Applying treated municipal wastewater to a forested catchment: Modelling effects on stream discharge, sediment and nutrient loads

Ph.D. Wang Me

Prof. David Hamilton

Dr. Jonathan Abell

Environmental Research Institute
Te Pūtahi Rangahau Taiao
THE UNIVERSITY OF WAIKATO

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

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Background

- The use of forested areas for wastewater irrigation has been increasingly adopted for tertiary treatment in inland cities
- The Soil and Water Assessment Tool (SWAT) has been used to evaluate impacts of alternative land management practices
- Few studies have applied the hourly routing algorithm in SWAT to simulate nutrient fluxes, or to evaluate forestry irrigation

Wastewater disposal at Nipawin, Canada
Photo: SaskWater

Wastewater disposal at Penn State, US
Photo: Matthew Laposata

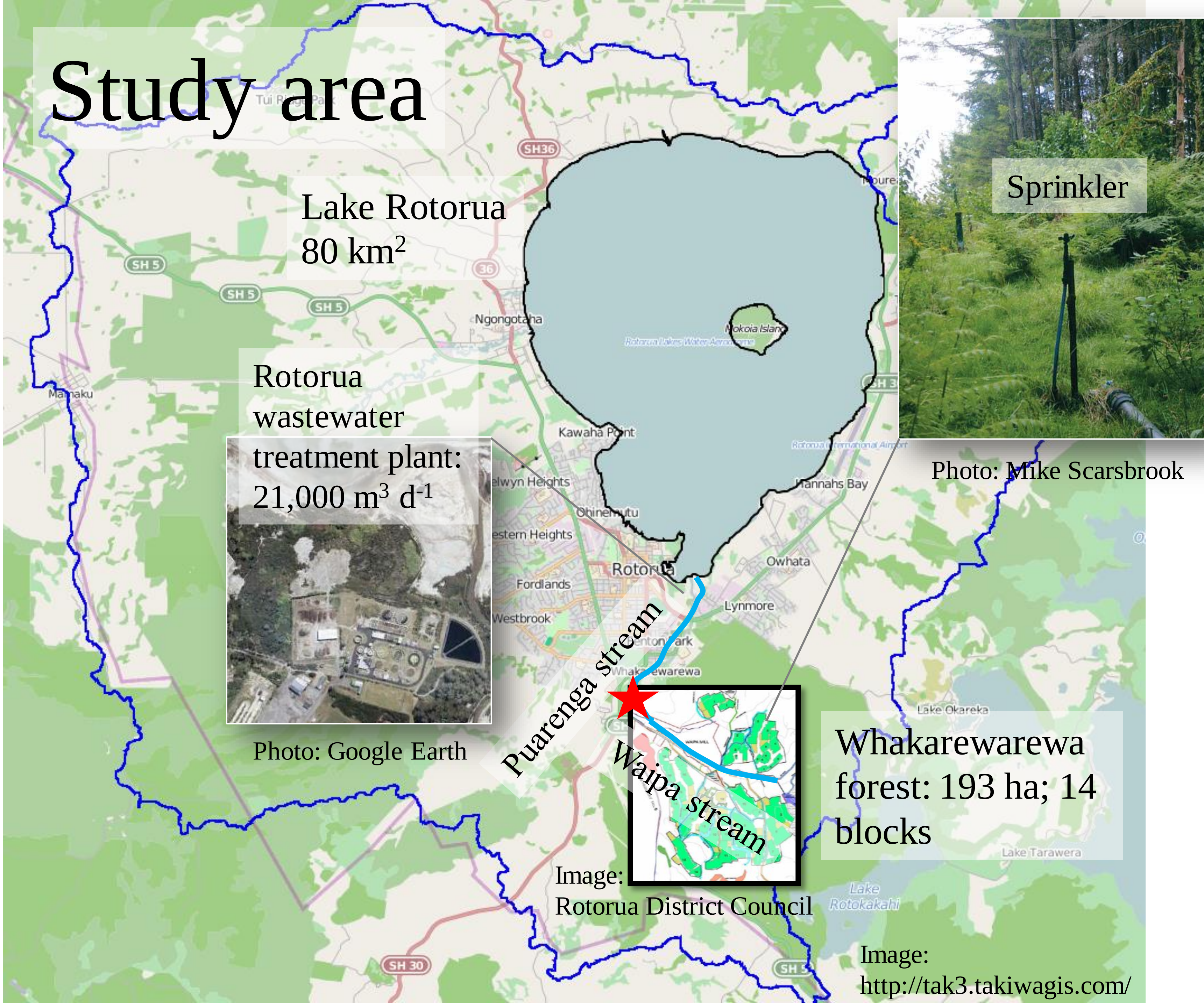
Photo: Centuries–old trees, Rotorua, New Zealand

