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Does increased hydrochemical model complexity decrease robustness?

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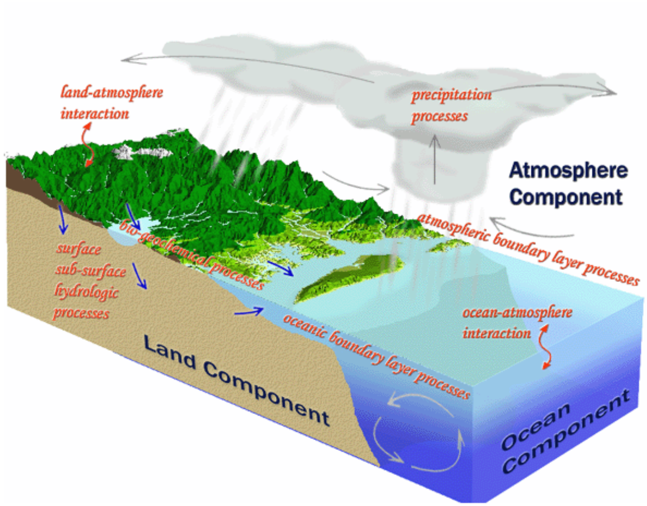
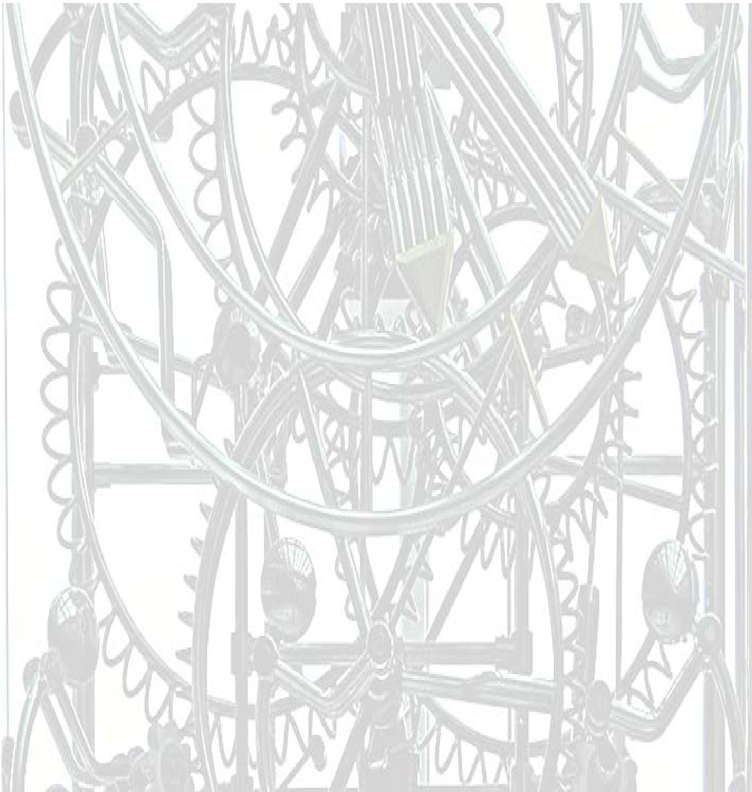
CATCHMENT CHANGE NETWORK

INTRODUCTION:



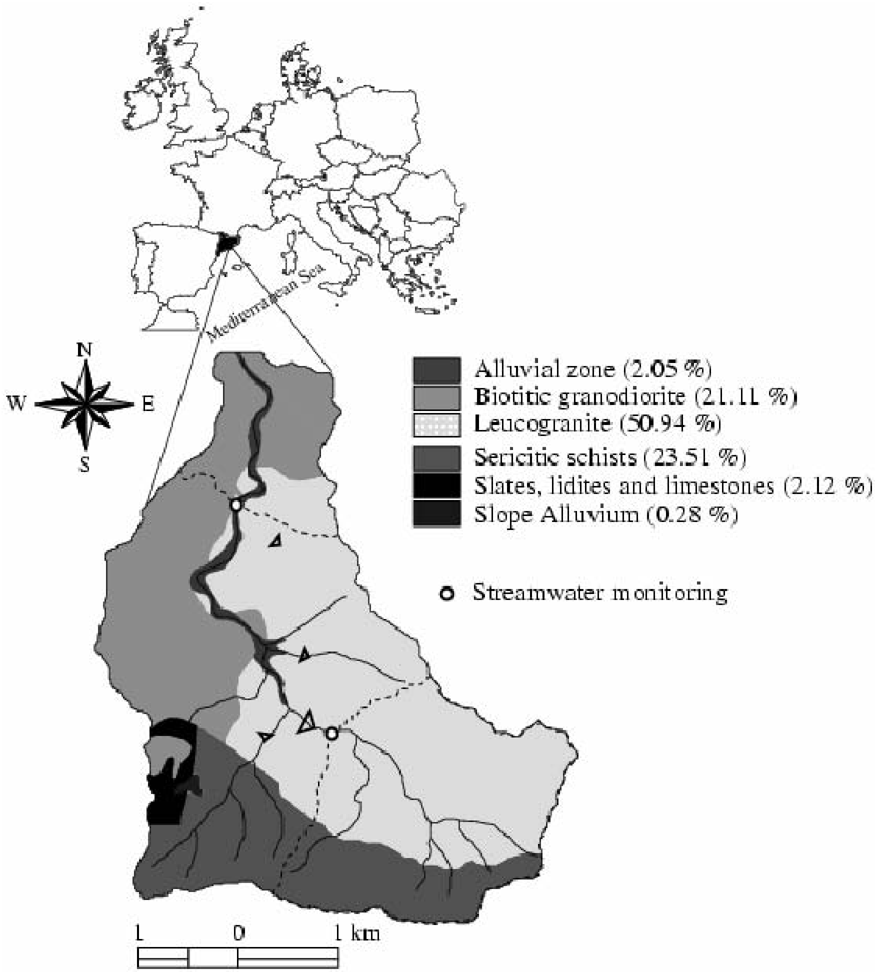
- **Integrated understanding** of catchment : DIFFICULT!
- **Model applications:** EXPLORE POSSIBLE EXPLANATIONS for the observed behaviour
- **Equifinality**: many equally good fits to data
- **Realistic representation** of real-world thresholds and non-linearities: COMPLEX MATHEMATICAL MODELS

OBJECTIVE:



To determine if additional model *complexity gives better capability* to model the hydrology and nitrogen dynamics of a small Mediterranean catchment

STUDY CASE:



Fuirosos catchment

(Catalonia)

- 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

RESEARCH QUESTIONS:

1. Are the additional mechanisms/parameters progressively introduced *influential* on the result?

2. Does additional model complexity give more acceptable model *behaviours* or lead to *over-parameterisation*?

3. Which is the *most appropriate* model for the study case considered?

METHODOLOGY:

