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Modelling the efficiency of nitrate removal by denitrification in the SWAT model

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INTRODUCTION

- Riparian zones are the interfaces between terrestrial and aquatic ecosystems, which have high efficiency in reducing nitrate originating from upland agricultural fields.

- River basin-scale models are promising tools to support the quantification of the pollution sources originating from different sources under various climatic and land use conditions.

- The Soil and Water Assessment Tool (SWAT) is a widely used river basin-scale model which has been applied for a variety of hydrologic and environmental problems, however, there are still limited SWAT studies in riparian zone modelling.

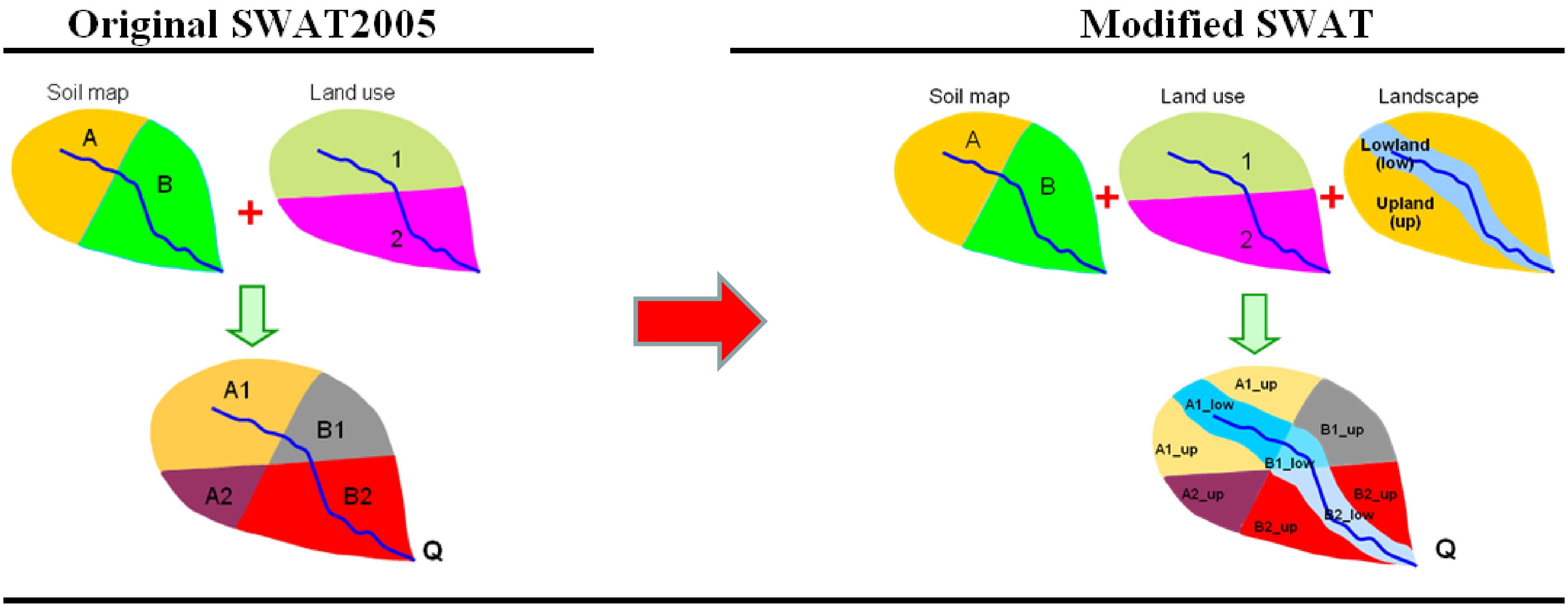
OBJECTIVES

This study presents the integration of a conceptual riparian nitrogen model which is based on the Riparian Nitrogen model (RPN) in the SWAT model.

The integrated model aims at predicting efficiency in nitrate removal of riparian zones in a river basin-scale.

