Okaro ensemble modelling

LERNZ

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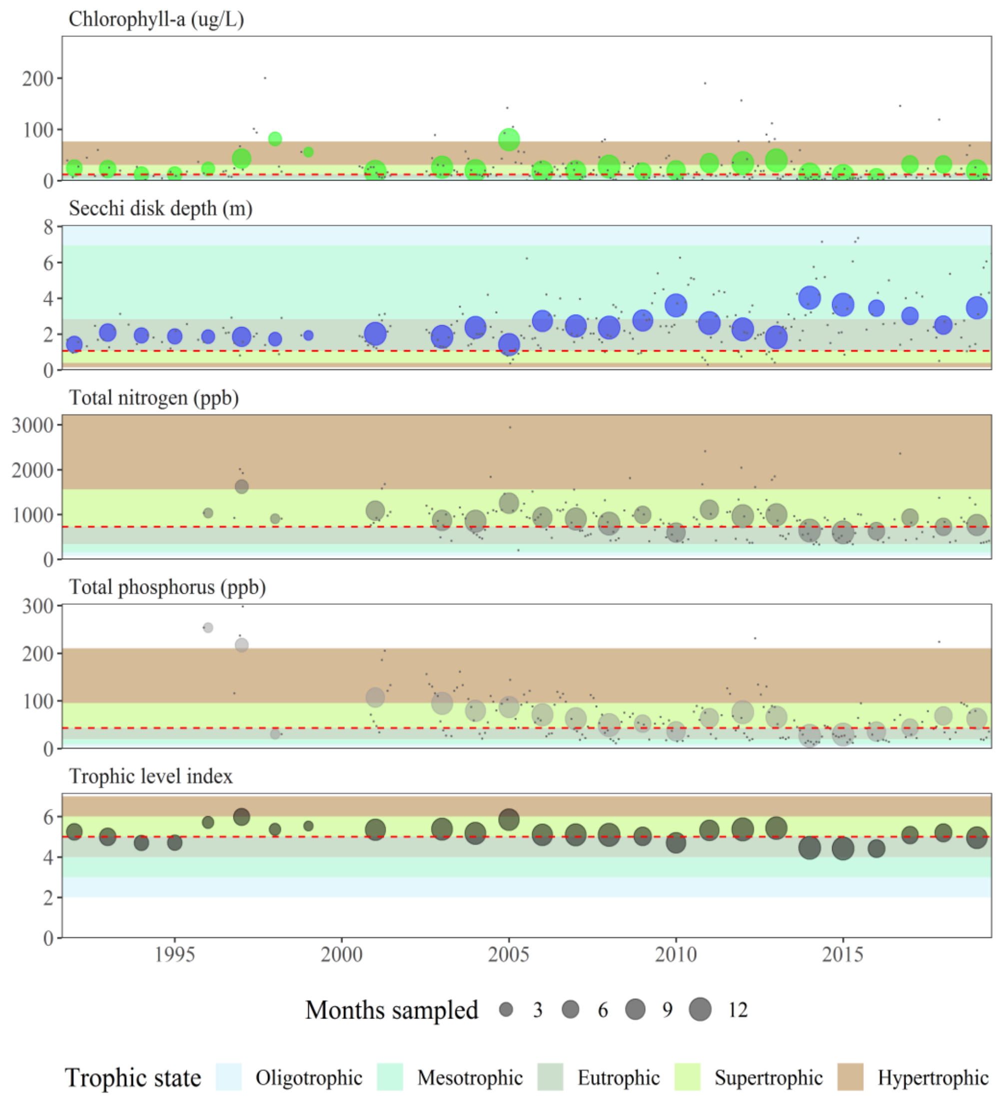
Lake Okaro drone picture captured by David G. Schmale, Ph.D., Fulbright U.S. Scholar, University of Waikato, New Zealand, 20 Feb 2020.

Background – Lake Okaro

- *Okaro on* the cusp of a supertrophic/eutrophic lake
- Current changes to the catchment to address nutrient inputs to the lake have not achieved the TLI
- An ecologically coupled 1-D hydrodynamic lake model would be informative to be able to demonstrate possible outcomes of current and changing land use on lake water quality targets



Lake restoration

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- Restoration actions
  - Aluminium sulfate (alum) dosing in December 2003 (Paul et al. 2008; Özkundakci et al. 2010)
  - Modified zeolite dosing in September 2007, construction of a 2.3 ha wetland in 2006 (Hudson and Hudson 2011)
  - Riparian planting, farm planning and farm nutrient management, detainment bunds (Birchall and Paterson 2011),
  - Continued applications of 15 tonnes of liquid alum annually from December 2011 onwards (McIntosh 2016).

Why model?

- Gain insight into complex lake ecosystem dynamics
- To evaluate:
  - Restoration efforts (supporting management actions)
    - Changing external/internal nutrient loading
    - Changing water level
    - Changing ecosystem balance (biomanipulation etc.)
  - Changing climate

Wetland/riparian

Dosing

Date	Material	Application method	Dose (tonnes)
Dec-2003	alum	Spraying from a moving boat as aluminium sulfate solution.	4.59t
August-2007	Aqual P	Applied using a fertilizer spreader on a barge.	110t
September-2009	Aqual P	Applied as a fine powder (<1mm) injected at 3m below surface as a slurry.	44t
Dec-2011	Aqual P	A slurry was applied by helicopter.	5t
July-2012	alum	Spraying from a moving boat. Lake water was mixed from top to bottom during application.	8t
August-2012	alum	Spraying from a moving boat. Lake water was mixed from top to bottom during application.	14t

Mallet 2015
(MSc)

Ensemble modelling

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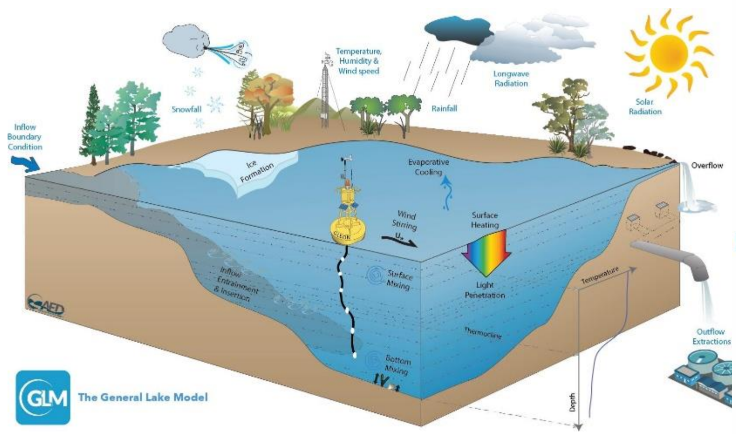
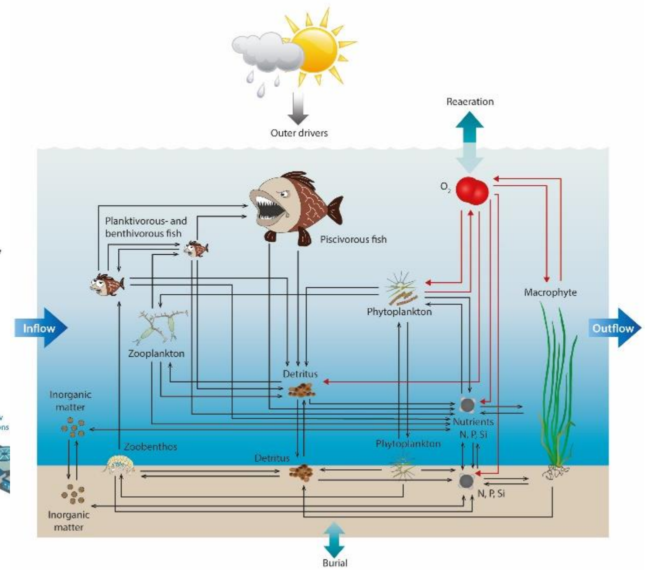
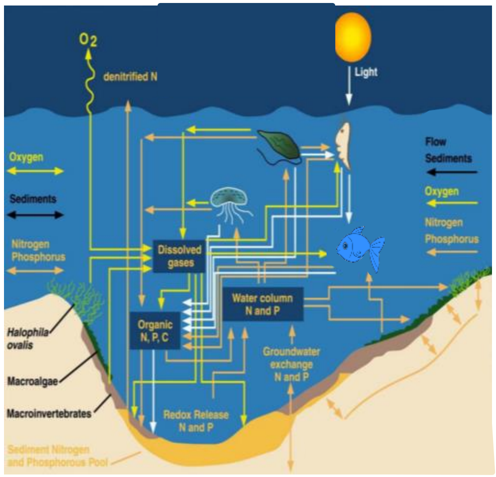
- The combination of different models can reduce the effects model structural and parameter derived uncertainty and provide better information to decision makers.
- The models applied are DYCD, GLM-AED and PCLake