- General Sensitivity Analysis – *GSA* (Hornberger and Spear, 1980)
- Generalised Likelihood Uncertainty Estimation – *GLUE* (Beven and Binley, 1992)
- Monte Carlo technique: random sampling of 100,000 parameter sets from uniform distribution

METHODOLOGY:

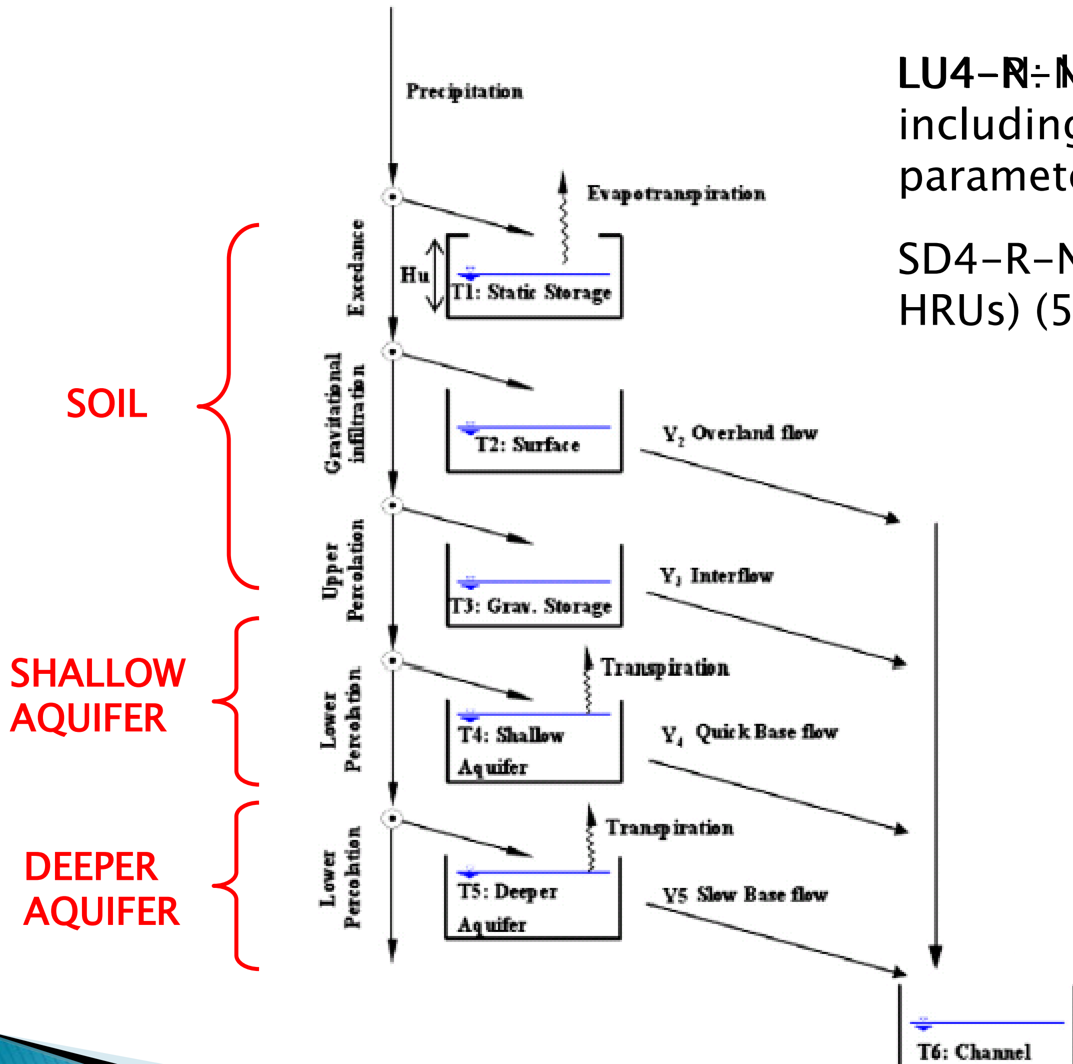
- **Objective functions:**
  - *Nash and Sutcliffe* efficiency index (E)

$$E = 1 - \frac{\sum_1^n (X_{sim} - X_{obs})^2}{\sum_1^n (X_{obs} - \overline{X}_{obs})^2}$$

    - $E_{tot}(Q)$: 1999-2002
    - $E_1(Q)$:1999-2000; $E_2(Q)$:2000-2001; $E_3(Q)$:2001-2002
    - $E_{123}(Q) = E_1(Q) + E_2(Q) + E_3(Q)$
  - *Relative Root Mean Squared Error* (RRMSE)

$$\mathrm{RRMSE} = \sqrt{\frac{\sum_1^n (X_{sim} - X_{obs})^2}{\sum_1^n X_{obs}^2}}$$

HYDROLOGICAL MODELS:

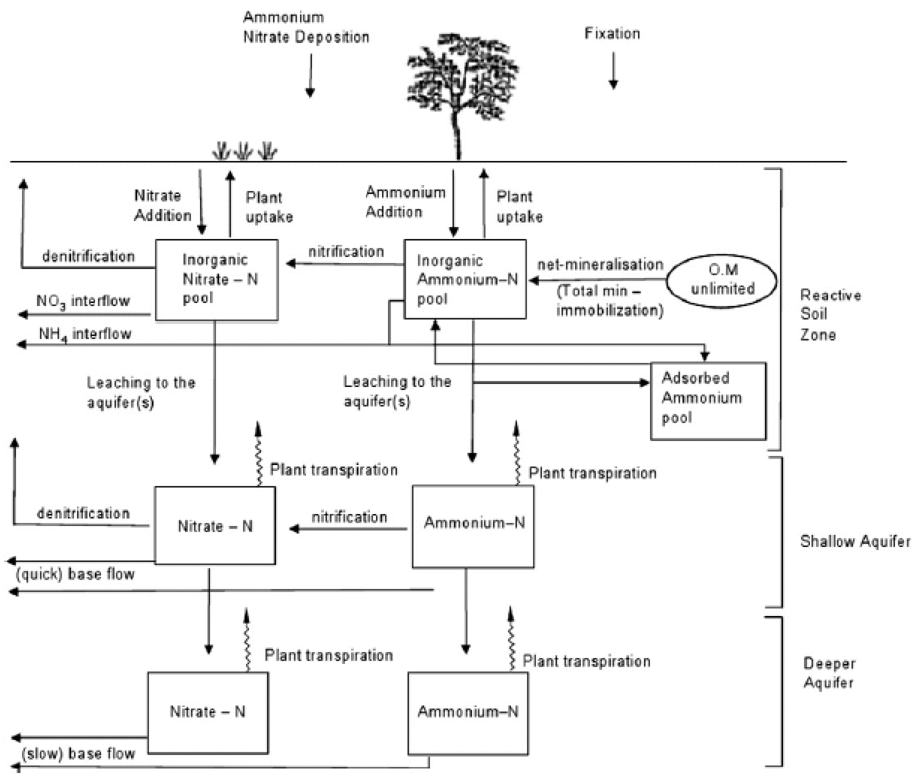


LU4-N: lumped model (27 parameters)

