavioural runs

	LU4-N	LU4-R-N	SD4-R-N
Discharge			
RRMSE	39,557	32,298	5,034
E_{tot}	22,639	15,784	2,805
E^{*}_{123}	14,283	8,301	3,084
Nitrate			
RRMSE	21	1,534	3,000
Discharge & Nitrate	----	59	127

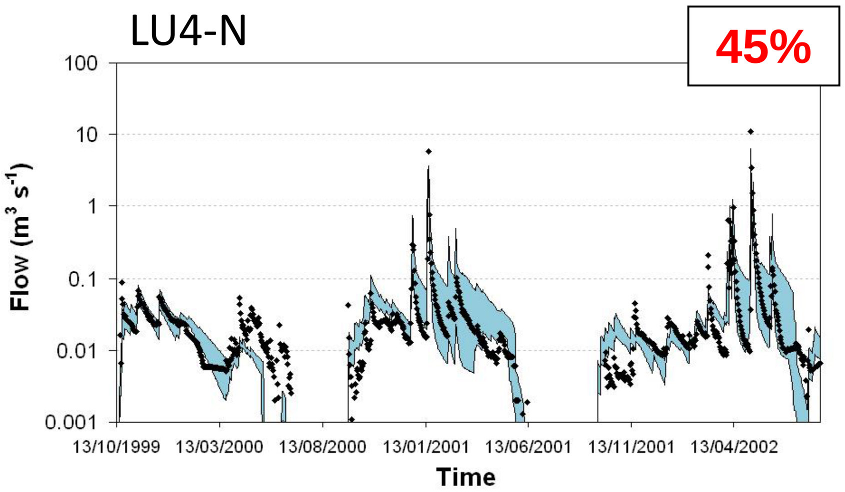
Discharge – 5% and 95% GLUE bounds (E_{tot})