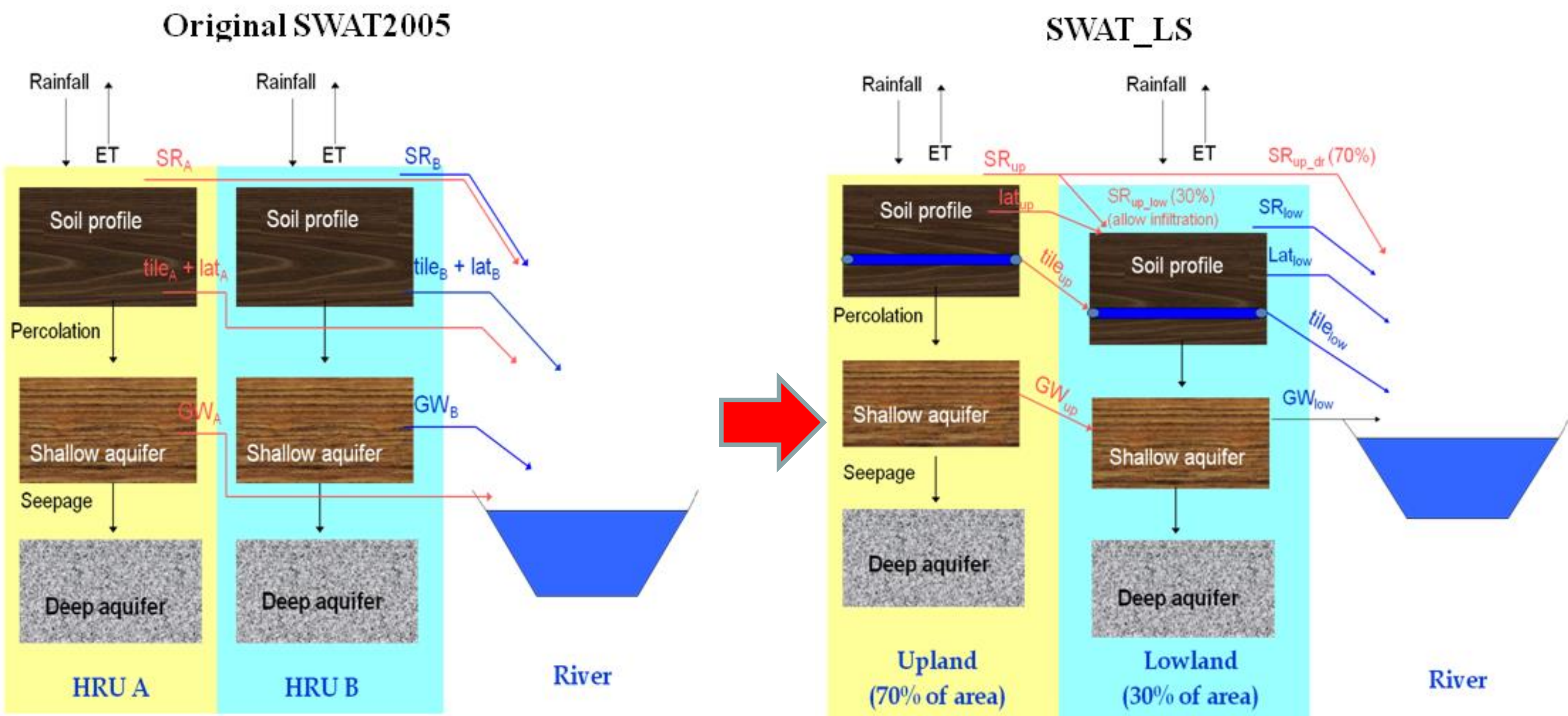
The modification to represent the landscape variability

HRU division



The modification to represent the landscape variability

Hydrological routing between modelling units

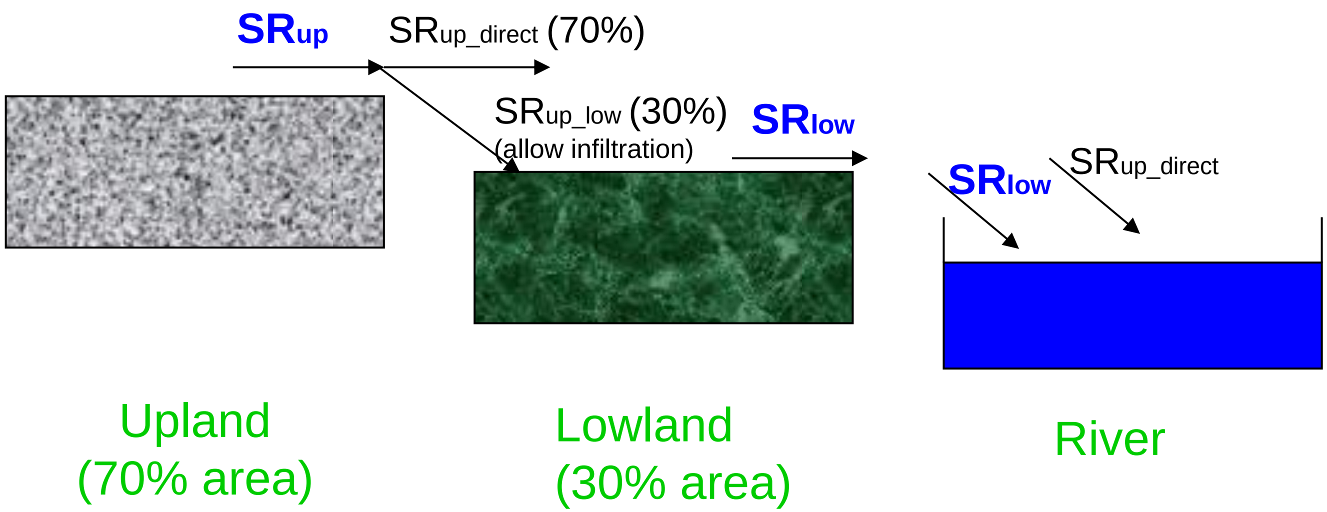


HRUs are routed directly to the river
There is no routing between HRUs

There is routing between HRUs in hillslope and HRUs in floodplain before reaching the river