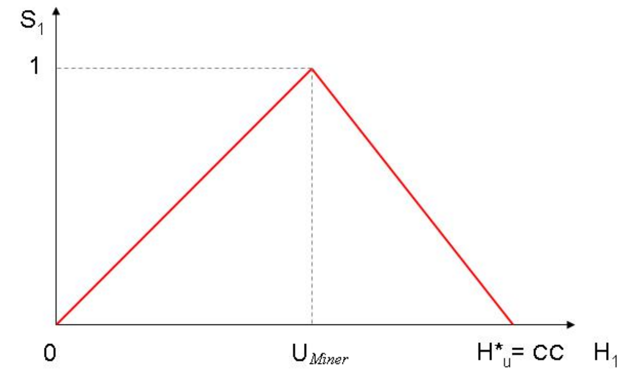
LU4-R-N: semidistributed model including the riparian zone (2 HRUs) (41 parameters)

SD4-R-N: semidistributed model (4 HRUs) (59 parameters)

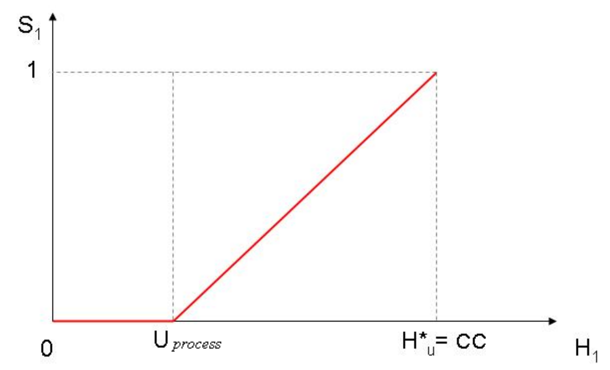
NITROGEN MODEL:



Mineralisation soil moisture thresholds



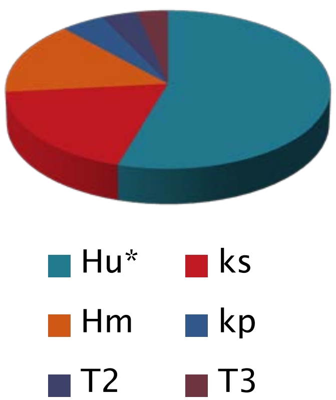
Rest of processes soil moisture thresholds



