Lake Ellesmere/Te Waihora Symposium
Lincoln, 15-16 November 2011

Lake restoration:
Is there a successful model?

David Hamilton
University of Waikato


Photo: Warrick Powrie

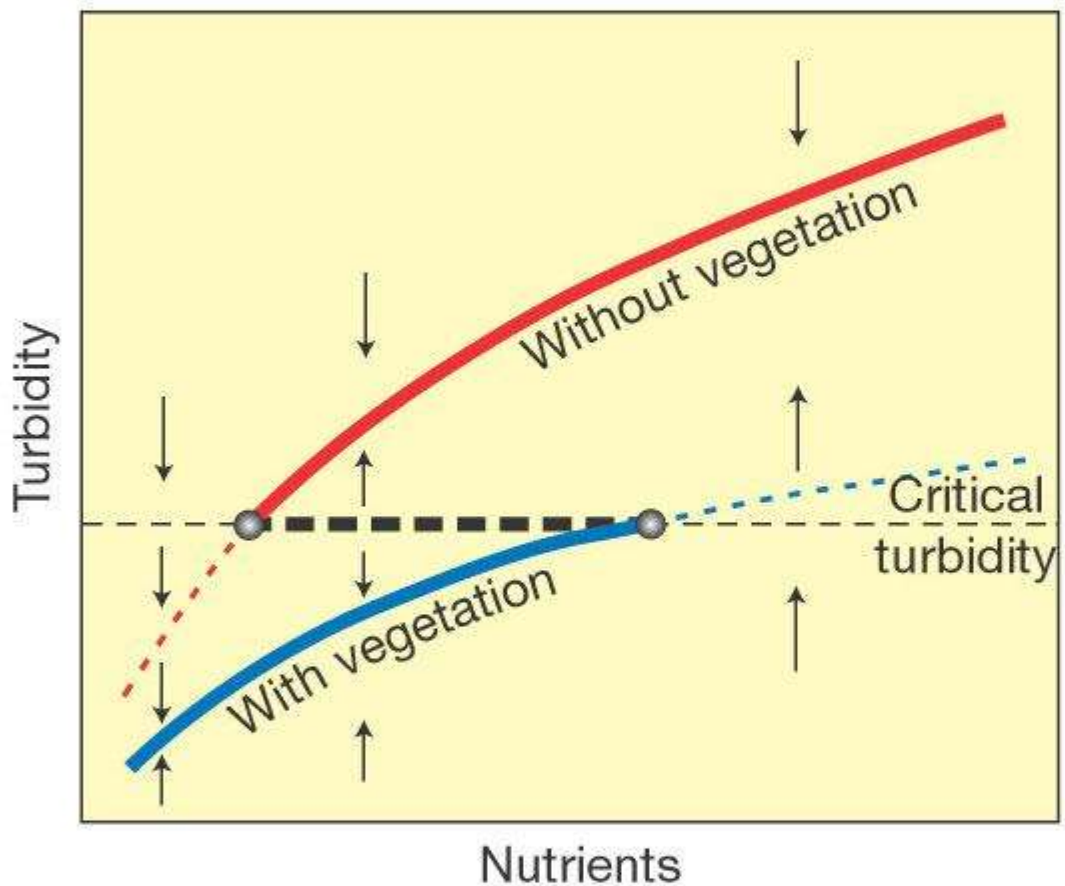
Lake restoration: Is there a successful model?

Outline

- Straight to the point – an overview of key needs for lake research/management
- What are the issues globally?
- A plea for models
- Case studies – Rotorua lakes
- So?