The modification to represent the landscape variability

SURFACE RUNOFF



Surface runoff generated in the upland area (SR_{up}) is separated into

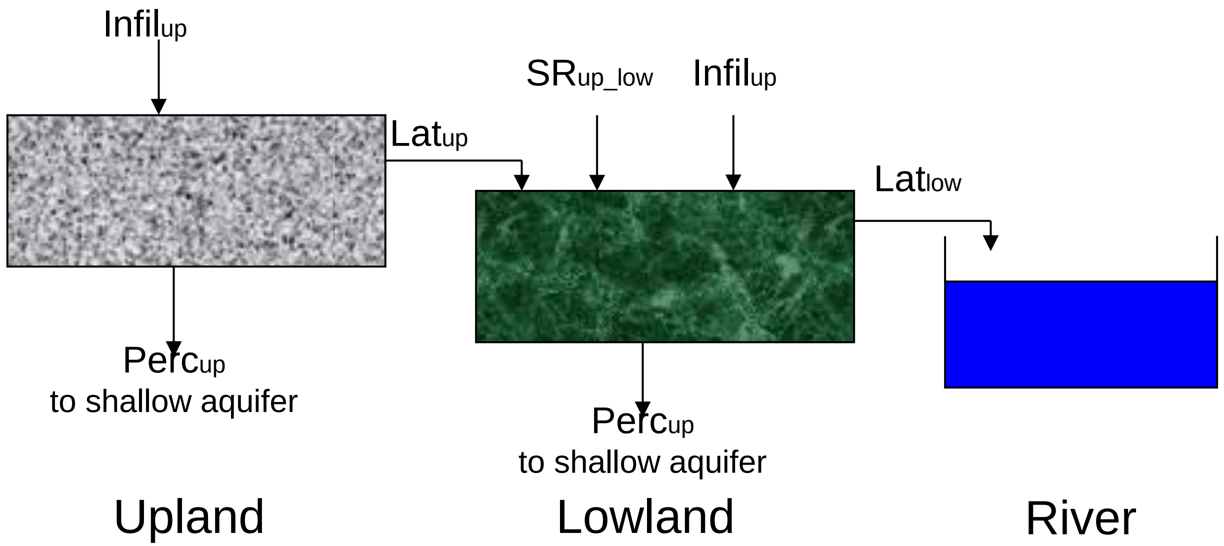
(i) flow entering lowland component as runon that is available for re-infiltration (SR_{up_low})

(ii) remaining flow that goes directly to the river (SR_{up_direct}).

The percentages of these two surface runoff components are assumed to be proportional to the respective areal fractions of landscape units.

The modification to represent the landscape variability

LATERAL FLOW



Lateral flow from upland area is input to the soil profile in lowland area

$$Q_{lat} = \left(Q'_{lat} + Q_{latstor,i-1}\right) \cdot \left(1 - \exp\left[\frac{-1}{TT_{lag}}\right]\right)$$

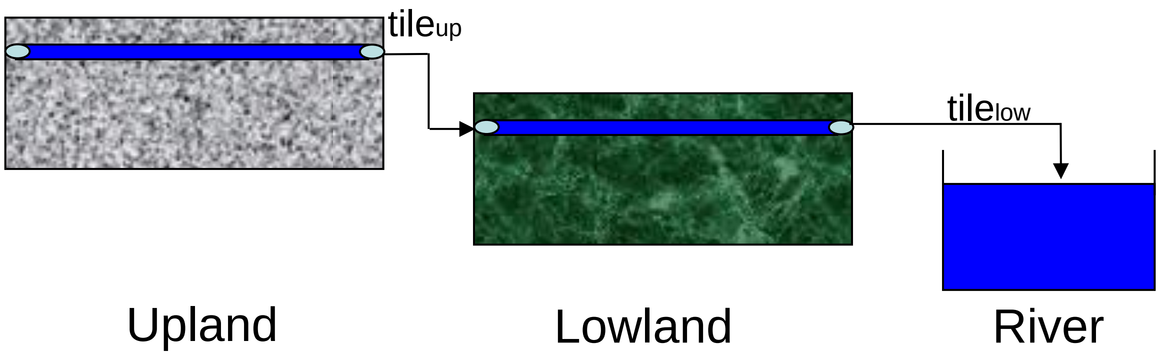
<u>**Assumption 3**</u>: TT_{lag} is the similar in upland and lowland areas