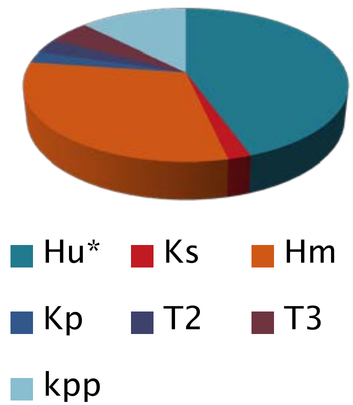
RESULTS: Discharge

LU4-N model

$E_{tot}(Q) \geq 0.77$

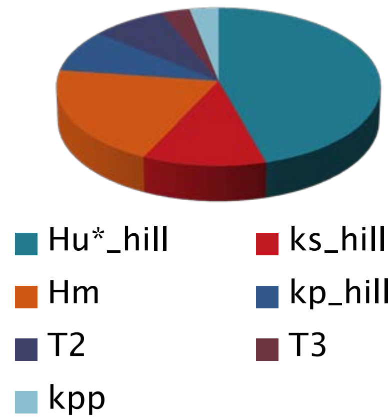


$E_{123}(Q) \geq 1.5$

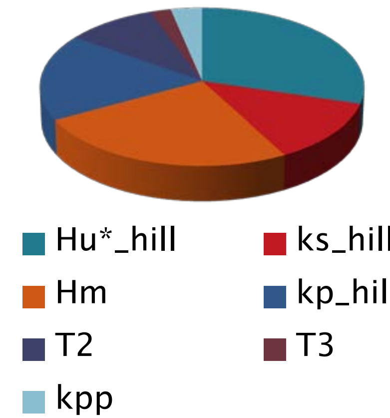


LU4-N-R model

$E_{tot}(Q) \geq 0.77$

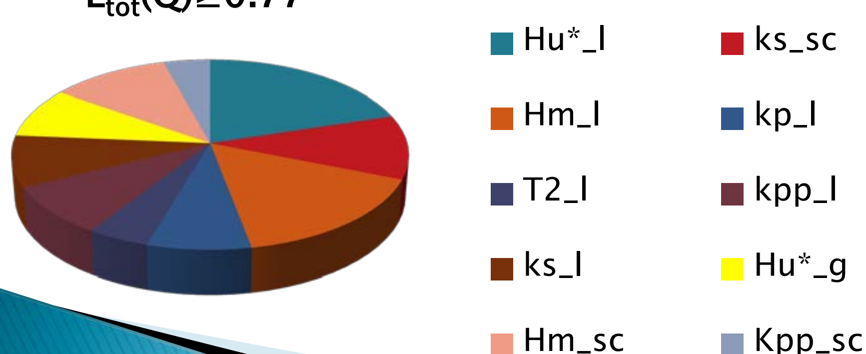


$E_{123}(Q) \geq 1.5$

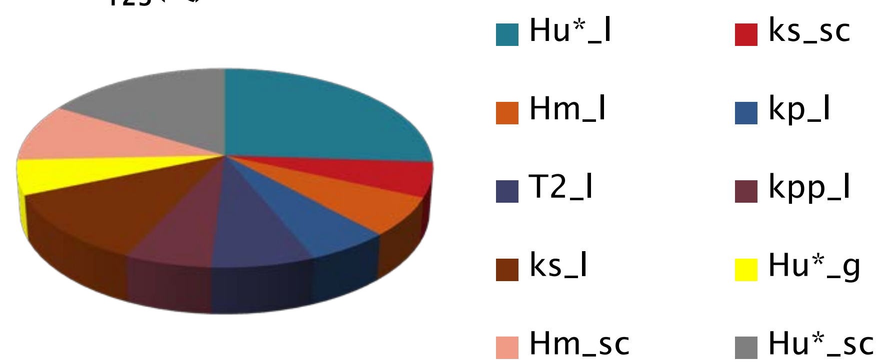


SD4-N-R model

$E_{tot}(Q) \geq 0.77$



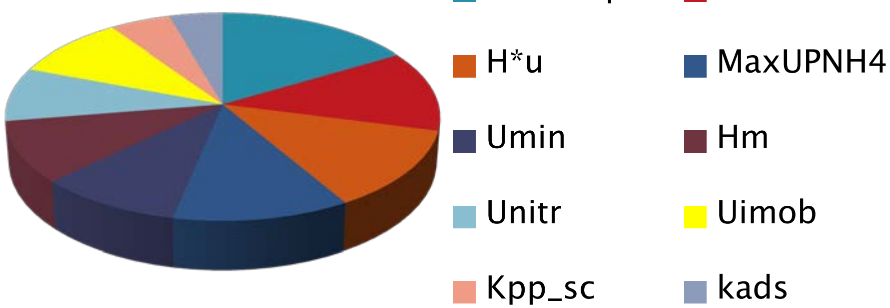
$E_{123}(Q) \geq 1.5$



RESULTS: Nitrate

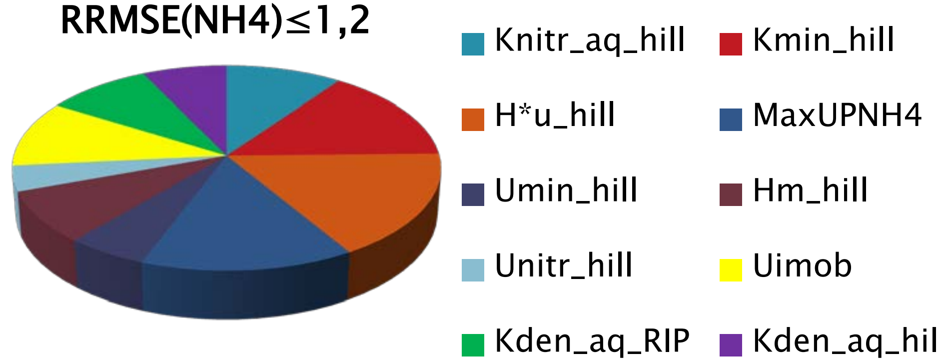
LU4-N model

RRMSE(NO3)≤0.8
RRMSE(NH4)≤1,4



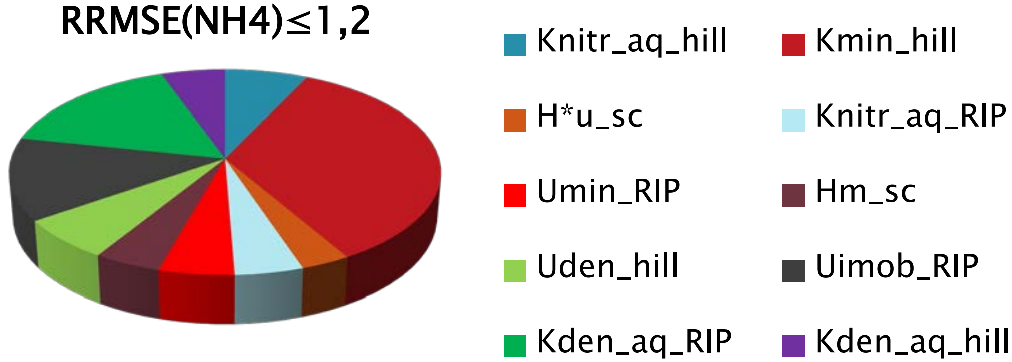
LU4-N-R model

RRMSE(NO3)≤0.6
