Estimating nutrient loss from a typical dairy farming catchment in New Zealand using SWAT

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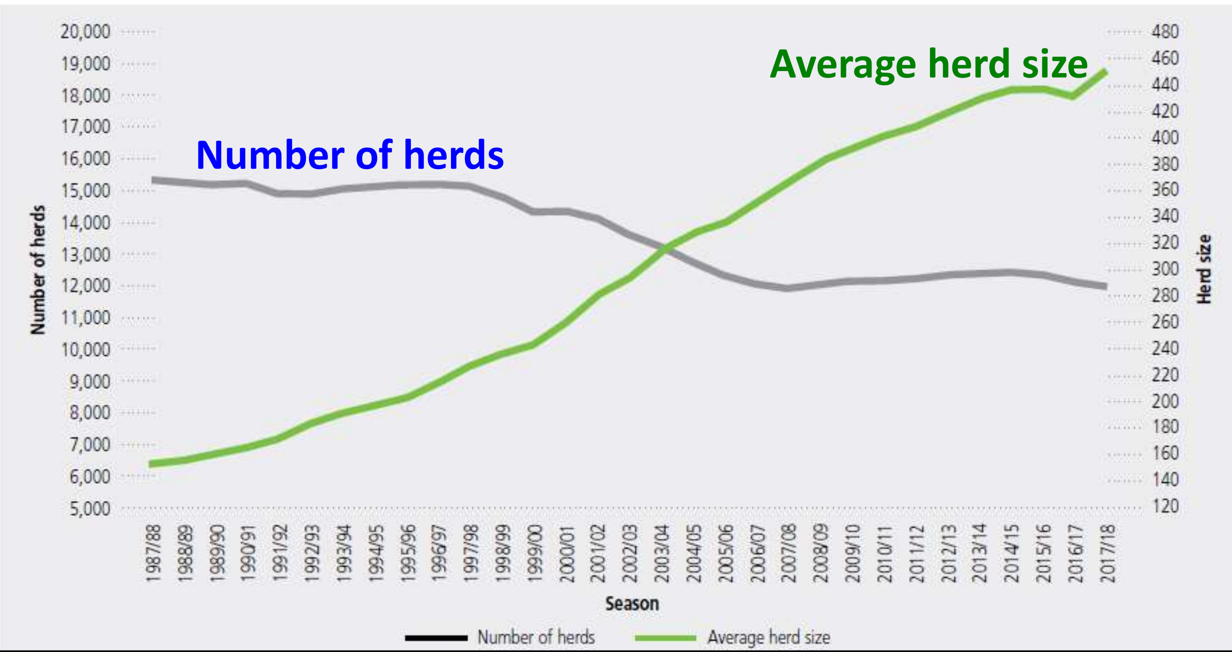
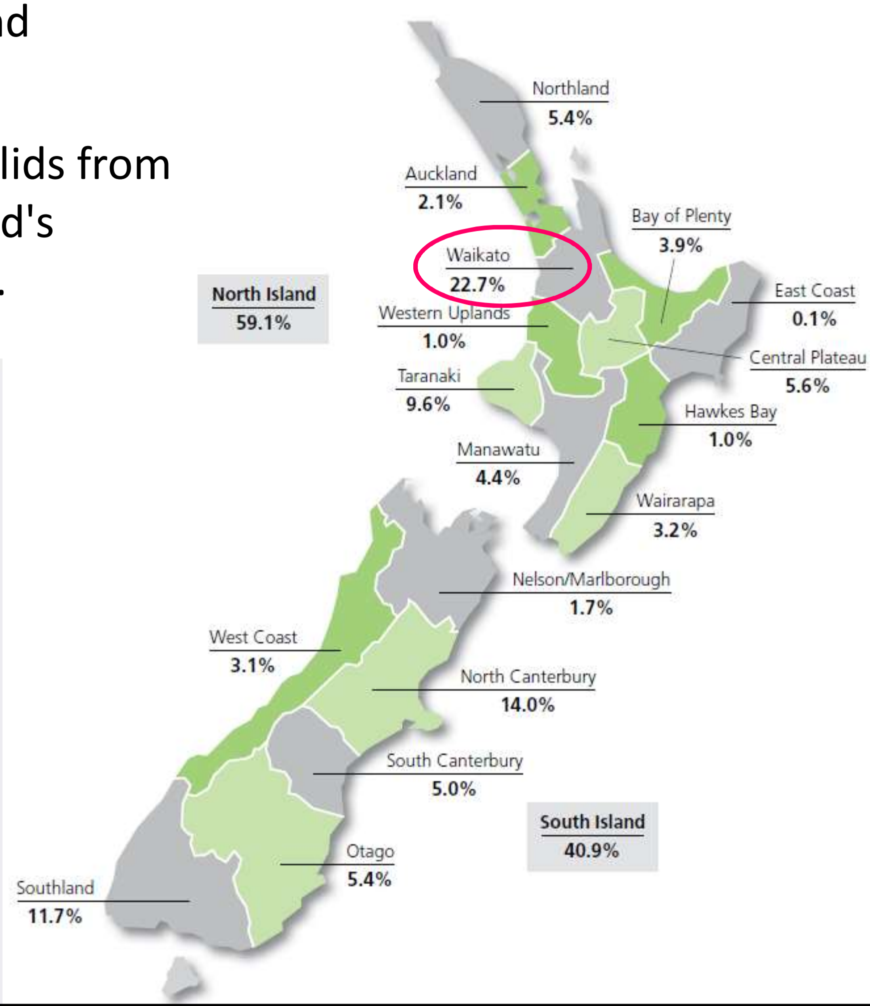
Introduction

- The dairy industry is a significant contributor to New Zealand economy (NZ$13.4 billion industry by 2017).
- New Zealand's total production was 1.8 billion kg of milk solids from 21.0 billion litres of milk, which makes the country the world's eighth largest milk producer in the 2016/2017 dairy season.



Regional distribution of dairy cows in 2017/2018



Introduction

Environmental impacts of dairy farming:

- Nitrate leaching
- Eutrophication
- Methane gas emissions
- High water use for irrigation
- Soil compaction

To estimate the impacts of dairy farming at catchment scale, dynamic catchment models are very useful tools because they can provide insights into catchment systems where direct measurement may not be feasible at large scale.

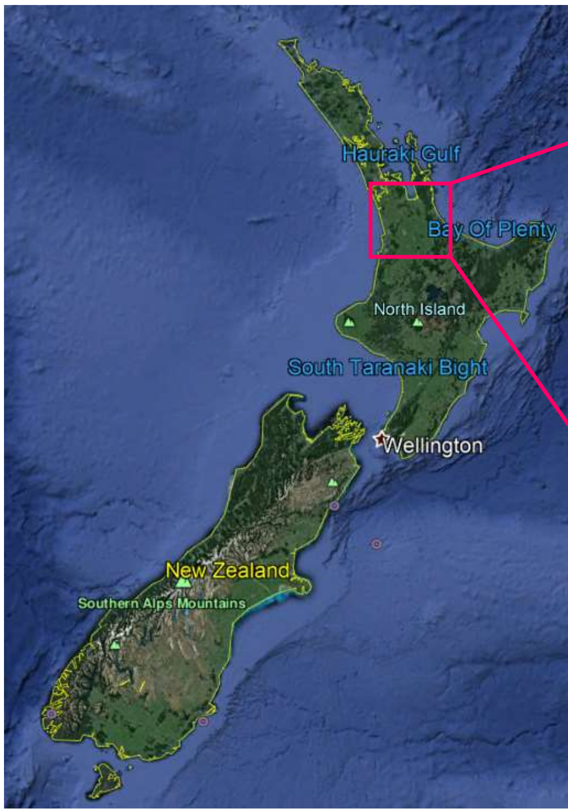
Dynamic catchment modelling allows the estimation of contamination loads from various sources and their relative importance. Such information can be valuable for catchment management plans.

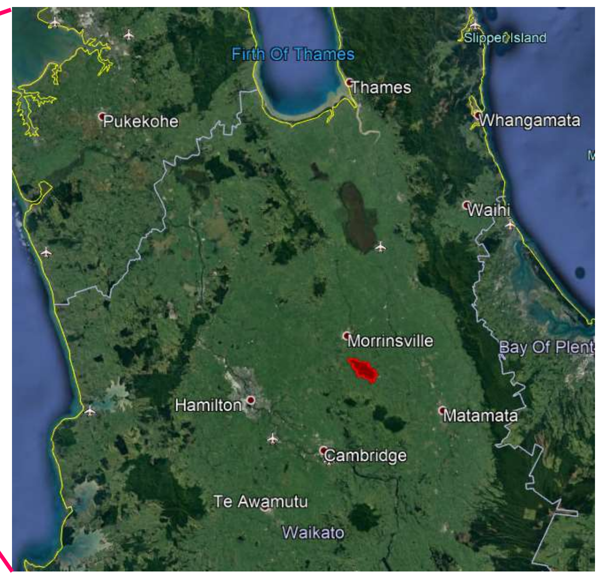
SWAT is the chosen dynamic catchment model in this study.

