SWAT modelling for the Hauraki Gulf catchment in New Zealand

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Climate, Freshwater & Ocean Science

NIWA
Taihoro Nukurangi

Introduction

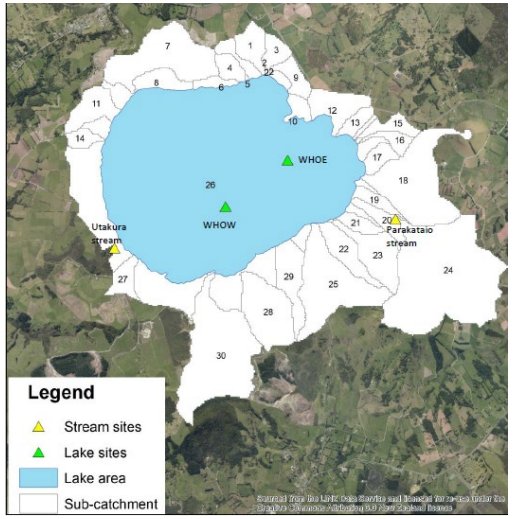
In New Zealand, the National Policy Statement for Freshwater Management (NPS-FM) was amended in 2020 which emphasizes:

- ❑ Adopting an integrated management approach that takes into account interconnection of whole environment, from mountain to lake, down the river to lagoons, estuaries into the sea
- ❑ Requiring regional councils to have specific plans including setting limits on resource use to achieve target attribute states.

→ Modelling, especially catchment modelling become more and more important to fulfill these requirements

The SWAT model has become well known and a more common choice for catchment modelling across New Zealand.

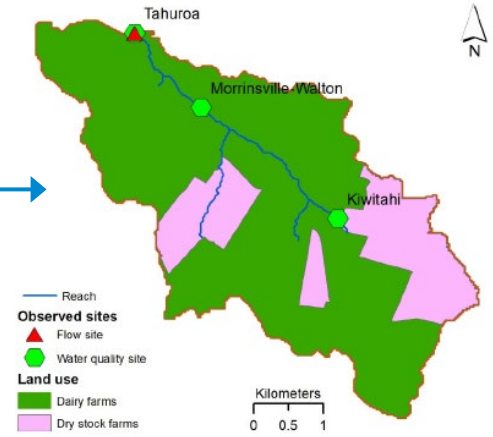
Lake Omapere catchment, 32km^2



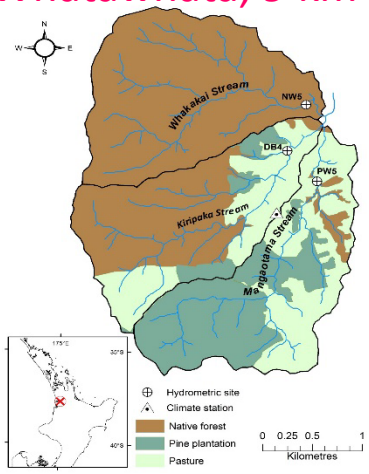
North island

Hauraki catchment, 5500km^2

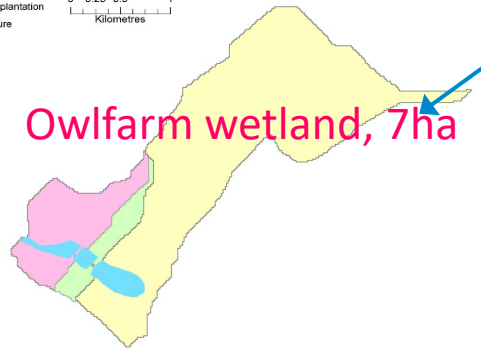
Toenepi, 15 km^2



Whatawhata, 9 km^2

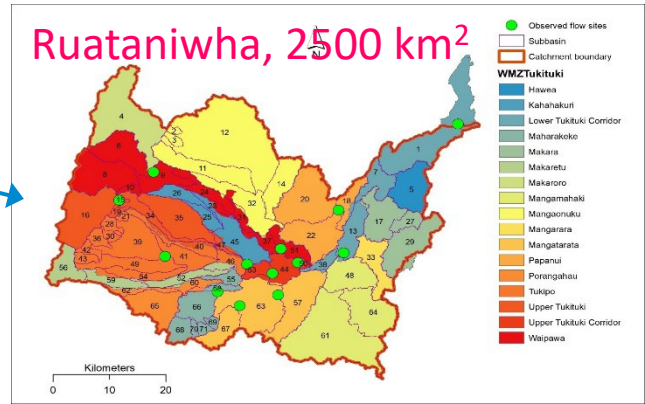


Owlfarm wetland, 7ha



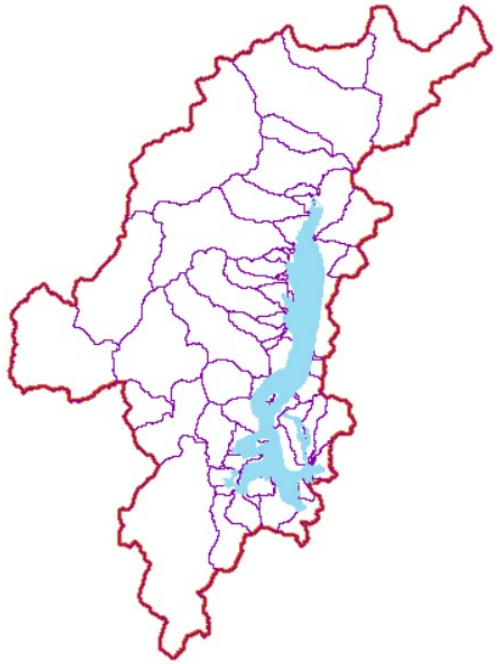
Clima

Ruataniwha, 2500 km^2

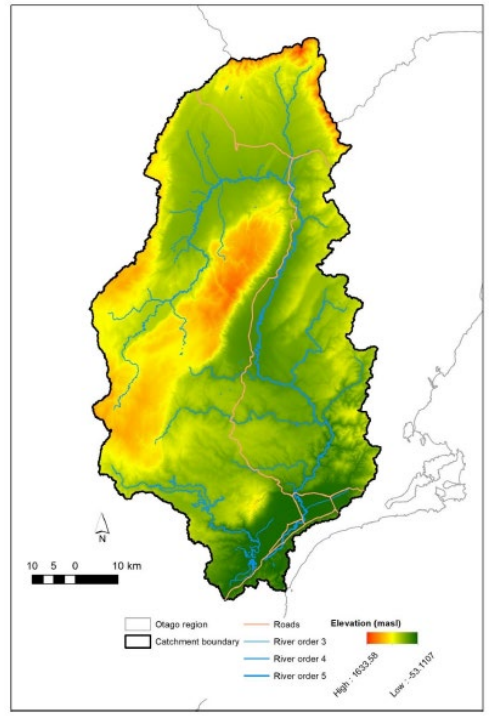


South island

Lake Wanaka, 2600 km^2



Taieri catchment, 5650 km^2



The Hauraki Gulf and its catchment

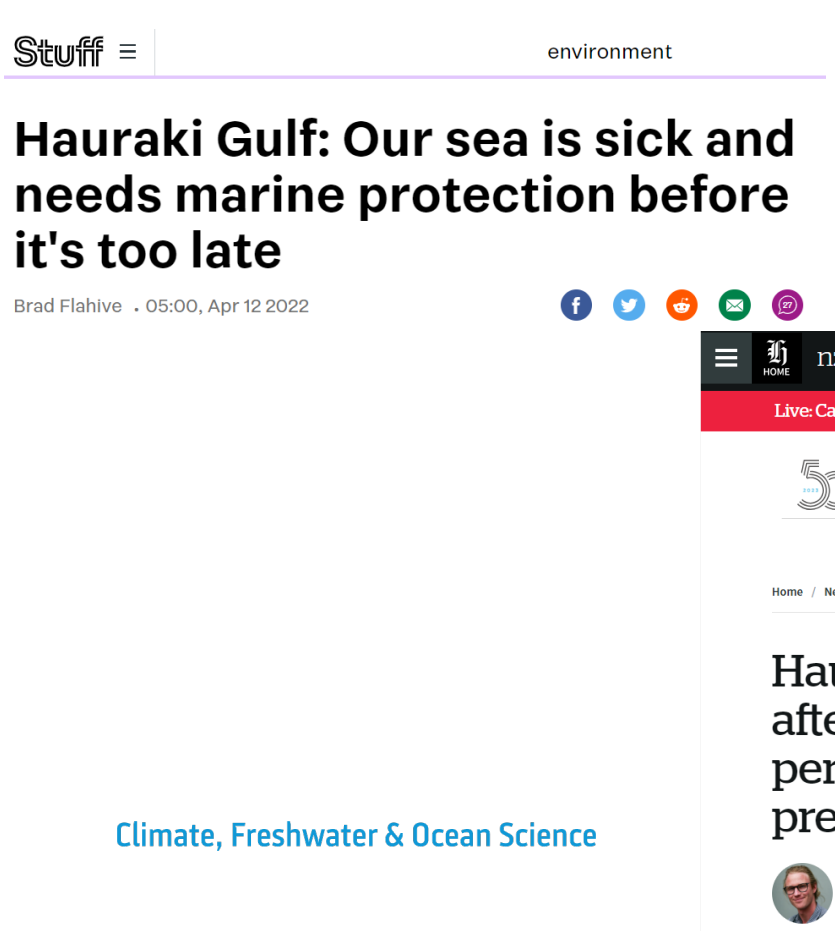
Importance

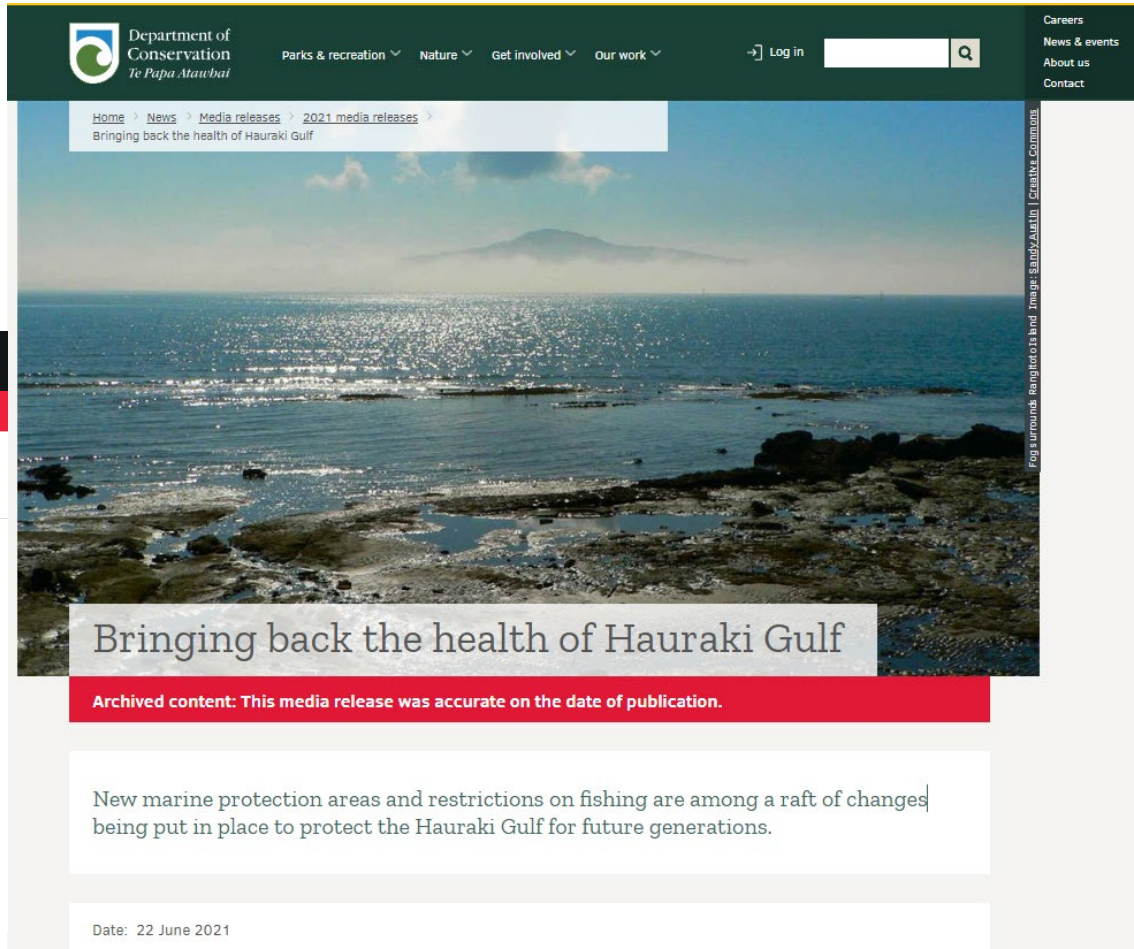
- The Hauraki Gulf, a significant economic asset and one of New Zealand's most valued resources, covering 1.2 million hectares of ocean.
- It is home to a diverse range of seabirds, marine life, and unique habitats.
- It was recognized as New Zealand's first marine park in 2000, owing to its national importance and features significant nature sanctuaries and five marine reserves.

The Hauraki Gulf and its catchment

Issues

The ecosystem of the inner Hauraki Gulf in New Zealand (NZ) is degraded, facing various issues of algae proliferations, oxygenation, reduced water clarity and muddier sediment due to historical land-derived contaminant inputs.





Hauraki Integrated Land-Water Modelling

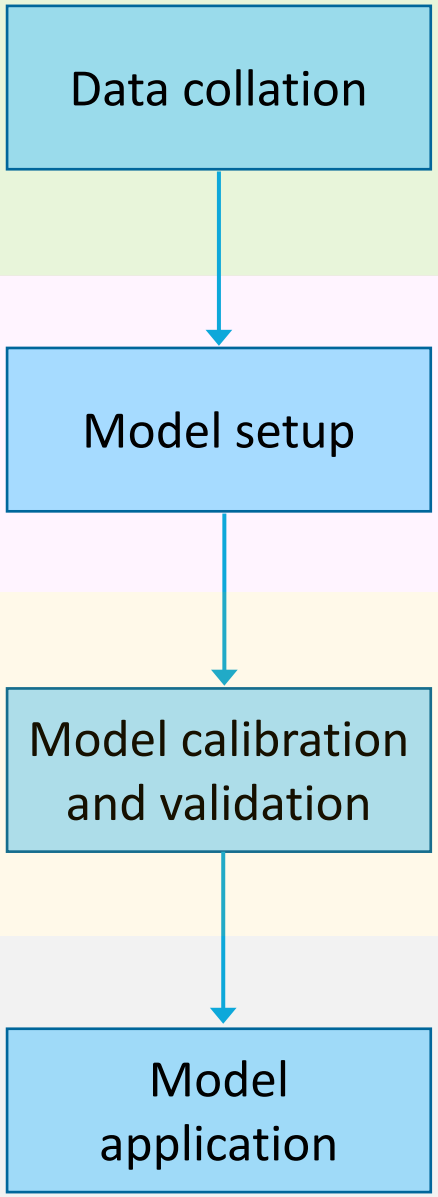
Regional planning initiatives have called for predictive models to help identify contaminant load limits for the Hauraki Gulf land-freshwater-marine system.