RRMSE(NH4)≤1,2

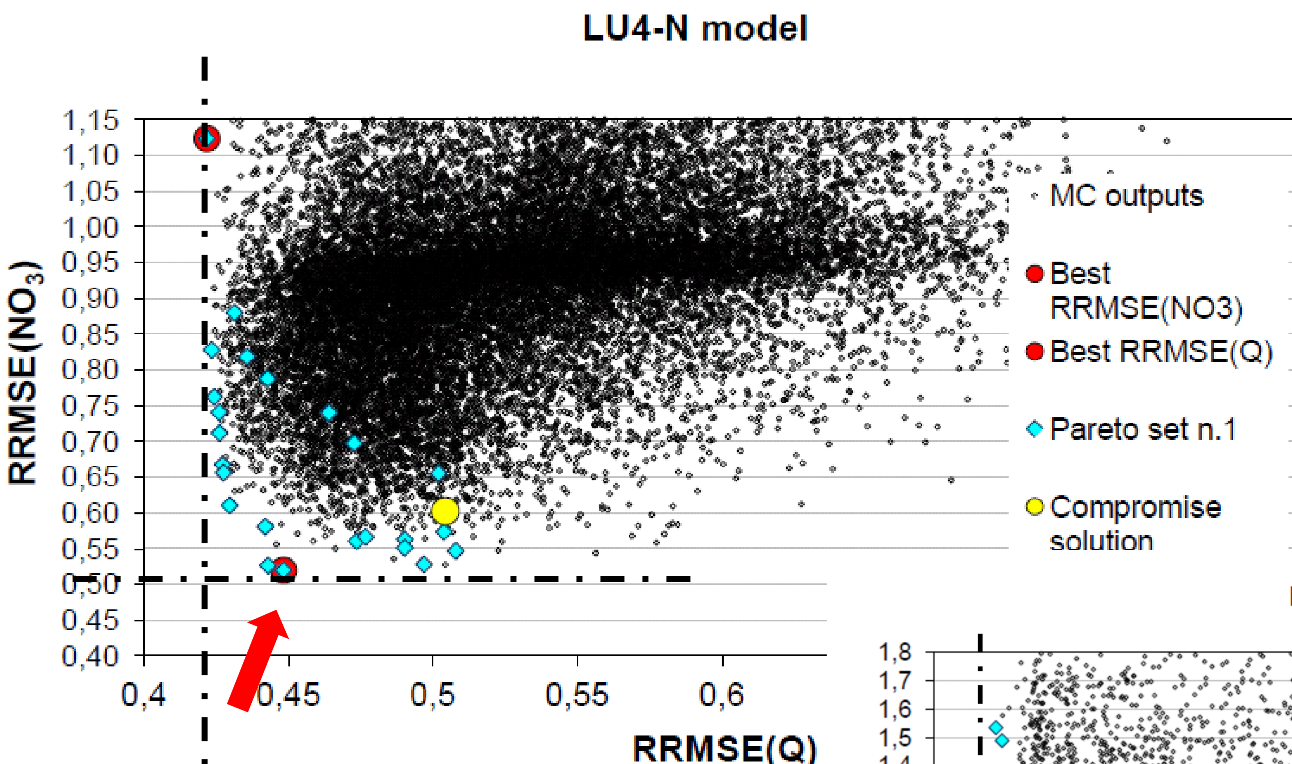


SD4-N-R model

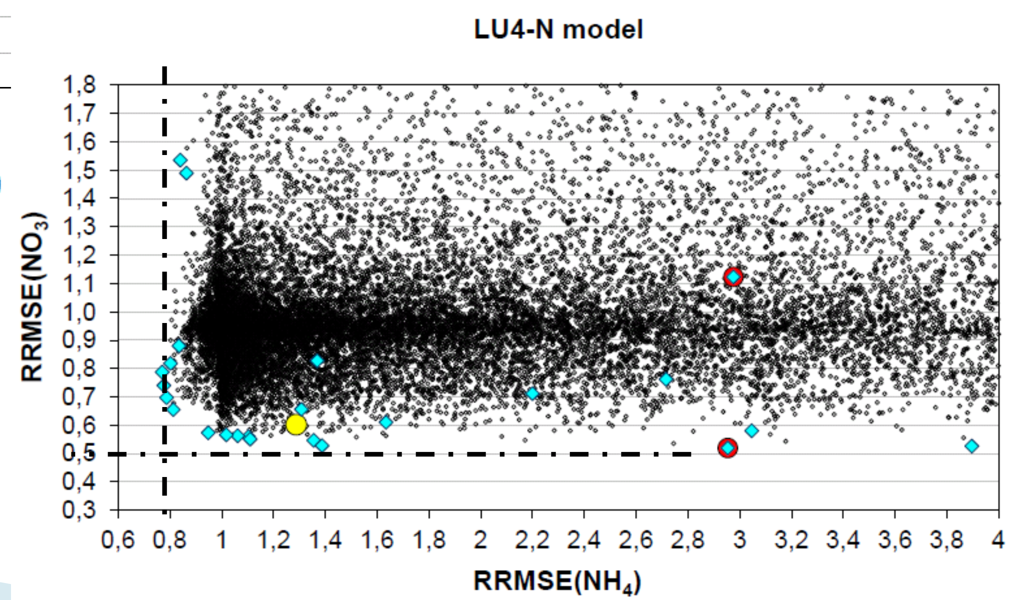
RRMSE(NO3)≤0.6
RRMSE(NH4)≤1,2



RESULTS:

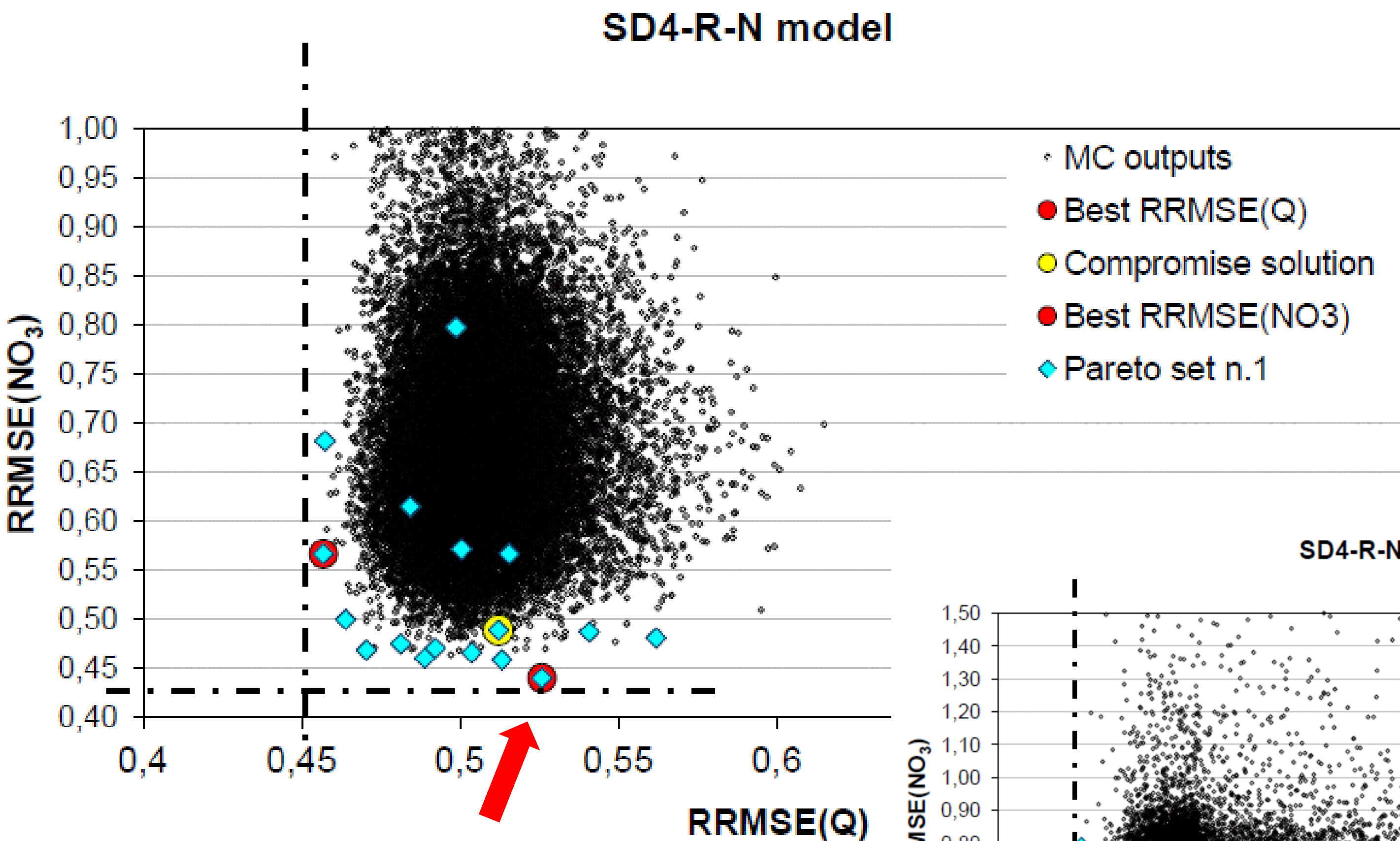


LU4-N model
RRMSE(NO$_3$)
RRMSE(Q)
1,15
1,10
1,05
1,00
0,95
0,90
0,85
0,80
0,75
0,70
0,65
0,60
0,55
0,50
0,45
0,40
0,4
0,45
0,5
0,55
0,6
MC outputs
Best RRMSE(NO3)
Best RRMSE(Q)
Pareto set n.1
Compromise solution

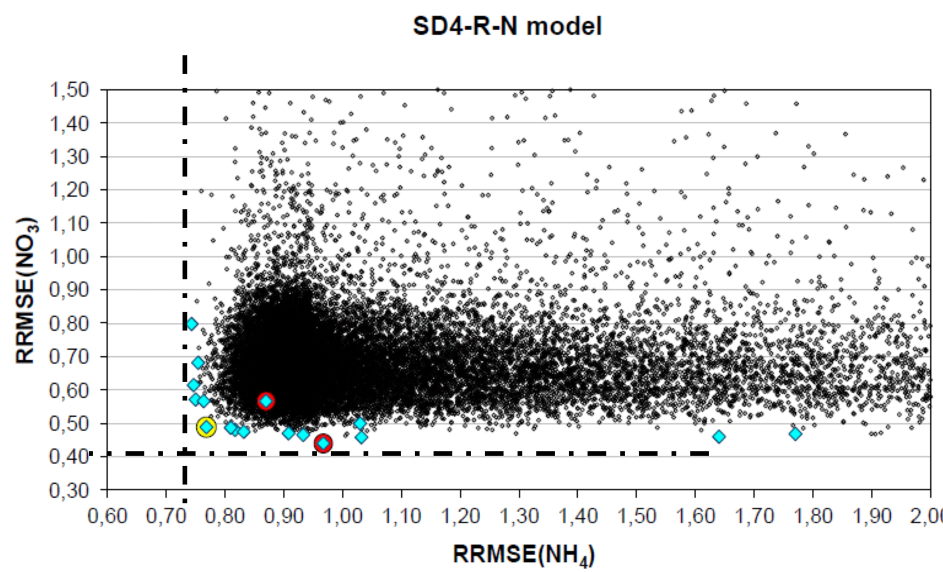


LU4-N model
RRMSE(NO$_3$)
RRMSE(NH$_4$)
1,8
1,7
1,6
1,5
1,4
1,3
1,2
1,1
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,6
0,8
1
1,2
1,4
1,6
1,8
2
2,2
2,4
2,6
2,8
3
3,2
3,4
3,6
3,8
4