Objective: Evaluate the performance of the SWAT model to simulate water quantity and water quality in a typical dairy farming catchment in New Zealand

Case study: the Toenepi catchment

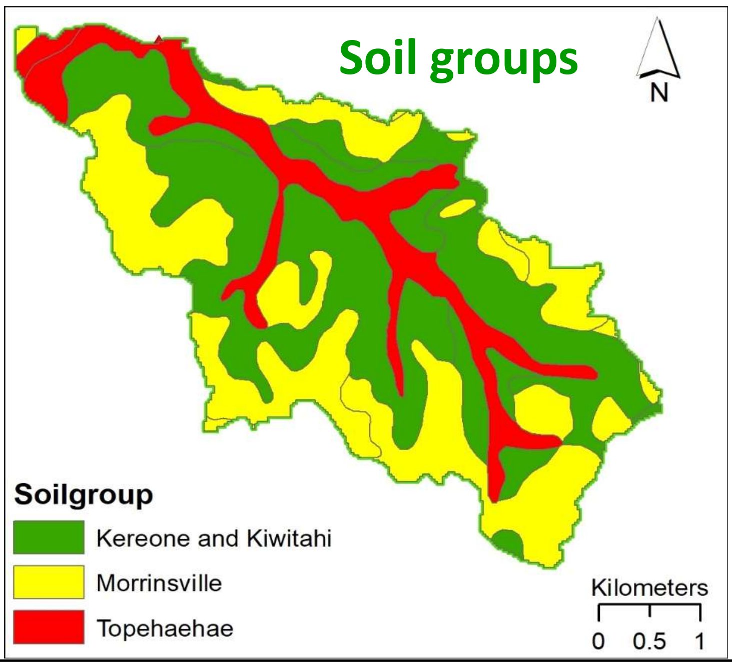
- The Toenepi catchment is located in a long-established dairying area near Morrinsville, Waikato, in the North Island of New Zealand.
- Toenepi is one of the Dairy Best Practice catchments with extensive long-term monitoring data, information about farm practices and knowledge about biophysical characteristics from previous studies.

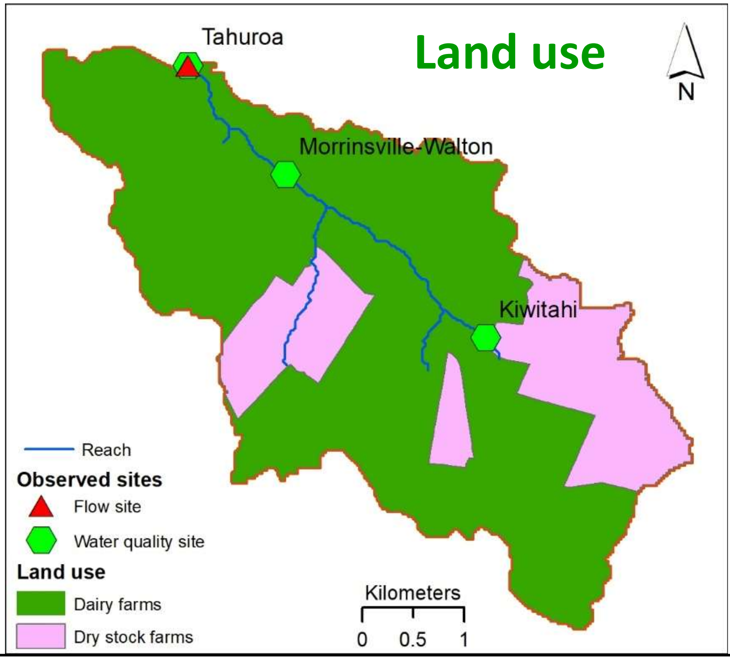




Case study: the Toenepi catchment

- *Catchment area*: approximately 15.1 km^2
- *Elevation*: 40 to 130 m above mean sea level
- *Climate*: Mean annual rainfall is approximately 1280mm, and mean annual air temperature is 14°C
- *Soil*: *Topehaehae* (poorly drained, in low lying area, 13%), *Kereone and Kiwitahi (*well drained, on easy to rolling slope, 47%), and *Morrinsville (*well drained, on rolling slopes, 40%)
- *Land use*: Dairy farms (76%) and dry stock farms (26%)

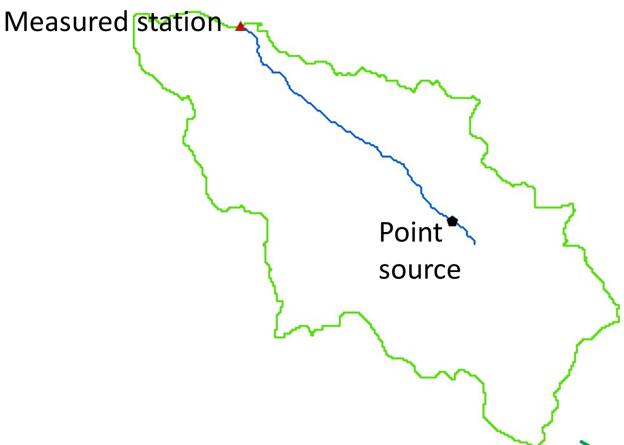




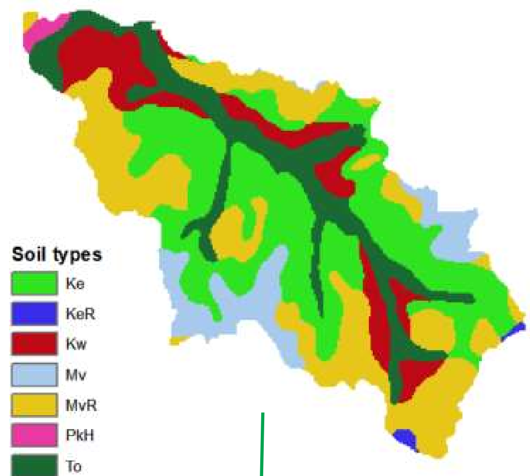
SWAT model setup for the Toenepi catchment

Dividing into Hydrological Response Units (HRUs)