The modification to represent the landscape variability

TILE FLOW

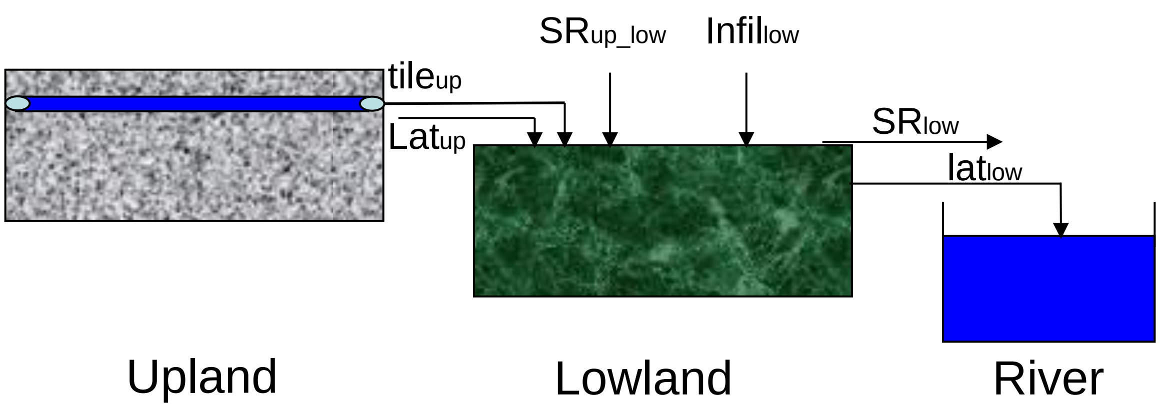
Case 1: both upland and lowland have tile drains

Tile flow from upland will go to tiles in lowland and join tile flow from lowland to the river.



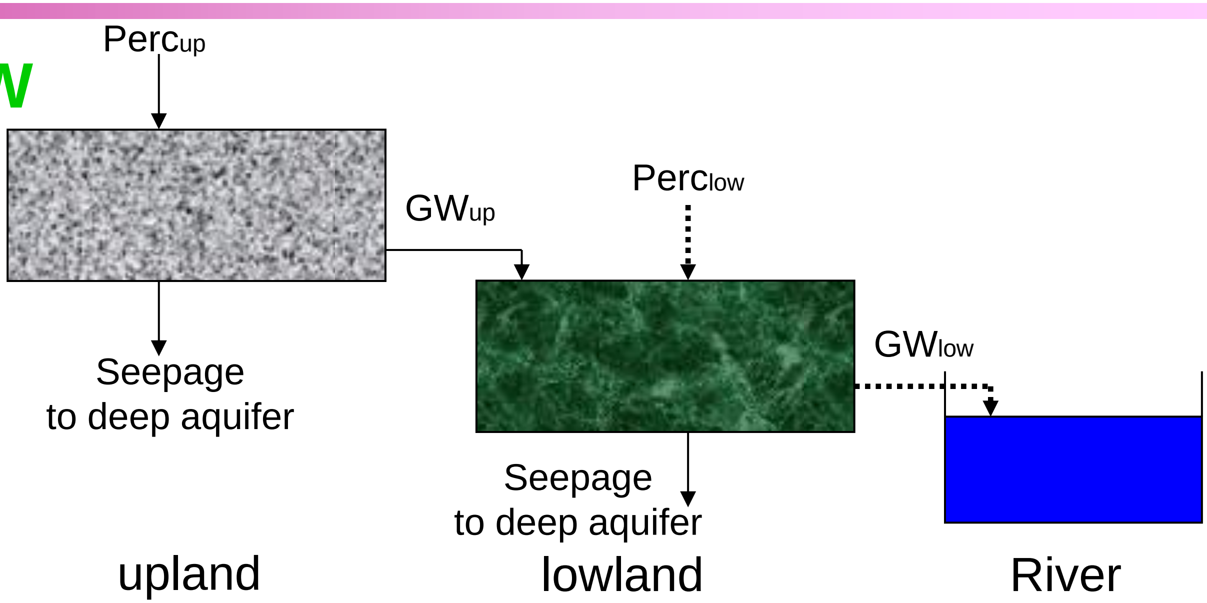
Case 2: tile drain only applied in upland but not lowland

Tile flow from upland is an input to the soil profile in lowland together with surface runoff and lateral flow from upland and infiltration in lowland area



SWAT_landscape model

GROUNDWATER FLOW



Groundwater flow from upland area is input to the shallow aquifer in lowland area

Modelling the efficiency of nitrate removal by denitrification in the SWAT model

- ❑ Description of Riparian Nitrogen model
- ❑ Integrate the RPN model in the SWAT model
- ❑ Testing the integrated model in a hypothetical case study

Description of the Riparian Nitrogen model

The Riparian Nitrogen (RPN) model (Rassam et al., 2008) is a conceptual model that estimates the removal of nitrate as a result of denitrification,.