An integrated model framework that links models representing different sections of the system, i.e. catchment, estuary, coastal, ocean are necessary.

Options of modelling tools

Catchment	River	Gulf
• CLUES (steady state water quality model) + TOPNET (dynamic hydrology model) • SWAT	• MIKE 11 • DELWAQ 1D • LSPC	• DELFT3D • ROMS

Develop SWAT model for Hauraki-Gulf catchment



- Digital elevation model (DEM)
- Climate
- Soil
- Land use
- Observations (flow and water quality)

- Catchment delineation
- Preparation of input maps (soil, land use, slope)
- Dividing the catchment into modelling units (HRUs)

- Calibrate the model using SWATplusR and R-SWAT
- Speed up model calibration by utilising High-Performance Computing (HPC) facilities of New Zealand's National eScience infrastructure (NeSI).

- Couple with river and marine models
- Climate change, land use change scenarios
- Predict changes under the impact of mitigation systems

Step 1: Data collation

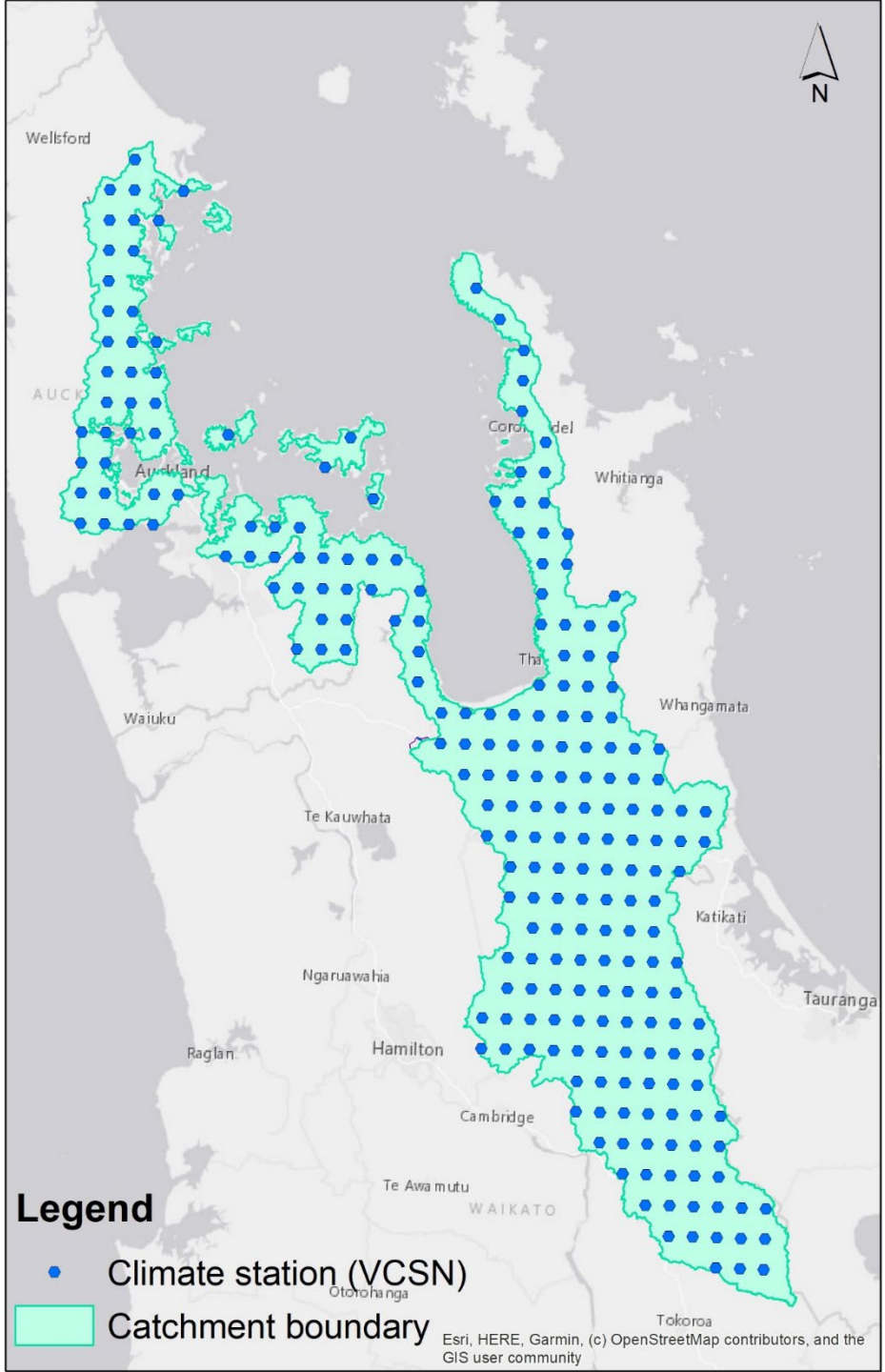
Climate data

Time step: daily

Source: Virtual Climate Station Network (VCSN), 5x5 km grided interpolated climate product from observations that is available for all over New Zealand

245 VCSN stations are available

- 65 stations in Auckland region
- 180 stations in Waikato region

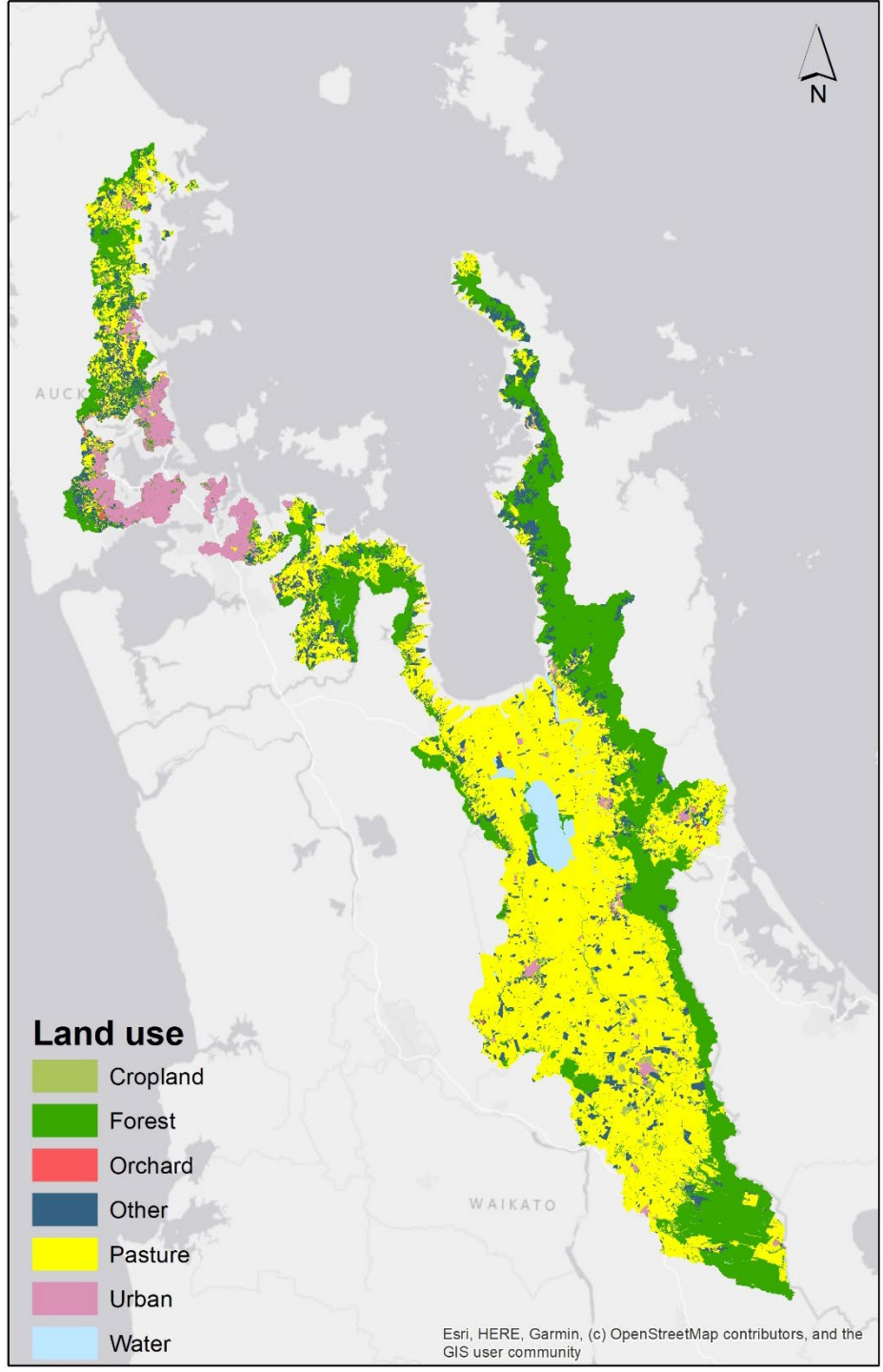


Step 1: Data collation

Land use data

Land use	Areal percentage
Pasture	52
Forest	29
Urban	4
Water	2
Cropland	1
Orchard	1
Other	11

Source: combination of land cover database (LCDB) and Agribase (AsureQuality)



Soil data

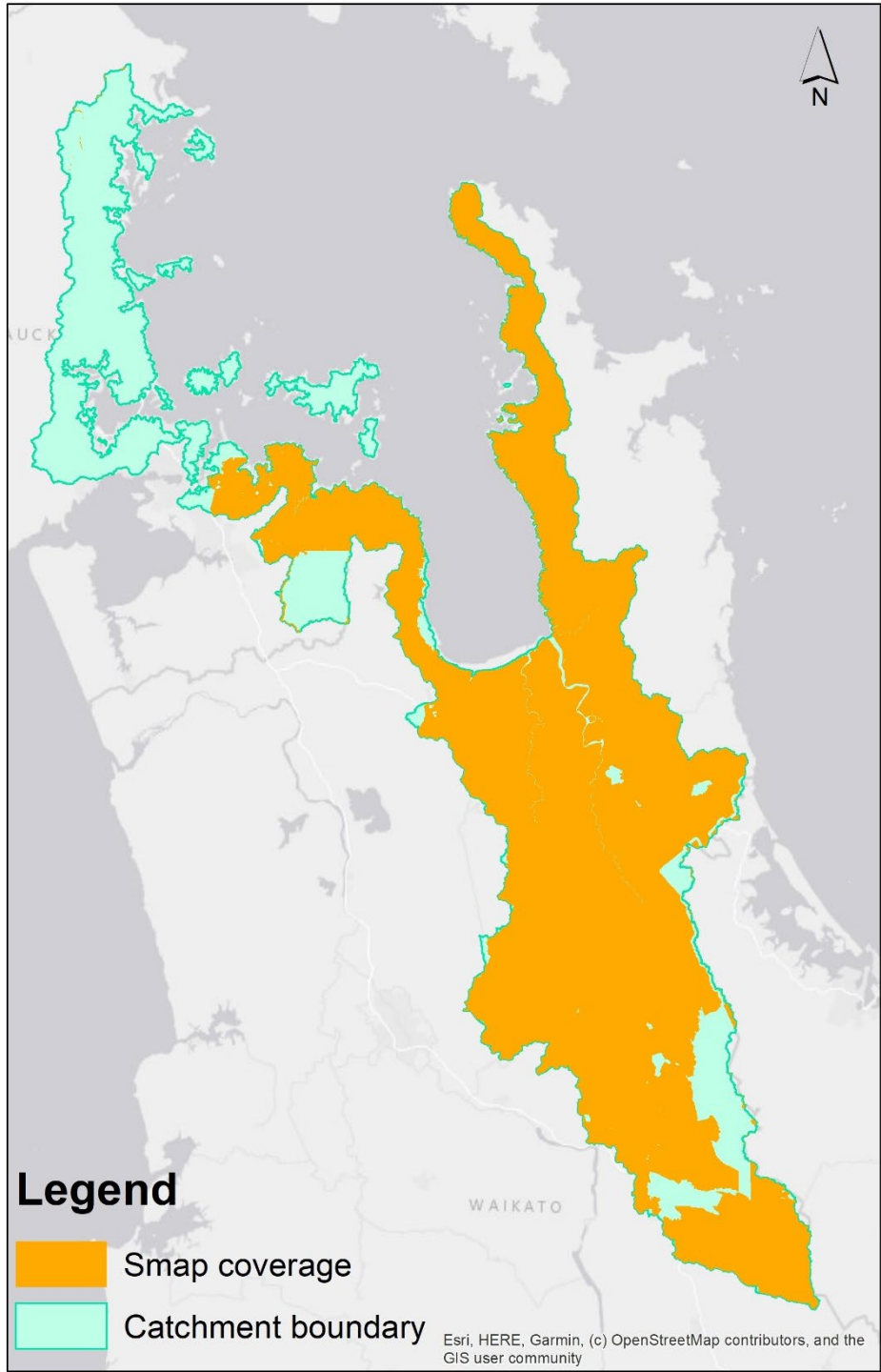
Using S-map (http://smap.landcareresearch.co.nz, Lilburne et al., 2012), the most detailed soil map and digital database in NZ.

Challenges

- S-map only covers 37% of NZ, and 76% of the Hauraki catchment
- There are some inconsistencies between the soil characteristics required by SWAT and the soil characteristics available in S-map.