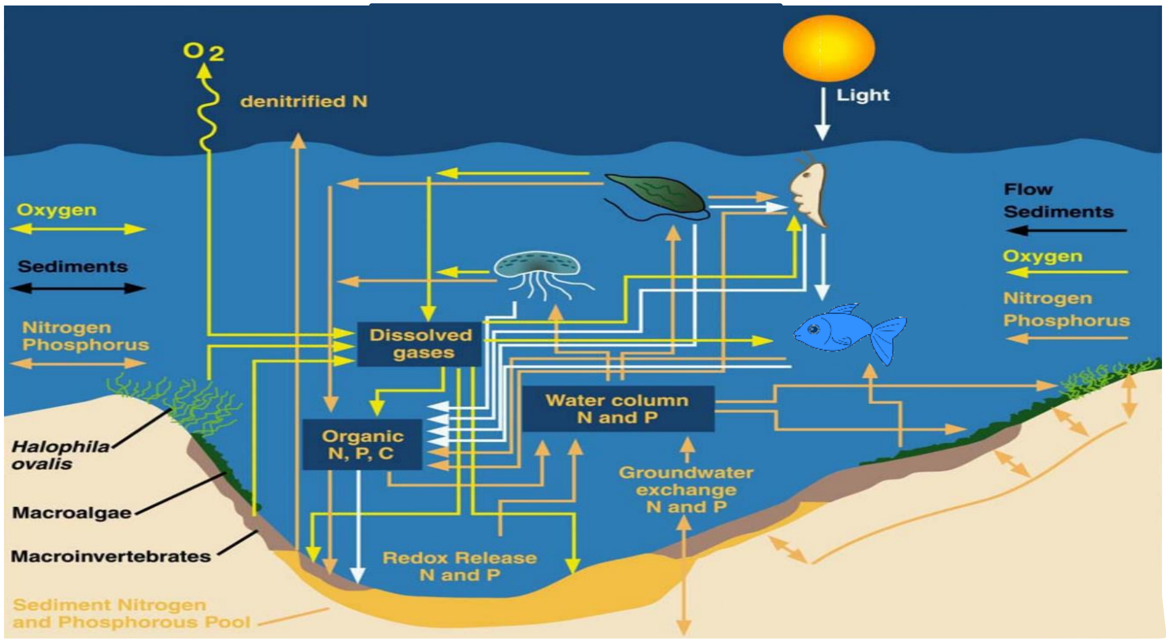






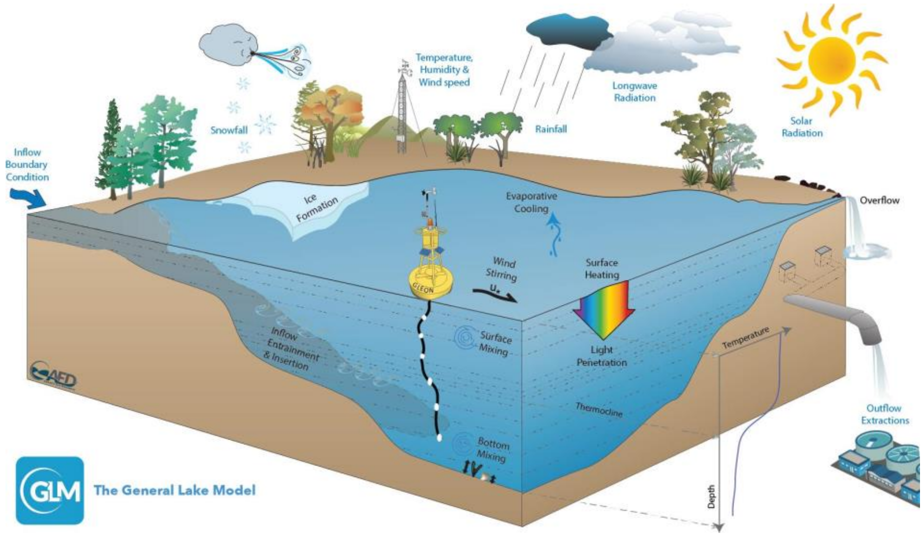
DYCD

- Modified from ÖZKUNDAKCI (2010)
- Updated with new inflow and met data 2003-2019



GLM AED

- Modified from **SANTOSO** (2016)
- Updated with new inflow and met data 2003-2019



PCLake-GOTM-FABM

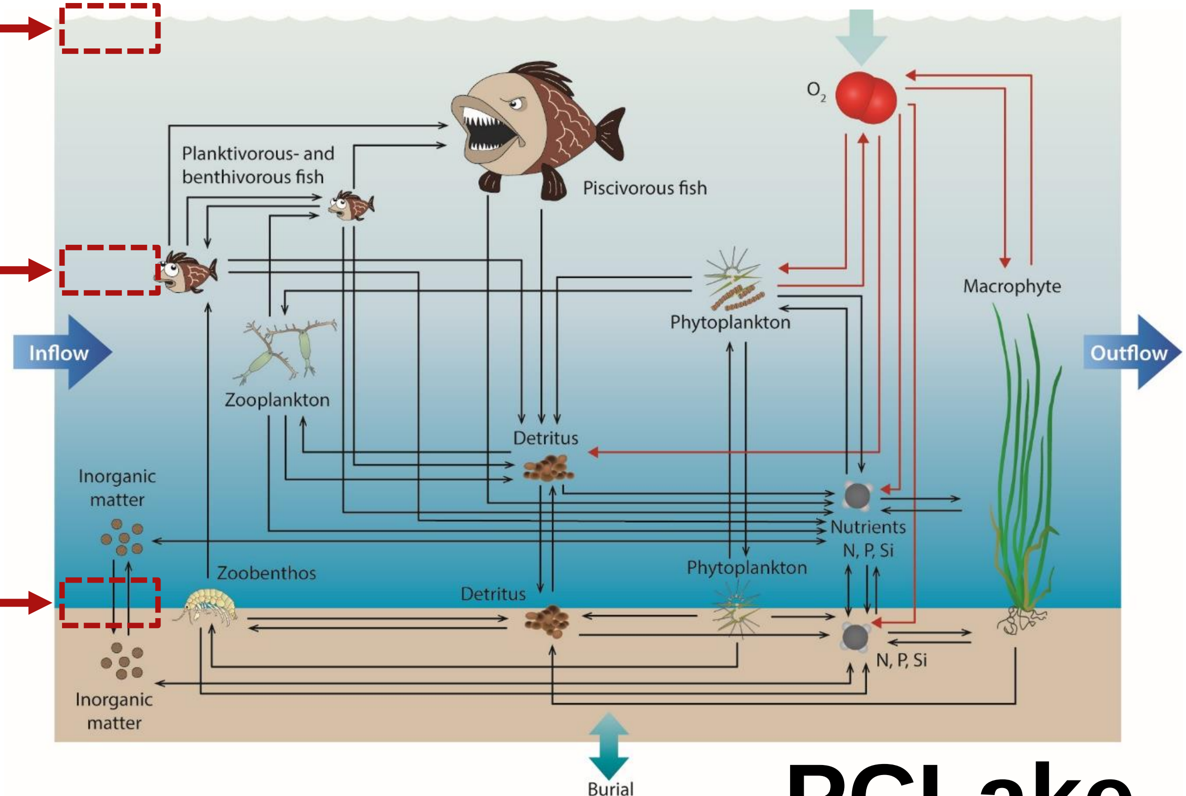
Physical processes

Water-atmosphere interface:
- Surface fluxes
- Atmospheric forcing input

Water column:
- Advection
- Molecular and turbulent diffusion
- Settling
- Active vertical movement

Water-sediment interface:
- Bottom fluxes
- Settling
- Resuspension (shear stress)

Biogeochemical model



PCLake

- New deployment
- Inflow and met data 2003-2019
- Differs from other models as sediment is dynamic, and has well developed fish/macrophyte modules

ParSAC – Parallel Sensitivity Analysis and Calibration

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- Tested and running on NESI!
- Python to perform sensitivity and *automatic* optimization (in the Maximum Likelihood sense)
- Nelder-Mead (simplex) from 1965 and Differential Evolution from 1997

R

- All modelling, met and inflow generation scripted in R
- Advantages:
  - Repeatable
  - Traceable
  - Updateable
  - Transferrable
  - Python/R platform independent