Photo: Warrick Powrie

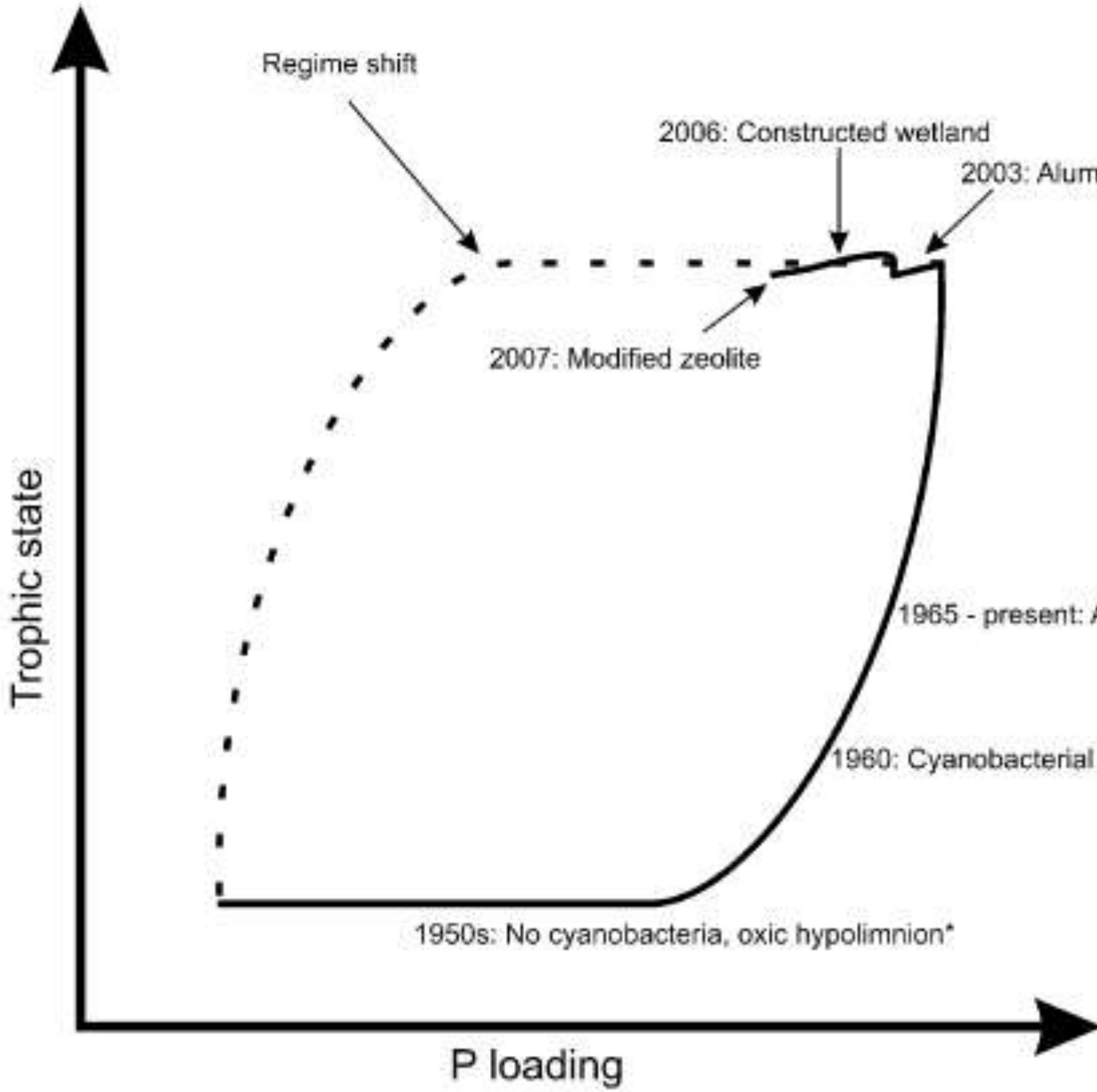
Point 1. Ecological processes in lakes will generally <u>not</u> follow linear trajectories expected from linear changes in external forcings (e.g. catchment nutrient loads)