Solutions

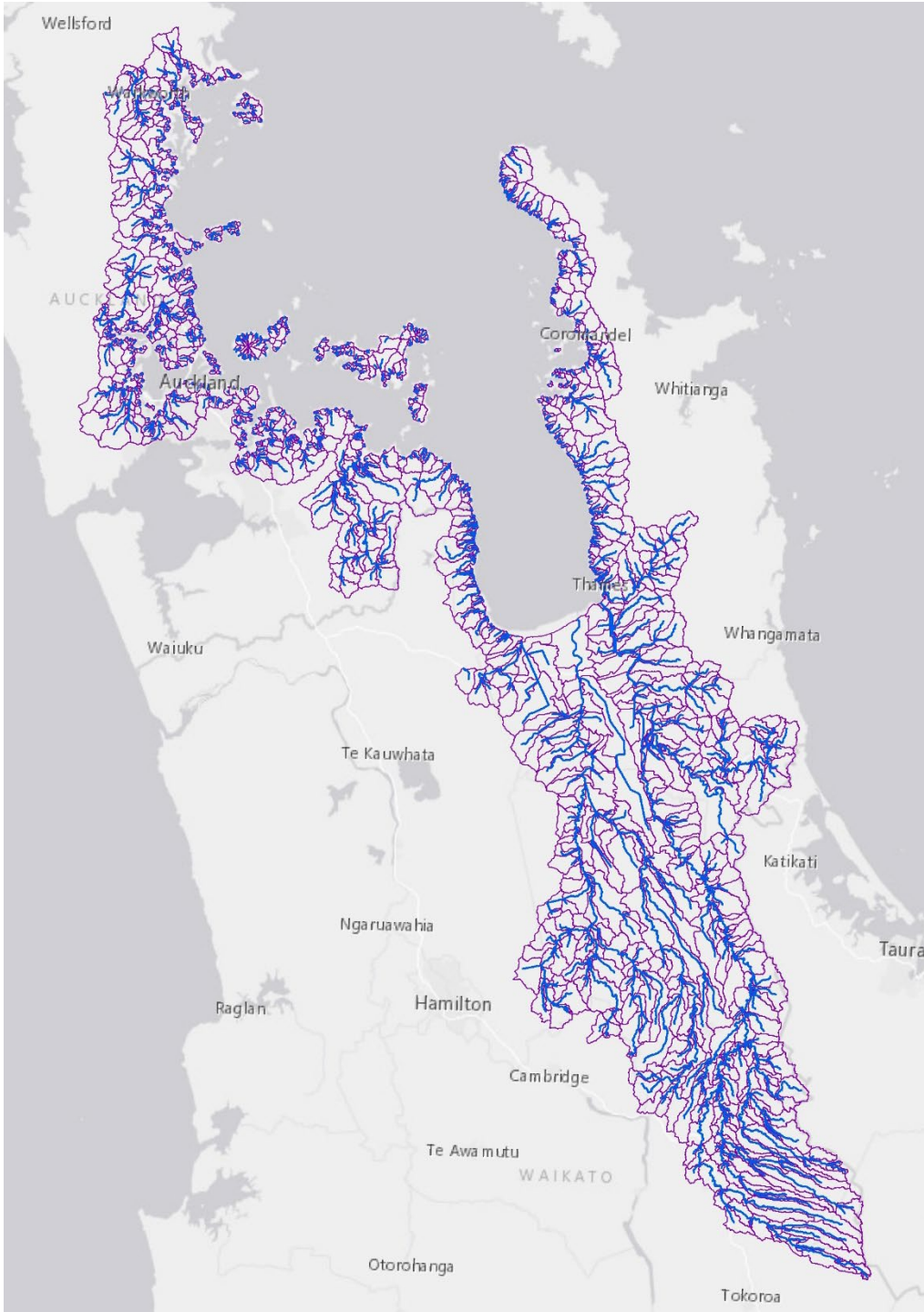
- NIWA has worked with soil experts in Landcare Research to appropriately convert soil parameters in S-map to soil parameters required in SWAT
- For the area of missing S-map data, Soil data was obtained by linking soil types from the Fundamental Soil Layers (FSL) database to soil types within S-map.



Step 2: SWAT model setup

Catchment delineation

- Stream and subcatchment maps were derived from NZ River Environment Classification (REC) version 2.5, but simplified to stream order 3.
- Stream and sub-catchment map were then renumbered and reformat to the format of SWAT pre-defined stream and sub-catchment network.
- 1534 streams and sub-catchments in the Hauraki Gulf catchment.



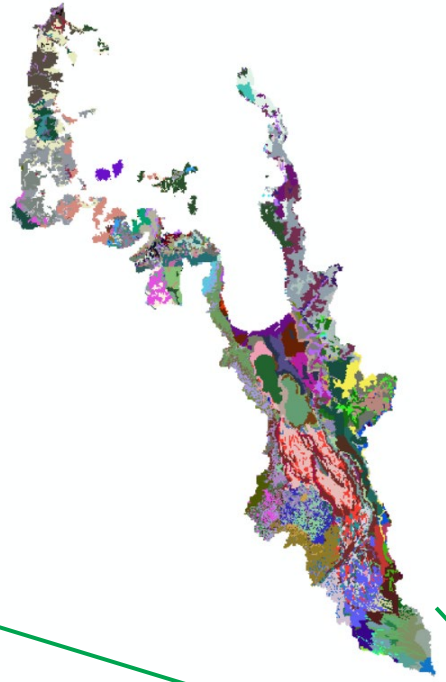
Step 2: SWAT model setup

Sub-catchment map

1534 subbasins

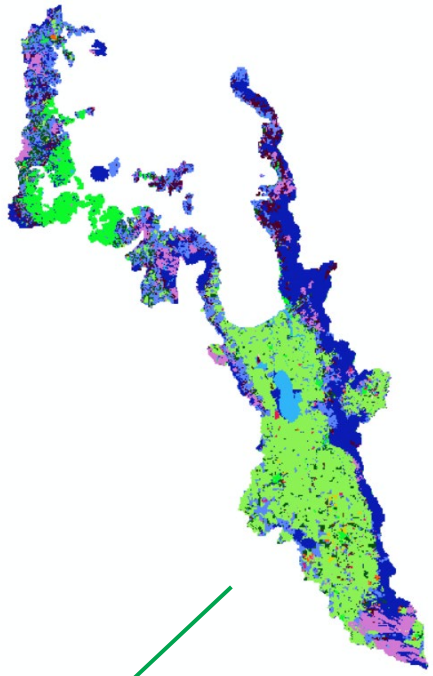
Soil map

255 soil types



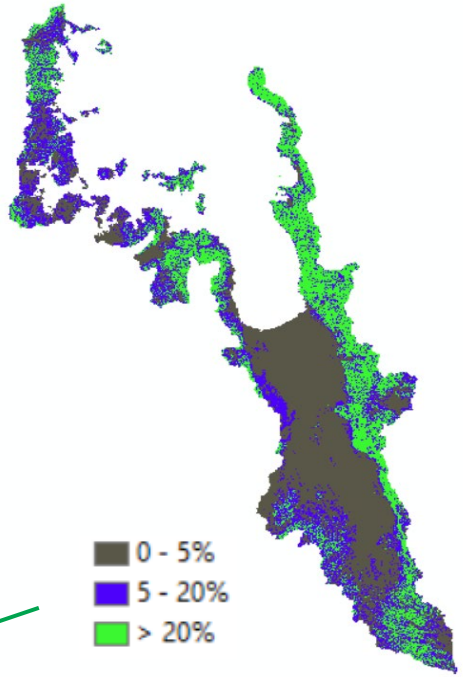
Land use map

18 land use types



Slope map

3 slope categories



OVERLAY

18585 HRUs in which all processes are simulated

Challenges/questions:

- Is the setup too complex?
- Is the setup highly computationally intensive?
- It is too difficult to calibrate?
- Is it better to divide the whole area to several catchments?

Step 3: Model calibration and validation

Use SWATplusR and R-SWAT for model calibration

Scaling and speeding up model calibration on High performance computers (HPC).

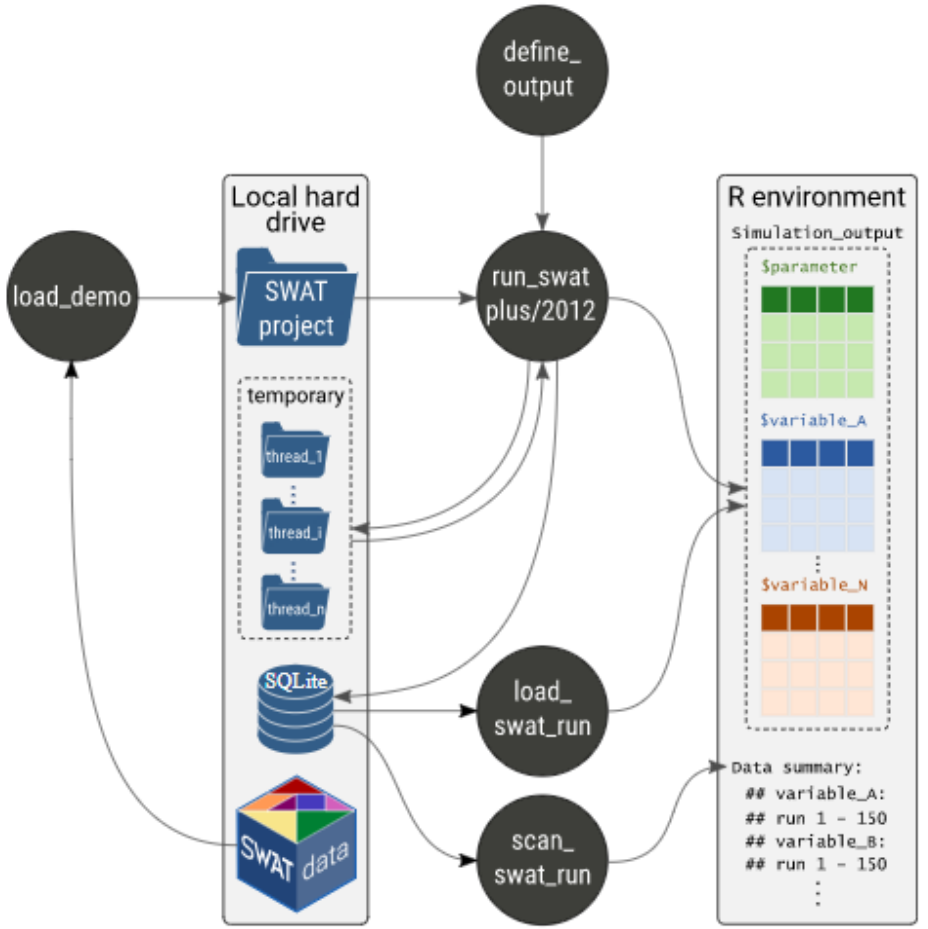
SWATplusR integrates SWAT projects in R modelling workflow.

Some good features of SWATplusR:

- Parallel processing
- Writing required simulation outputs to a database to store large outputs
- Safely perform computationally expensive simulation experiments

R-SWAT: parallel processing, availability of different optimization methods

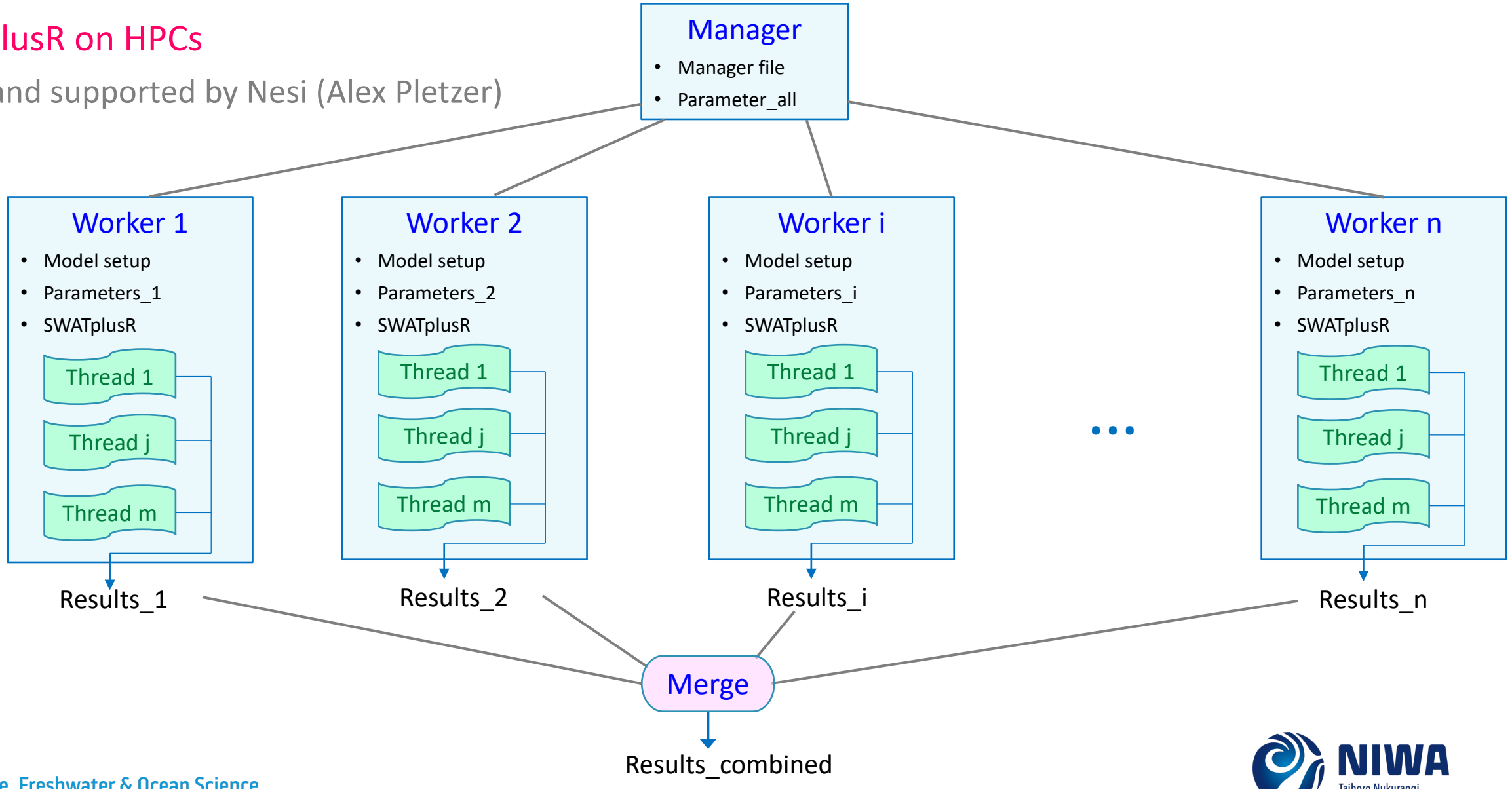
SWATplusR workflow



Step 3: Model calibration and validation

SWATplusR on HPCs

Set up and supported by Nesi (Alex Pletzer)