Objectives

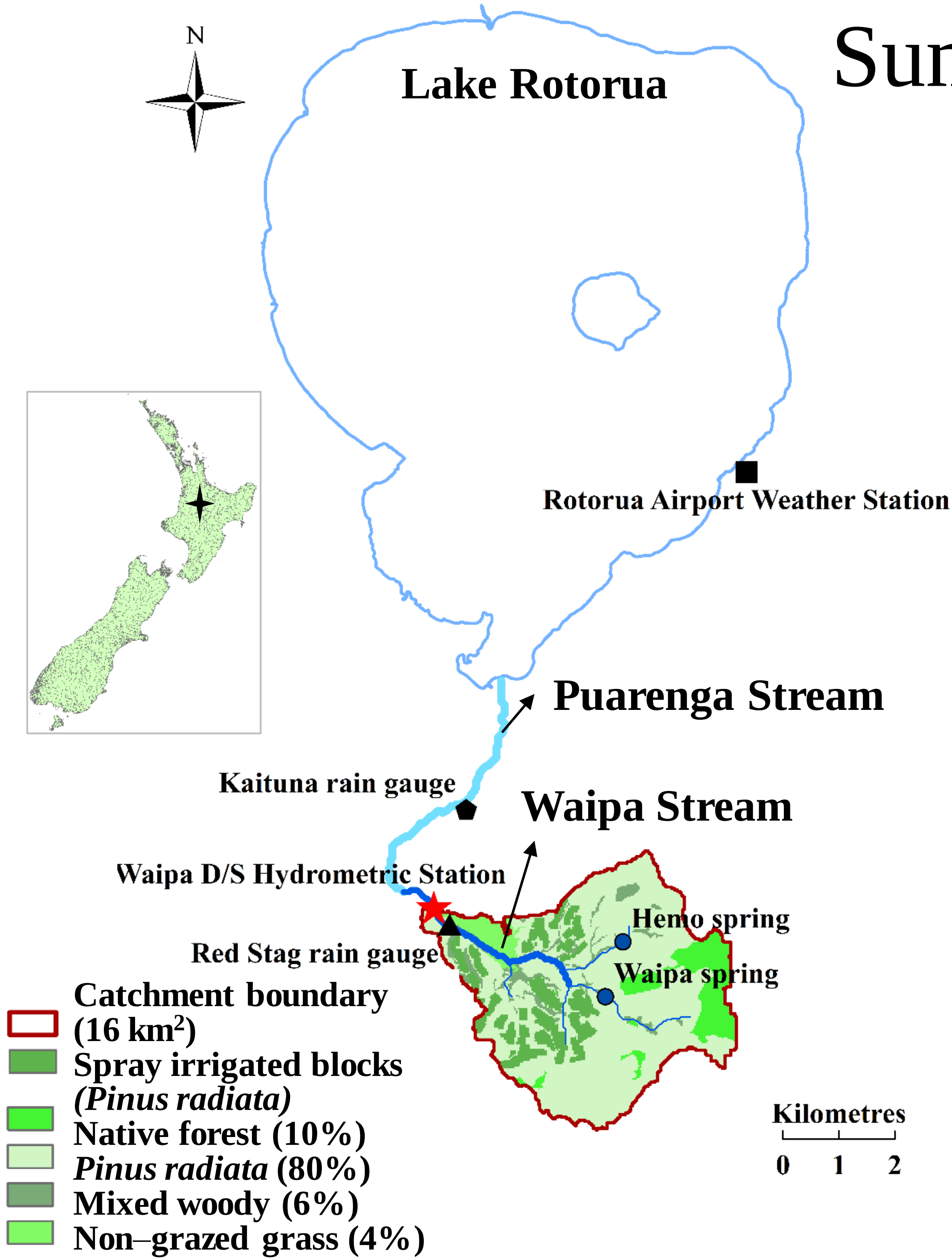
- Evaluate the effectiveness of a Land Treatment System (LTS) for nutrient removal from treated wastewater

- Examine and simulate (with SWAT) long–term (10–year) effects of treated wastewater irrigation, forestry harvesting, and altered rainfall on LTS

- Run scenarios to provide information on the effects of different management strategies for wastewater irrigation


Study area
Lake Rotorua
80 km²
Rotorua wastewater treatment plant: 21,000 m³ d⁻¹
Photo: Google Earth
Sprinkler
Photo: Mike Scarsbrook
Puarenga stream
Waipa stream
Whakarewarewa forest: 193 ha; 14 blocks
Image: Rotorua District Council
Image: http://tak3.takiwagis.com/

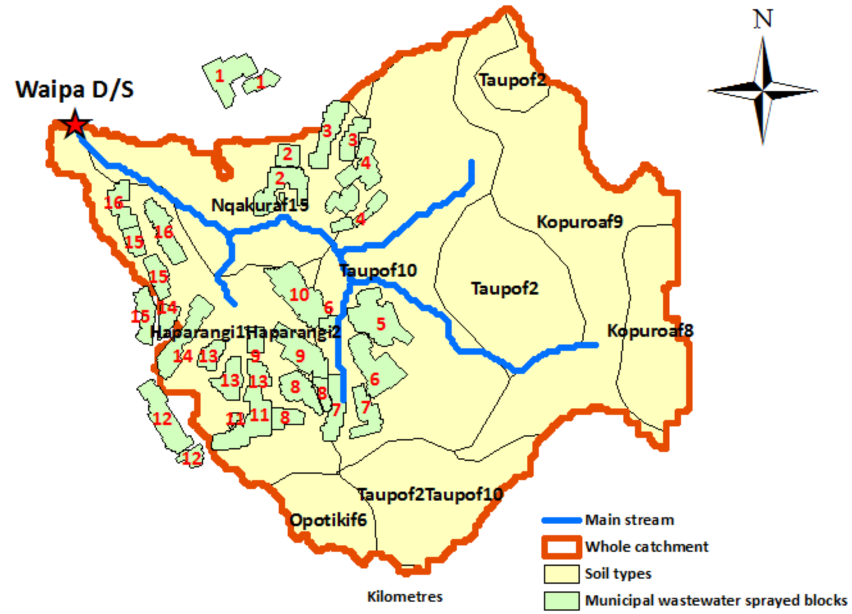
Summary of SWAT setup



- ✓Digital Elevation Model
- ✓Meteorological records
- ✓Atmospheric deposition
- ✓Soil parameterization
- ✓Land use classification
- ✓Plant growth
- ✓Management schedules
- ✓Point sources (e.g. spring)
- ✓Monitoring station
- ✓Hydrologic forcing data:
  - Hourly rainfall
- ✓ **Hourly rainfall/infiltration (Green and Ampt, 1911)/hourly routing algorithm**

Management schedule setup

- Each block was assumed to be planted and mature at the start of the modelling period.
- Pine harvesting operations were configured by the harvesting date.