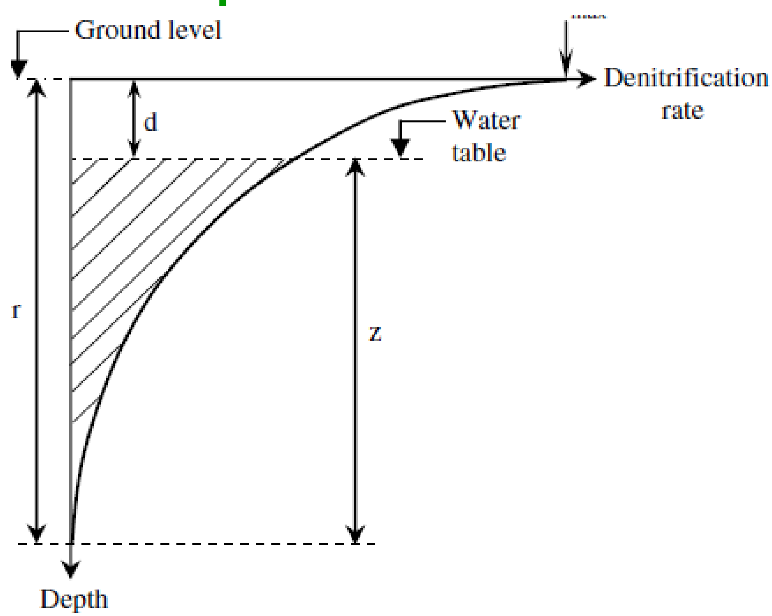
The denitrification occurs when groundwater and surface waters interact with riparian buffers via two mechanisms:

- ❖ groundwater passes through the riparian buffer before discharging to the stream (base flow model)
- ❖ surface water is temporarily stored within the riparian soils during flood event (bank storage model)

Modelling variable denitrification rates through the soil profile

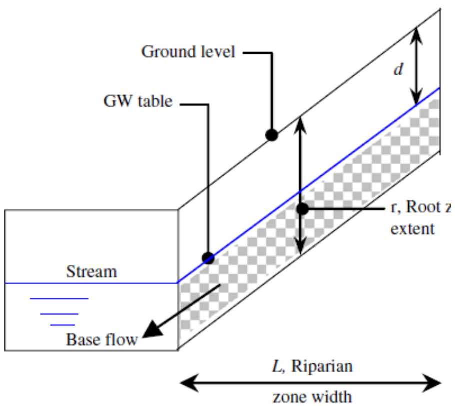
$$R_d = R_{\max} \frac{e^{-kd} - e^{-kr}}{1 - e^{-kr}}$$

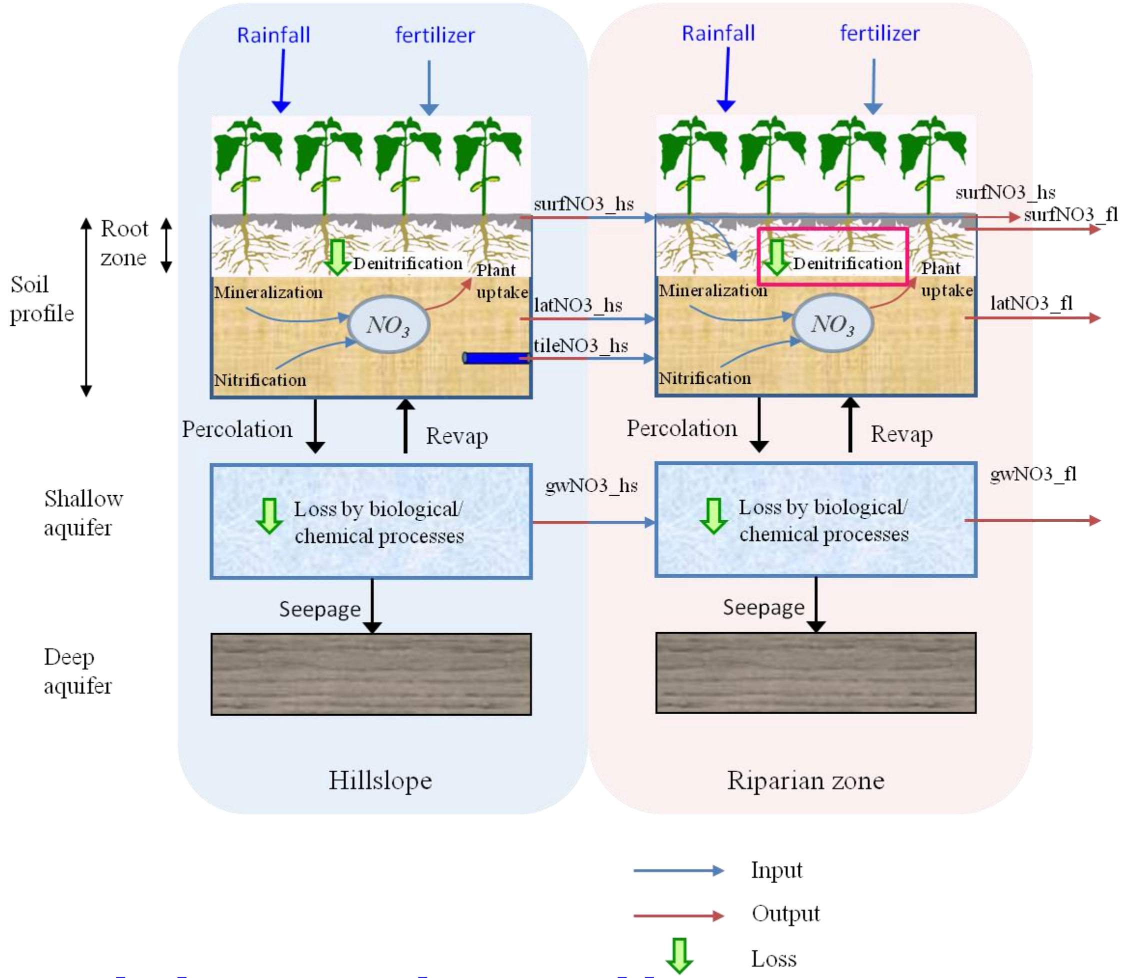
R_d is the nitrate decay rate at any depth d
R_{max} is the maximum nitrate decay rate at the soil surface
r is the depth of the root zone (L)
k is a parameter describing the rate at which the nitrate decay rate R declines with depth (L^{-1}).