Model calibration and validation

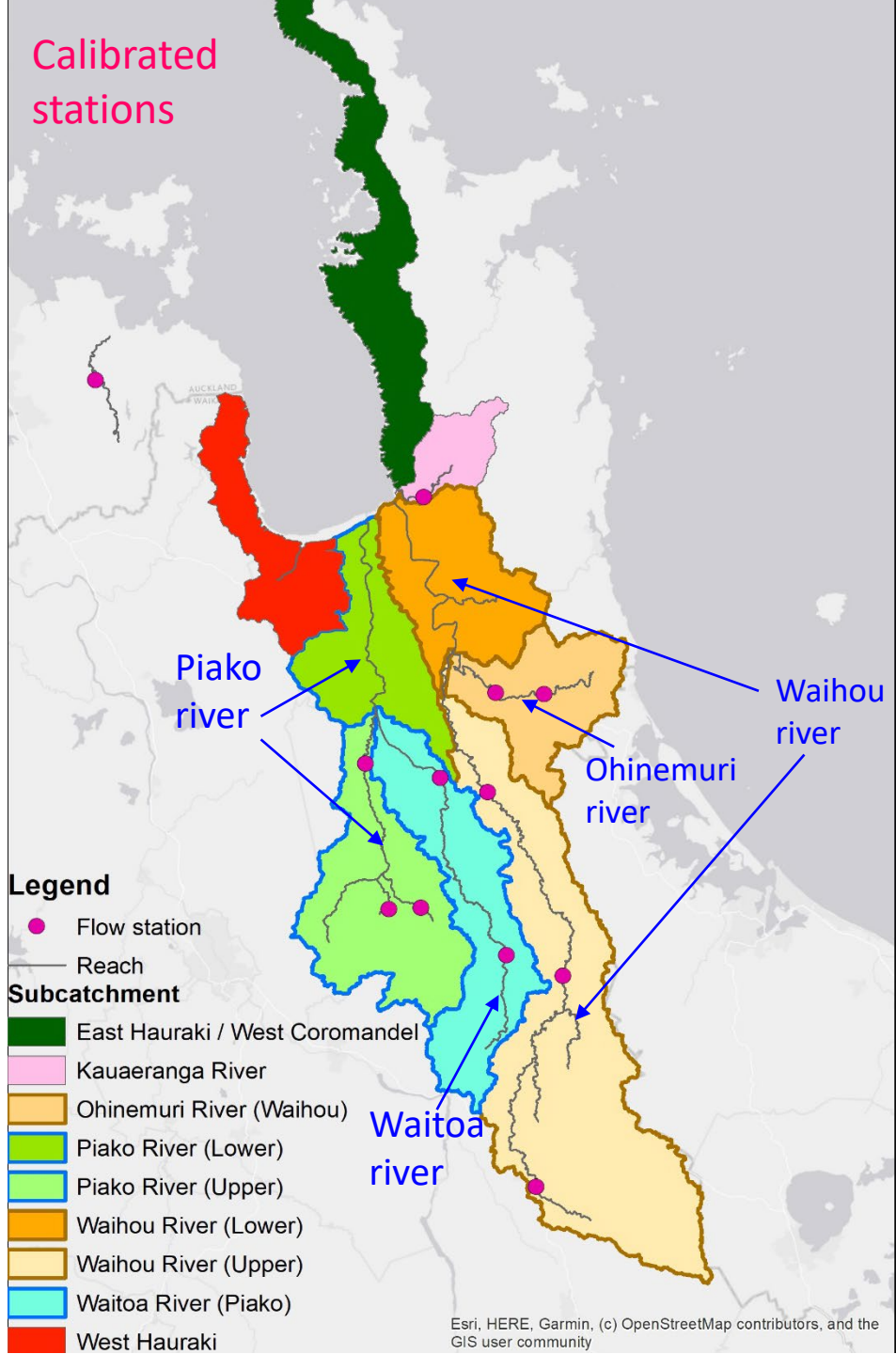
Simulation period:

- *Warming up period:* 2002-2003
- *Calibration period:* 2004 - 2011
- *Validation period:* 2011 - 2019

Calibration method:

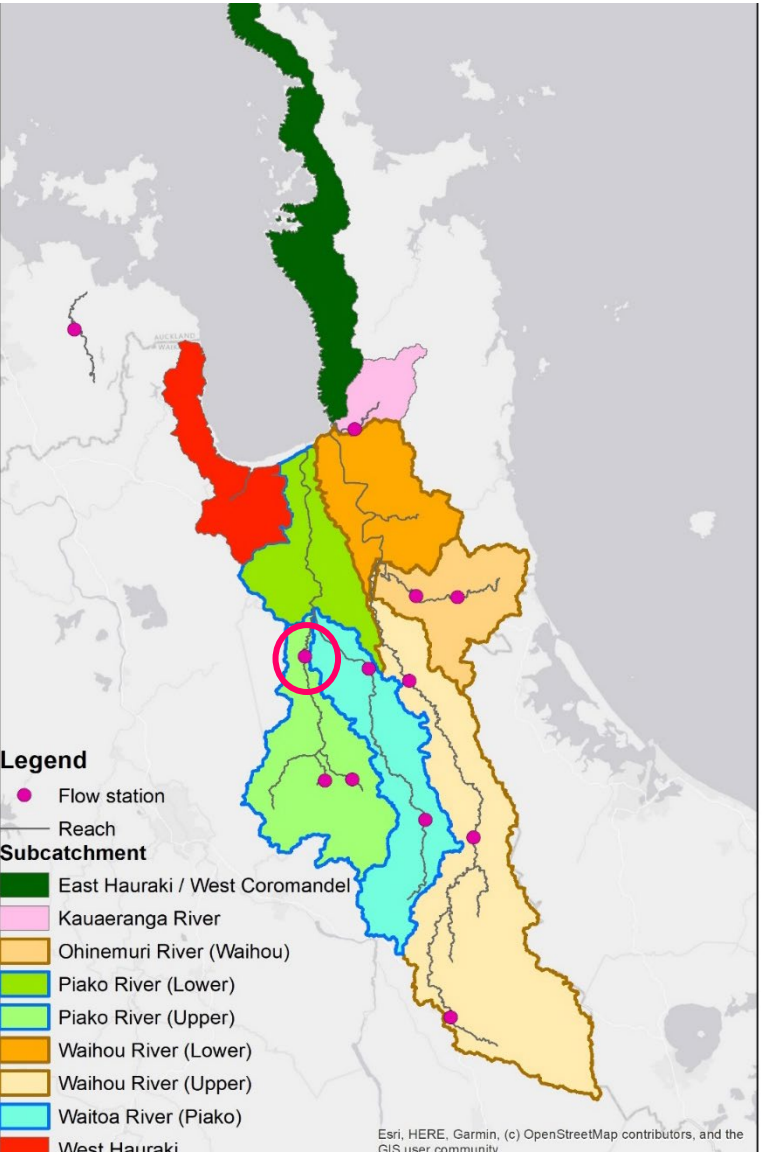
Calibrate in two stages: (i) hydrological calibration, and (ii) water quality calibration

- Generate 10,000 random parameter sets by Monte Carlo sampling method
- Run 10,000 simulations with SWAT on HPCs
- Choose the best performance parameter sets based on commonly used statistical metrics



Preliminary results for hydrological calibration

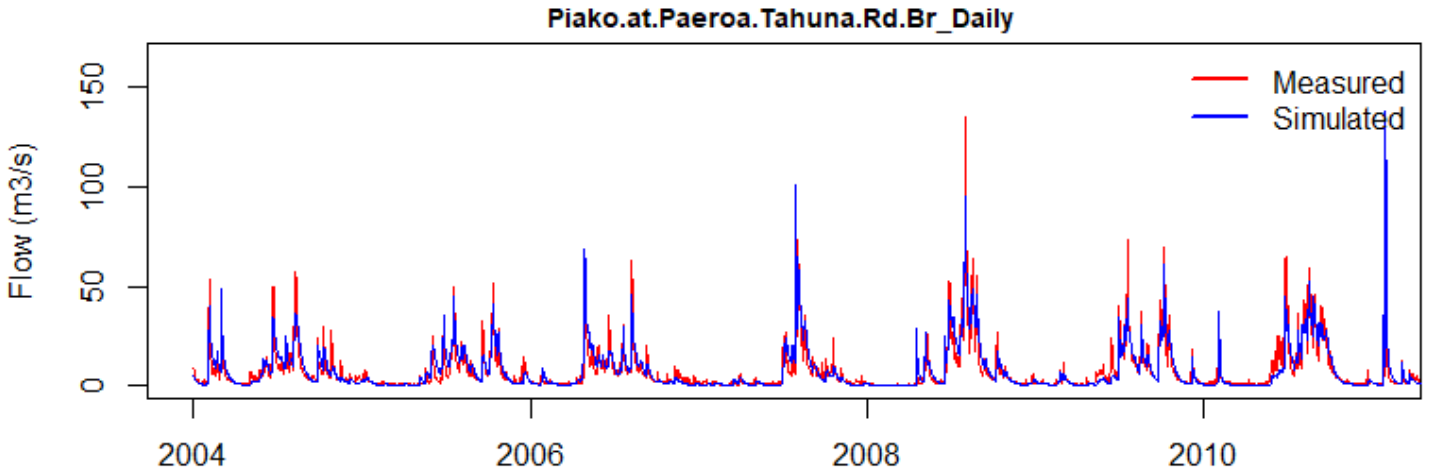
Piako at Paeroa Tahuna Road (upper Piako catchment)



Daily

NSE = 0.82

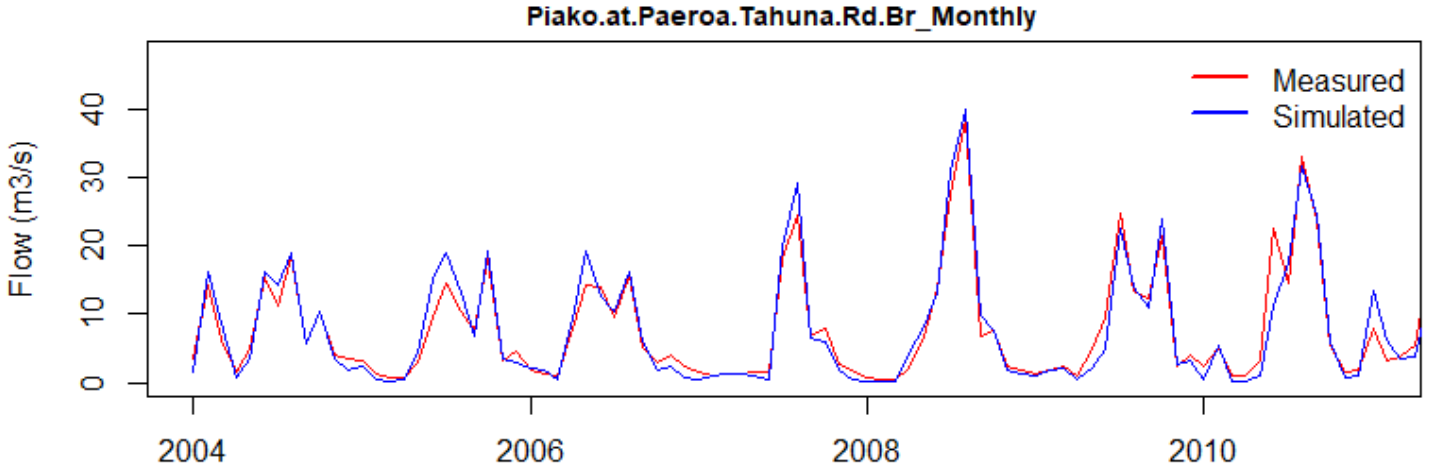
R^2 = 0.82



Monthly

NSE = 0.92

R^2 = 0.93



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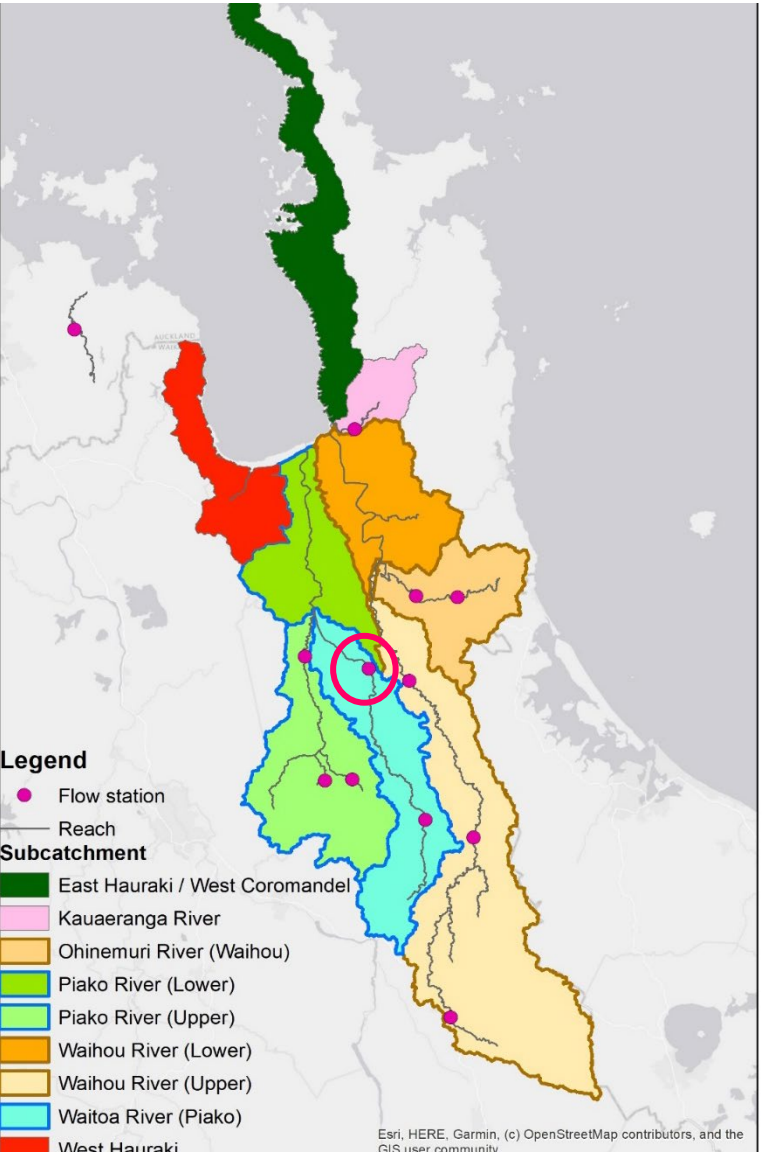
Preliminary results for hydrological calibration