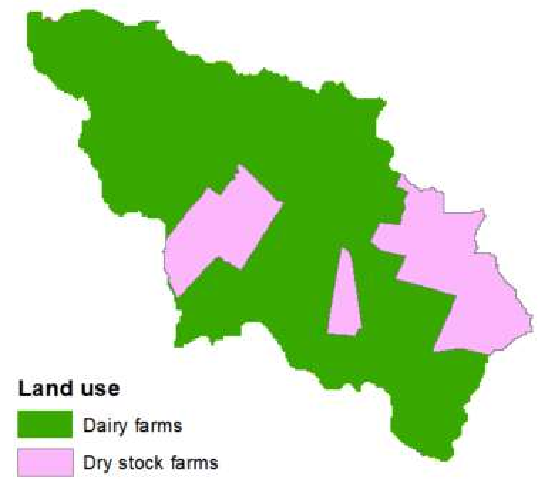
Subbasins



Soil map



Land use map



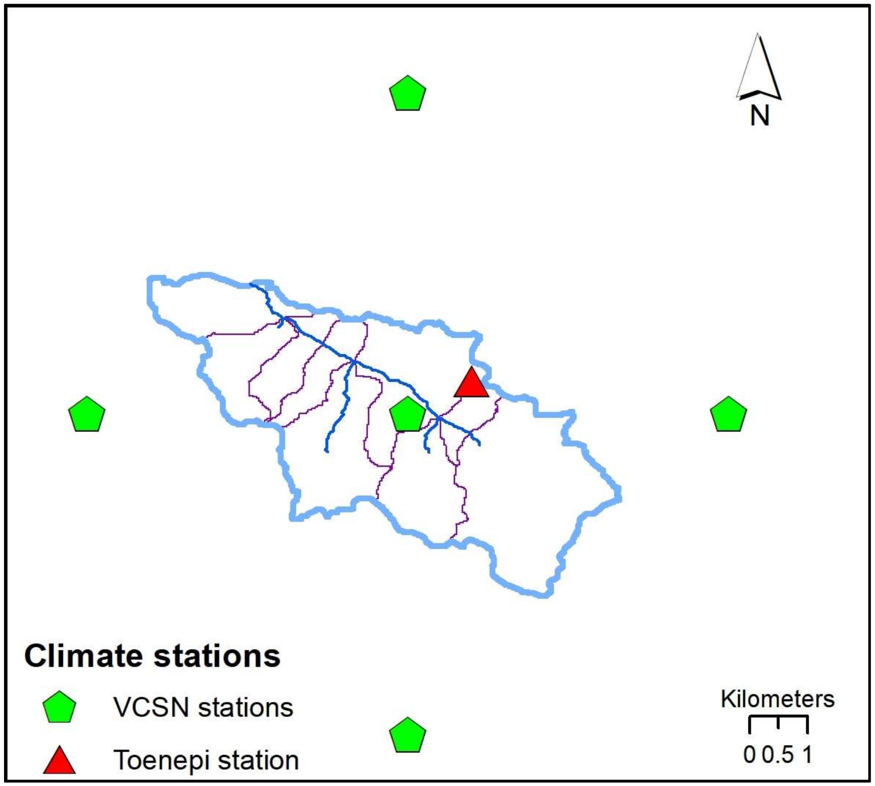
OVERLAY

HRUs in which all processes are simulated

SWAT model setup for the Toenepi catchment

Climate data

- Local station: Toenepi station
- Virtual Climate Station Network (VCSN): 5x5 km gridded climate data

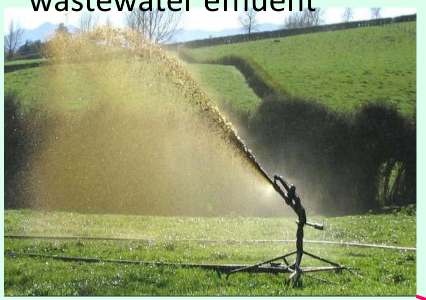


SWAT model setup for the Toenepi catchment

Nutrient sources

Diffuse sources

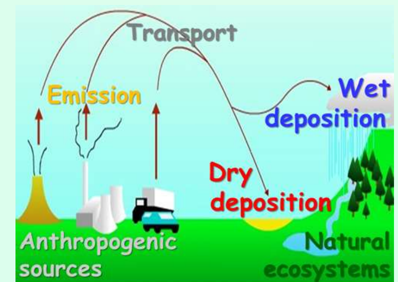
Application of dairy shed wastewater effluent



Cattle manure

Fertilizer application

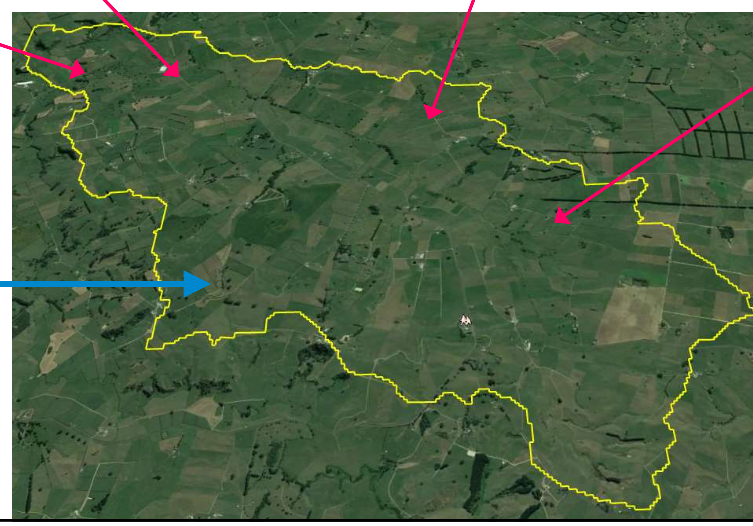
Atmospheric deposition



Point sources

Dairy shed wastewater discharge from oxidation ponds

50 L cow^{-1} day^{-1}



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SWAT model setup for the Toenepi catchment

Estimate nutrient inputs to SWAT

Sources	Details	Estimating method	Nitrogen input	Phosphorus input
Point sources	Dairy shed effluent discharged to streams	*Amount of dairy shed effluent * % discharged directly to streams*	1-11 kg N/day for 270 lactation days	0.3 – 2.3 kg P/day for 270 lactation days
Diffuse sources	Manure from cattle grazing	*Number of animal * amount of manure/animal * %nutrient in manure* *Data taken from farm survey and Agricultural Waste manual*	280 – 325 kgN/ha/year	29-34 kg P/ha/year
	Fertilizer application	Wilcock et al. (2013) and farm surveys	65-120 kgN/ha/year	20-78 kg P/ha/year
	Nitrogen fixation	Parfitt et al (2012)	~ 40 kgN/ha/year	-
	Dry deposition	Parfitt et al (2012) reported 5- 10 kgN/ha	7.5 kgN/ha/year *(50% NH_4, 50% NO_3)*	- (SWAT does not consider P in atmospheric deposition)
	Wet deposition	Parfitt et al (2012)	1.5 kgN/ha/year *(50% NH_4, 50% NO_3)*	-
	Application of dairy shed effluent to land	*Amount of dairy shed effluent * % applied on land* (Wilcock et al., 2013)	0.12-2.4 kgN/ha/year	0.2-0.5 kg P/ha/year

Results and discussion

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Evaluation of SWAT model performance in hydrology