RESULTS:

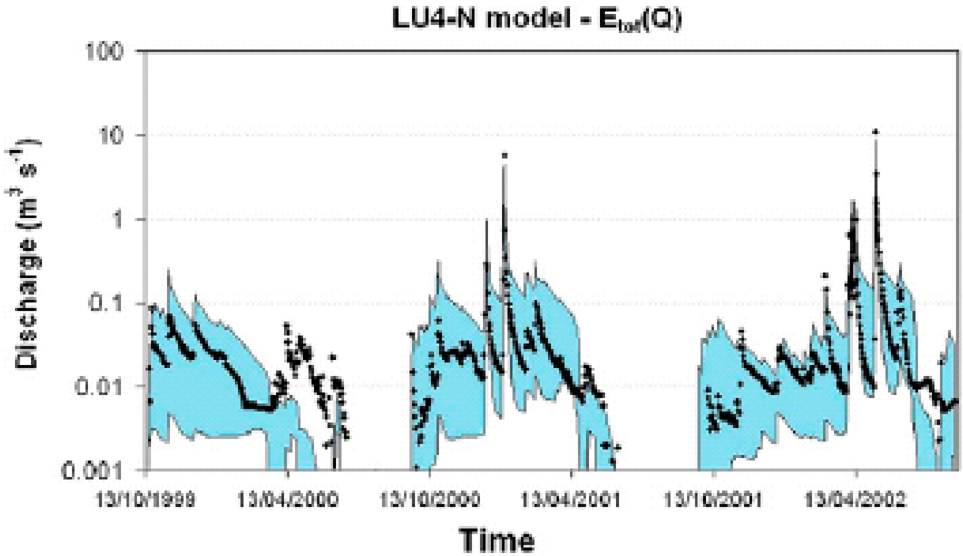


SD4-R-N model
MC outputs
Best RRMSE(Q)
Compromise solution
Best RRMSE(NO3)
Pareto set n.1
RRMSE(NO$_3$)
RRMSE(Q)
1,00
0,95
0,90
0,85
0,80
0,75
0,70
0,65
0,60
0,55
0,50
0,45
0,40
0,4
0,45
0,5
0,55
0,6

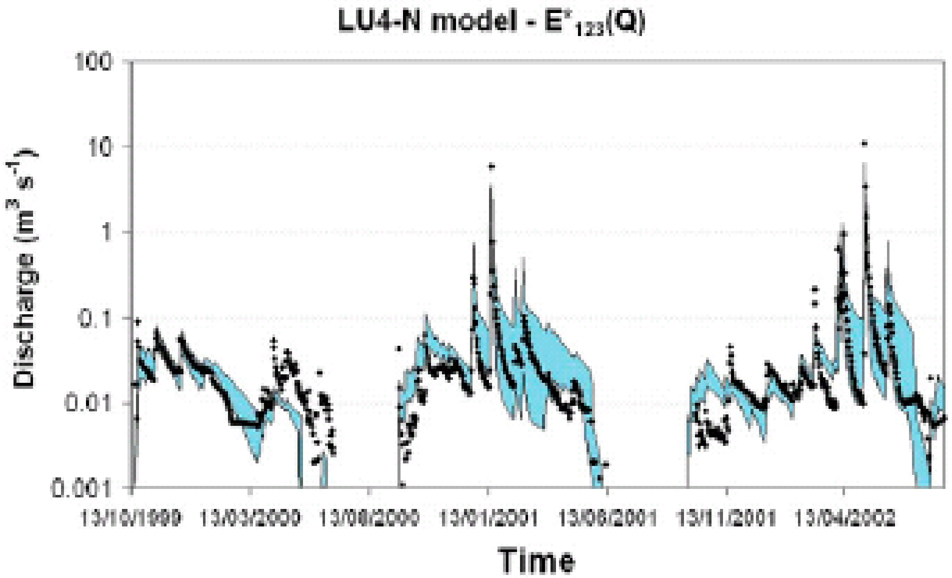


SD4-R-N model
RRMSE(NO$_3$)
RRMSE(NH$_4$)
1,50
1,40
1,30
1,20
1,10
1,00
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,60 0,70 0,80 0,90 1,00 1,10 1,20 1,30 1,40 1,50 1,60 1,70 1,80 1,90 2,00