Study site- Lake Okaro

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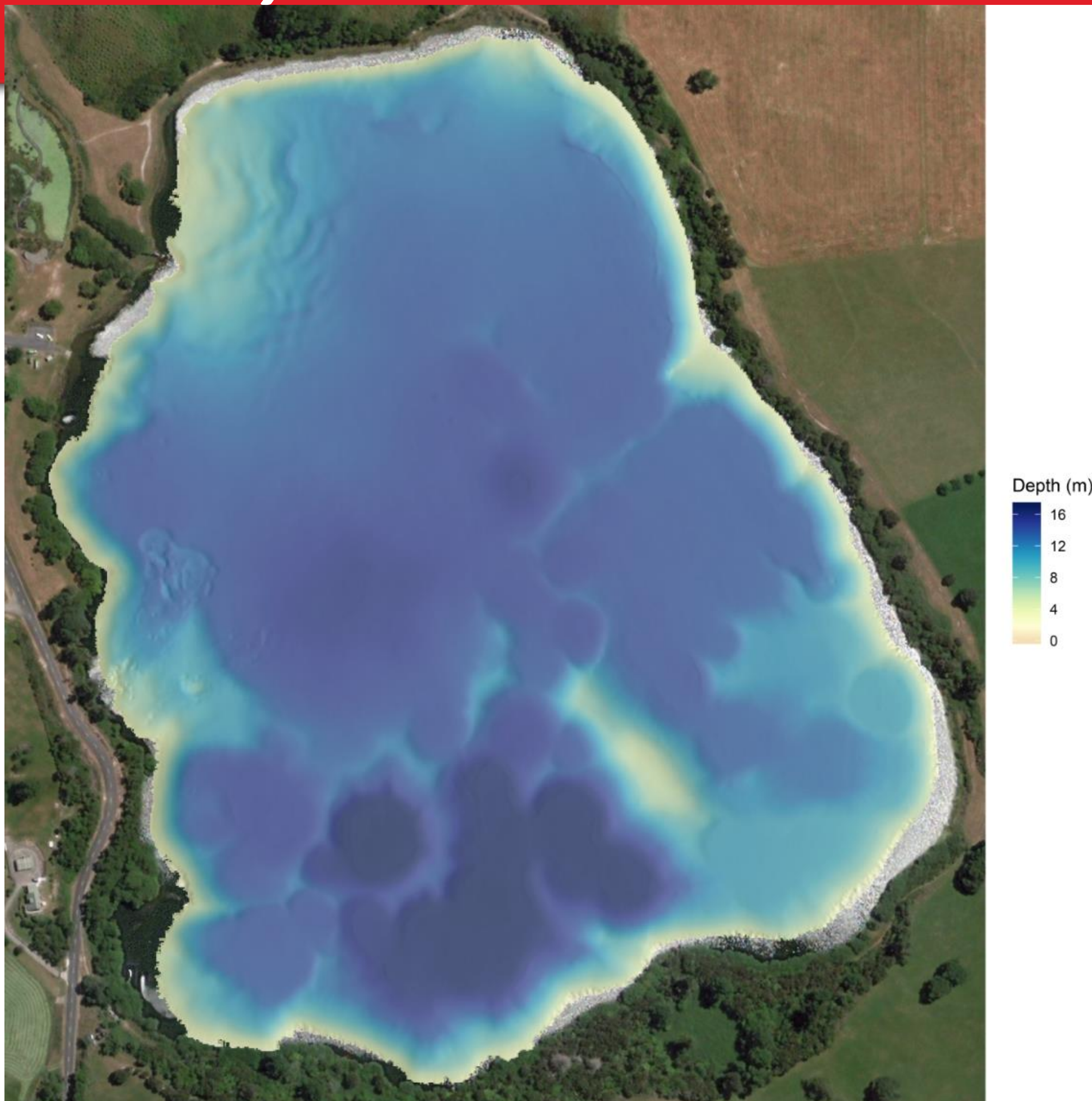


Catchment of Lake Okaro

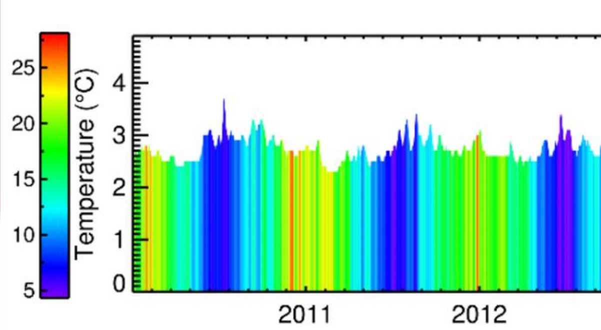
Land Cover

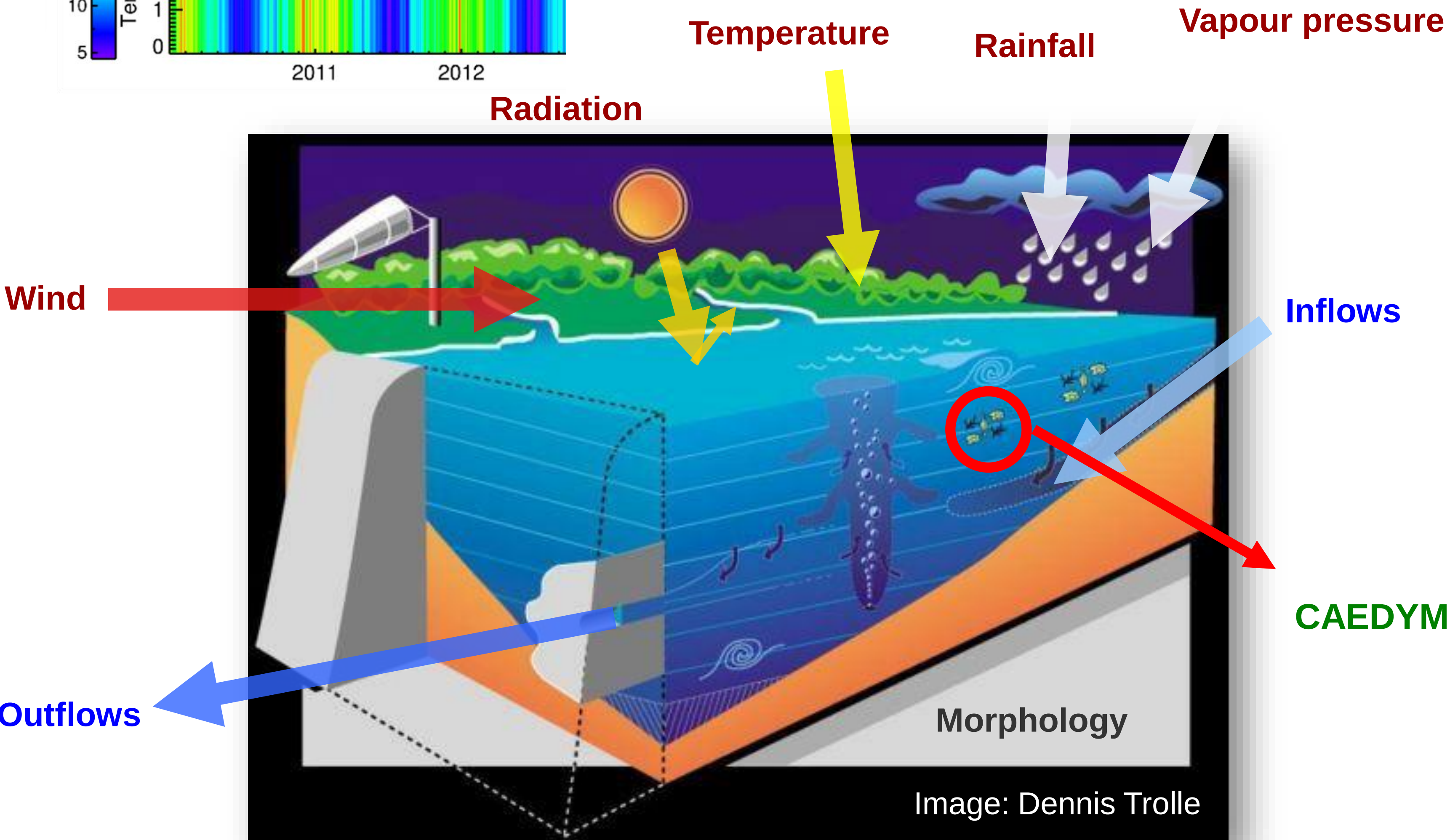
- Forest indigenous 3.6 %
  Forest planted 0.7 %
- Pasture exotic 95.7 %
- TOTAL 375 ha

Lake

- Monomictic
- Supertrophic/eutrophic lake
- Area 30.13 ha
- Submerged vegetation
- Catchment (360 ha) is mainly comprised of dry stock (84%) with some dairy (13%)
- Av. Max depth 16.85 m
- Anoxic events during stratification