Variable	Definition	Specification
IRR_AMT	Depth of irrigation water applied on HRU	Daily irrigation volume
IRR_SQ	Surface runoff ratio (fraction)	Web–based Hydrograph Analysis Tool
IRR_SC	Irrigation source	Outside of the catchment
FRT_KG	Amount of fertilizer applied to HRU (kg ha^{-1})	Contaminants in the wastewater
FRT_SURFACE	Fraction of fertilizer applied to top 10 mm of the soil	Web–based Hydrograph Analysis Tool

Challenges

- The complexity of irrigation operations
  - ✓ Multiple blocks were configured with daily input for up to three operations (irrigation, fertiliser application and tree harvesting) for a period of 10 years
- Limited consideration in hourly routing algorithm of modelling nutrient transport

Photo: Redwood Grove, Rotorua, New Zealand

SWAT2012 code modifications

Management schedules

Apply daily fertilizer (kg) onto each forested block which covers numerous HRUs

‘sched_mgt.f’
‘fert.f’
‘soil_write.f’

Management schedules

Operate a 10–year daily management schedule

‘iopera’
‘allocate_parms.f’

Sediment erosion

Simulate sediment load using hourly routing algorithm

‘rthsed.f’
‘rtout.f’
‘route.f’
‘ysed.f’

Phosphorus simulations

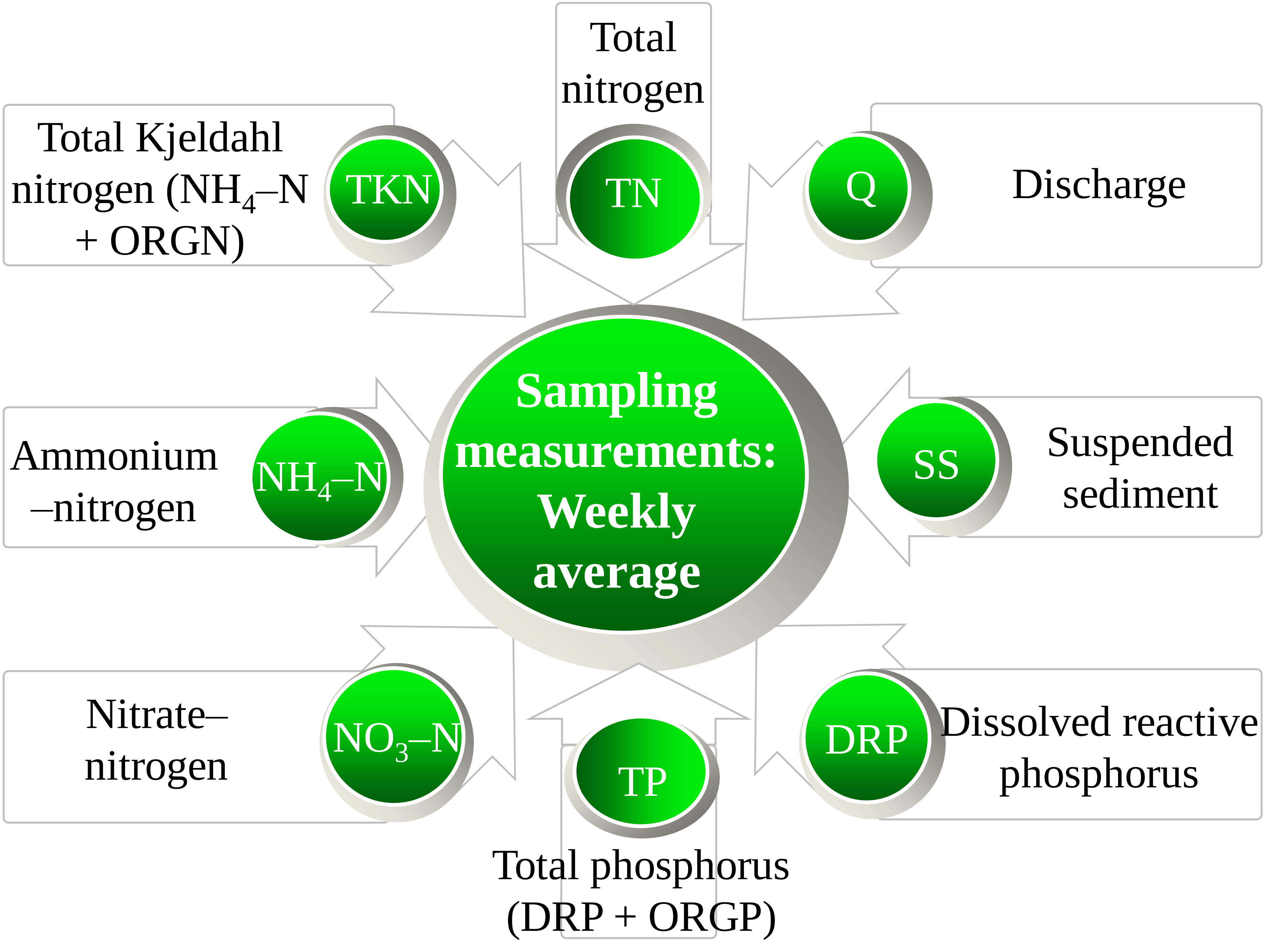
Simulate inorganic P bound to sediment

‘soil_chem.f’
‘psed.f’
‘enrsb.f’
‘solp.f’