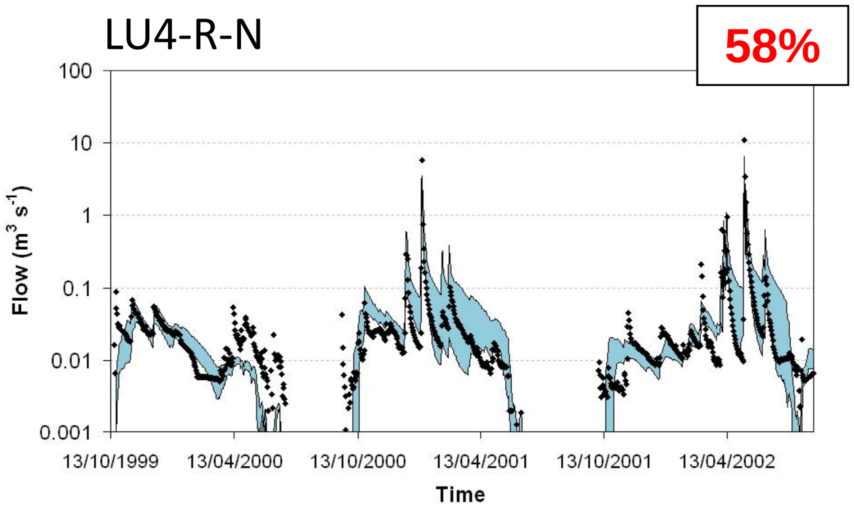


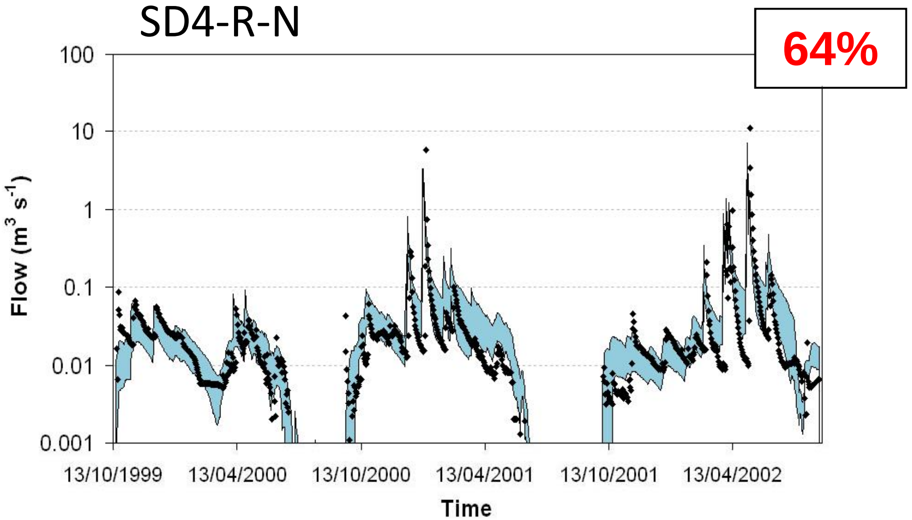




Discharge – 5% and 95% GLUE bounds (E^*_{123})