- *Daily flow*

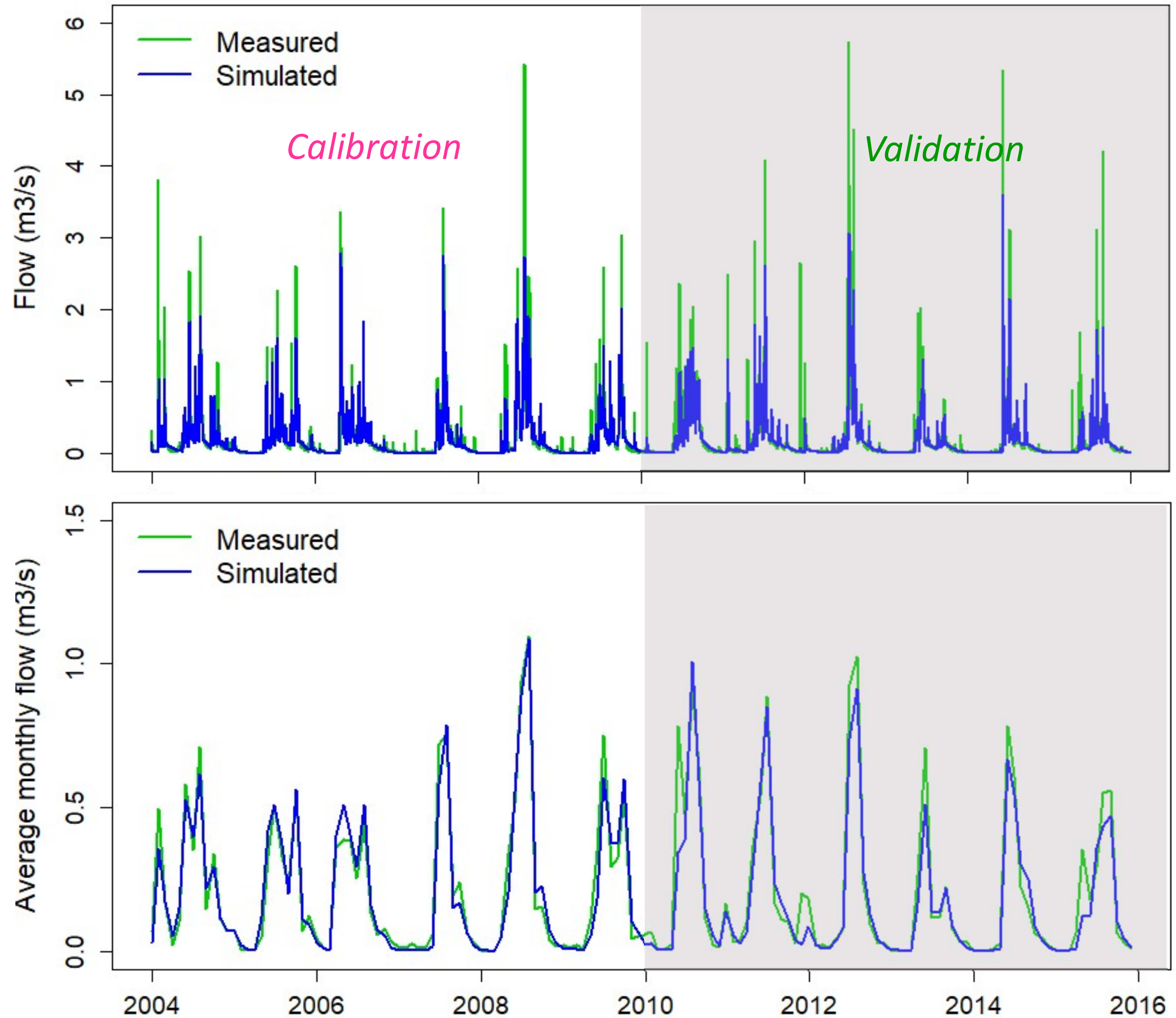
  $NSE_{cal} = 0.83$

  $NSE_{val} = 0.78$

- *Monthly flow*

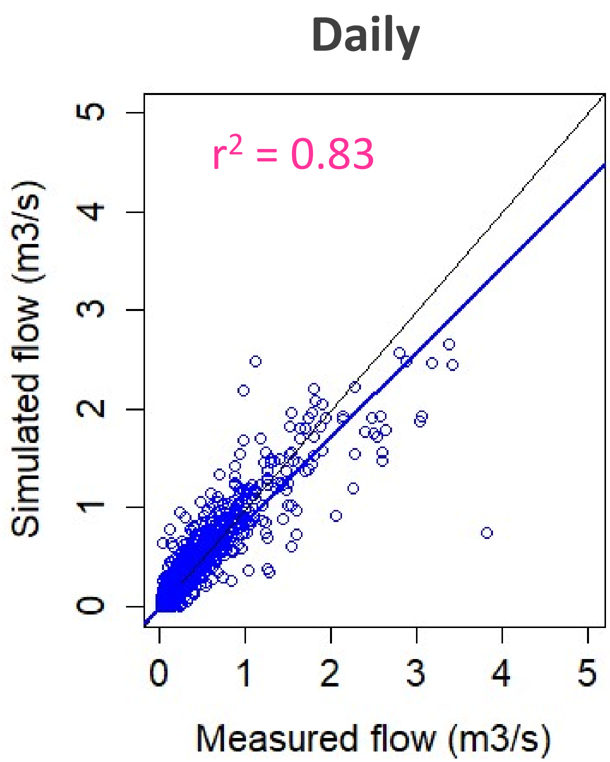
  $NSE_{cal} = 0.95$

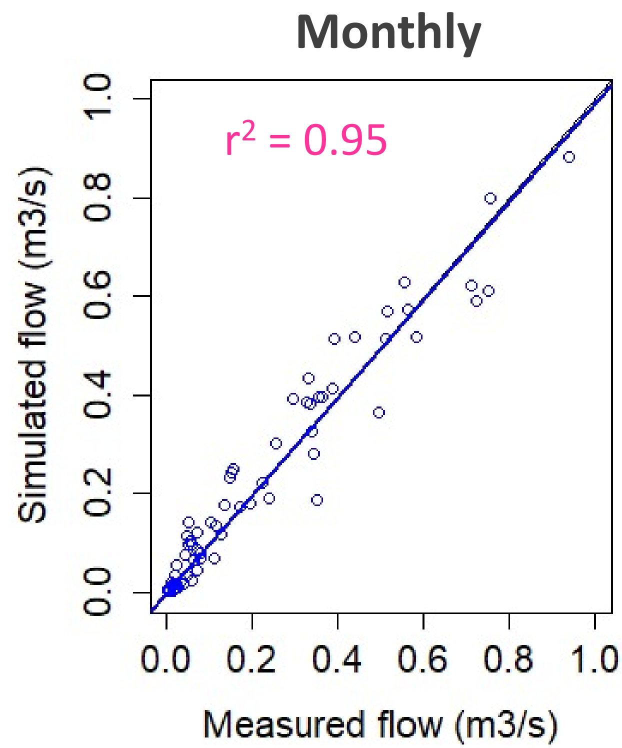
  $NSE_{val} = 0.92$



Evaluation of SWAT model performance in hydrology

Scatter plot

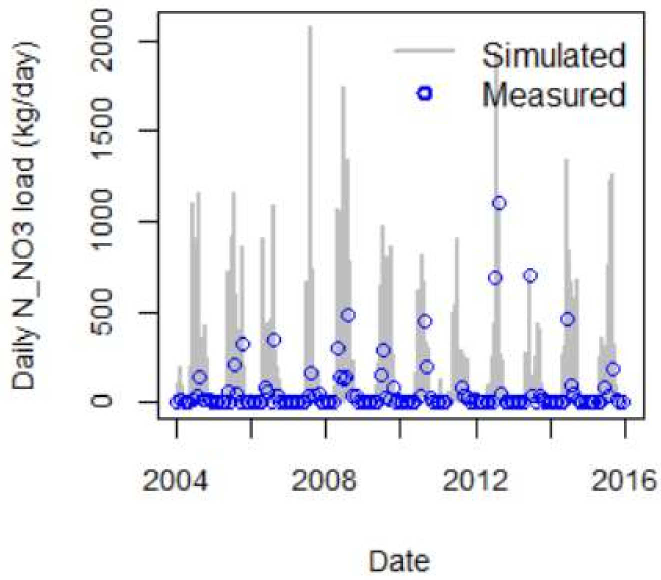


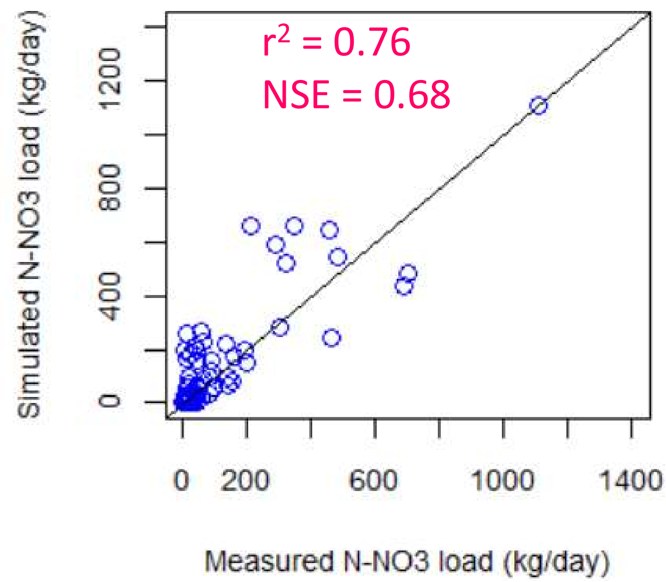


- Overall, SWAT gives a reasonable streamflow prediction for both daily and monthly time steps.
- Monthly streamflow have better fit to observations than the daily ones.

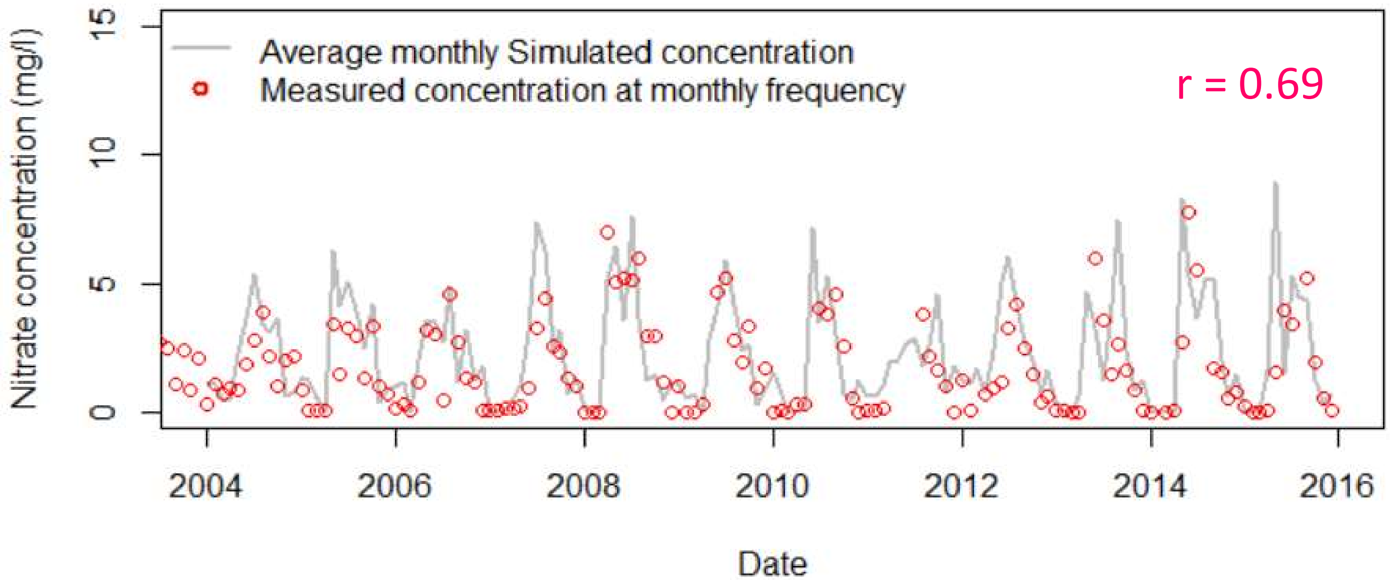
Evaluation of SWAT model performance for Nitrogen