Scheffer et al. (2004)
Souce: www.nature.com


Lake Waihola, Otago

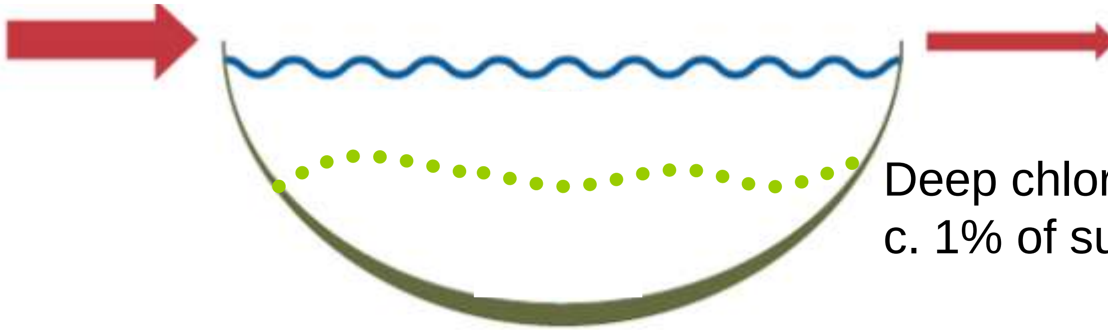
Regime shift in a eutrophic Rotorua lake



Ozkundakci et al. (2010), Ecological Engineering

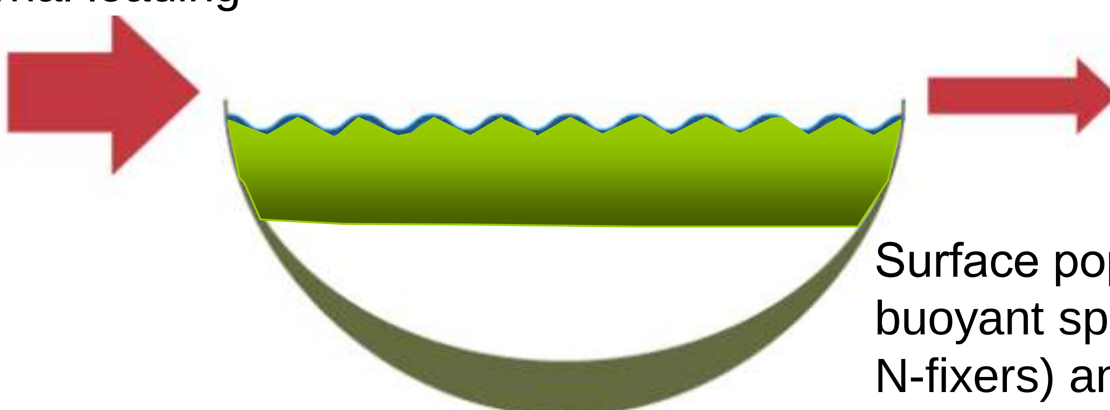
Effects of increasing nutrients loads on chlorophyll distributions (deep lakes)

Natural/low external loading



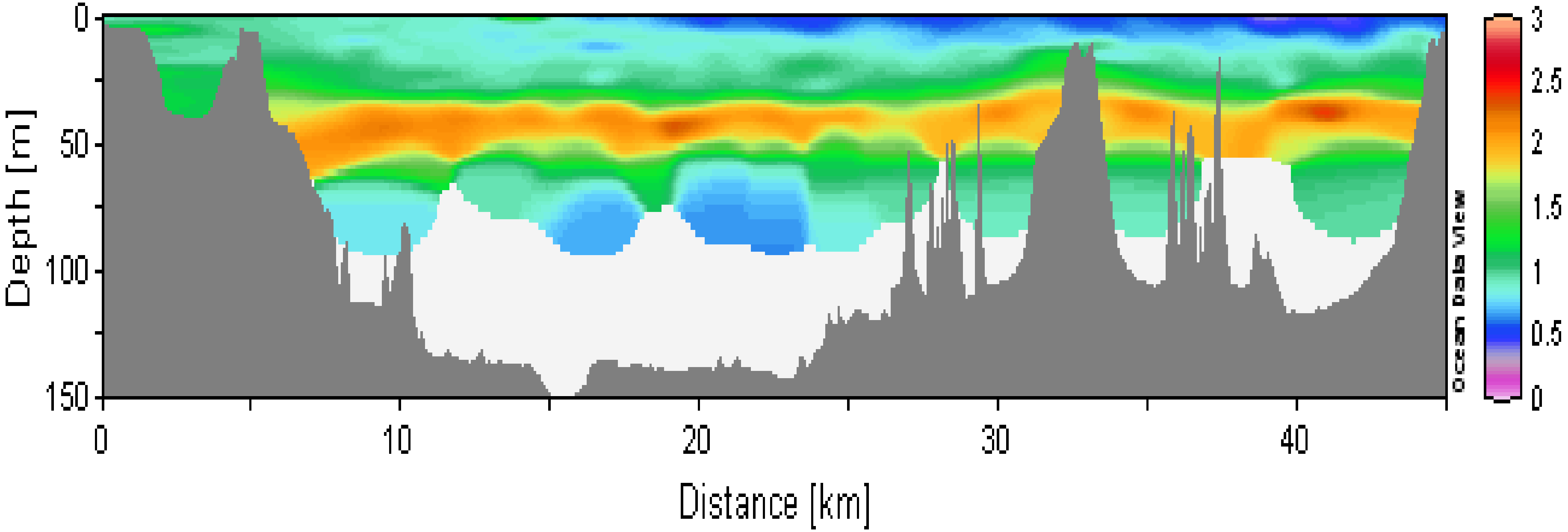
Deep chlorophyll maximum
c. 1% of surface light