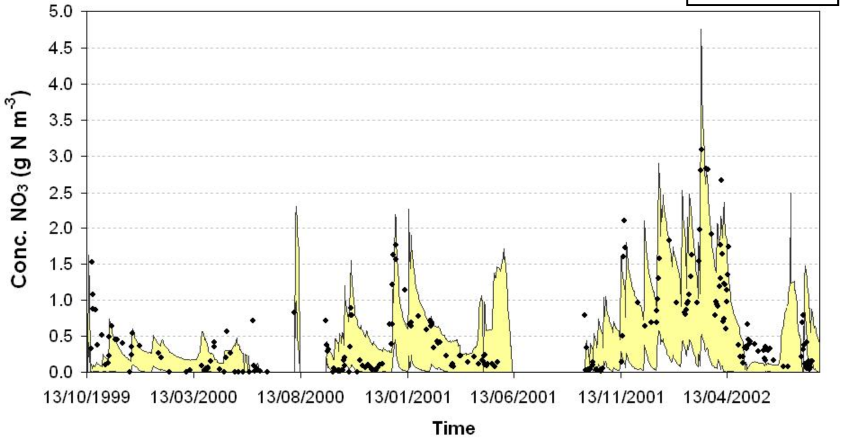




Nitrate – 5% and 95% GLUE bounds

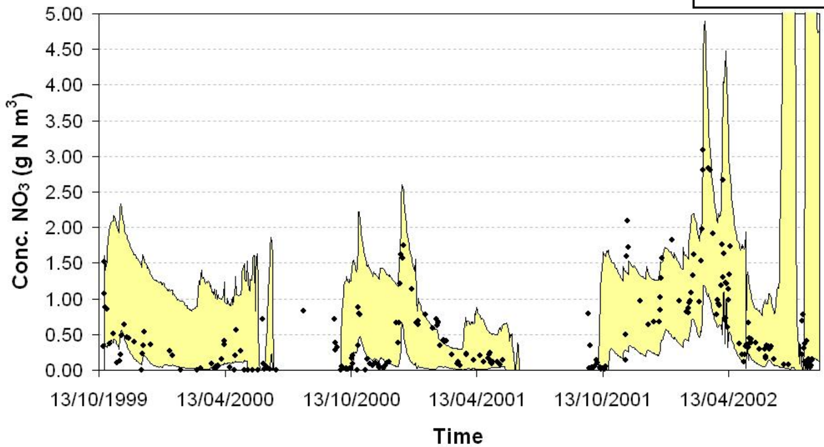
LU4-N model

59%



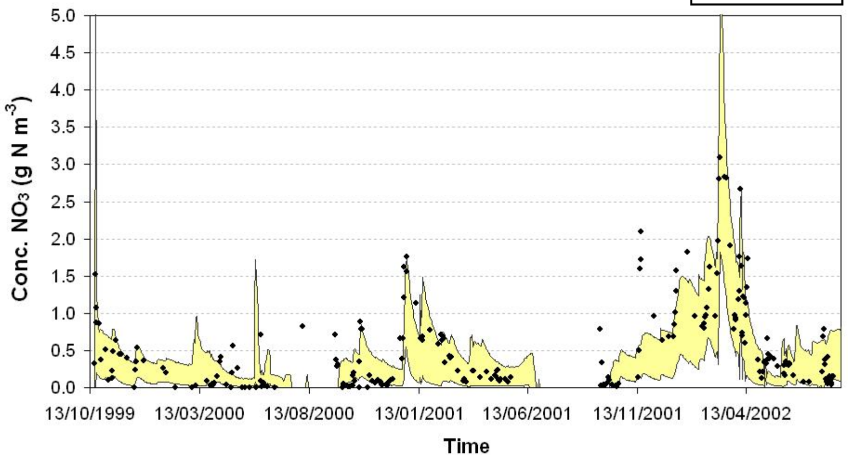
LU4-R-N model

68%

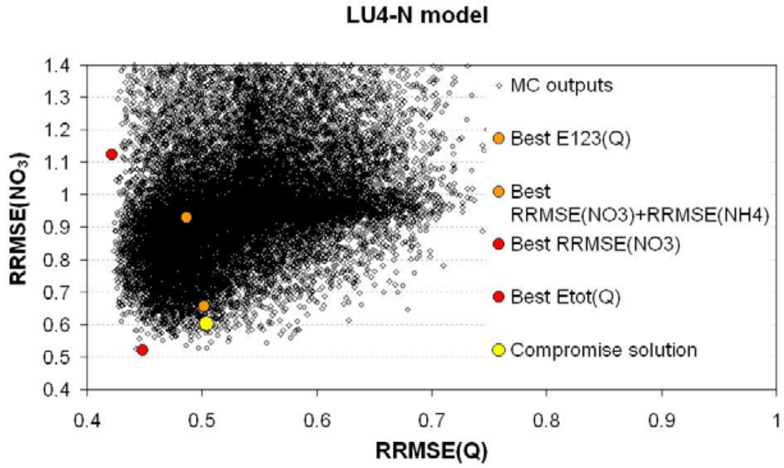


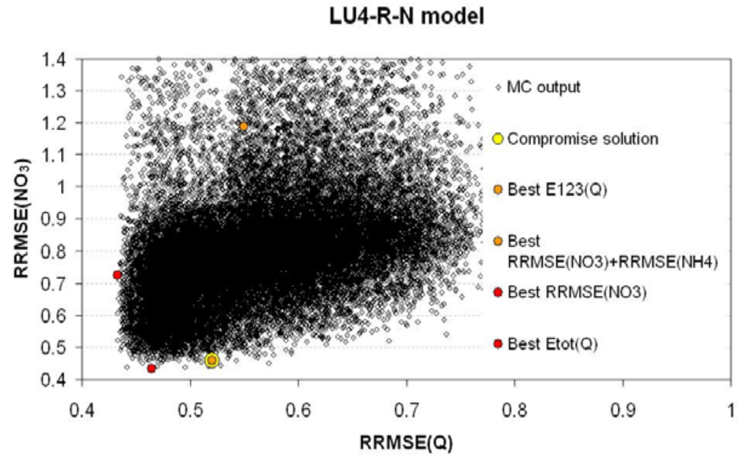
SD4-R-N model

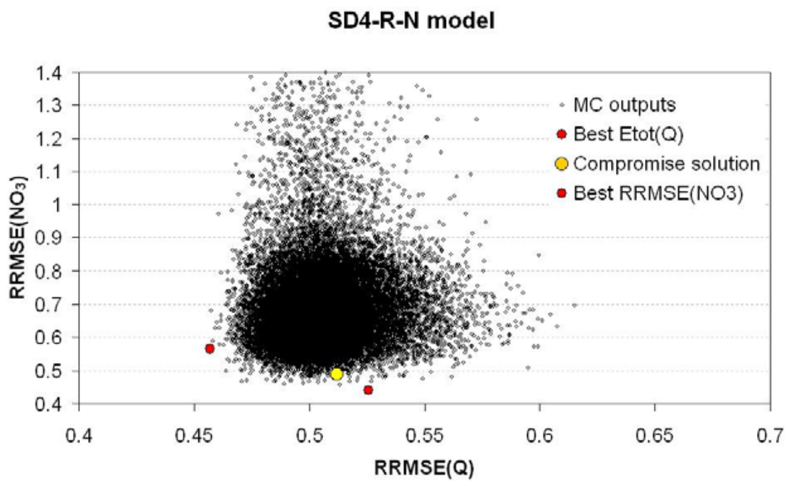
64%



RRMSE(NO_3) & RRMSE(Q)







Conclusions (Hydrology)

- ❑ The hydrological modelling led to a perceptual model that involves **four different hydrological responses**: overland flow; interflow; quick base flow and slow base flow

- ❑ The results obtained suggested that **water flow paths** were essentially **different during wet and dry conditions**

- ❑ Also highlighted the importance of considering the **spatial variability** for the **evapotranspiration process**, since in Mediterranean ecosystems it is generally one of the most important factors of catchments water balance

Conclusions (Hydrology)

- Several mechanisms were taken into account to explain the catchment non linear behaviour:
  - The permanent saturated zone '**switching behaviour**'
  - Water from the **permanent saturated zone** is lost by **transpiration** rather than lateral flow
  - The formation of a **perched water table** at the interface between the soil and the upper part of the weathered bedrock layer
  - The **non-linear recharge to the permanent saturated zone** that can occur only when the catchment recovers a **certain saturation degree**
  - **Riparian pumping** effect: the **riparian zone vegetation** may induce a **reverse flux** from the stream to the riparian zone

Conclusions (Inorganic Nitrogen)

- The results suggested that soil nitrogen processes were highly influenced by the **rain episodes** and that **soil microbial processes** occurred in '**pulses**' stimulated by soil moisture after rain

- The **riparian zone** was highlighted as a **key element** to simulate catchment nitrate behaviour:
  - It can act as a source as well as a sink for nitrate