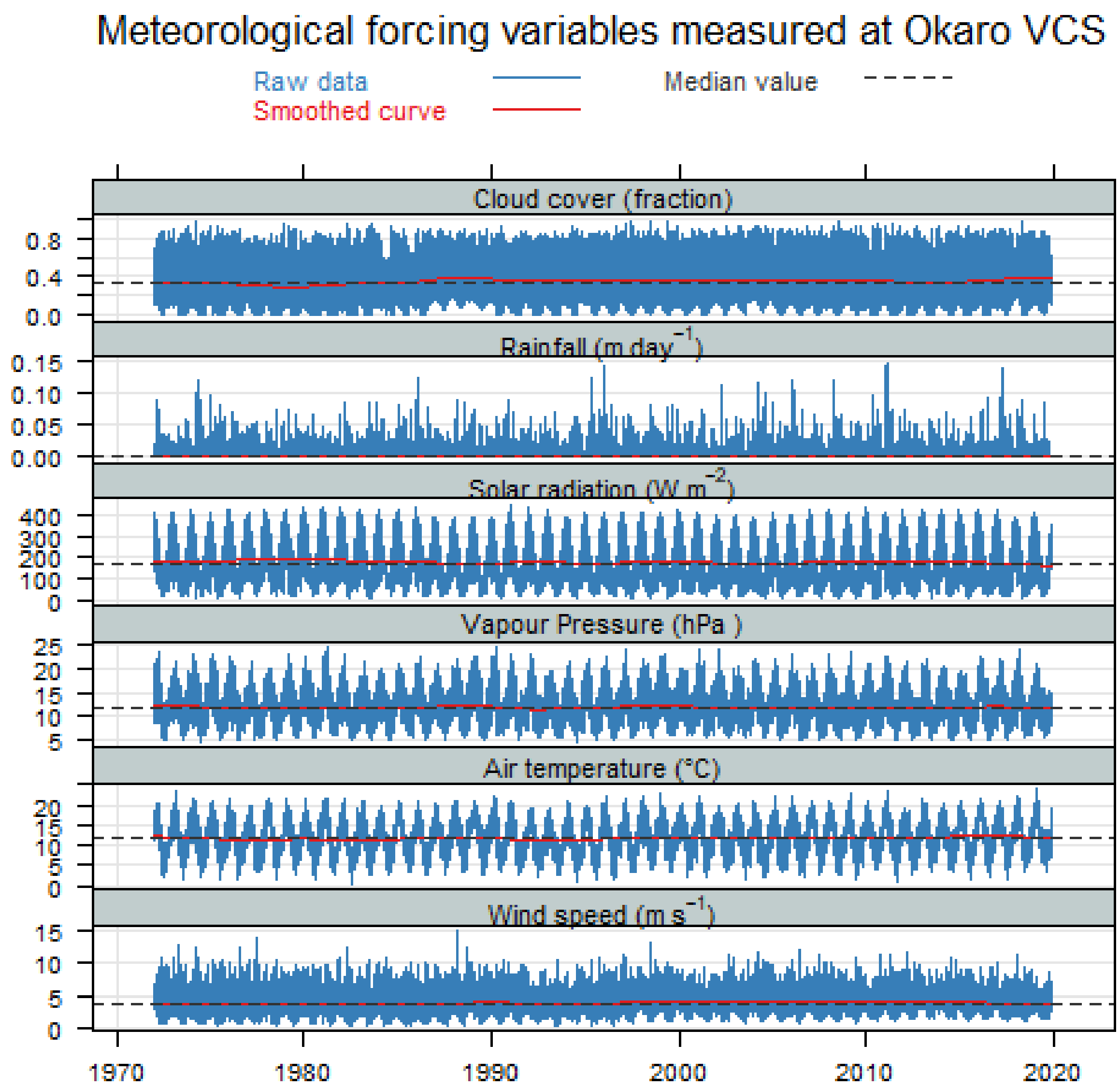
1-D modelling





1-D hydrodynamic model developed at CWR Australia (Schladow & **Hamilton**, 1997)

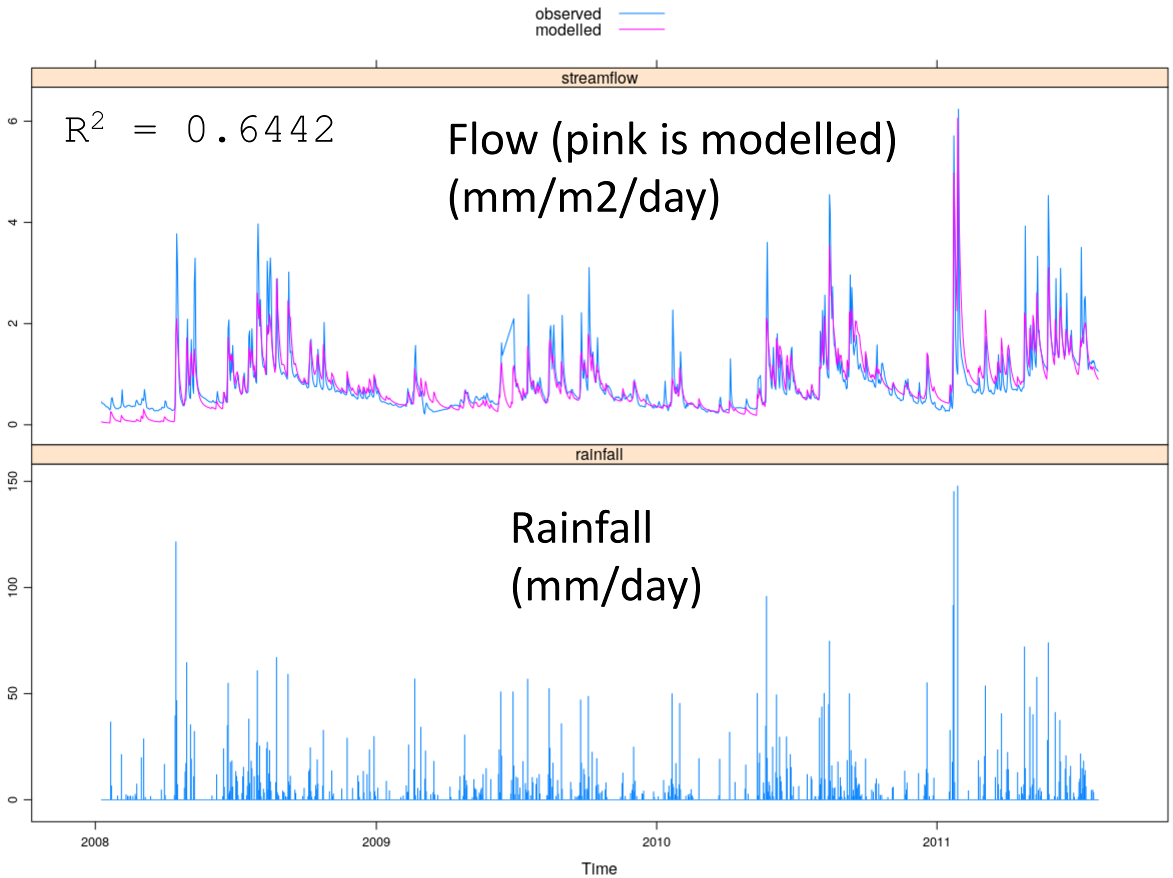
Met data



Meteorological forcing variables measured at Okaro VCS
Raw data
Median value
Smoothed curve
Cloud cover (fraction)
0.8
0.4
0.0
Rainfall (m day^{-1})
0.15
0.10
0.05
0.00
Solar radiation (W m^{-2})
400
300
200
100
0
Vapour Pressure (hPa)
25
20
15
10
5
Air temperature (°C)
20
15
10
5
0
Wind speed (m s^{-1})
15
10
5
0
1970
1980
1990
2000
2010
2020

Inflow modelling - HYDROMAD

- Rainfall runoff model **Hydromad** R package which optimizes parameters
- Forced by NIWA VCS data
- Inflow volume estimated from 1972-2019
- Inflow nutrients interpolated from 2003-2019



- Reasonable fit to measured data at wetland outlet
- Other flow estimated using a water balance
- Residual inflow was about 15 %, which would include storm wetland bypass and groundwater