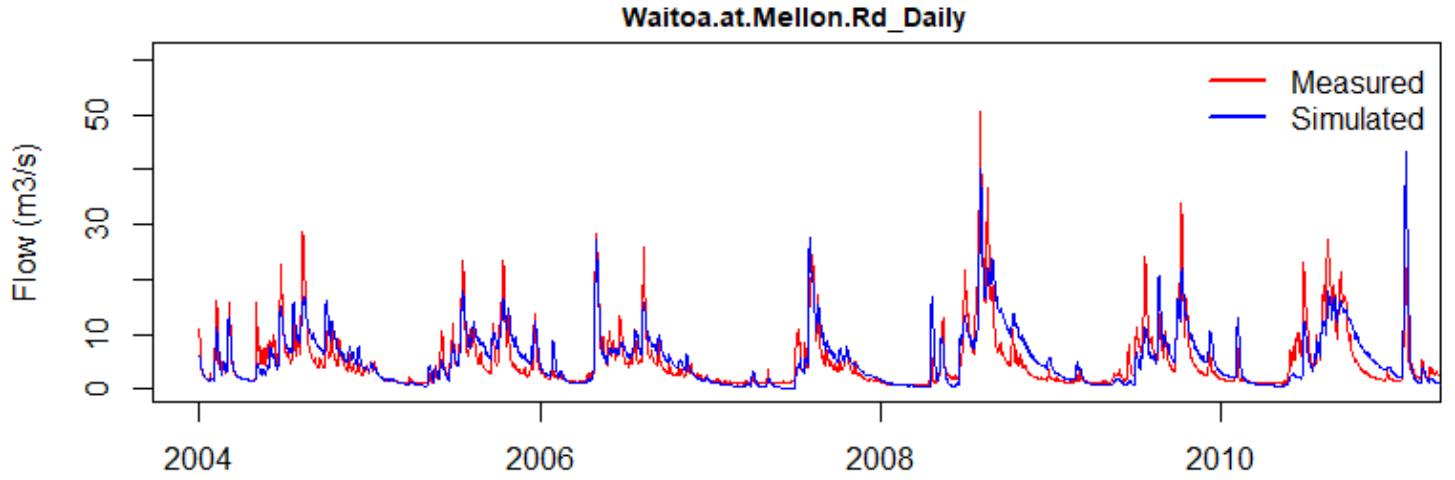
Waitoa at Mellon road (Waitoa catchment, a part of whole Piako catchment)



Daily

NSE = 0.68

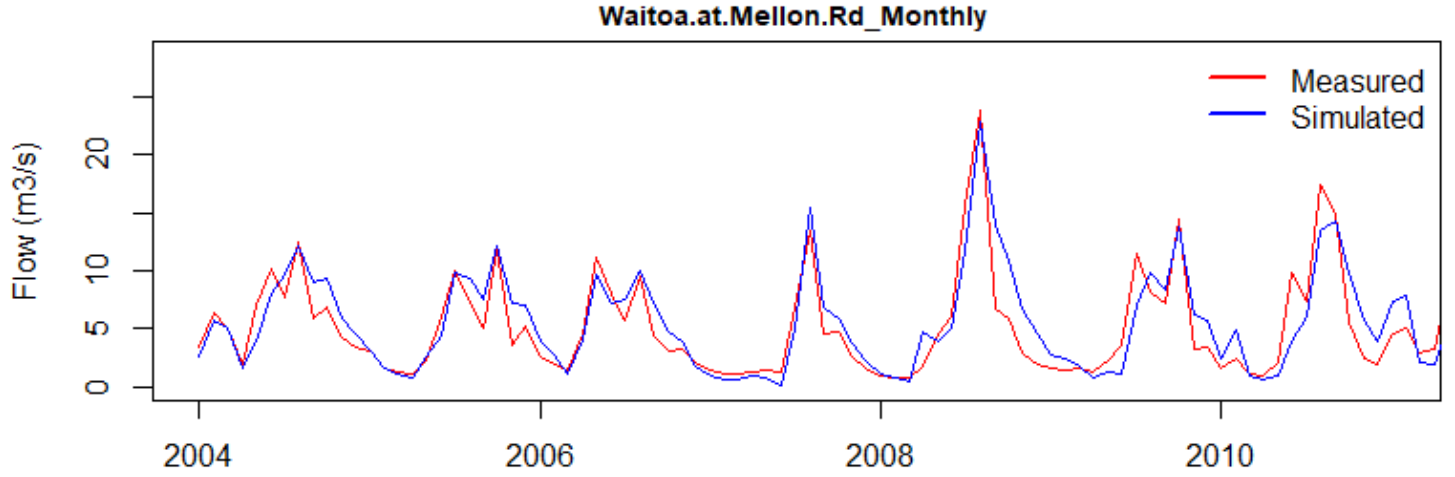
R^2 = 0.70



Monthly

NSE = 0.75

R^2 = 0.76



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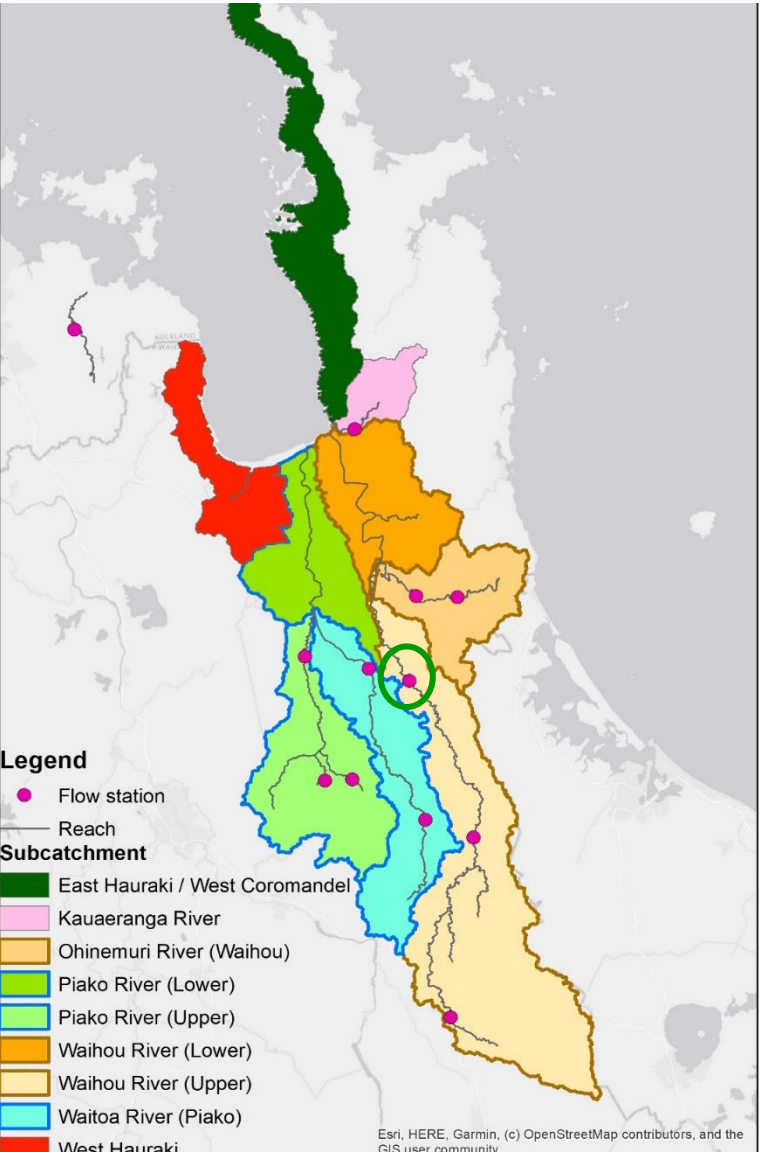
Preliminary results for hydrological calibration

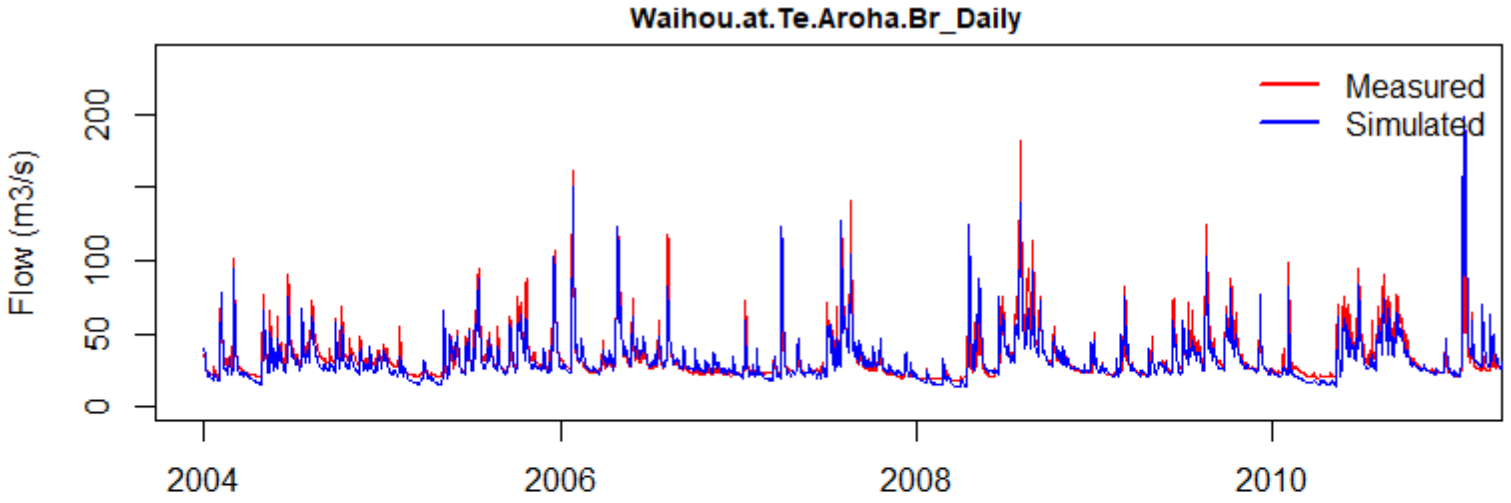
Waihou at Te Aroha bridge (lower Waihou catchment)