Integrating the Riparian Nitrogen Model in SWAT_LS

❖Applying the base flow model of RPN model in the modified SWAT model





→ Groundwater table is a necessary variable to apply the RPN model which is not available in SWAT

Procedure to calculate groundwater table depth from soil moisture in SWAT (Vazques-Amabile and Engel, 2005)

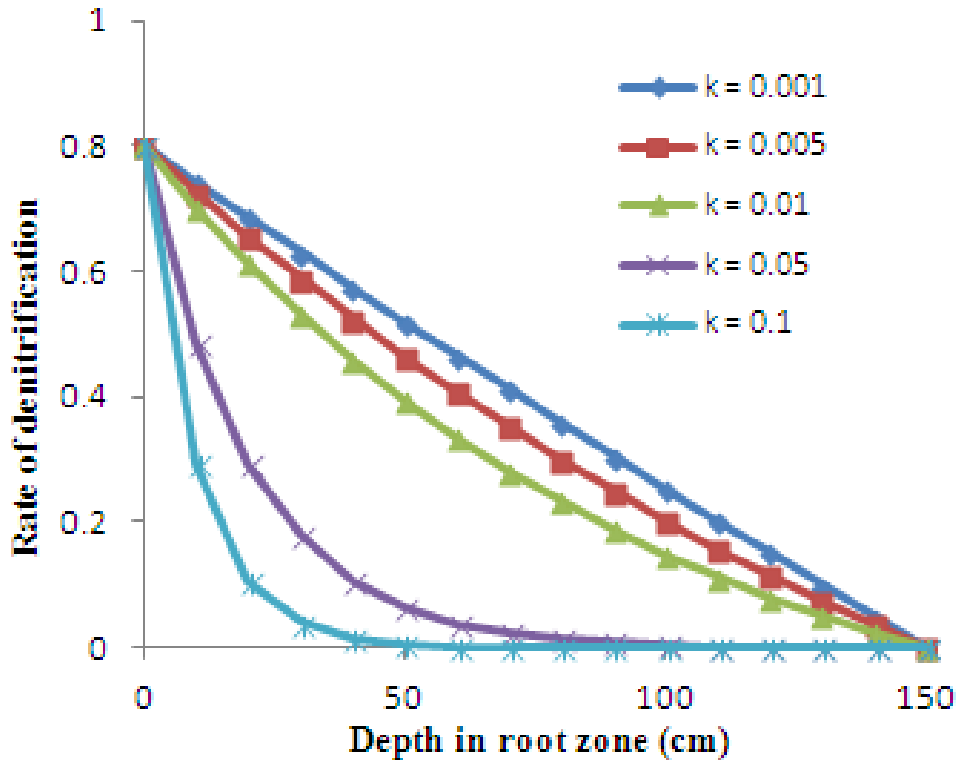
Testing the integrated model in a hypothetical case study

❖ Sensitivity of parameters related to the simulation of denitrification in the riparian zone

Denitrification rate change by depth

$$R_d = R_{\max} \frac{e^{-kd} - e^{-kr}}{1 - e^{-kr}}$$

Sensitivity of k



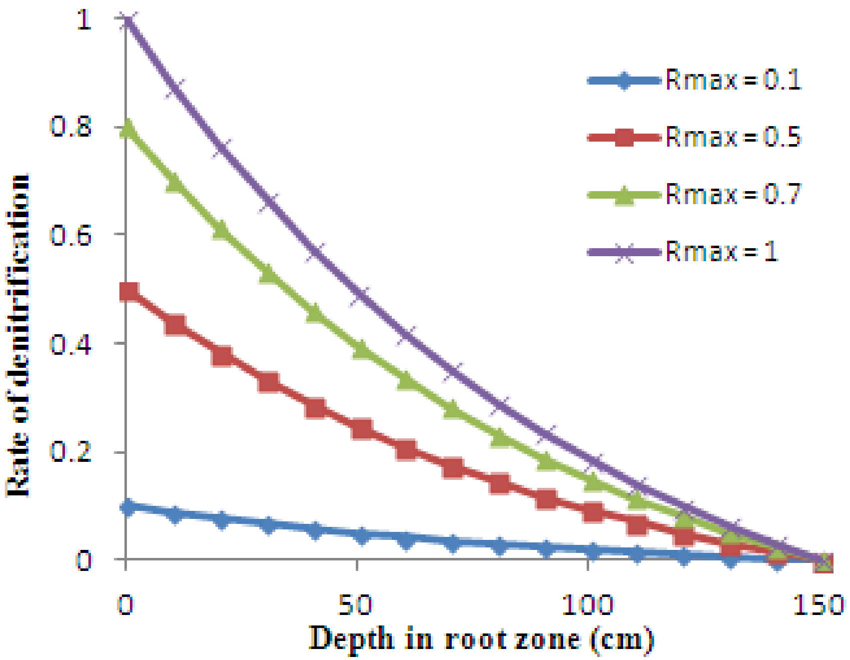
Testing the integrated model in a hypothetical case study