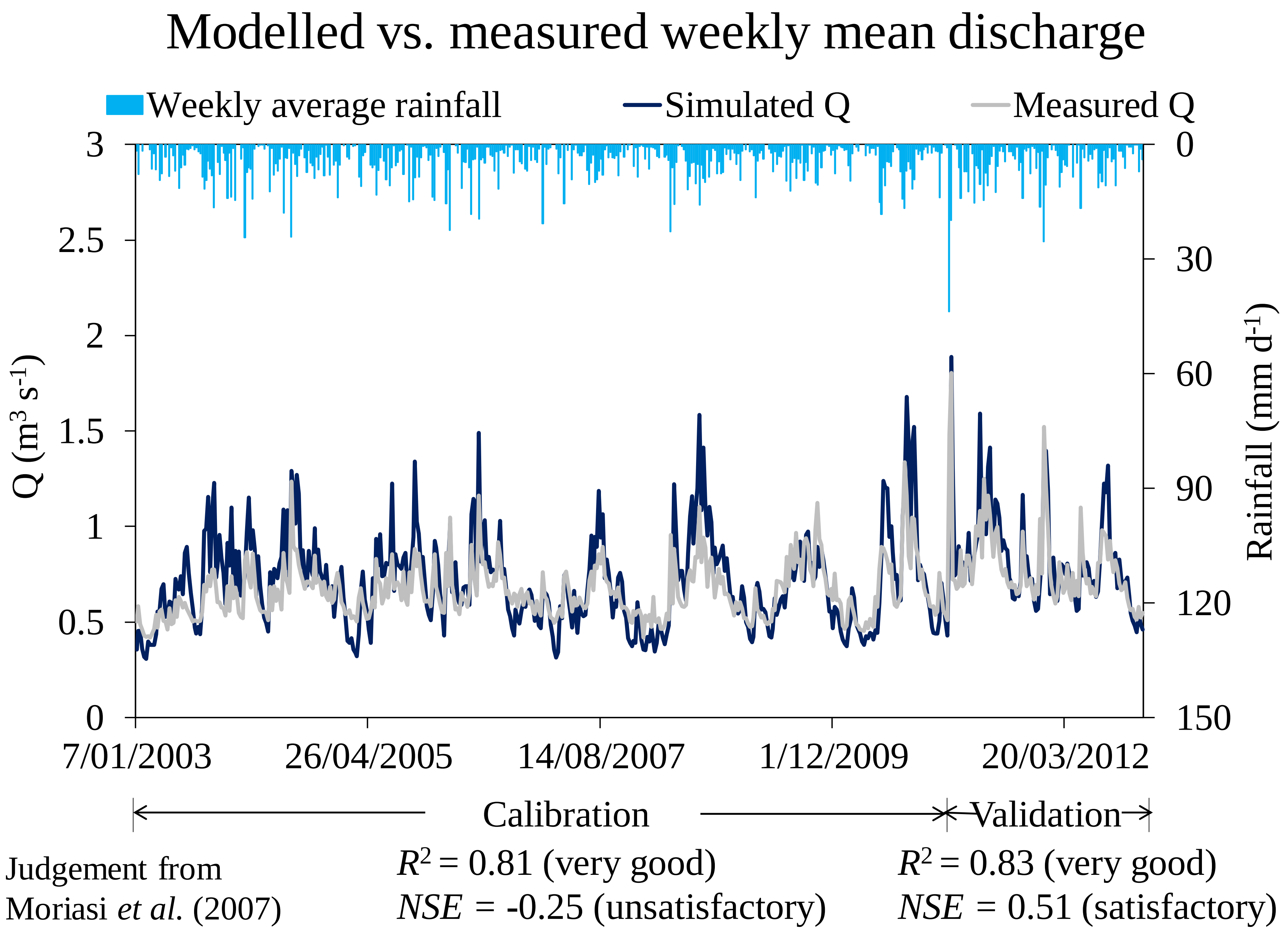
Nitrogen simulations

Constrain values of parameters for hydrolysis rate within the default range

‘orgn.f’