Nitrate load





Nitrate concentration



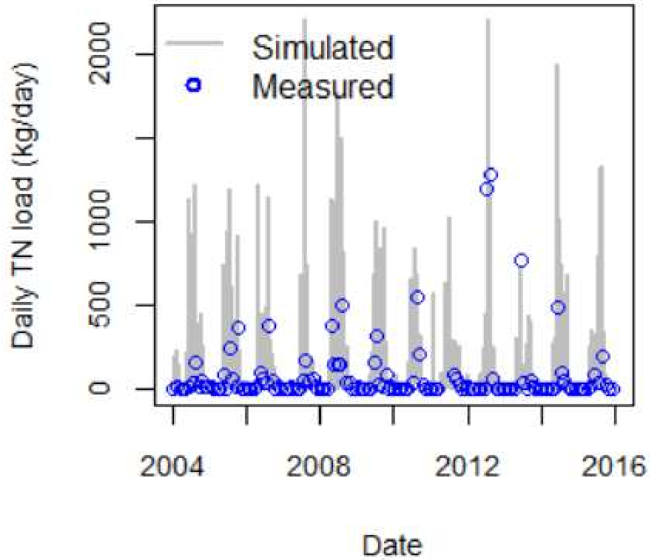
NSE: Nash-Sutcliffe efficiency

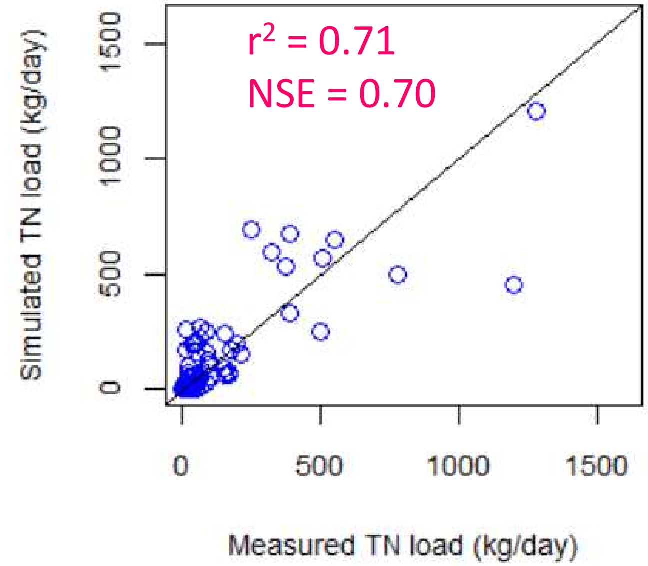
r^2: Coefficient of determination

r: Correlation coefficient

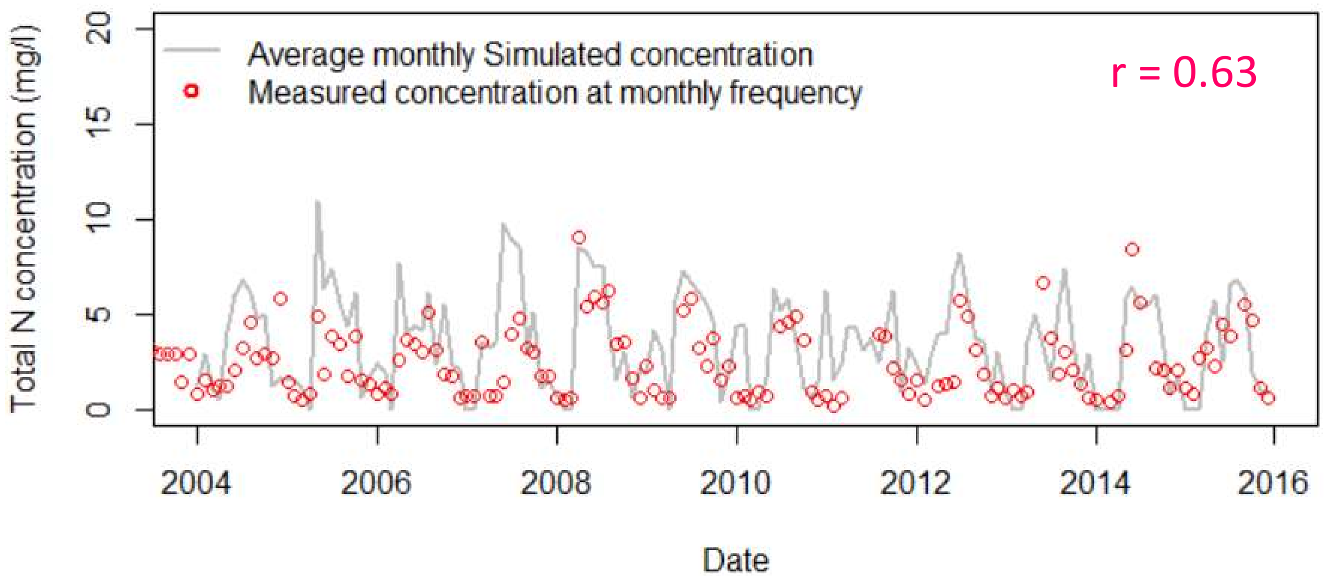
Evaluation of SWAT model performance for Nitrogen

Total N load





Total N concentration



r^2: Coefficient of determination

r: Correlation coefficient

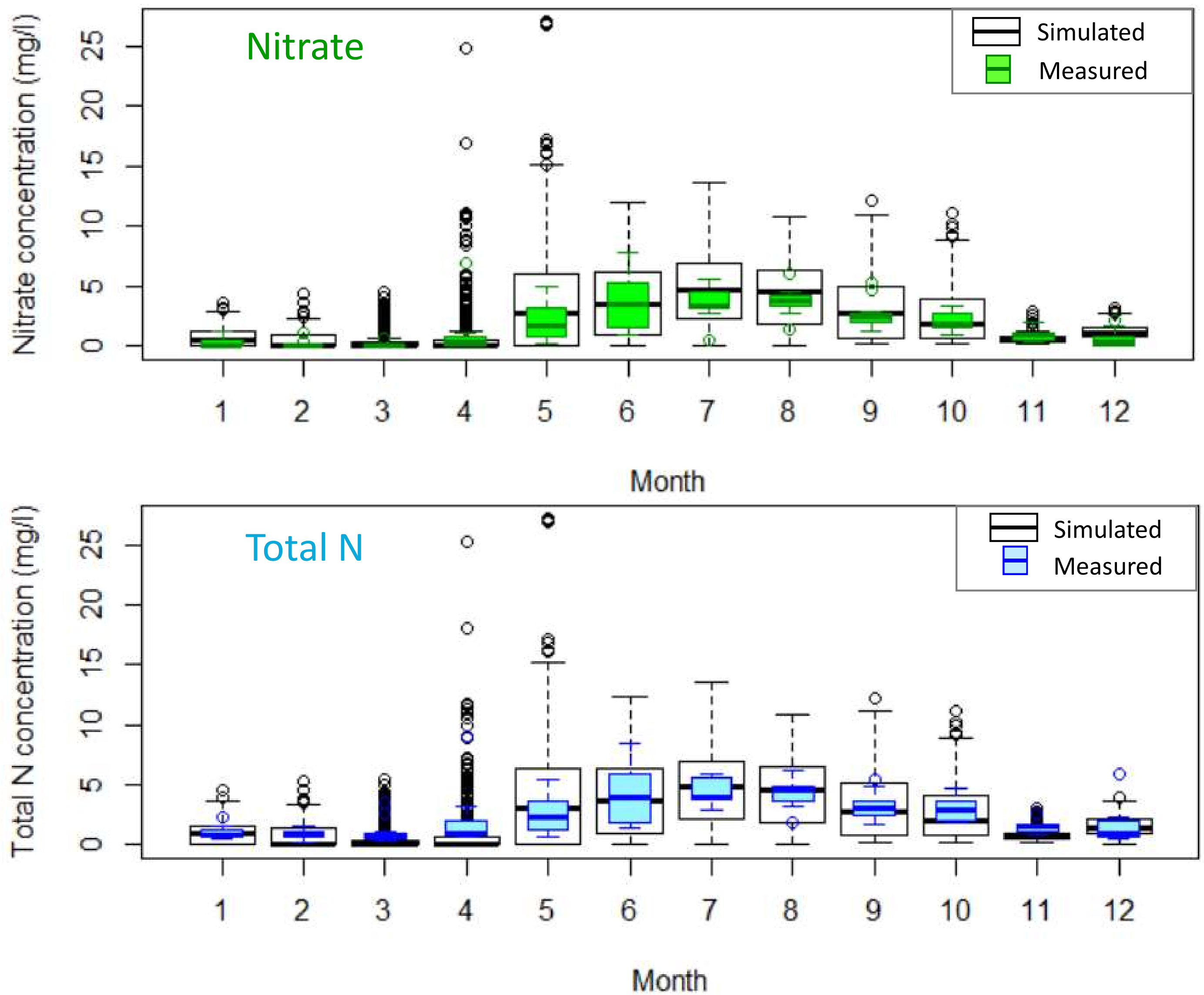
Evaluation of SWAT model performance for Nitrogen