❖ **Sensitivity of parameters related to the simulation of denitrification in the riparian zone**

Denitrification rate change by depth

$$R_d = R_{\max} \frac{e^{-kd} - e^{-kr}}{1 - e^{-kr}}$$

Sensitivity of Rmax



Effect of R_{max} on denitrification rate at different depth in the root zone

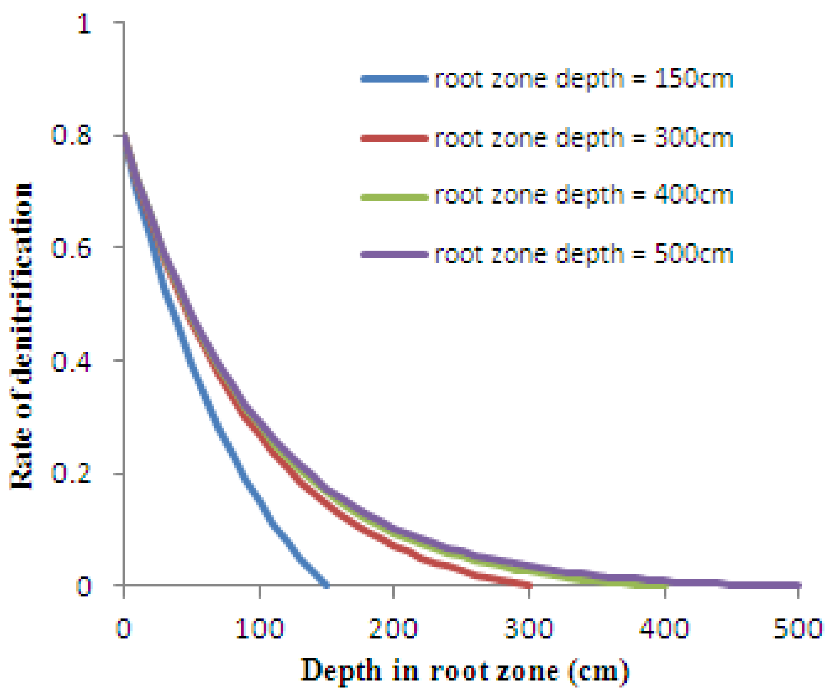
Testing the integrated model in a hypothetical case study

- **Sensitivity of parameters related to the simulation of denitrification in the riparian zone**

Denitrification rate change by depth

$$R_d = R_{\max} \frac{e^{-kd} - e^{-kr}}{1 - e^{-kr}}$$

Sensitivity of depth of root zone r



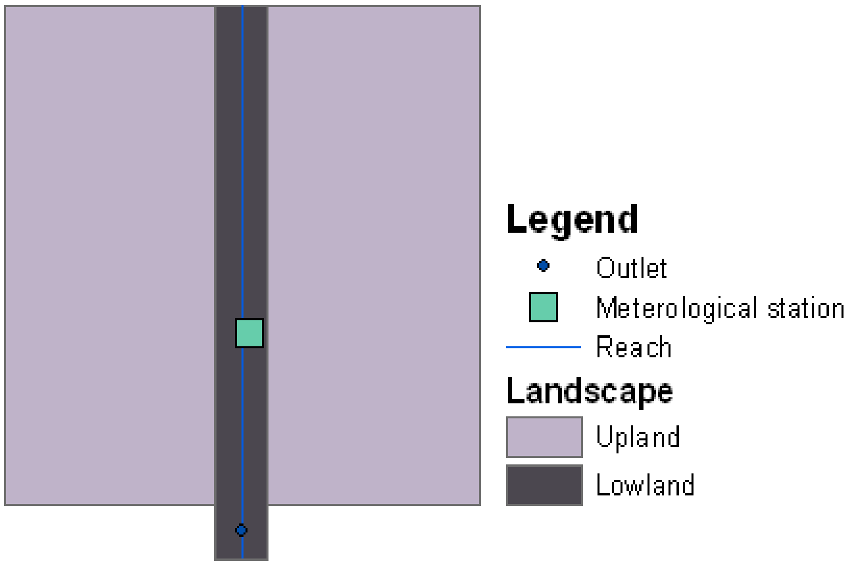
Effect of root zone depth on denitrification rate at different depth in the root zone

TESTING THE NEW APPROACH WITH A HYPOTHETICAL CASE STUDY

Objectives:

- Test the hydrological response when the landscape concept is included in SWAT and compare the results with the original SWAT2005