Inflows

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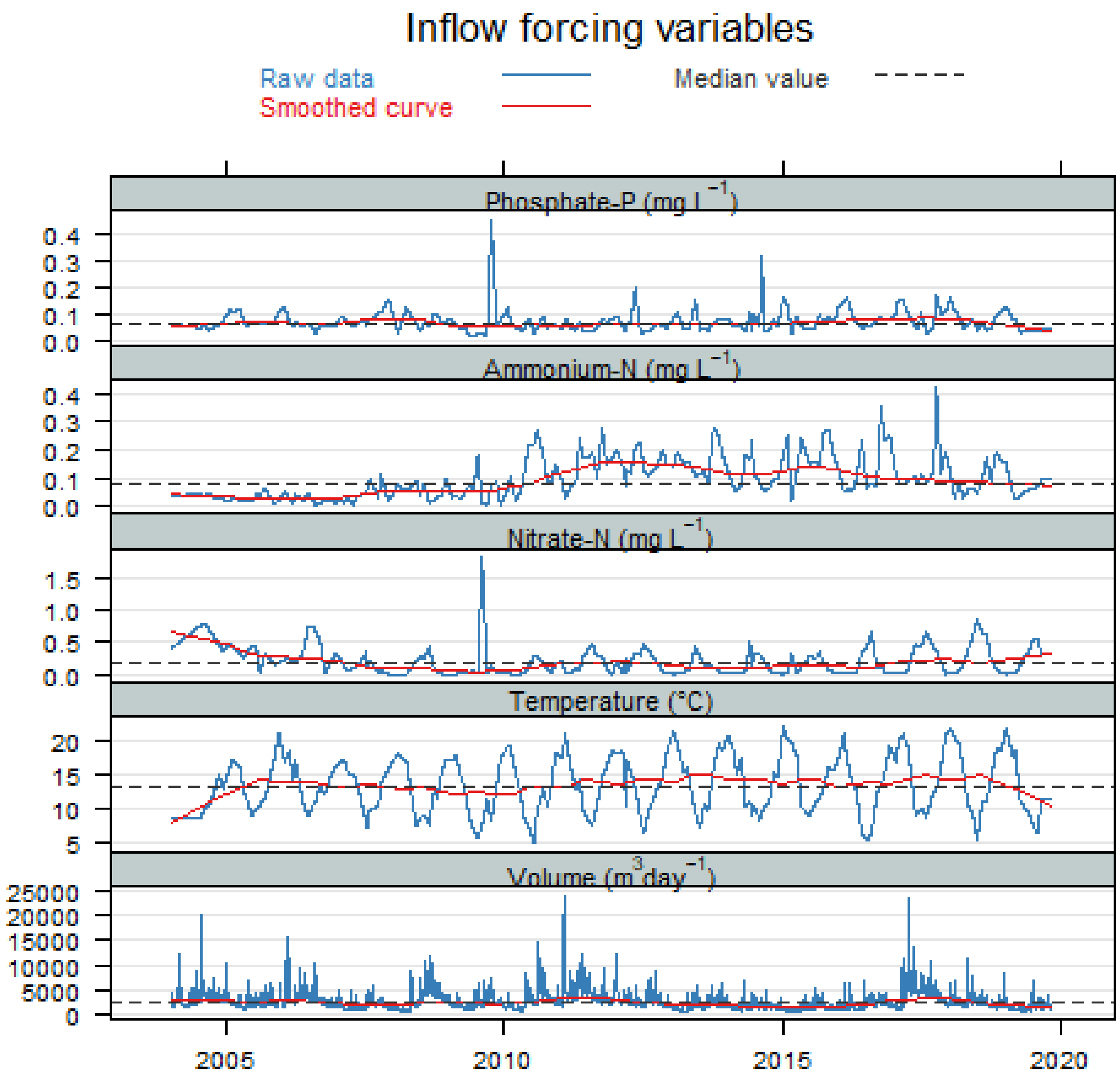
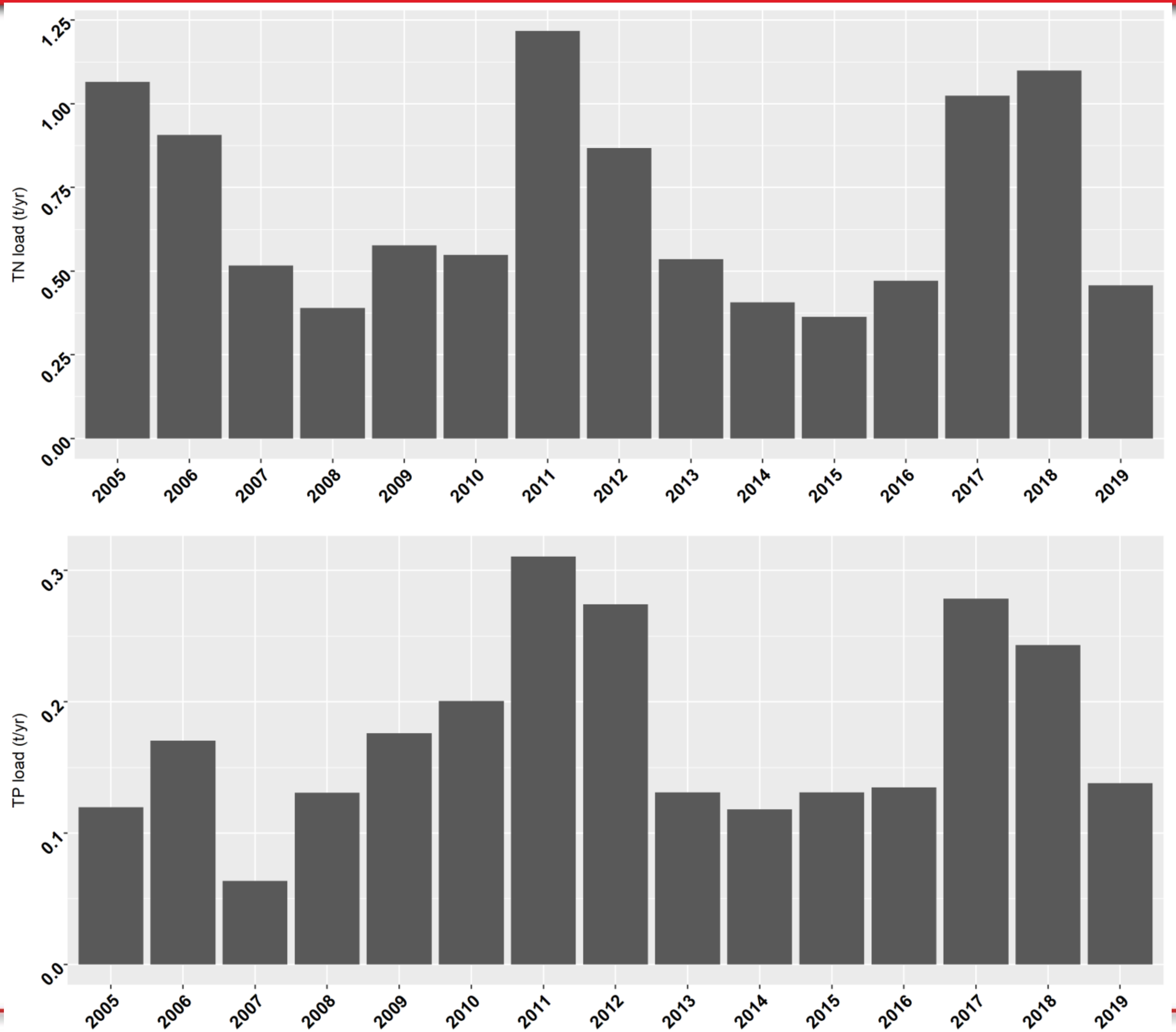