Seasonal variation of

Simulated N concentration

versus

Measured N concentration



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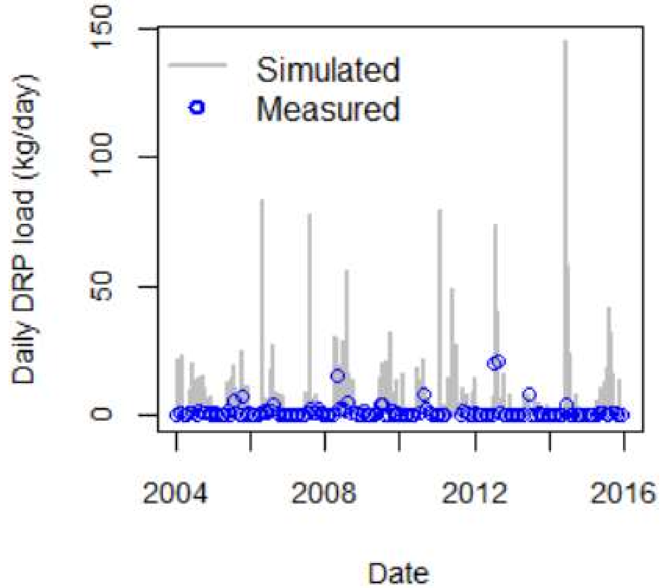
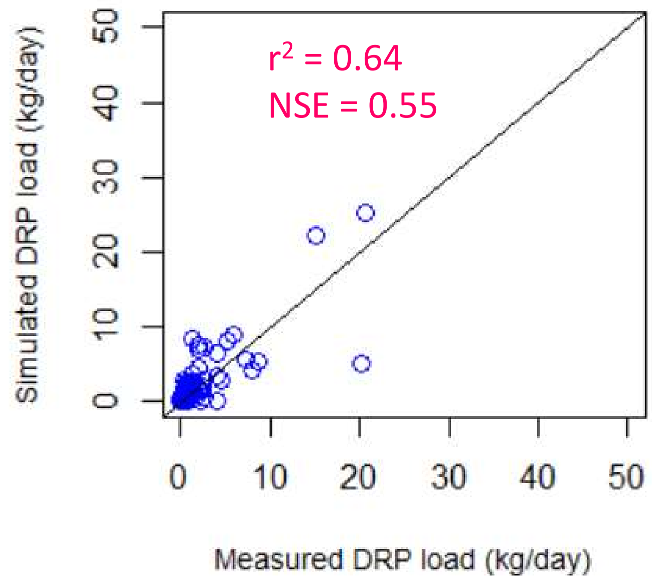
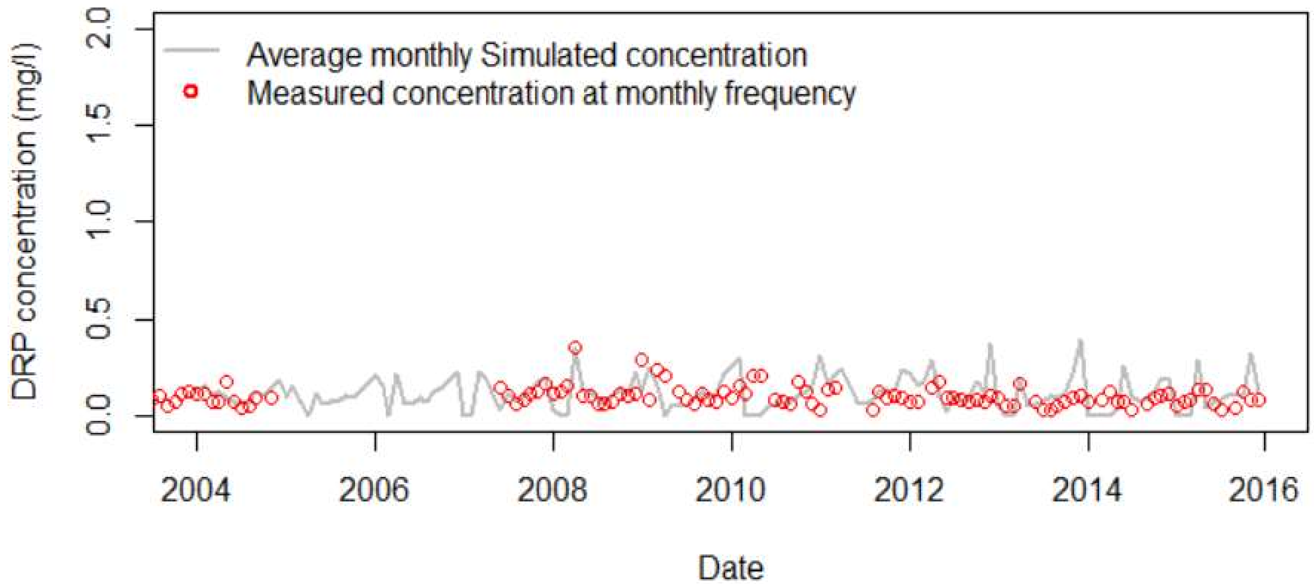
Evaluation of SWAT model performance for Phosphorus