Daily

NSE = 0.76

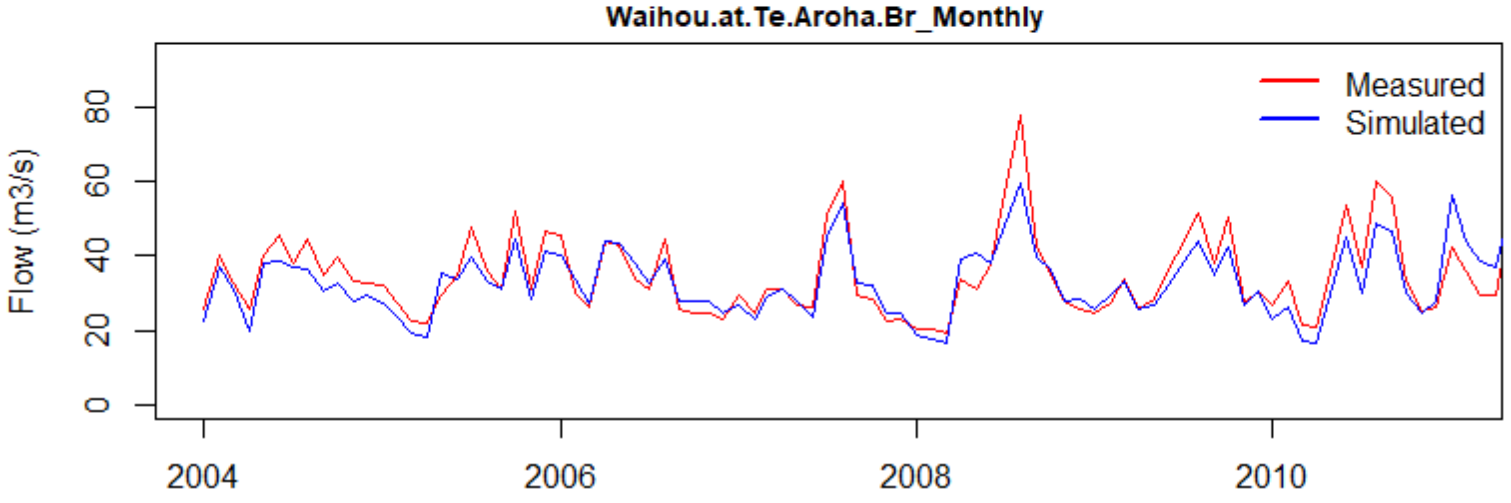
R^2 = 0.78



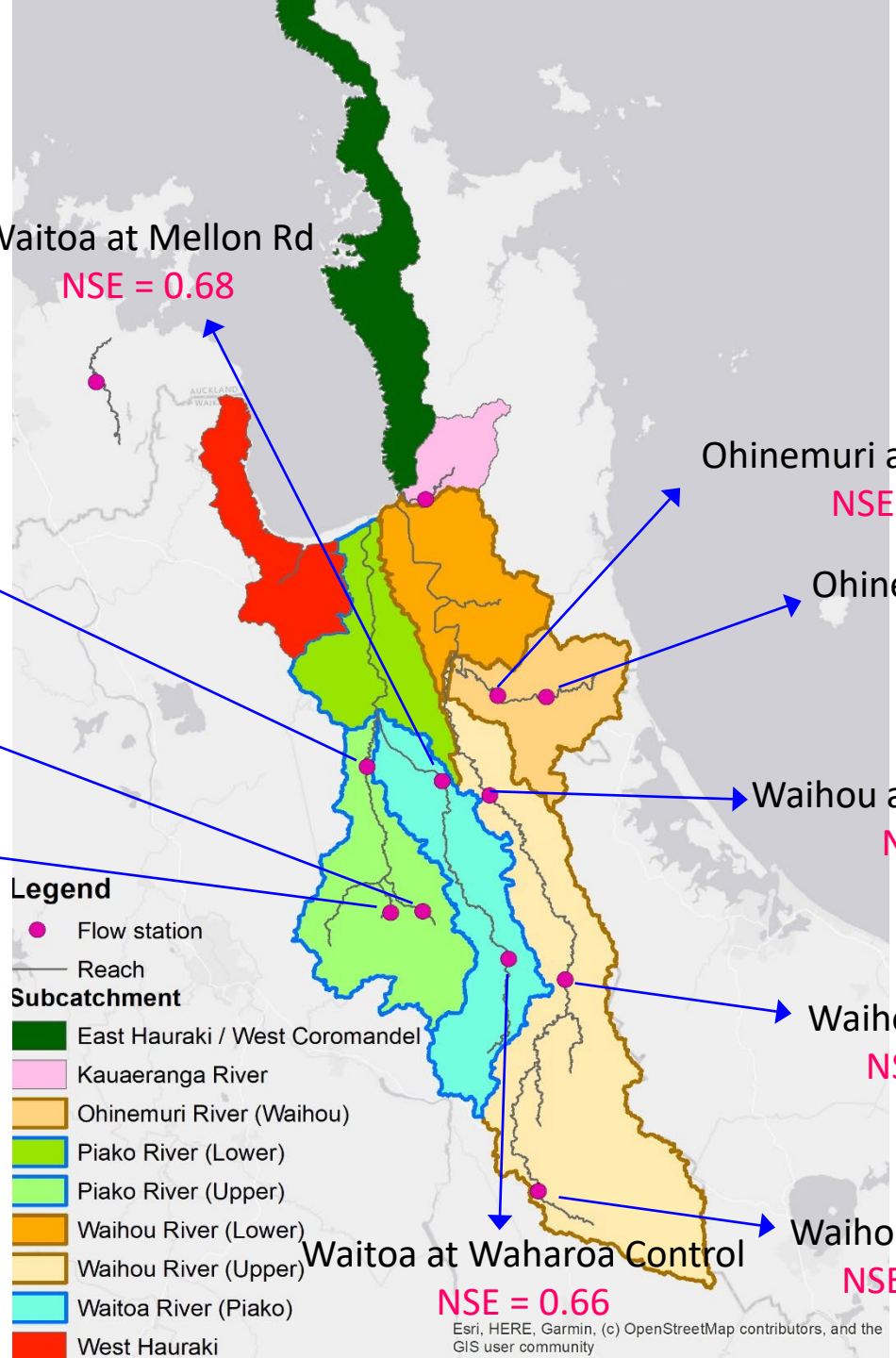
Monthly

NSE = 0.76

R^2 = 0.80



Preliminary results for hydrological calibration



Waitoa at Mellon Rd
NSE = 0.68

Piako at Paeroa Tahuna Rd Br
NSE = 0.76

Piako at Kiwitahi
NSE = 0.74

Toenepi at Tahuroa Rd Br
NSE = 0.66

Ohinemuri at Karangahake
NSE = 0.47

Ohinemuri at Queens Head Rock
NSE = 0.33

Waihou at Te Aroha Bridge
NSE = 0.76

Waihou at Okauia
NSE = 0.44

Waihou at Okauia
NSE = -1.23

Waitoa at Waharoa Control
NSE = 0.66

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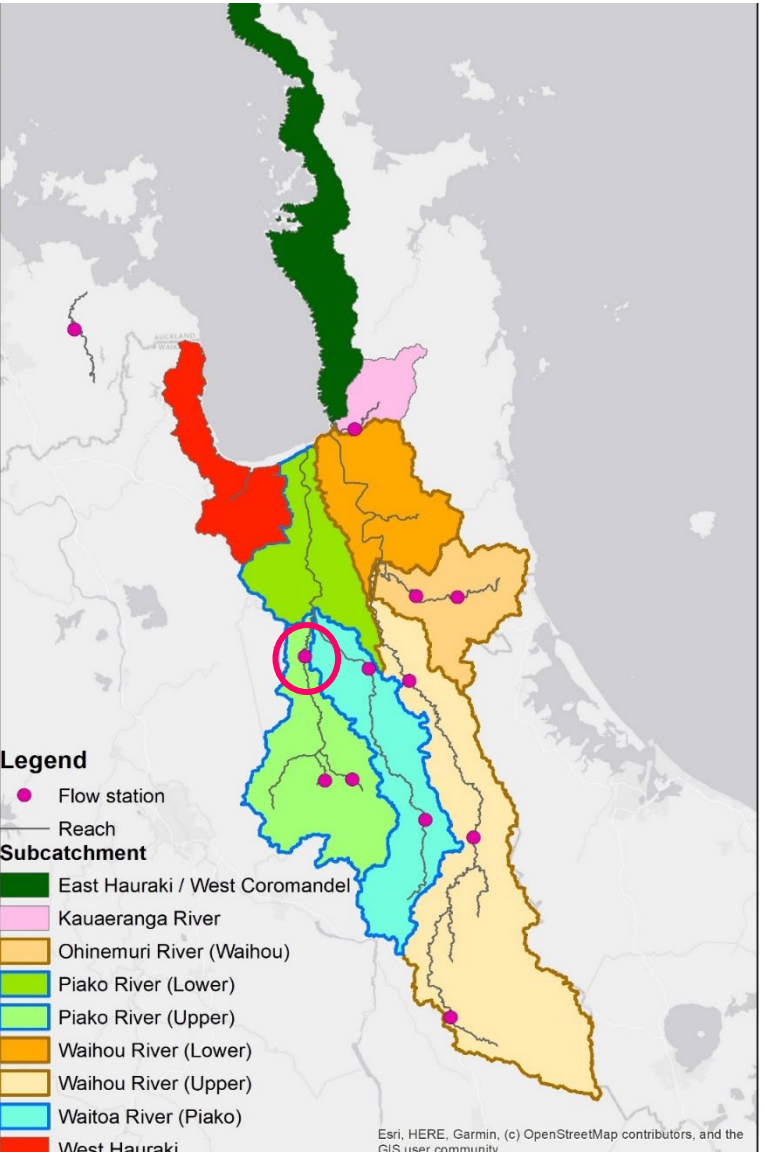
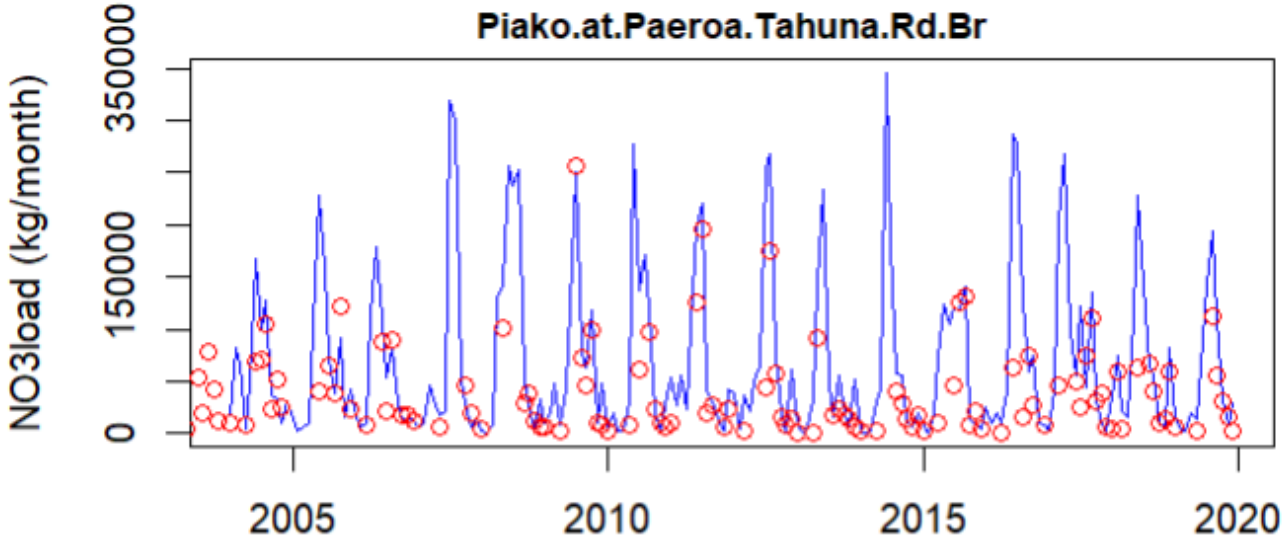
Preliminary results for nitrogen calibration

Piako at Paeroa Tahuna Road (upper Piako catchment)



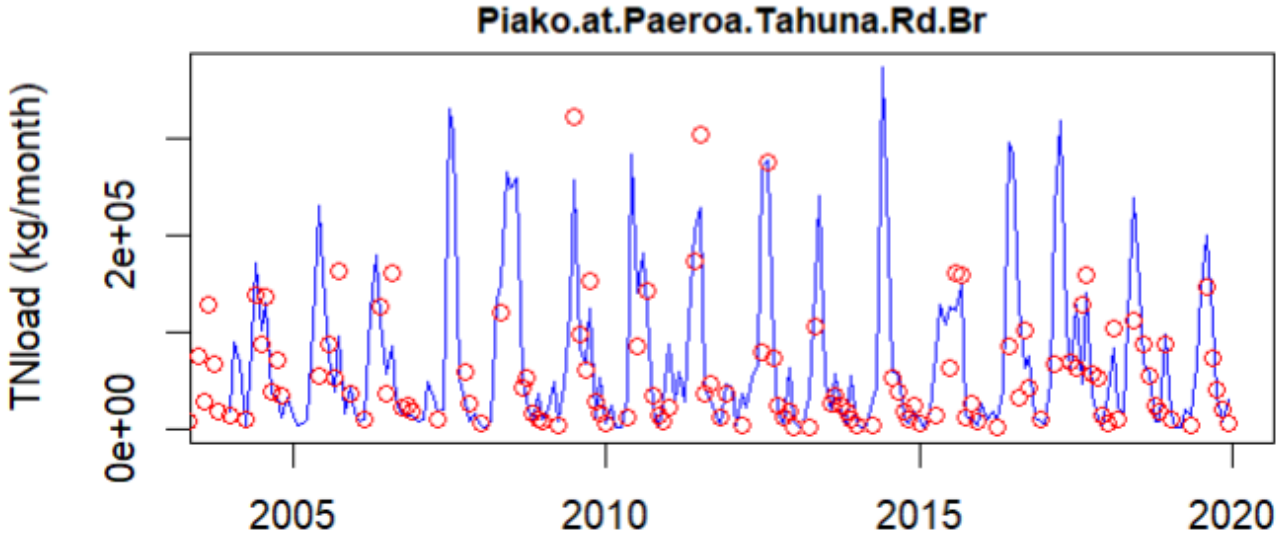
Nitrate

$R^2 = 0.65$



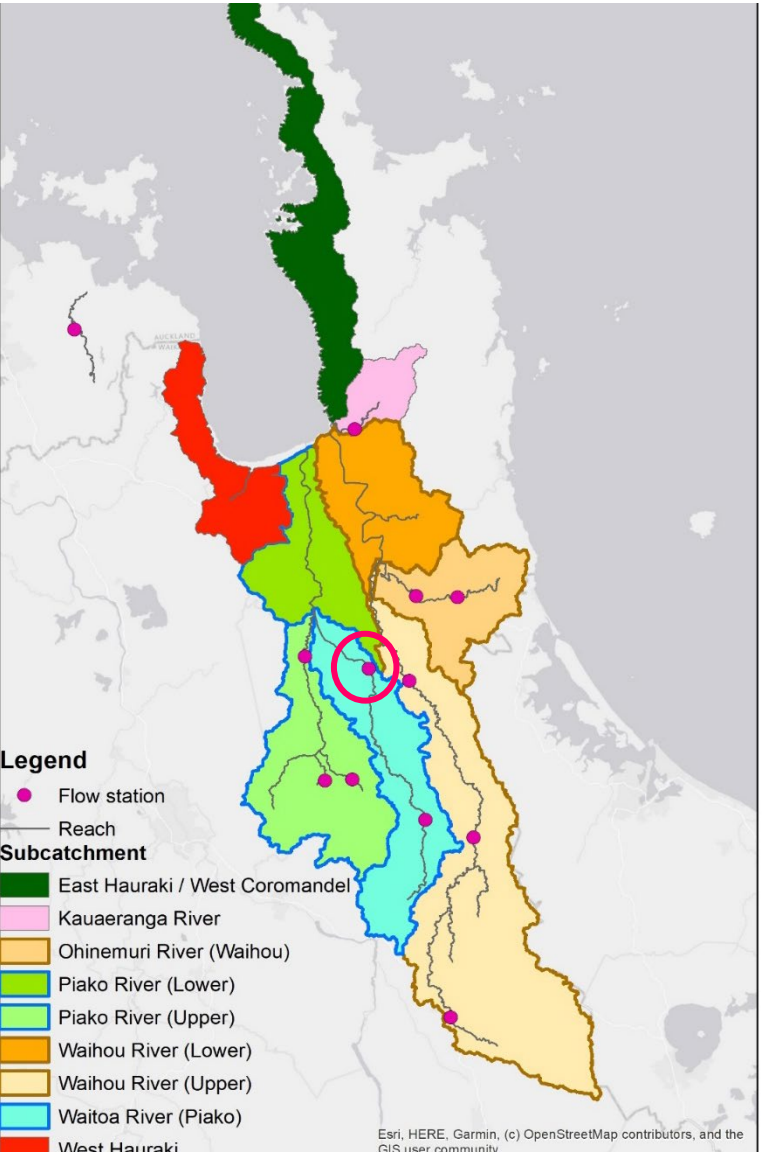
TN

$R^2 = 0.57$



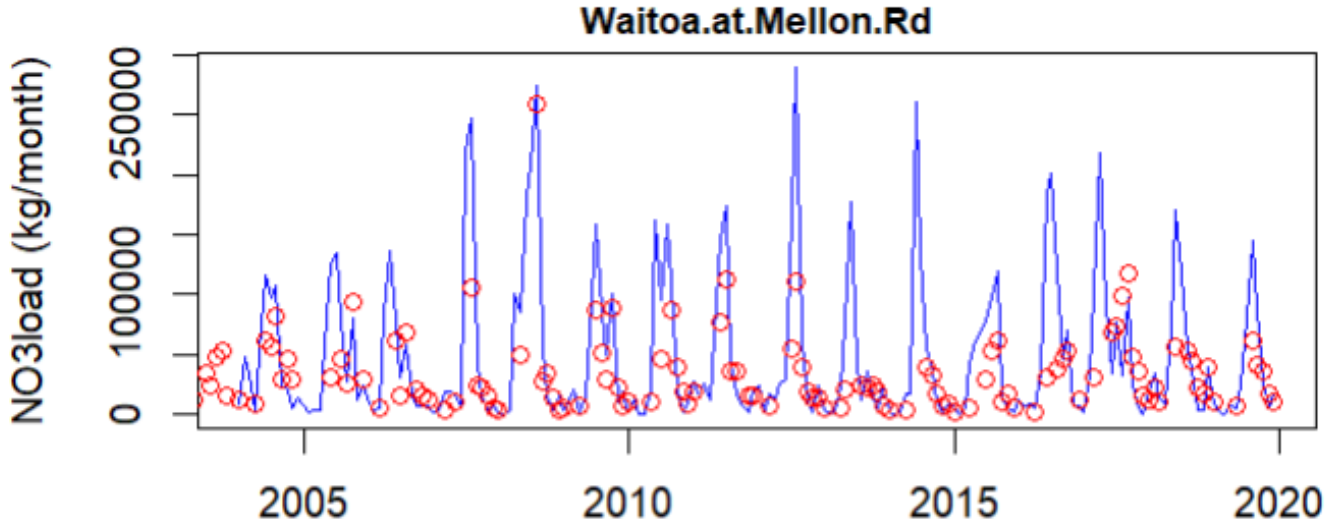
Preliminary results for nitrogen calibration

Waitoa at Mellon Road (Waitoa catchment, a part of whole Piako catchment)