TN TP Stream load



Bottom waters

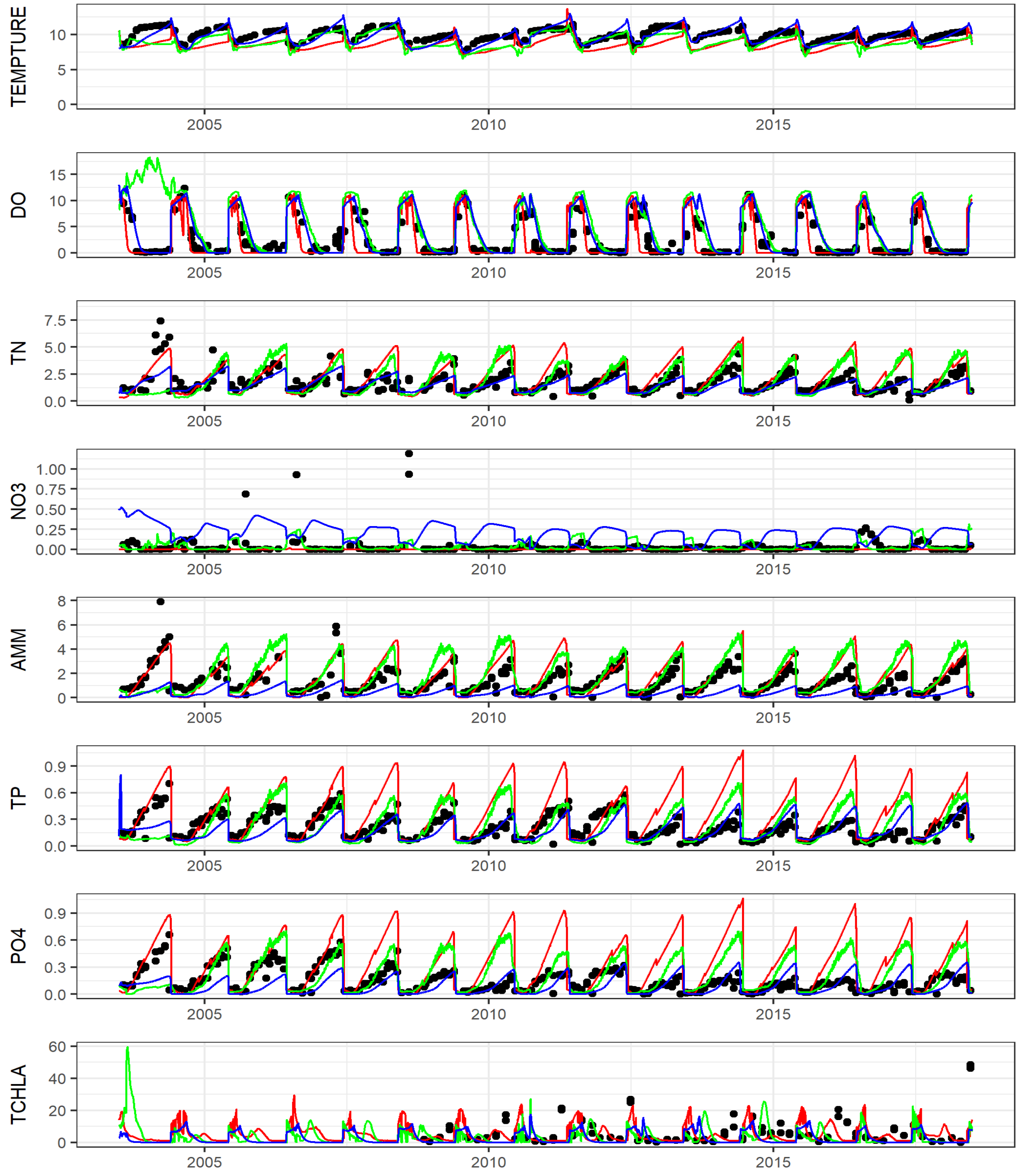
KEY

DYRESM CAEDYM

GLM-AED

PCLAKE_GOTM_FABM

BOPRC



Surface waters

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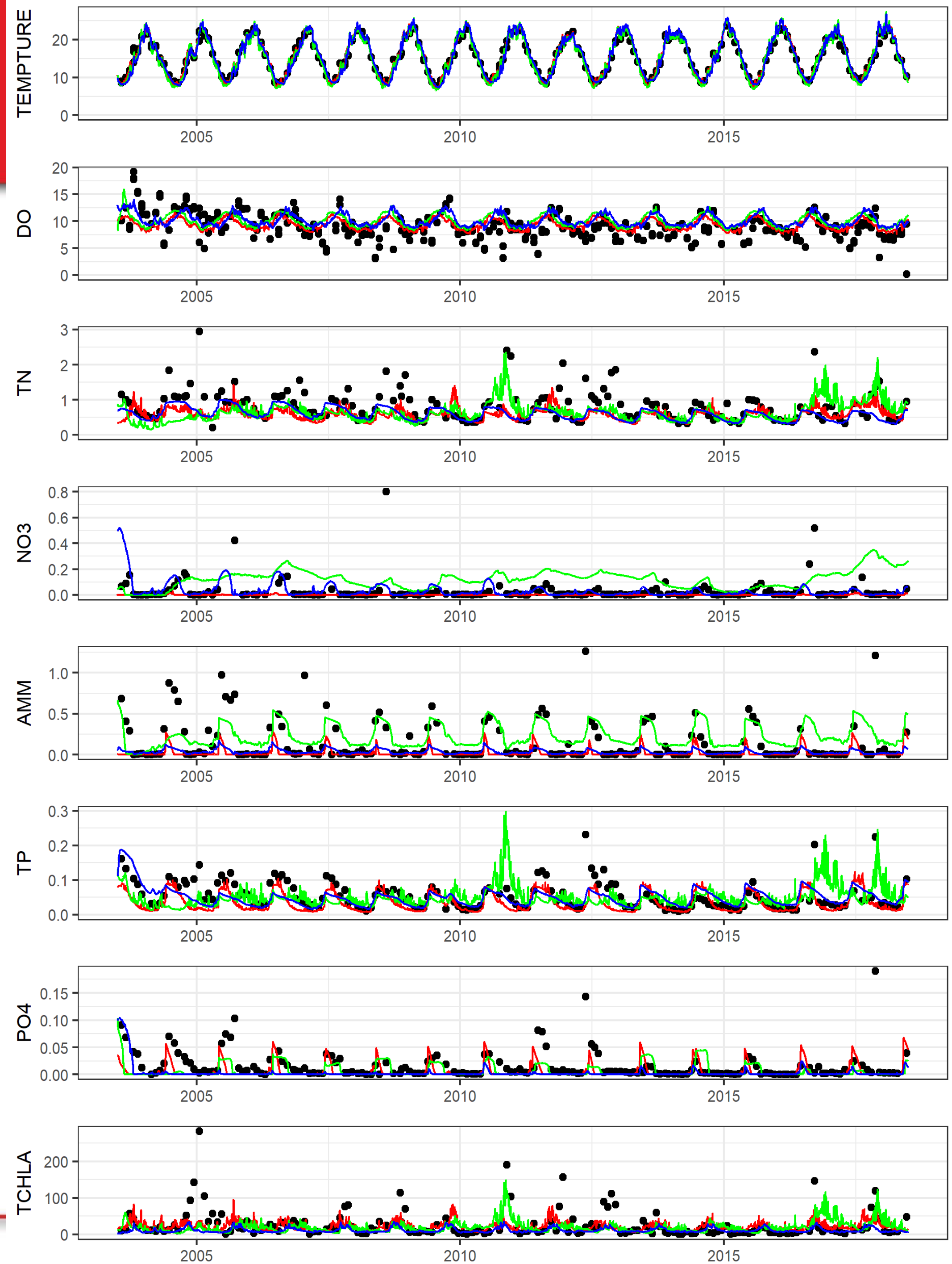
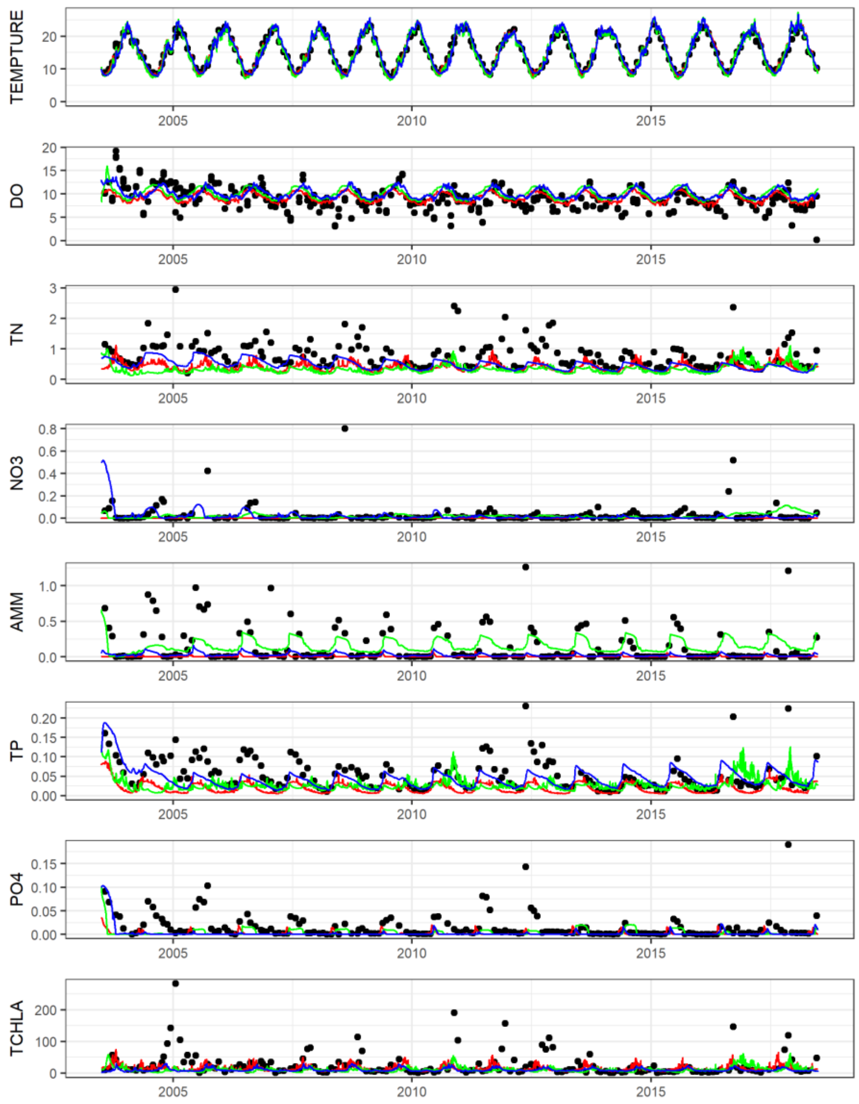