Increased external loading



Surface populations, ↑ buoyant species (including N-fixers) and horizontal variability

Distributions of chlorophyll: Lake Taupo



Hamilton et al. 2010, Aquatic Sciences

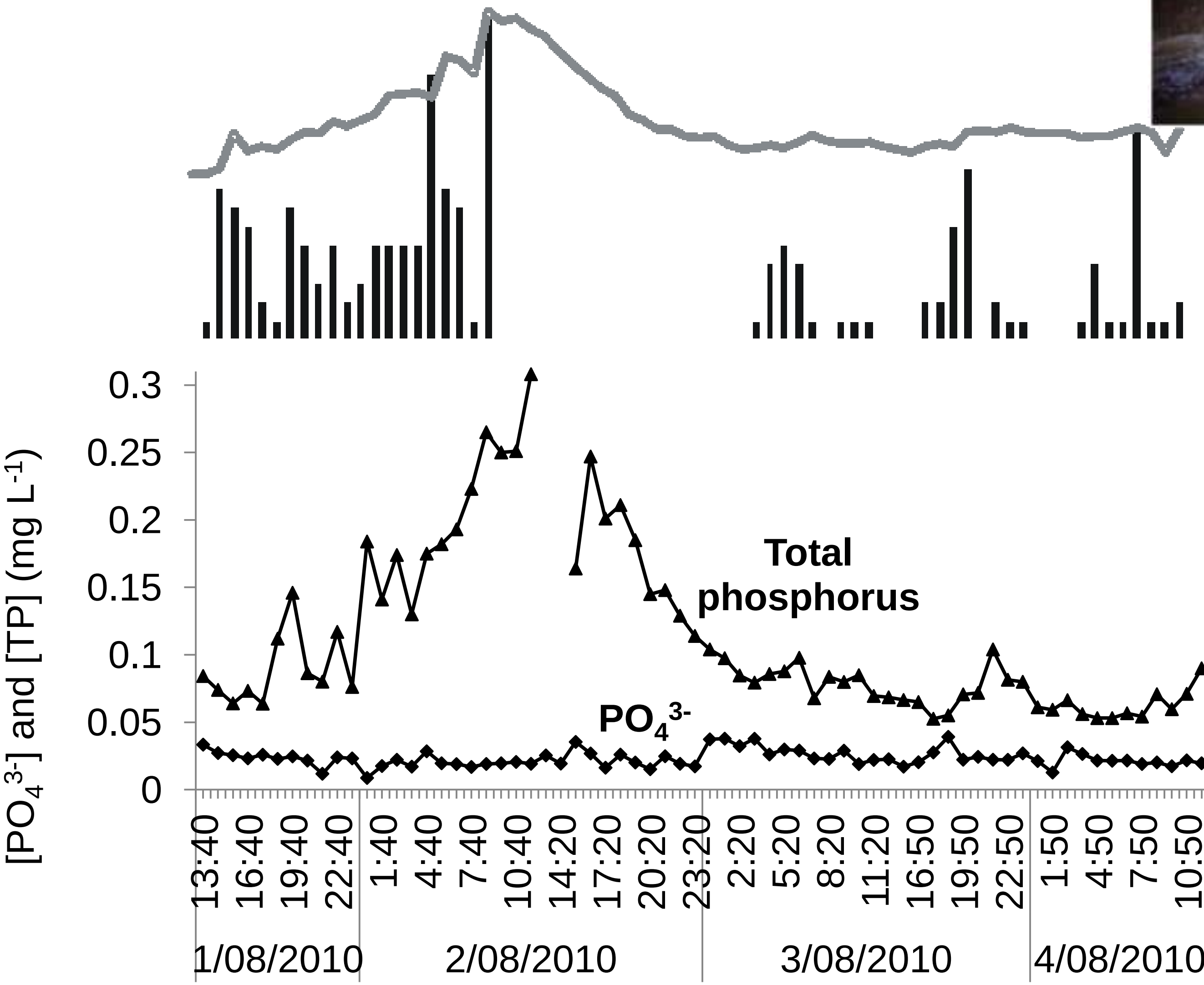
Lake Rotoiti

Point 2. Reductions in external loading are fundamental to effective control of eutrophication. Diffuse sources