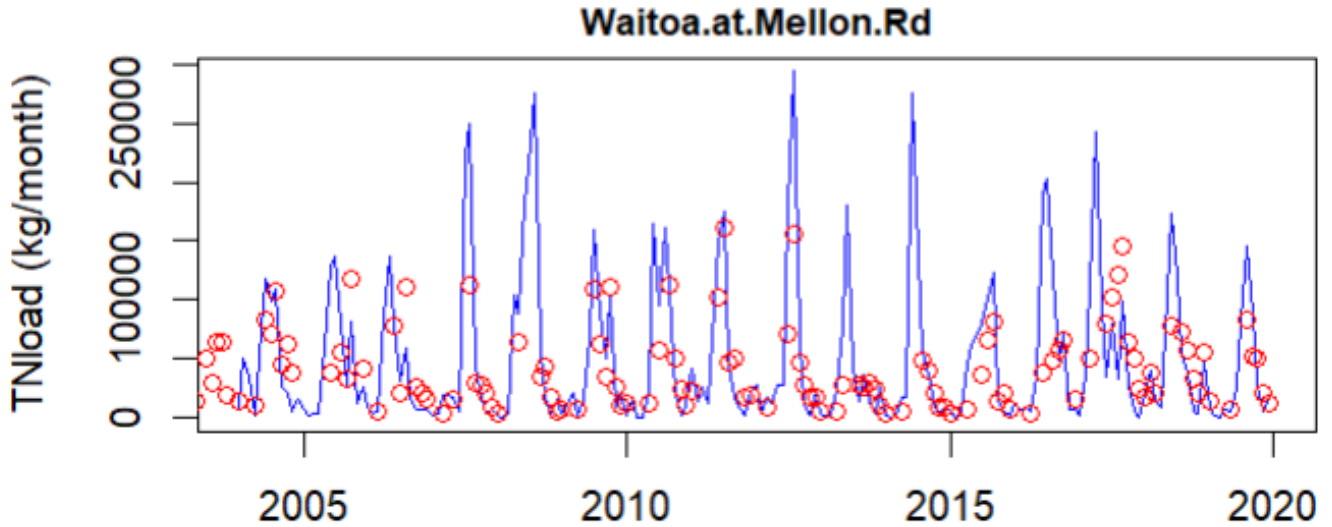
Nitrate

$R^2 = 0.78$



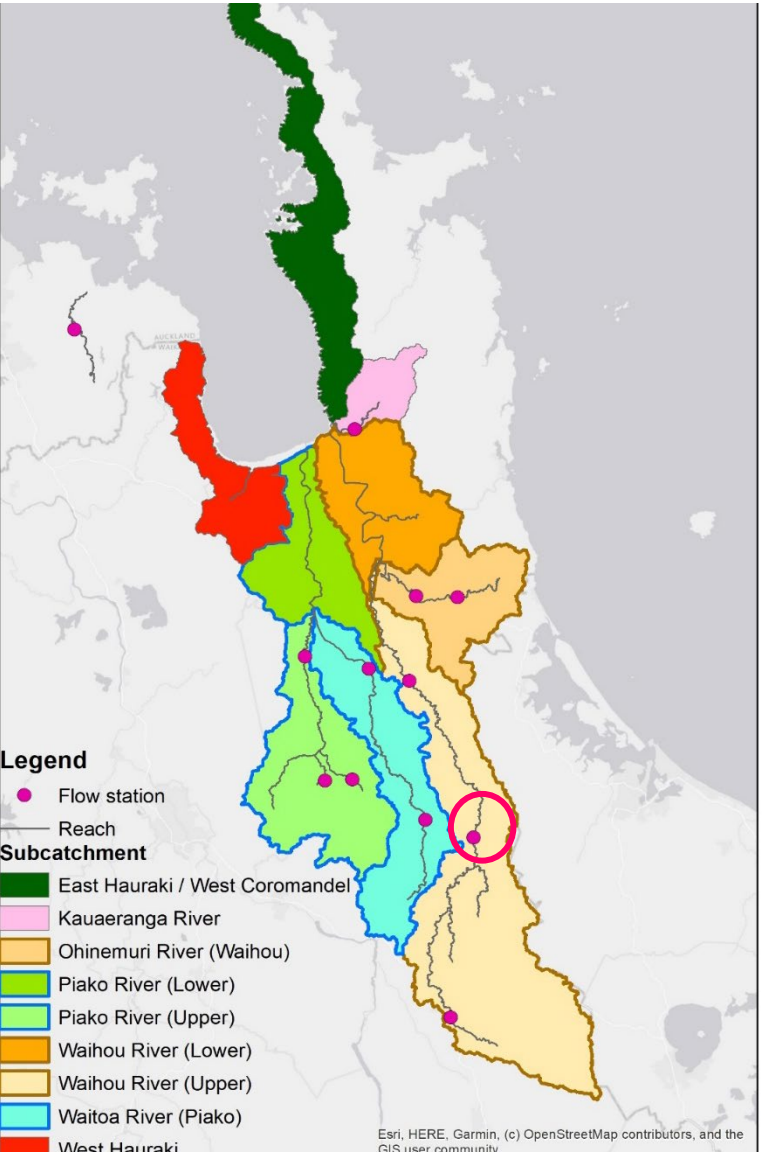
TN

$R^2 = 0.72$



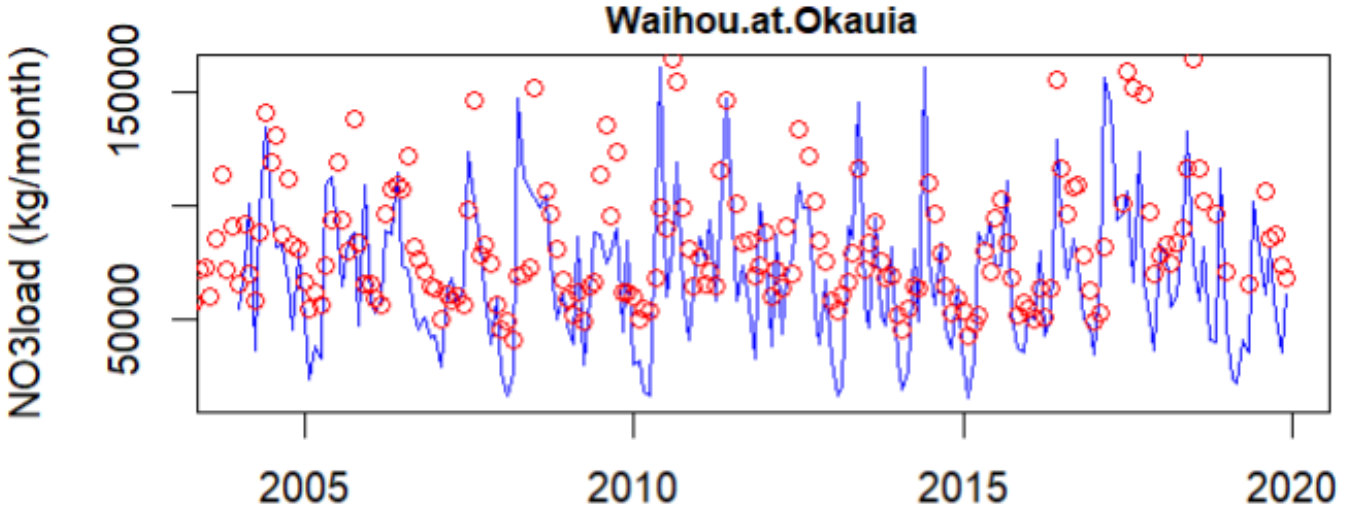
Preliminary results for nitrogen calibration

Piako at Paeroa Tahuna Road (upper Piako catchment)



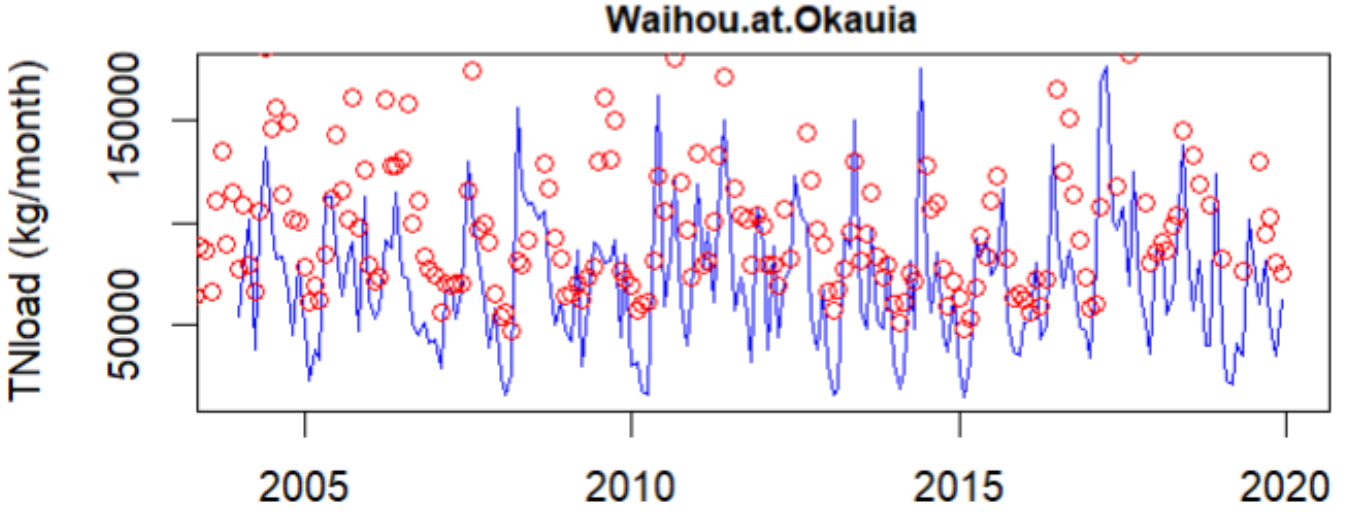
Nitrate

$R^2 = 0.3$



TN

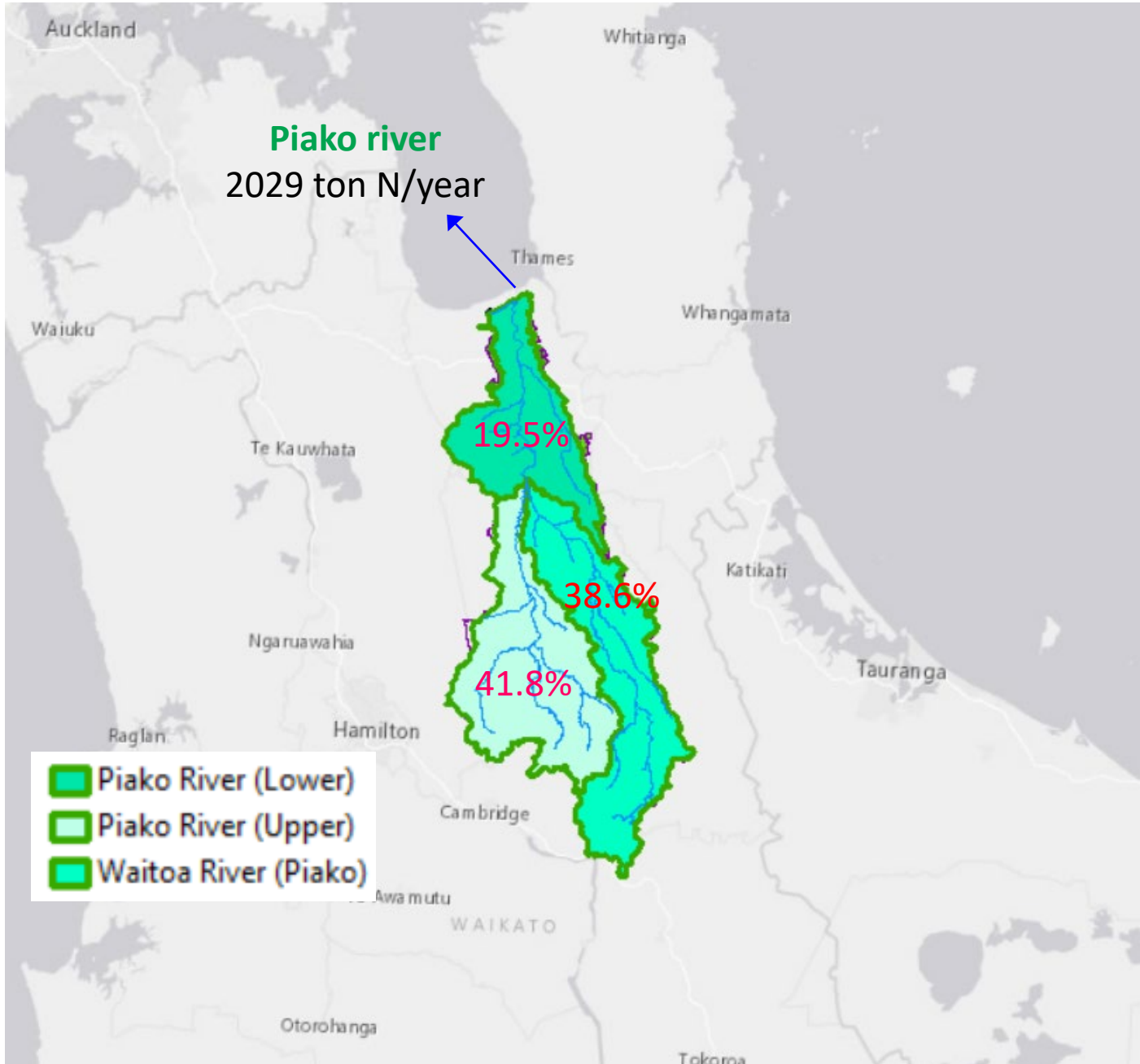
$R^2 = 0.28$



Preliminary results for nitrogen calibration

Piako catchment

Subcatchment	Draining area (km^2)	Nitrate load (ton/year)
Piako River (Upper)	565	850 (41.8%)
Waitoa River	544	783 (38.6%)
Piako River (Lower)	371	396 (19.5%)
Whole Piako catchment	1480	**2029**