Soluble P load





Soluble P concentration



r^2: Coefficient of determination

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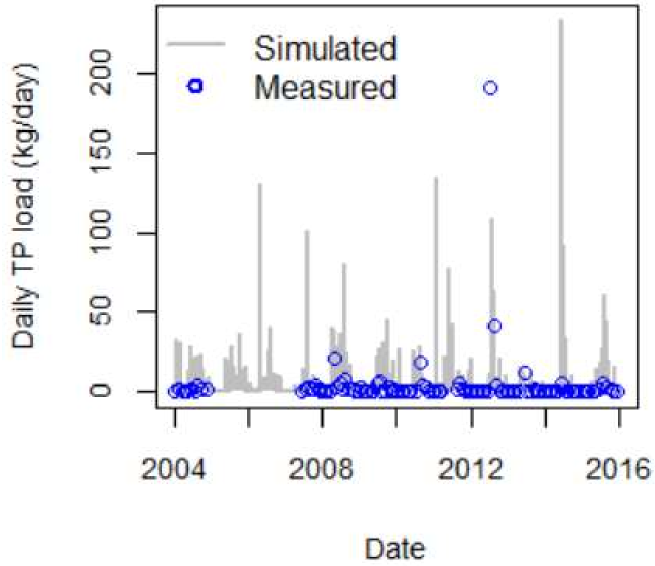
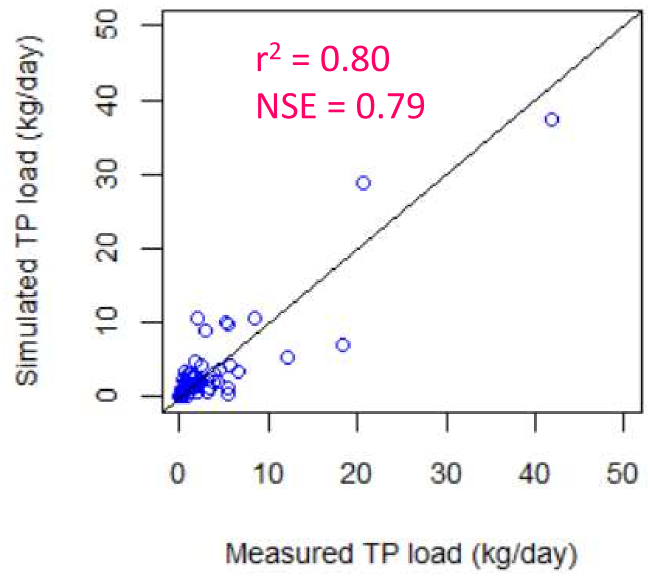
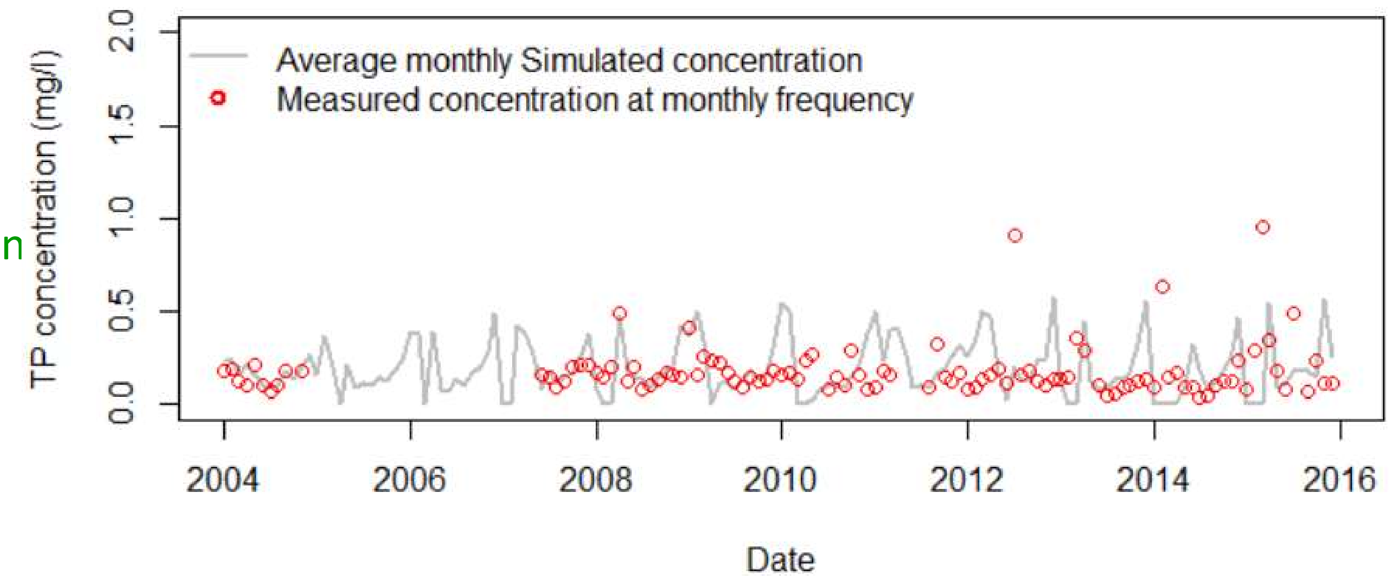
Evaluation of SWAT model performance for Phosphorus