1999–2002 – 5% and 95% discharge GLUE bands

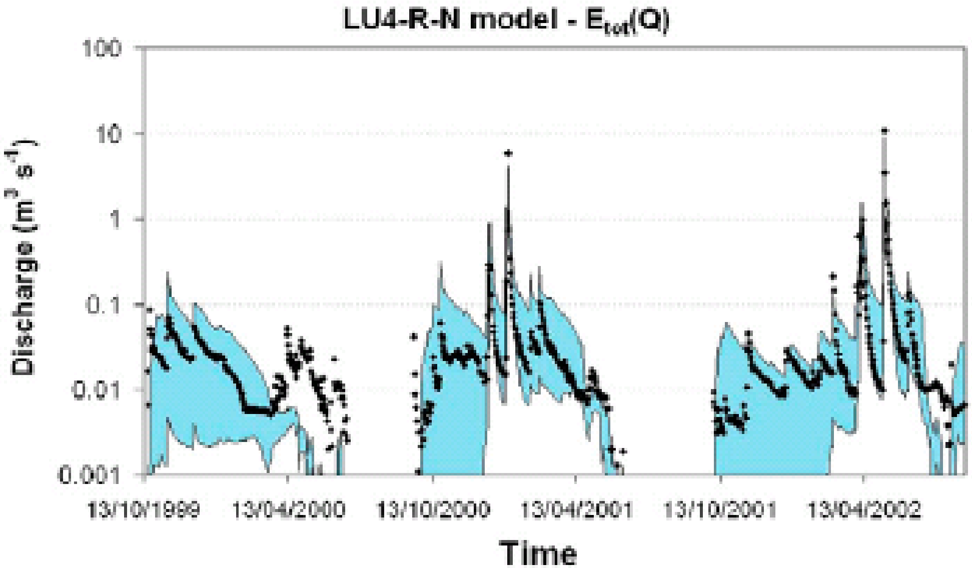


- 22,639 behavioural runs
- 72% observed data included

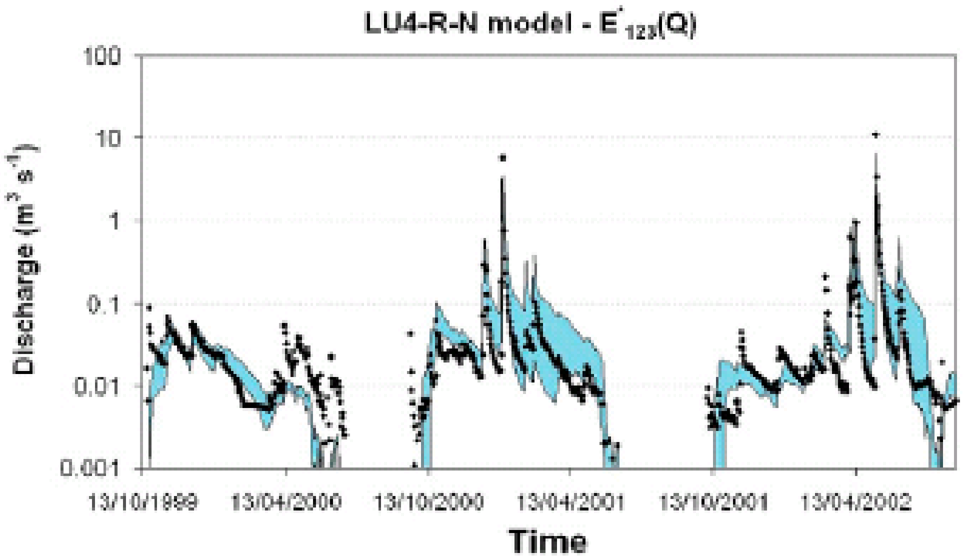


- 14,283 behavioural runs
- 45% observed data included

1999–2002 – 5% and 95% discharge GLUE bands

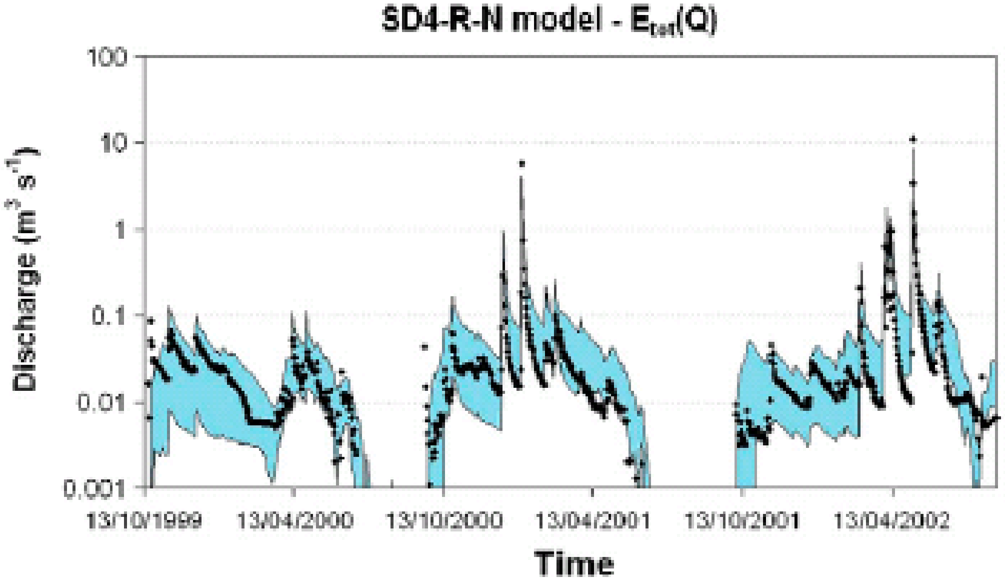


- ➢ 15,784 behavioural runs
- ➢ 76% observed data included

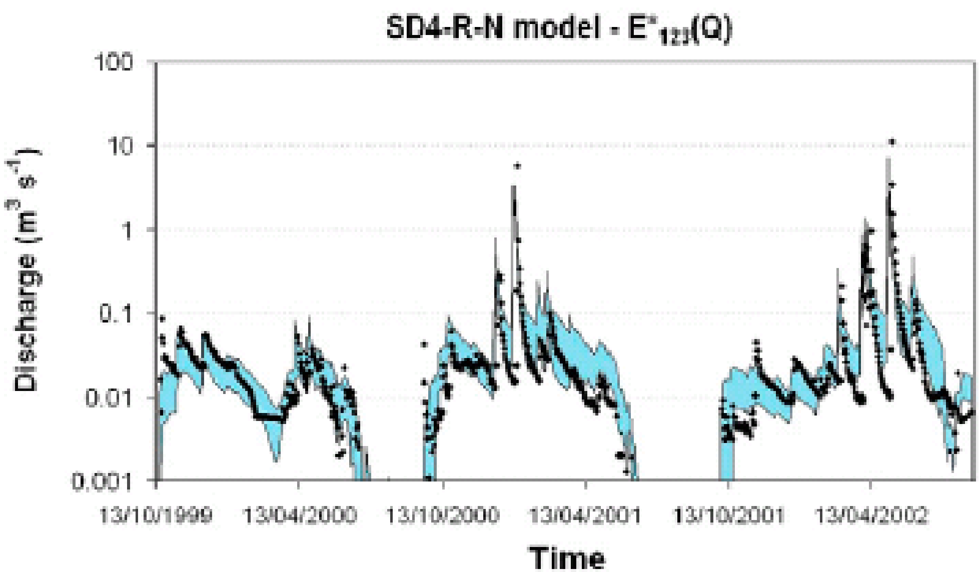


- ➢ 8,301 behavioural runs
- ➢ 58% observed data included

1999–2002 – 5% and 95% discharge GLUE bands



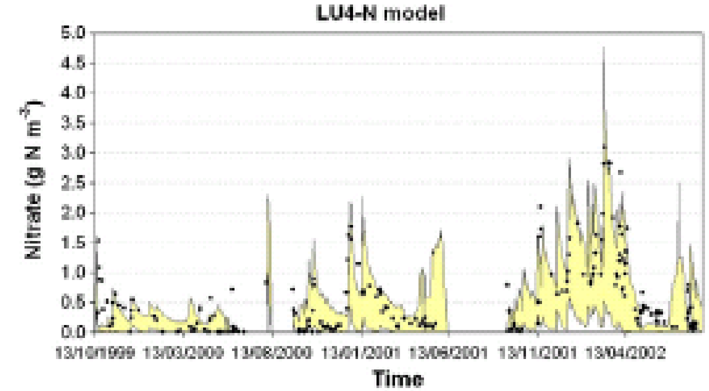
- 2,805 behavioural runs
- 75% observed data included