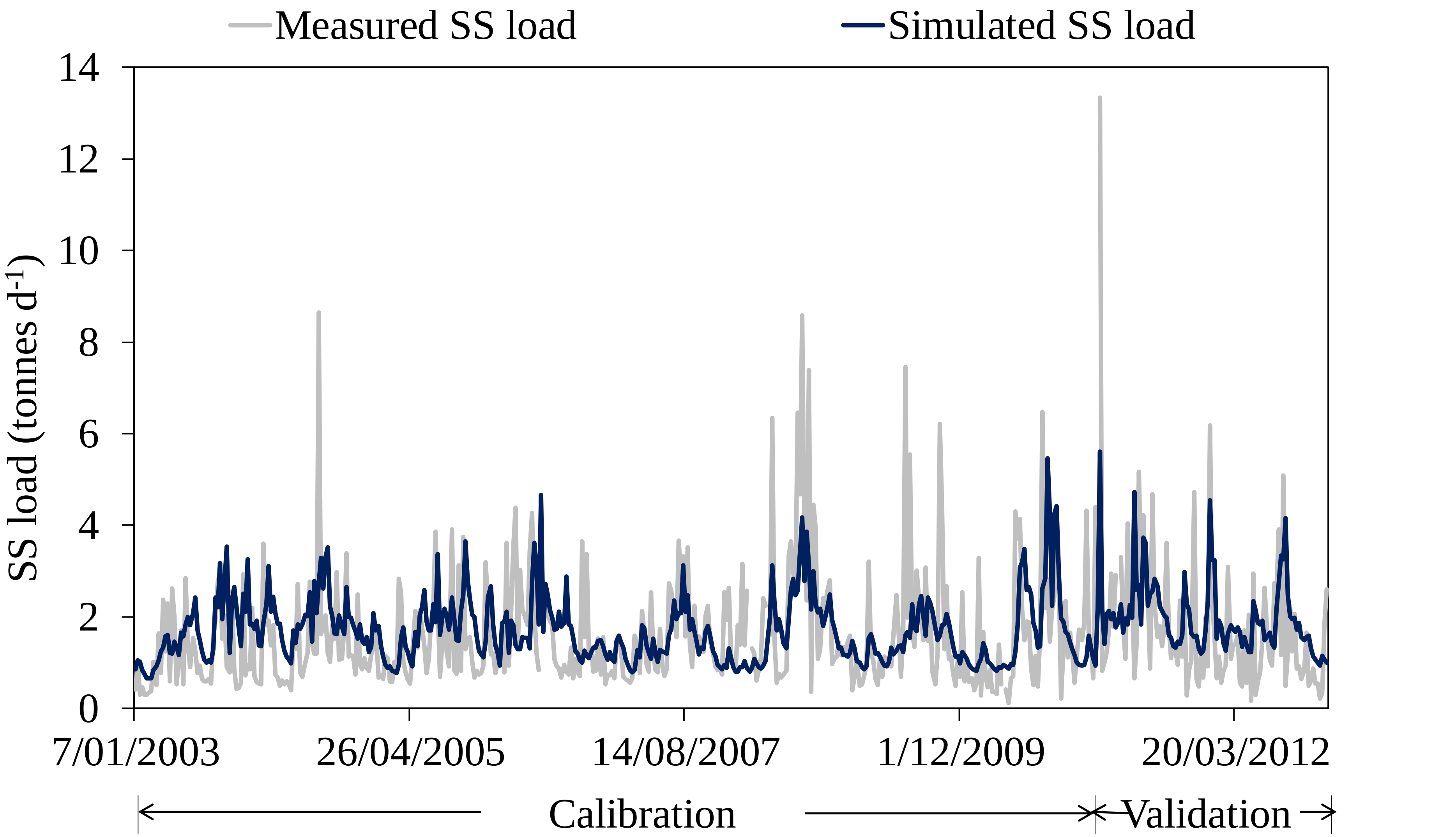


Sampling measurements: Weekly average
TKN
Total Kjeldahl nitrogen (NH_4–N + ORGN)
TN
Total nitrogen
Q
Discharge
NH_4–N
Ammonium–nitrogen
SS
Suspended sediment
NO_3–N
Nitrate–nitrogen
TP
Total phosphorus (DRP + ORGP)
DRP
Dissolved reactive phosphorus



Modelled vs. measured weekly mean discharge
Weekly average rainfall
Simulated Q
Measured Q
Q (m3 s-1)
Rainfall (mm d-1)
3
2.5
2
1.5
1
0.5
0
0
30
60
90
120
150
7/01/2003
26/04/2005
14/08/2007
1/12/2009
20/03/2012
Calibration
Validation
Judgement from
Moriasi et al. (2007)
R2 = 0.81 (very good)
NSE = -0.25 (unsatisfactory)
R2 = 0.83 (very good)
NSE = 0.51 (satisfactory)

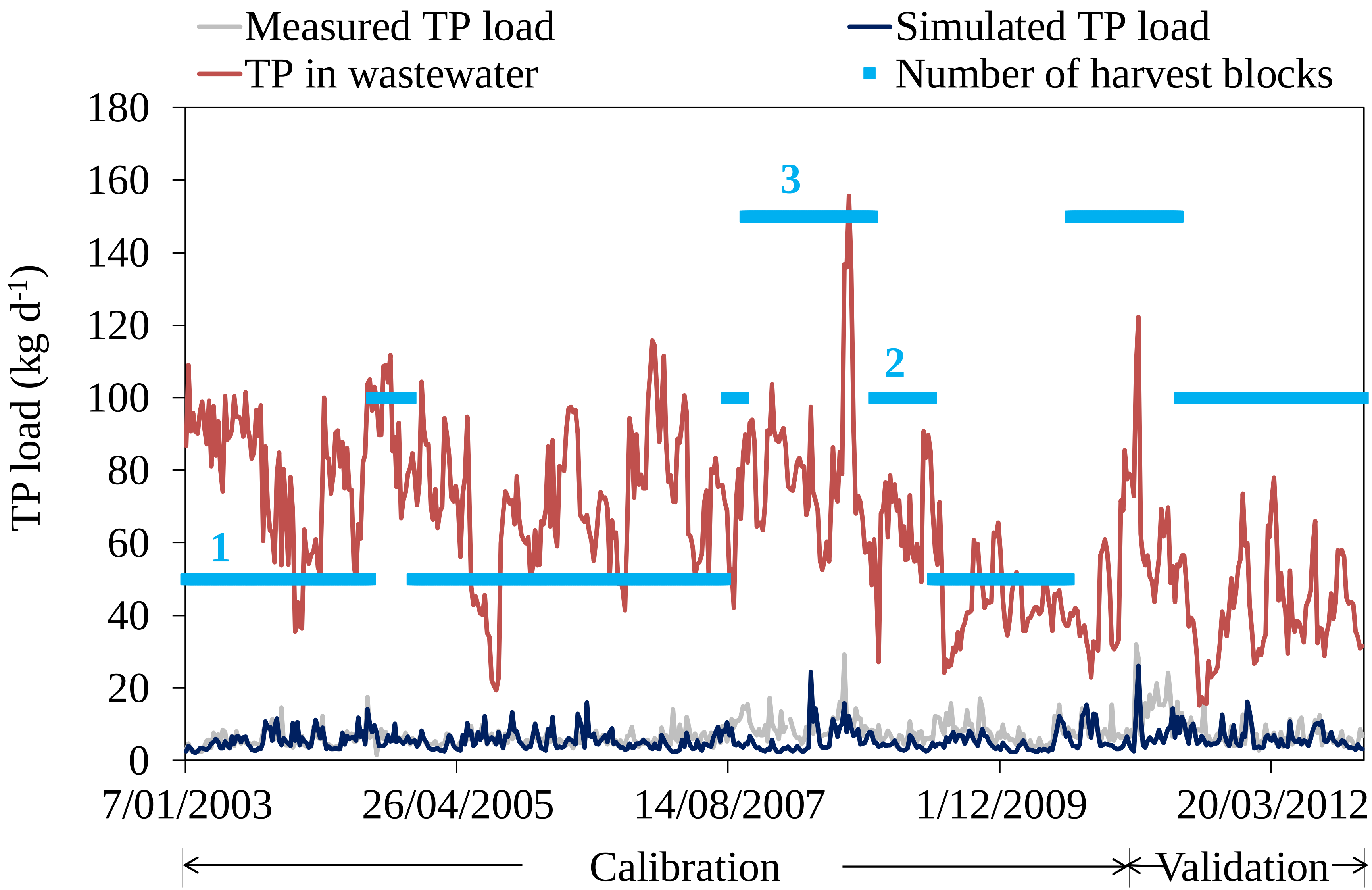
Modelled vs. measured weekly mean suspended solids



Judgement from Moriasi *et al.* (2007)