Preliminary results for nitrogen calibration

Piako catchment

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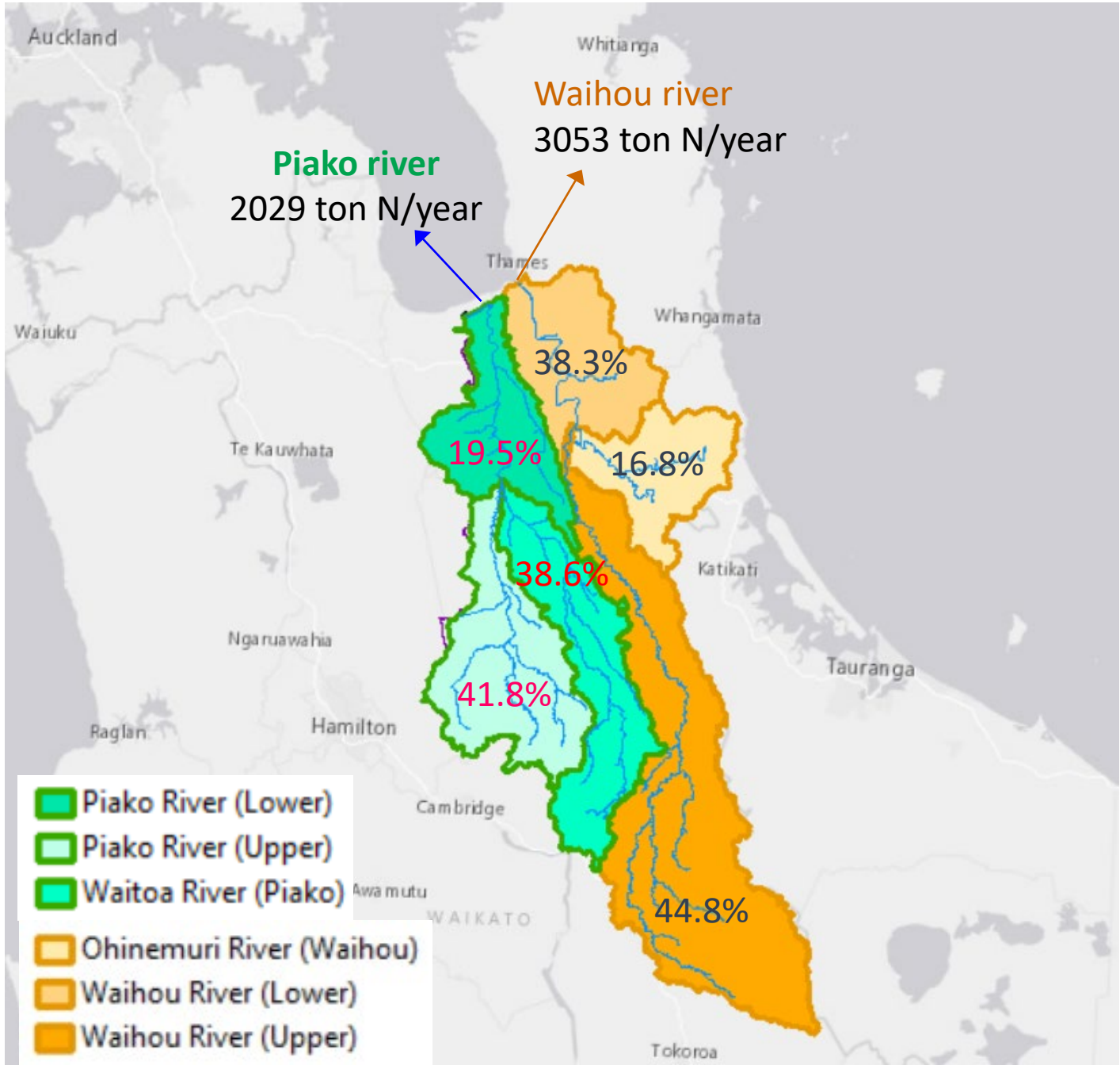
Piako River (Lower)	371	396 (19.5%)
Whole Piako catchment	1480	**2029**

Waiho catchment

Subcatchment	Draining area (km^2)	Nitrate load (ton/year)
Waihou river (Upper)	1210	1369 (44.8%)
Ohinemuri river	350	514 (16.8%)
Waihou River (Lower)	420	1170 (38.3%)
Whole Waihou catchment	1980	**3053**



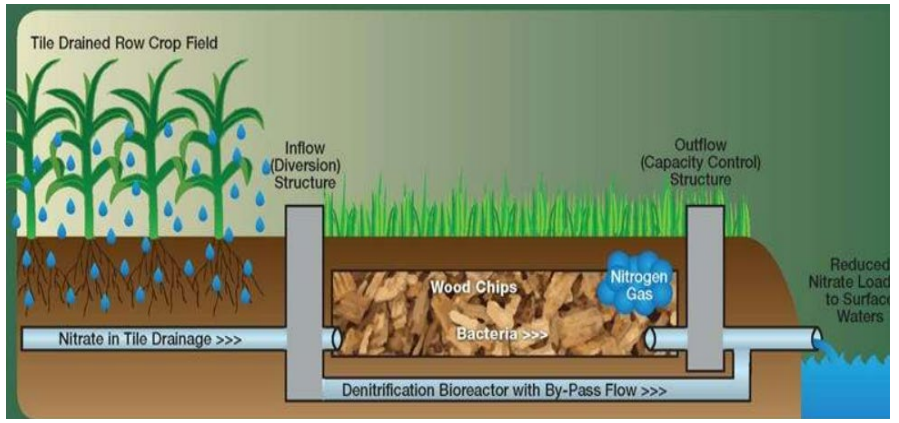
Future plans

- Finalize SWAT model setup and improve the SWAT model performance
- Modelling mitigation systems at catchment scale:

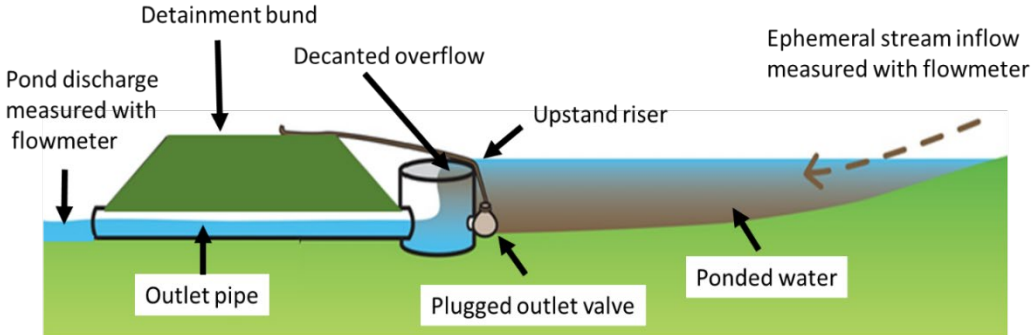
Constructed wetland

Riparian buffer

Woodchip bioreactors



Detainment bunds



Filamentous Algae Nutrient Scrubbers (FANS)

Thank you

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Climate, Freshwater & Ocean Science

NIWA
Taihoro Nukurangi

Model calibration and validation

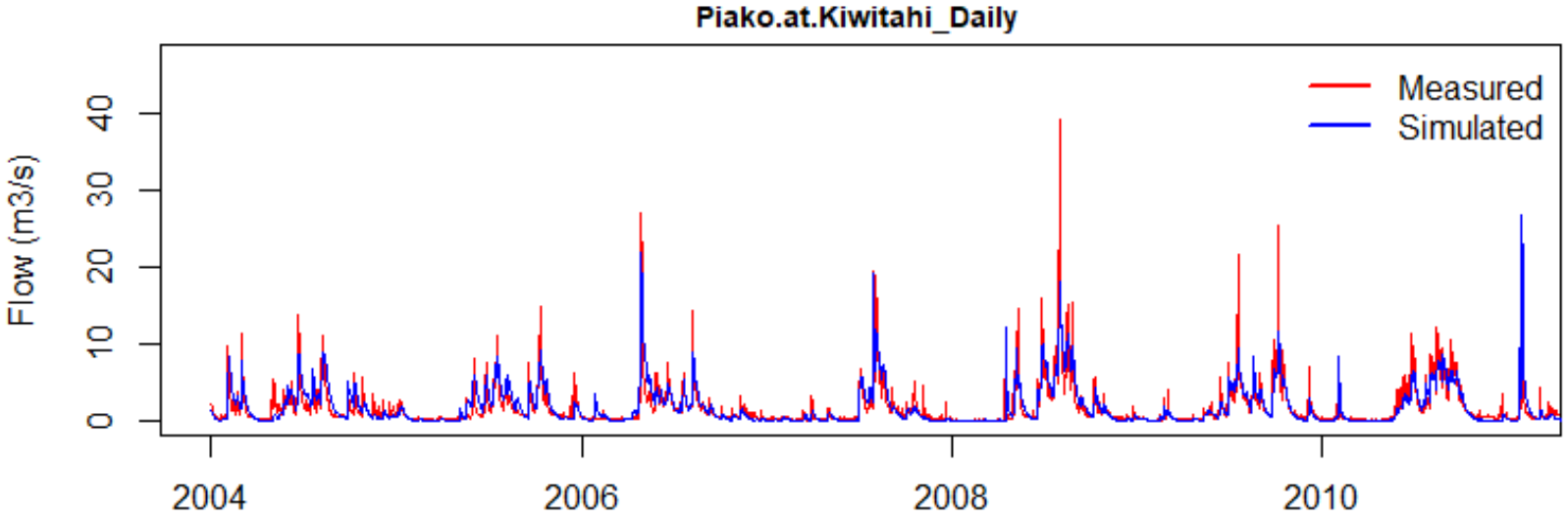
Piako at Kiwitahi

Daily

NSE = 0.71

R^2 = 0.71

PBIAS = 1.6%

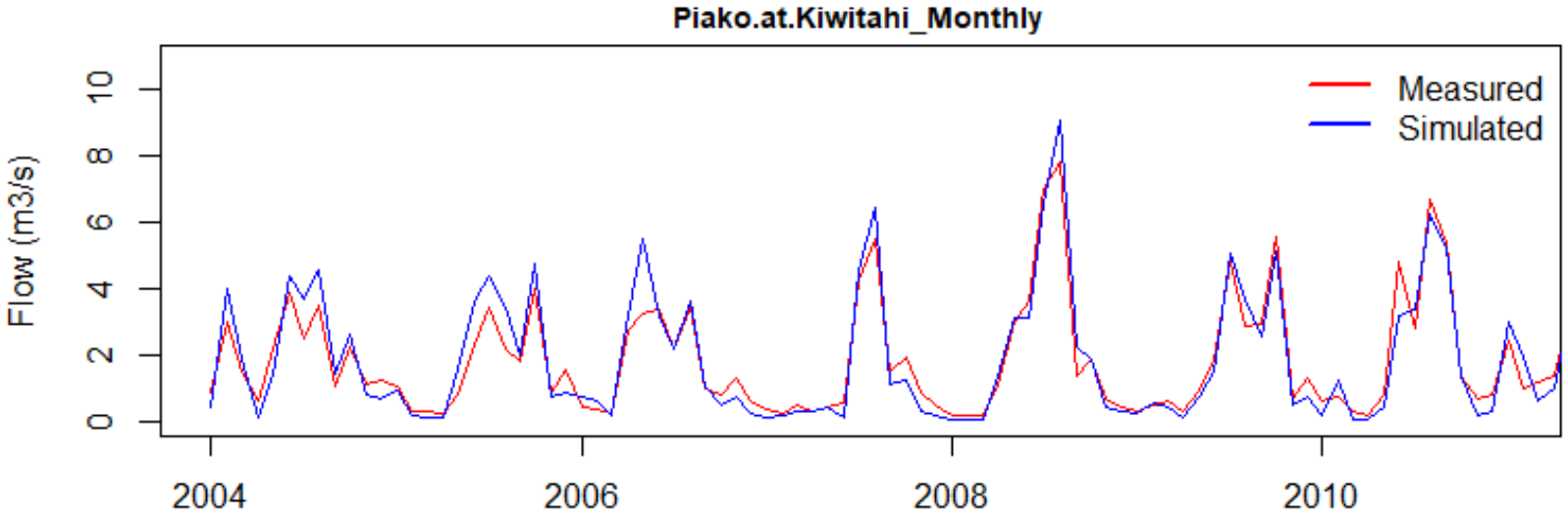


Monthly

NSE = 0.89

R^2 = 0.92

PBIAS = 1.9%



Model calibration and validation

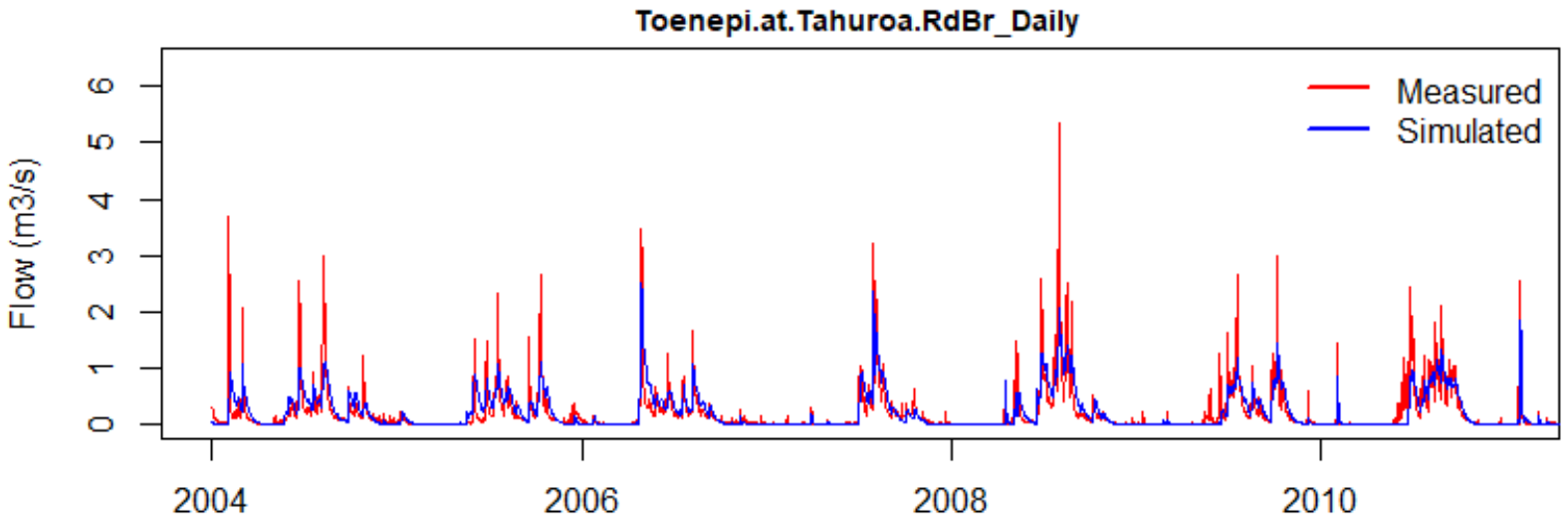
Toenepi at Tahuroa Road bridge

Daily

NSE = 0.60

R^2 = 0.60

PBIAS = 0.2%



Monthly

NSE = 0.87

R^2 = 0.88

PBIAS = 0.2%