  - The mineralisation/nitrification mechanism is essentially different from the rest of the catchment

Conclusions (Inorganic Nitrogen)

- The models reproduce **higher mineralisation** rates **after the summer drought** period which can be related with the well known '**Birch effect**' (Birch, 1959, 1960 and 1964)

- The results highlighted the **nitrification and denitrification** in the **unsaturated weathered granite**, below the soil organic horizon, **as important processes** as suggested by Legout et al., 2005

- Further work is needed to improve the simulation of stream ammonium concentration

Conclusions (GSA and GLUE)

- For the **discharge**, the number of **behavioural runs decreases with model complexity** and the **GLUE bands get narrower tending to include a higher percentage of observed data**.
  - Additional model constrains to observed data.
  - Less model sensitivity to parameter variations, hence increased model robustness
- For **nitrate**, the number of **behavioural runs increases with model complexity**, while the **GLUE bands get narrower**
  - For the **SD4-R-N model**, it has been attributed to a **better hydrological simulation**

Conclusions (GSA and GLUE)

- ❑ The best parameter sets for nitrate, generally provided acceptable simulations for the discharge
  - ➢ A **simultaneous calibration strategy** represented the best solution for this study case, as found by McIntyre (2005)
- ❑ Multiple-response calibration of these conceptual models reduces the level of uncertainty
- ❑Not only the N simulation but also the simulation of water discharge become more reliable when using several sets of data for the calibration
  - ➢ Multiple-response calibration forces the hydrological parameters to a **new optimum**, which results in a better description of the internal model variables hence to reduce the **equifinality problem** through a better understanding of the system

Thank you for your attention!

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