Stats

Epilimnion	Model	RMSE	PearsonR	Model	RMSE	PearsonR	Model	RMSE	PearsonR
NH4-N	DY-CD	0.29	0.36	GLM-AED	0.21	0.62	PCLake	0.28	0.67
DO	DY-CD	2.35	0.24	GLM-AED	2.55	0.23	PCLake	2.31	0.50
NO3-N	DY-CD	0.13	0.15	GLM-AED	0.16	0.15	PCLake	0.12	0.30
PO4-P	DY-CD	0.02	0.21	GLM-AED	0.02	0.60	PCLake	0.03	0.03
TCHLA	DY-CD	43.54	0.18	GLM-AED	44.39	0.24	PCLake	46.04	0.14
TEMPERATURE	DY-CD	0.74	0.99	GLM-AED	0.87	0.99	PCLake	1.13	0.98
TN	DY-CD	0.54	0.25	GLM-AED	0.55	0.29	PCLake	0.49	0.30
TP	DY-CD	0.03	0.69	GLM-AED	0.04	0.46	PCLake	0.03	0.71
TOTAL		**47.66**	**3.06**		**48.78**	**3.58**		**50.42**	**3.63**
Hypolimnion	**Model**	**RMSE**	**PearsonR**	**Model**	**RMSE**	**PearsonR**	**Model**	**RMSE**	**PearsonR**
NH4-N	DY-CD	1.09	0.57	GLM-AED	1.18	0.64	PCLake	1.25	0.79
DO	DY-CD	2.77	0.71	GLM-AED	2.17	0.84	PCLake	2.37	0.86
NO3-N	DY-CD	0.20	0.02	GLM-AED	0.32	0.41	PCLake	0.24	-0.37
PO4-P	DY-CD	0.19	0.67	GLM-AED	0.16	0.72	PCLake	0.13	0.82
TCHLA	DY-CD	3.35	-0.09	GLM-AED	4.71	-0.49	PCLake	8.55	-0.06
TEMPERATURE	DY-CD	1.22	0.70	GLM-AED	0.76	0.89	PCLake	0.64	0.84
TN	DY-CD	1.18	0.41	GLM-AED	0.66	0.50	PCLake	0.75	0.64
TP	DY-CD	0.18	0.64	GLM-AED	0.12	0.75	PCLake	0.12	0.86
TOTAL		**10.18**	**3.62**		**10.08**	**4.26**		**14.05**	**4.38**

Scenario 50% reduction TN TP



Scenario 50% reduction TN TP

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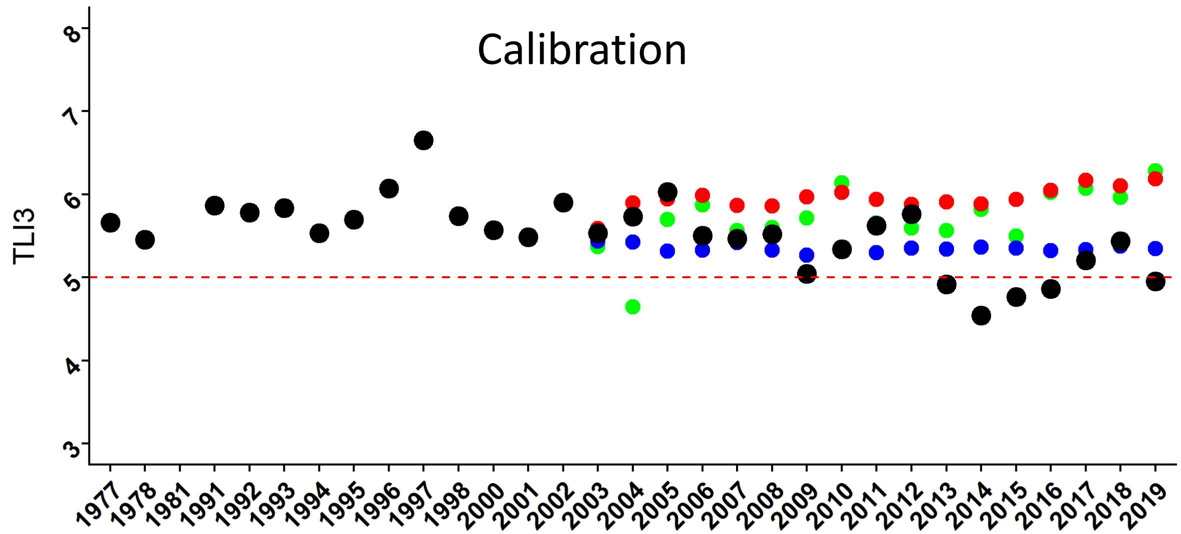

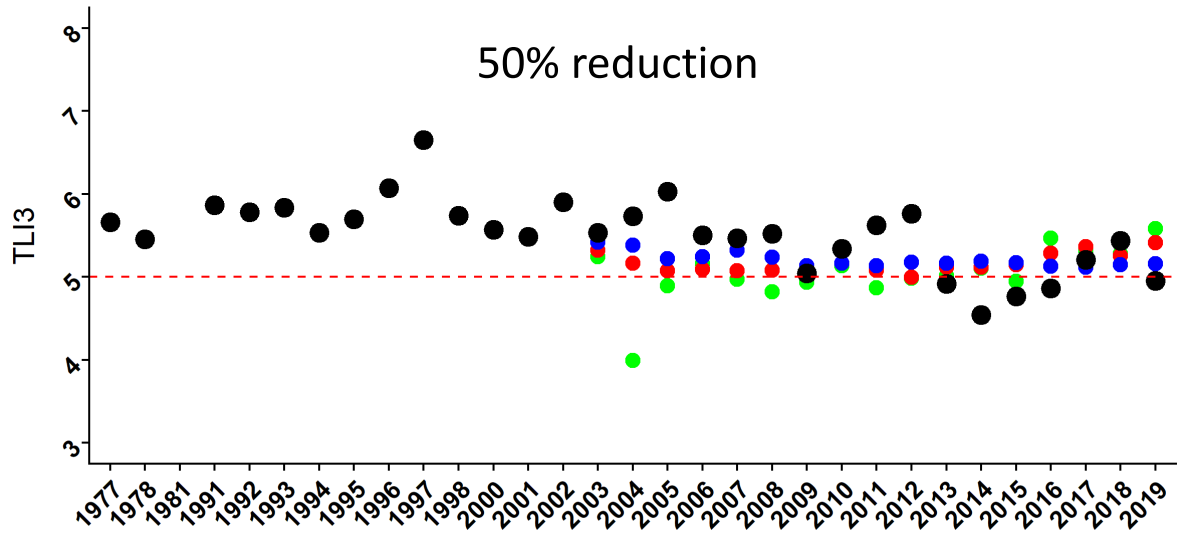

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Scenario 50% TN

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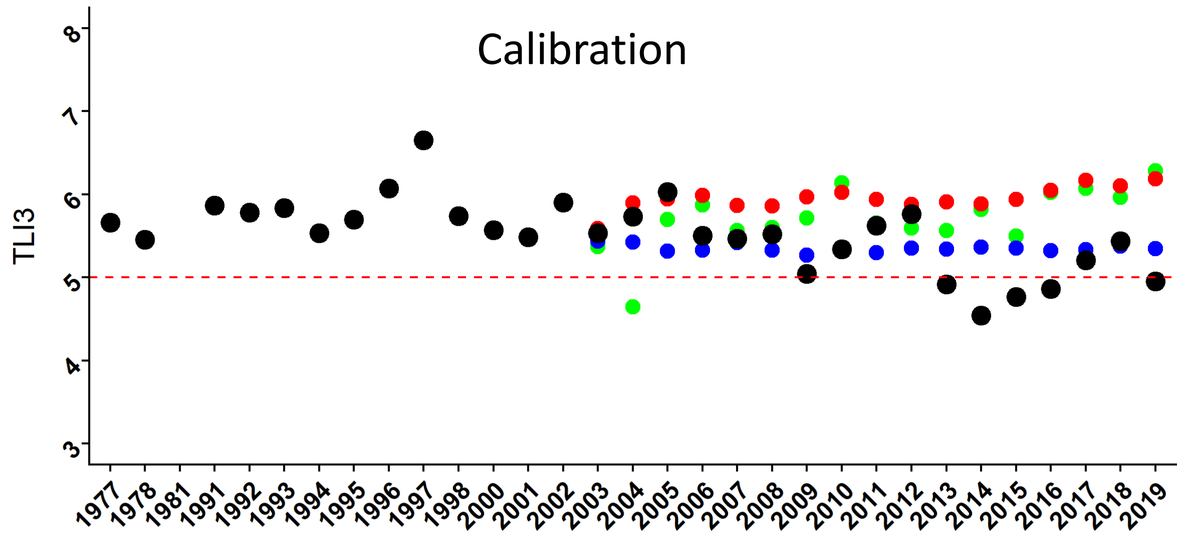