- 3,084 behavioural runs
- 64% observed data included

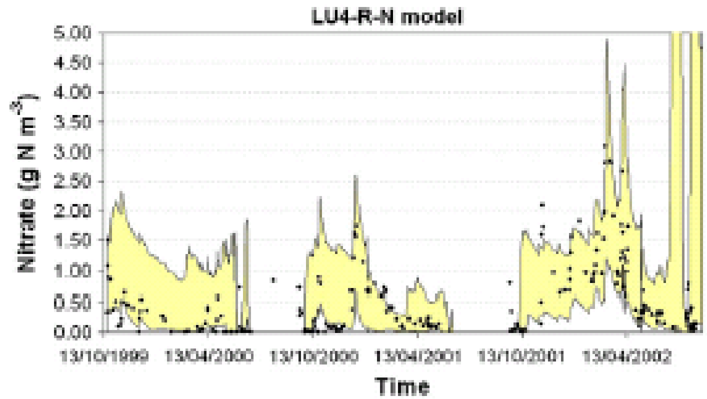
1999-2002 – 5% and 95% **nitrate** GLUE bands

- 1000 behavioural runs*
- 59% observed data included



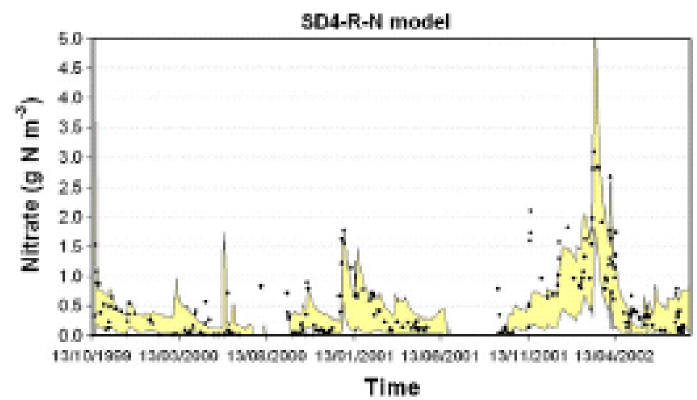
(a)

- 1534 behavioural runs
- 68% observed data included



(b)

- 3000 behavioural runs
- 61% observed data included



(c)

*Less severe criteria

CONCLUSIONS:

- The importance of the *riparian zone* in controlling the short-term daily streamwater nitrogen dynamics, but it exerts a very limited influence on daily discharge
- The *sensitivity ranking* of the hydrological parameters changed when considering different objective functions.
- The *multi-objective approach* led to more robust parameter sets as showed by the 5 and 95% GLUE bands obtained

CONCLUSIONS:

- The most complex structure → the most appropriate
  - *HYDROLOGY*: increased model complexity can lead to *over-parameterisation* since only an input-output response is simulated
  - *WATER QUALITY*: increased model complexity allows greater process representation which can lead to *greater explanatory power* of a model

CONCLUSIONS:

- *Further work* is required to find out which is the optimum level of complexity before there is a deterioration in the model robustness

- More details about this work can be found in Medici et al., (2012), *J. Hydrol*.

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Thank you for your attention!

RESULTS

Sensitivity ranking for the ten most influential parameters based on the Kolmogorov-Smirnov two-sample test showed in brackets

Hydrological models

	LU4-N model		LU4-R-N model		SD4-R-N model	
	$E_{tot}(Q) \geqslant 0.77$	$E^*_{123}(Q) \geqslant 1.5$	$E_{tot}(Q) \geqslant 0.77$	$E^*_{123}(Q) \geqslant 1.5$	$E_{tot}(Q) \geqslant 0.77$	$E^*_{123}(Q) \geqslant 1.5$
1	H^*_u (0.729)	H^*_u (0.537)	$H^*_{u\_hill}$ (0.736)	$H^*_{u\_hill}$ (0.497)	$H^*_{u\_Leuco}$ (0.547)	$H^*_{u\_Leuco}$ (0.538)
2	K_s (0.270)	H_m (0.372)	H_m (0.324)	H_m (0.419)	H_{m_Leuco} (0.432)	$H^*_{u\_Schst}$ (0.338)
3	H_m (0.215)	K_{pp} (0.151)	K_{s_hill} (0.187)	K_{p_hill} (0.299)	K_{s_Schst} (0.295)	K_{s_Leuco} (0.241)
4	K_p (0.067)	T3 (0.059)	K_{p_hill} (0.140)	K_{s_hill} (0.209)	K_{s_Leuco} (0.273)	H_{m_Schst} (0.193)
5	T2 (0.056)	T2 (0.036)	T2 (0.129)	T2 (0.162)	K_{pp_Leuco} (0.231)	$T2_{Leuco}$ (0.148)
6	T3 (0.047)	K_p (0.029)	K_{pp} (0.050)	K_{pp} (0.056)	$H^*_{u\_Granod}$ (0.230)	$H^*_{u\_Leuco}$ (0.130)
7		K_s (0.024)	T3 (0.049)	T3 (0.037)	K_{p_Leuco} (0.204)	K_{pp_Leuco} (0.125)
8					$T2_{Leuco}$ (0.122)	K_{p_Leuco} (0.118)
9					H_{m_Schst} (0.121)	K_{s_Schst} (0.118)
10					K_{pp_Schst} (0.116)	$H^*_{u\_Granod}$ (0.117)

Nitrogen models

	LU4-N model	LU4-R-N model	SD4-R-N model
	$RRMSE(NO_3) \leqslant 0.8$ $RRMSE(NH_4) \leqslant 1.4$	$RRMSE(NO_3) \leqslant 0.6$ $RRMSE(NH_4) \leqslant 1.2$	$RRMSE(NO_3) \leqslant 0.6$ $RRMSE(NH_4) \leqslant 1.2$
1	K_{nitr_acuif} (0.390)	$H^*_{u\_hill}$ (0.365)	K_{min_hill} (0.526)
2	K_{min} (0.298)	K_{min_hill} (0.323)	$K_{denitr\_acuif\_ripz}$ (0.248)
3	H^*_u (0.295)	$MaxUPNH_4$ (0.317)	U_{immob_ripz} (0.198)
4	$MaxUPNH_4$ (0.278)	$K_{nitr\_acuif\_hill}$ (0.216)	$K_{nitr\_acuif\_hill}$ (0.108)
5	U_{min} (0.227)	$K_{denitr\_acuif\_ripz}$ (0.196)	U_{denitr_hill} (0.099)
6	H_m (0.227)	H_{m_hill} (0.180)	$K_{denitr\_acuif\_hill}$ (0.083)
7	U_{nitr} (0.199)	$K_{denitr\_acuif\_hill}$ (0.157)	$H^*_{u\_schst}$ (0.050)
8	U_{immob} (0.227)	U_{imm_hill} (0.127)	U_{min_ripz} (0.076)
9	K_p (0.121)	U_{min_hill} (0.119)	$K_{nitr\_acuif\_ripz}$ (0.069)
10	K_{ads} (0.106)	U_{nitr_hill} (0.088)	H_{m_schst} (0.068)