	Calibration	Validation
R^2	= 0.43 (unsatisfactory)	= 0.54 (satisfactory)
NSE	= 0.16 (unsatisfactory)	= 0.28 (unsatisfactory)

Modelled vs. measured weekly mean total phosphorus

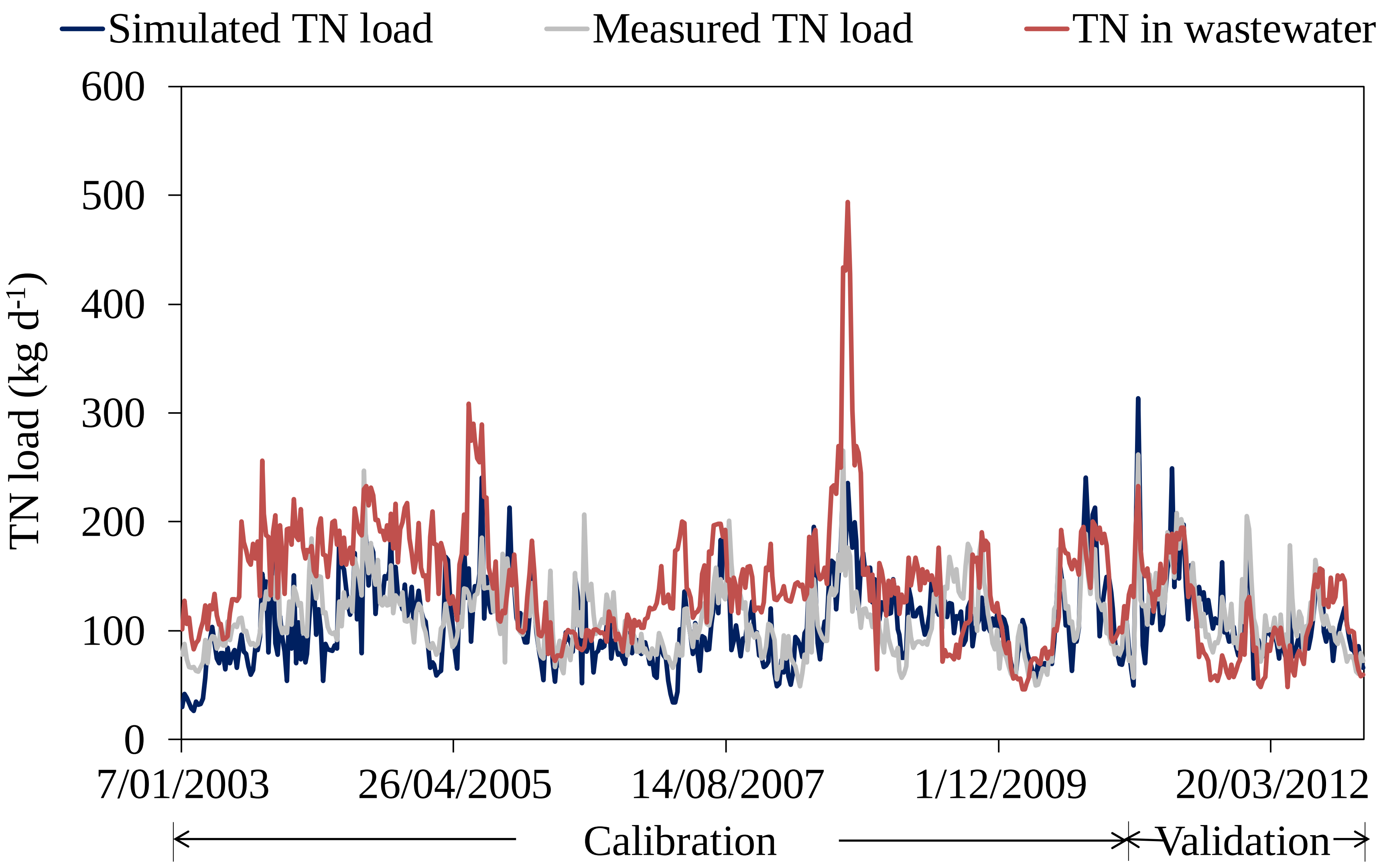


Judgement from Moriasi *et al.* (2007)

R^2 = 0.48 (unsatisfactory)
NSE = -0.2 (unsatisfactory)

R^2 = 0.52 (satisfactory)
NSE = 0.07 (unsatisfactory)

Modelled vs. measured weekly mean total nitrogen



Judgement from Moriasi *et al.* (2007)

R^2 = 0.7 (very good)
NSE = 0.25 (unsatisfactory)