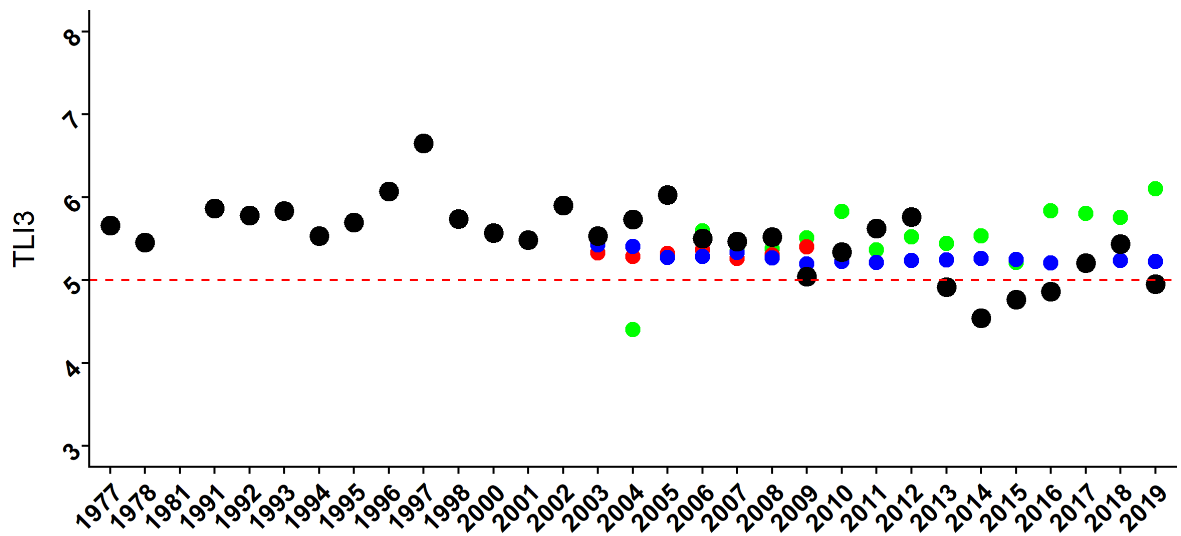

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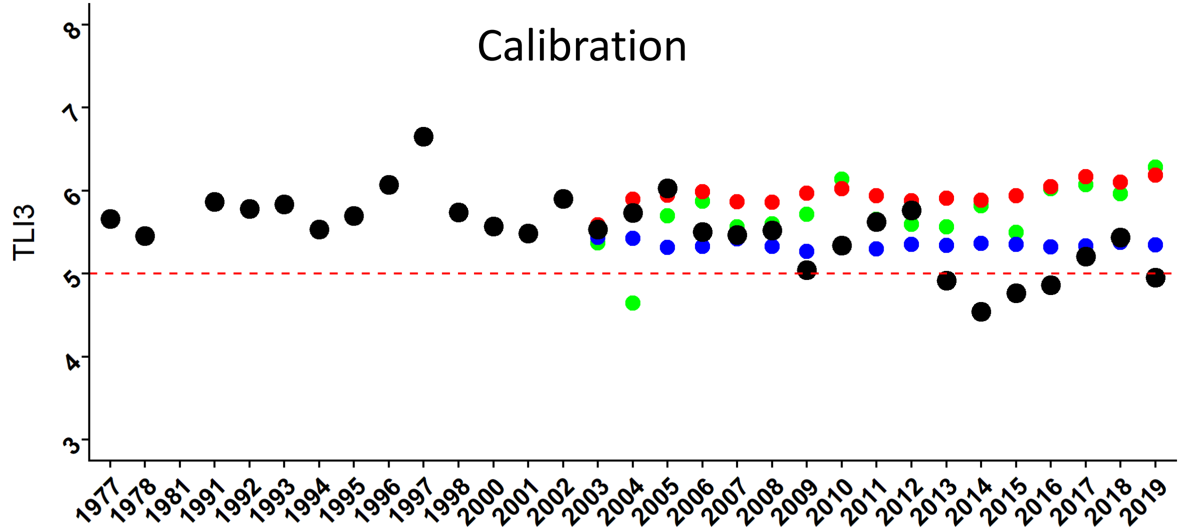
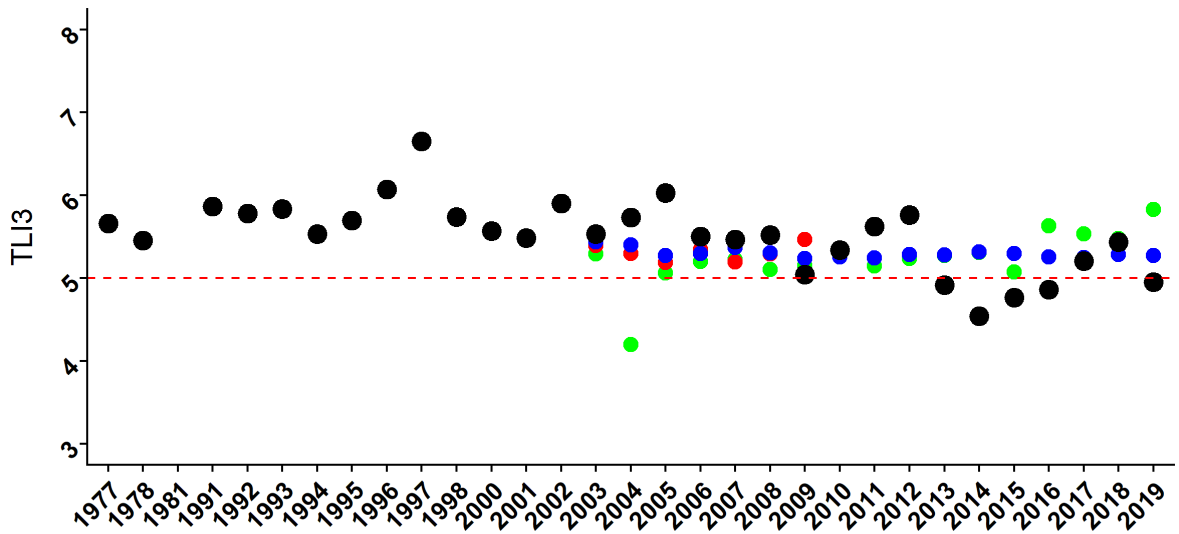
Scenario 50% TP





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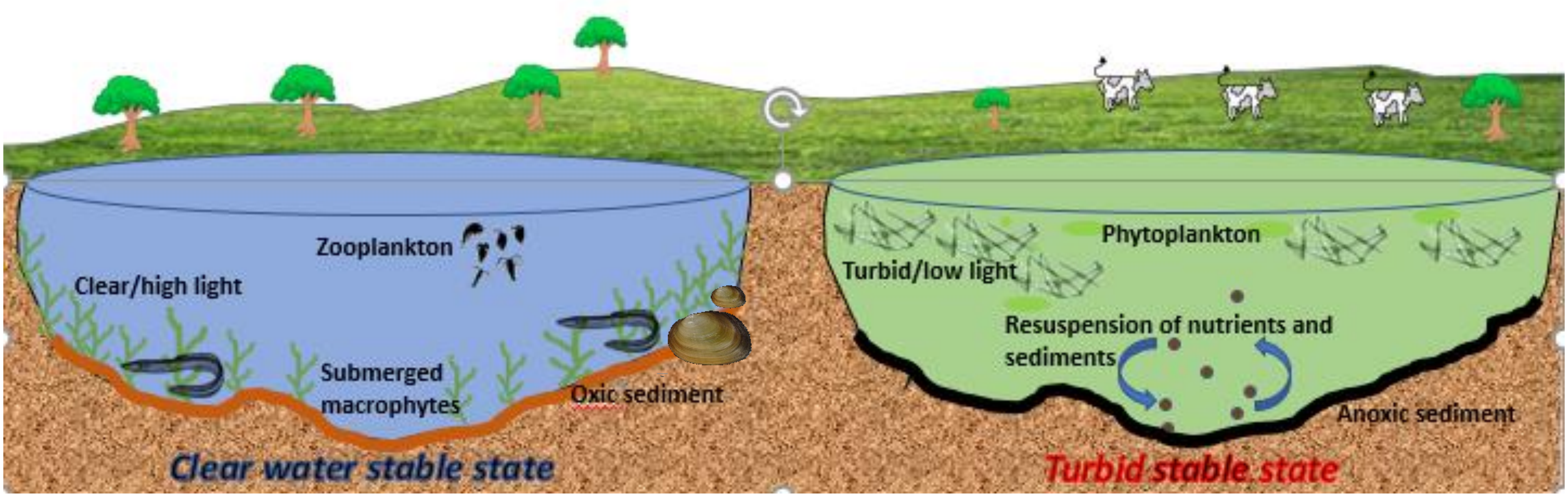
Summary

- Findings consistent with previous studies in Lake Okaro, 50 % reduction of load can lead to a reduction of TLI by approximately 0.5 (Özkundakci et al. 2011)
- The lag time for sediments to reach equilibrium could be between 10 and 15 years (Jeppesen et al. 2005)
- The ensemble modelling approach gives more certainty to the estimation of nutrient load reductions needed to meet TLI target of 5.0
- And important question arises from apparent increasing LOADS of nitrate and ammonium?
- New capability: **ParSAC** – Parallel Sensitivity Analysis and Calibration
  - This is an autocalibration capability. We have successful tested **ParSAC** in parallel mode on NESI
  - The present version of ParSAC has Nelder-Mead (simplex) from 1965 and Differential Evolution from 1997

Acknowledgements

EBOP staff
Denizo
Ari
Kohji

Lake water quality - alternate stable states



Resilience: amount of change/disruption required for transformation of a system from being maintained by one set of mutually reinforcing processes and structures, to a different set of processes and structures

Hysteresis: a condition wherein the reverse path is not the same as the forward path

For example reducing nutrient load to 1950's levels may not result in 1950's water quality!