Total P load





Total P concentration



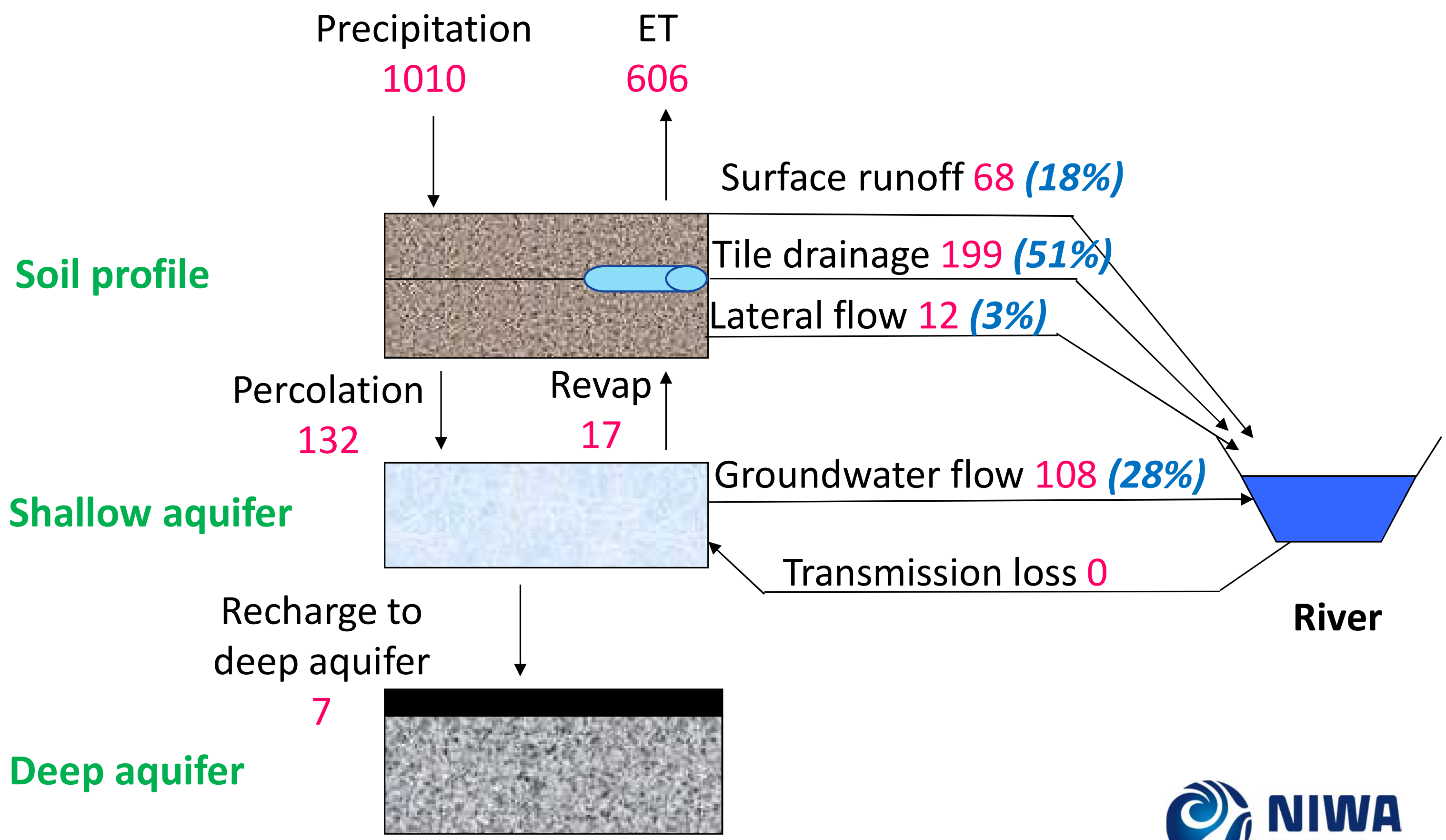
r^2: Coefficient of determination

r: Correlation coefficient

SWAT model predictions

Water balance

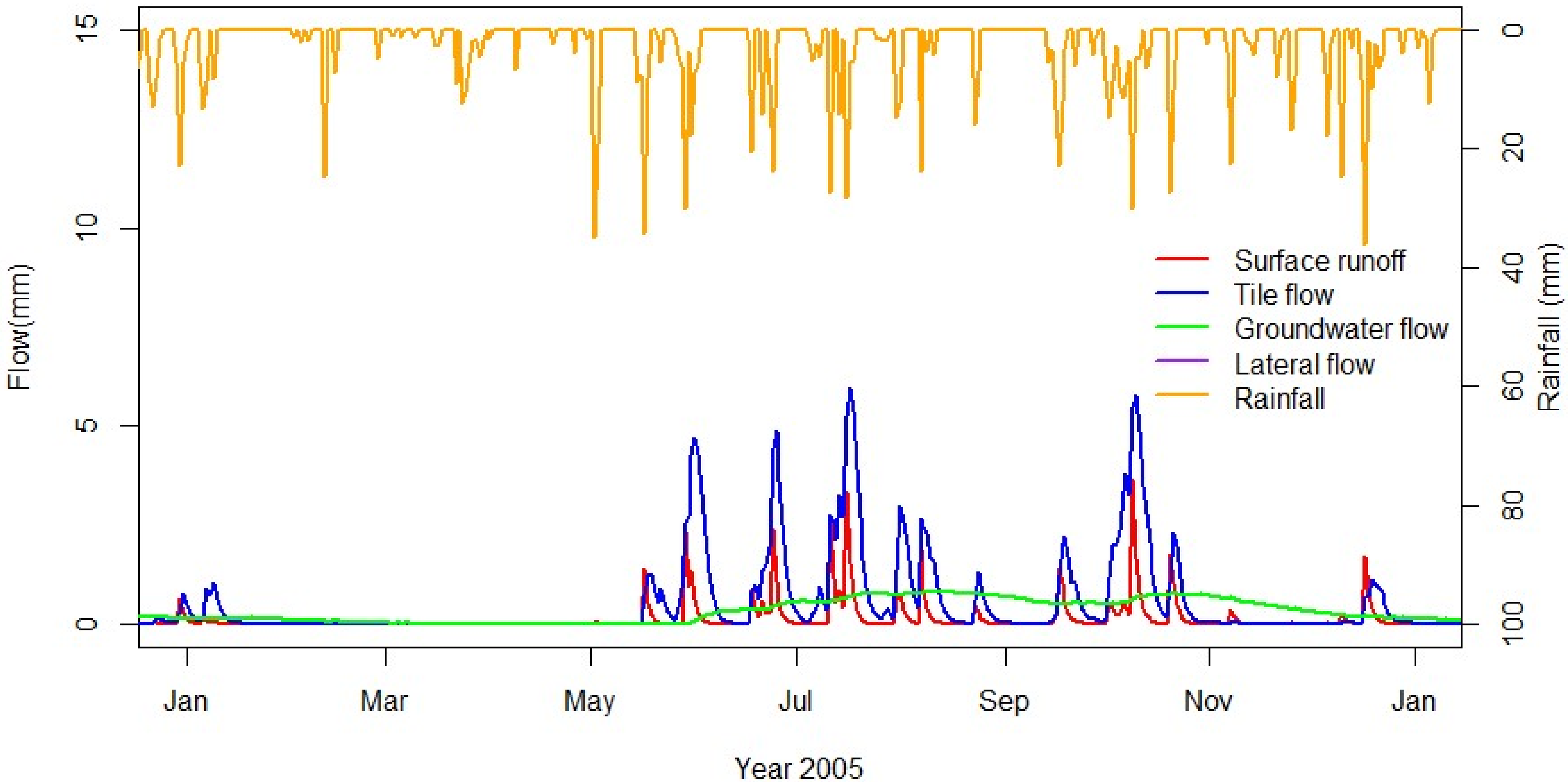
Average value from 2004-2015



SWAT model predictions

Flow components

Contribution from different flow components in year 2005



SWAT model predictions

Nitrogen inputs

No.	Sources of inputs	Value (kgN/ha/year)
1	Manure from cattle grazing	240
2	Fertilizer application	101
3	Nitrogen fixation	45
4	Dry deposition	7.5
5	Wet deposition	1.5
6	Application of dairy shed effluent to land	2.1

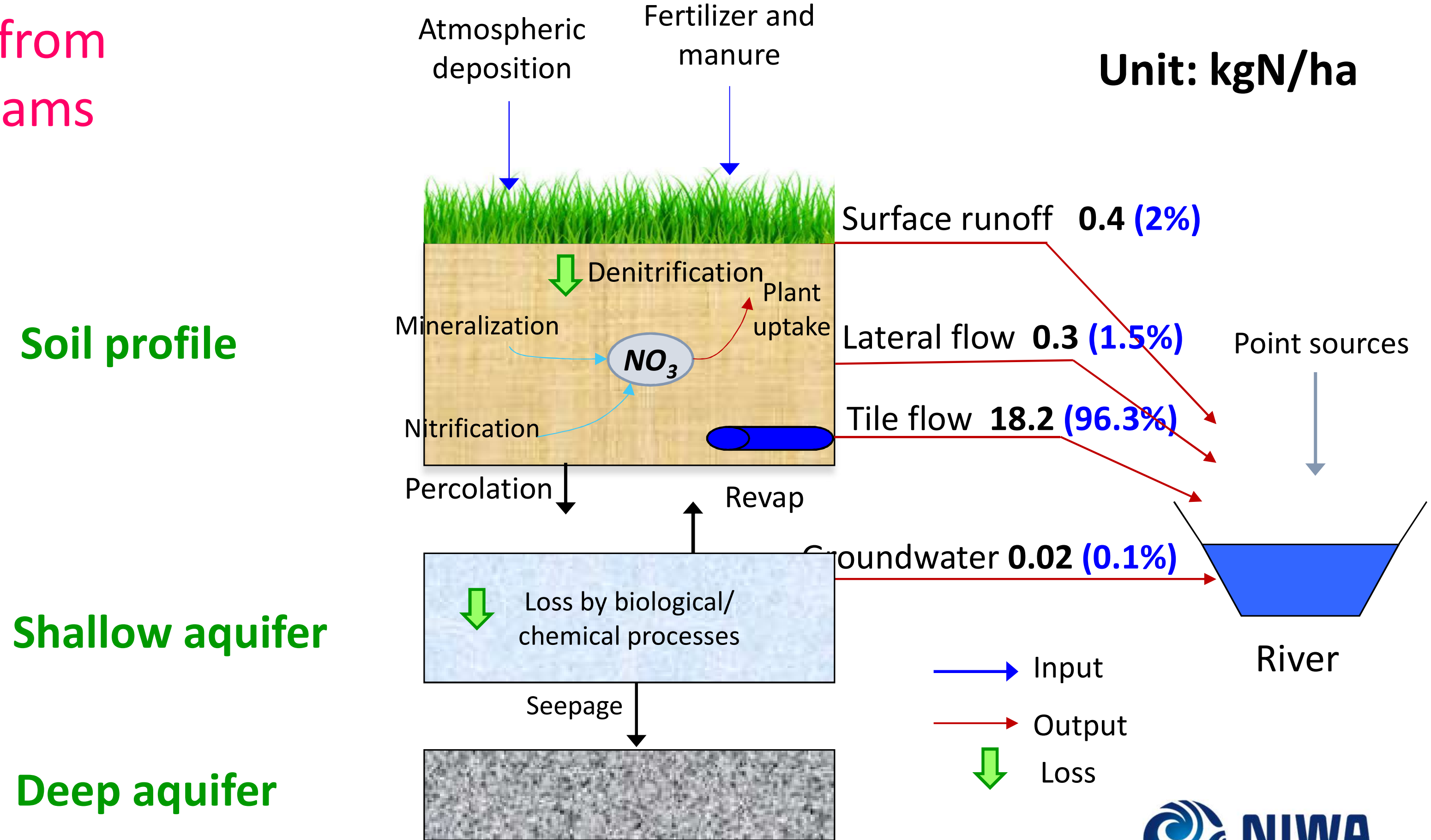
Nitrogen outputs

No.	Nitrogen loss	Value (kgN/ha/year)
1	Loss to biomass eaten by cattle	310
2	Loss to the stream ($N\text{-}NO_3$)	19
3	Denitrification	58
4	Ammonia volatilization	40
5	Loss by erosion (organic N)	5

Average value from 2004-2015

SWAT model predictions

Nitrate transport from catchment to streams



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Average value from 2004-2015

SWAT model predictions

Phosphorus inputs

No.	Sources of inputs	Value (kg P/ha/year)
1	Manure from cattle grazing	25
2	Fertilizer application	27
3	Application of dairy shed effluent to land	0.5

Phosphorus outputs

No.	Phosphorus loss	Type of P	Value (kg P/ha)
1	Loss to biomass eaten by cattle (Phosphorus uptake)	Fresh P	33
2	Loss by erosion	Particulate P	0.06
3	Loss to the streams	Soluble P	1.72
	- Through surface runoff		0.34 (20%)
	- Through tile drainage		1.39 (80%)

Conclusions

- The SWAT model obtained very good prediction for streamflow at both daily and monthly time steps. The model performance was better at the monthly time step.
- SWAT also produced reasonable estimates and seasonal variation for nutrient yield and concentration based on limited and low frequency observations
- Subsurface drainage is the main contribution to streamflow, as expected in a pastoral catchment with an extensive tile drain network. Consequently, it is the dominant pathway for Nitrate and soluble Phosphorus transport to the streams.

Thank you

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