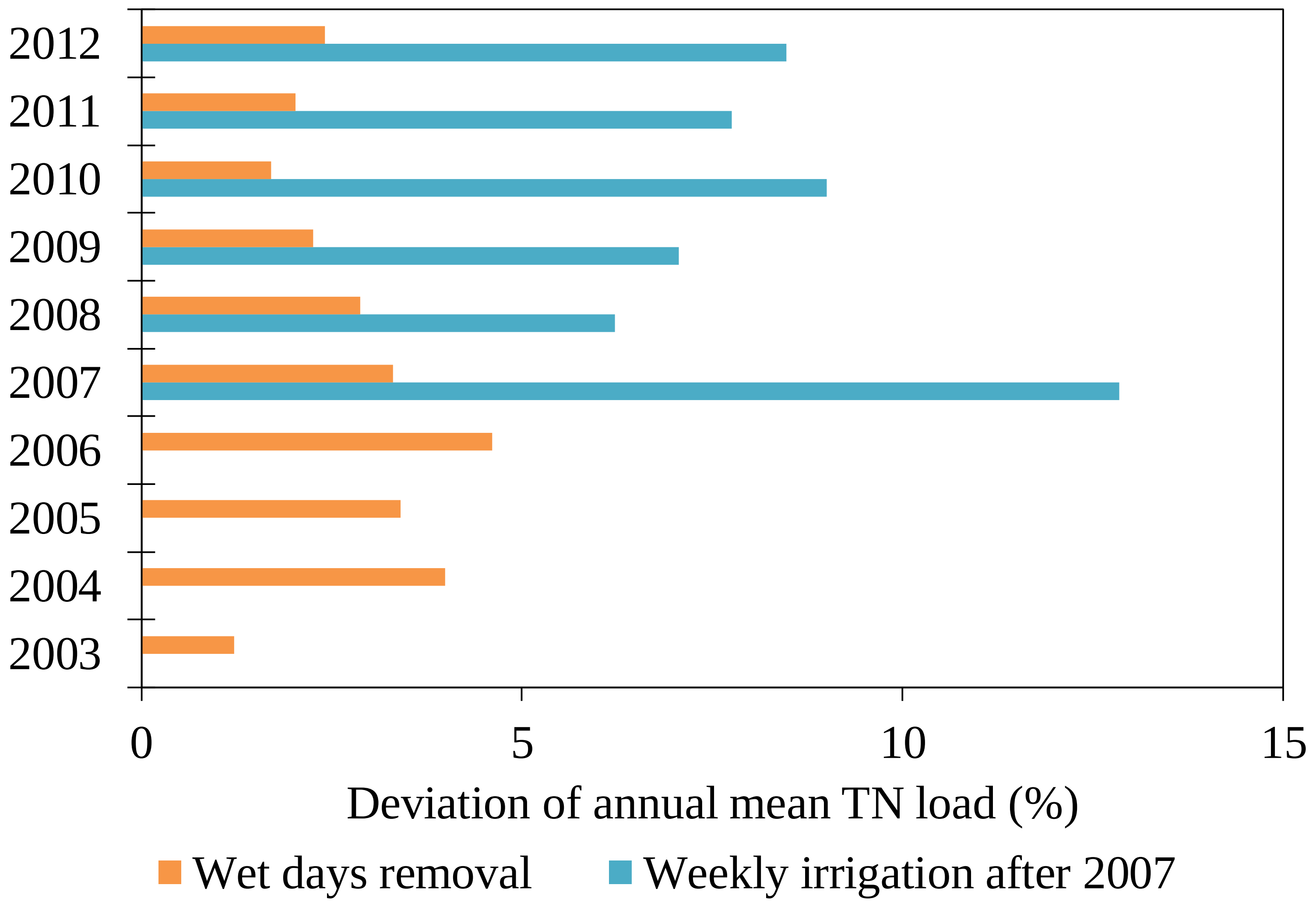
R^2 = 0.8 (very good)
NSE = 0.54 (satisfactory)