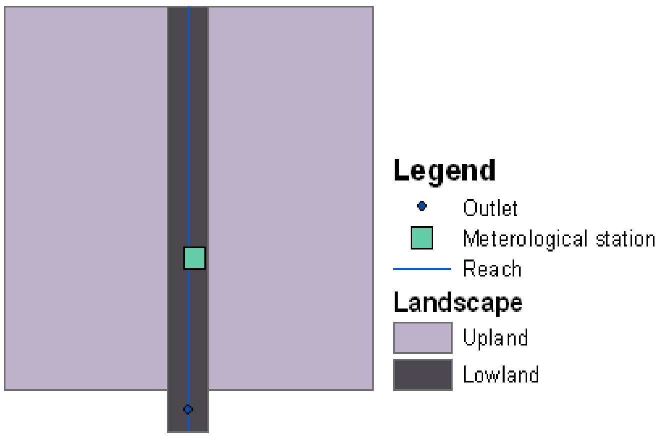
- Ensure that the applied equations give reasonable results and eliminate any possible mistakes.



- ✓ 1 subbasin, 1 outlet
- ✓ 2 landscape units (upland and lowland)
- ✓ 1soil type, 1 land use
- → 2 HRUs were created
- ✓ 1 meteorological station

Testing the integrated model in a hypothetical case study

❖ Testing with different scenarios



Scenario 1: *Groundwater flow is the most significant flow to the riparian zone*

Scenario 2: *Surface runoff is the dominating flow path*

Scenario 3: *Tile drains were applied in both upland and lowland areas which drive tile flow directly to the streams*

Scenario 4: *Tile drain is applied in the upland/agricultural area but not in lowland/riparian zone*

Testing the integrated model in a hypothetical case study

❖ Testing with different scenarios

Original SWAT2005

Table 2: Water components and nitrate fluxes in different scenarios by using original SWAT2005

Components	Scenario1		Scenario 2		Scenario 3		Scenario 4	
	Flow (mm)	Nitrate flux (kg/ha)	Flow (mm)	Nitrate flux (kg/ha)	Flow (mm)	Nitrate flux (kg/ha)	Flow (mm)	Nitrate flux (kg/ha)
Surface runoff	24.15	0.321	154.54	3.880	35.19	0.472	36.94	0.477
Lateral flow	0.08	0.008	0.06	0.008	0.13	0.020	0.13	0.020
Tile flow	0.00	0.000	0.00	0.000	160.88	96.064	133.27	96.011
Groundwater	227.47	135.99	142.37	104.848	97.80	57.998	112.21	58.016
Total flow	**251.70**	**136.319**	**296.97**	**108.736**	**294.00**	**154.554**	**282.55**	**154.524**
Loss of nitrate								
- By denitrification in the soil profile		0.00		0.00		0.00		0.00
- By denitrification in bank storage		Not calculated		Not calculated		Not calculated		Not calculated
- By processes in shallow aquifer		6.548		5.520		3.966		3.966

Testing the integrated model in a hypothetical case study

❖ Testing with different scenarios

SWAT_LS

Table 1: Water components and nitrate fluxes in different scenarios for testing the integrated wetland-SWAT_LS in year 1998

Components	Scenario1		Scenario 2		Scenario 3		Scenario 4	
	Flow (mm)	Nitrate flux (kg/ha)	Flow (mm)	Nitrate flux (kg/ha)	Flow (mm)	Nitrate flux (kg/ha)	Flow (mm)	Nitrate flux (kg/ha)
Surface runoff	21.68	0.28	139.02	3.404	31.62	0.42	44.47	0.476
Lateral flow	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.001
Tile flow	0.00	0.00	0.00	0.000	161.39	95.56	0.00 (From upland: 133.27)	0.00
Groundwater	199.52	116.25	138.02	89.178	83.76	46.62	175.60	64.410
Total	**221.20**	**116.53**	**277.04**	**92.582**	**276.77**	**142.60**	**220.08**	**64.487**
Loss of nitrate - By denitrification in the soil profile - By denitrification in bank storage		0.002 0.00		0.002 0.00		0.05 0.00		70.073 0.00
- By processes in shallow aquifer		10.77		8.782		5.64		6.299

Conclusions

❑ The adding of landscape variability and routing process between upland to lowland landscape units in the SWAT model give a better representation of hydrological and water quality processes in a river basin by setting up a relationship in flow and pollution fluxes between different landscapes in the river basin.

❑ Compared to the original SWAT2005 model, this modification slightly decrease both surface runoff and groundwater flow but does not give any significant change in tile flow in case tile drains are applied in all landscape units.

❑ According to nitrate simulation, the landscape approach does make a difference in modelling the denitrification process in case the lowland area receive a high amount of flow which is generated in the soil profile so that flow from upland can cause a high perched groundwater table that results in anaerobic condition and the interaction between groundwater with the organic matters in the root zone.

❑ Compared to the original SWAT2005 model, the integrated SWAT_Riparian Nitrogen model is able to evaluate the efficiency of riparian zone in nitrate removal by denitrification at the river basin scale.


THANK YOU FOR
YOUR ATTENTION