Photo: Irrigated block, Rotorua, New Zealand

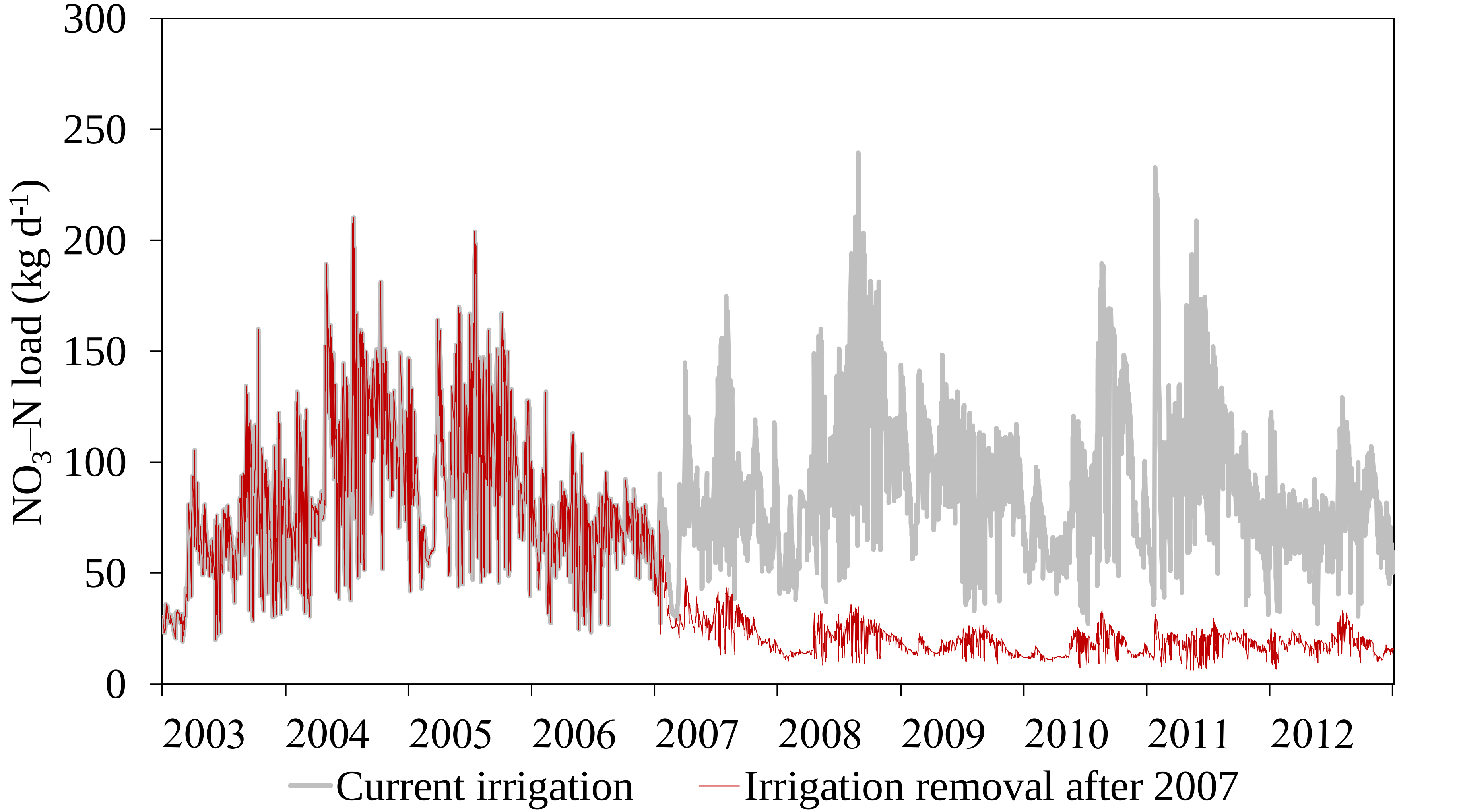
Irrigation scenarios

Scenario	Specification
(i) Increasing irrigated area	Wastewater applied evenly on two blocks, four blocks, or eight blocks on the same soil type
(ii) Avoiding irrigation during high rainfall	**Irrigation during ‘wet’ days with rainfall > 20 mm d^{-1} shifted to the first subsequent dry day**
(iii) Weekly irrigation frequency	**Total weekly wastewater was irrigated on the first day of a week and no irrigation was undertaken on the remaining days in that week**
(iv) Irrigation removal	**Irrigation removed for the period 2007–2012**

Annual mean TN load deviation from current irrigation schedule



Comparison of simulated Waipa Stream nitrate load with and without (after 2007) wastewater irrigation



Conclusions

- LTS was highly effective for TP removal but made much lesser contribution to TN removal
- Harvesting operations and extreme high rainfall appeared to result in peaks in SS and TP simulations
- Scenario simulations indicated:
  - avoiding irrigation during high rainfall events could increase nutrient leaching
  - daily irrigation frequency could be more effective in removing TN than less frequent irrigation
  - removing irrigation could rapidly reduce NO_3–N to earlier background levels

Photo: Hemo Spring, Rotorua, New Zealand

Future work

- To predict TN and TP load attenuation effects for Lake Rotorua: wastewater irrigation may cease by 2019
- To predict effects of future climate on stream loads and Lake Rotorua
- To consider groundwater processes and lag times in more detail

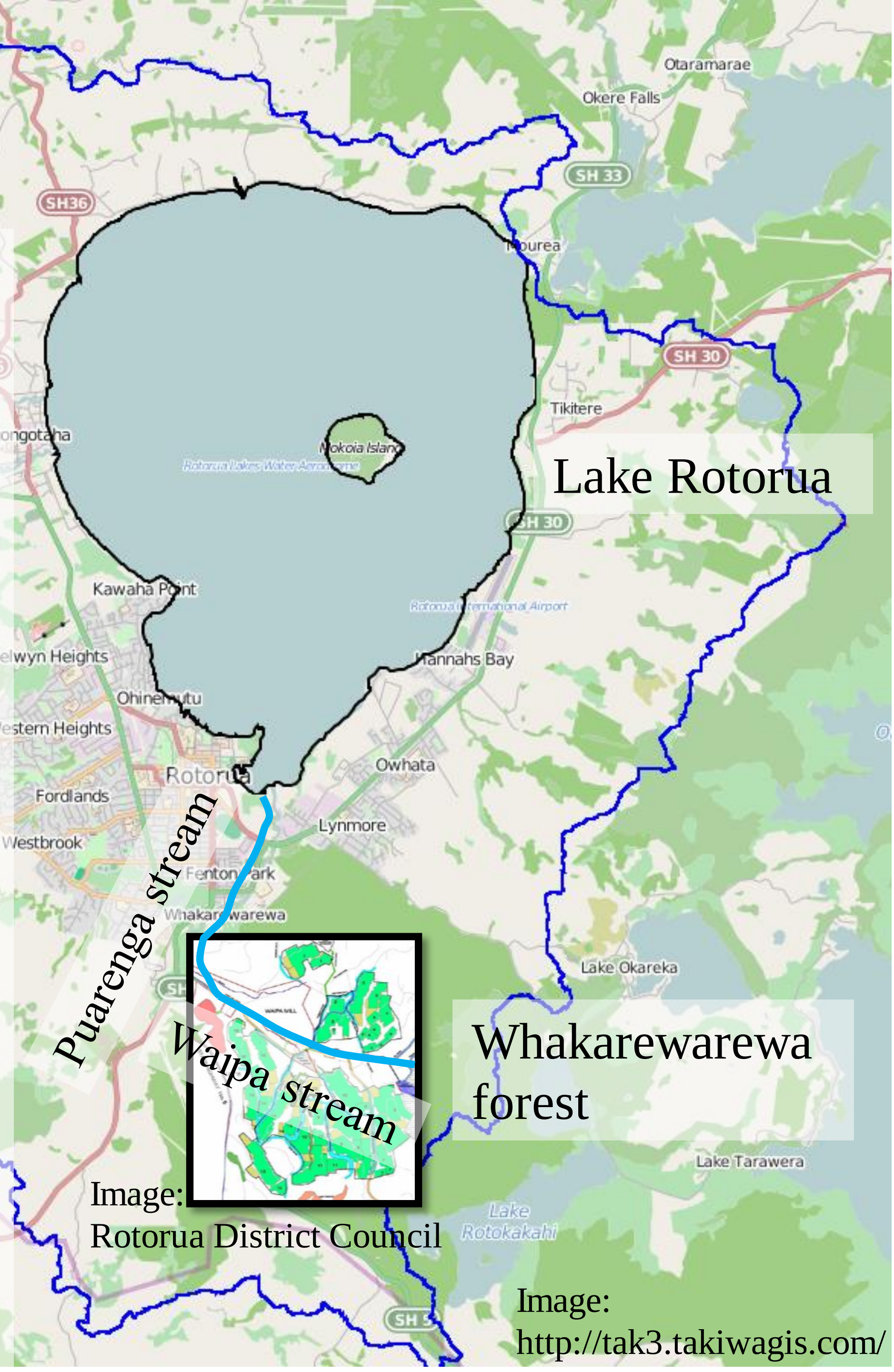


Image: Rotorua District Council

Image: http://tak3.takiwagis.com/

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The campus of the University of Waikato, Hamilton

Image: Geoscience News and Information; http://geology.com/

Photo: Sunset at Lake Rotorua, New Zealand

Thank you !