now represent the greatest challenge to external nutrient reductions


Lake Ngaroto,
Waikato

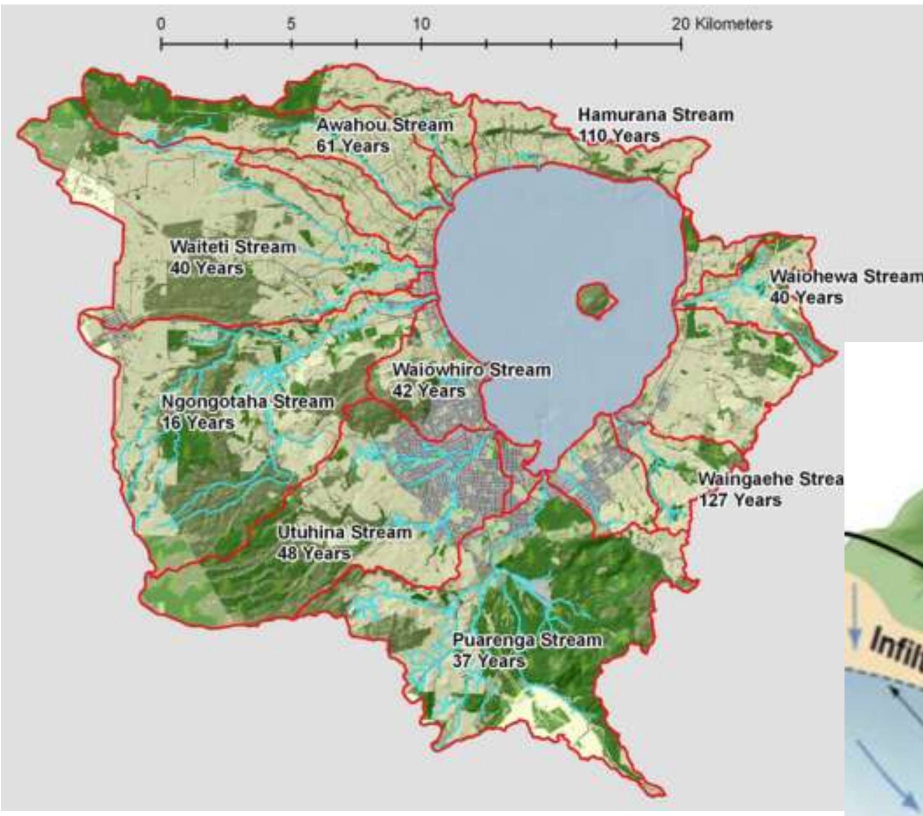
Point 3. Despite many years of theoretical, empirical and modelling studies, we have often failed to adequately capture and quantify nutrient loads, particularly stormloads

Changes in phosphorus concentrations in a stormflow event

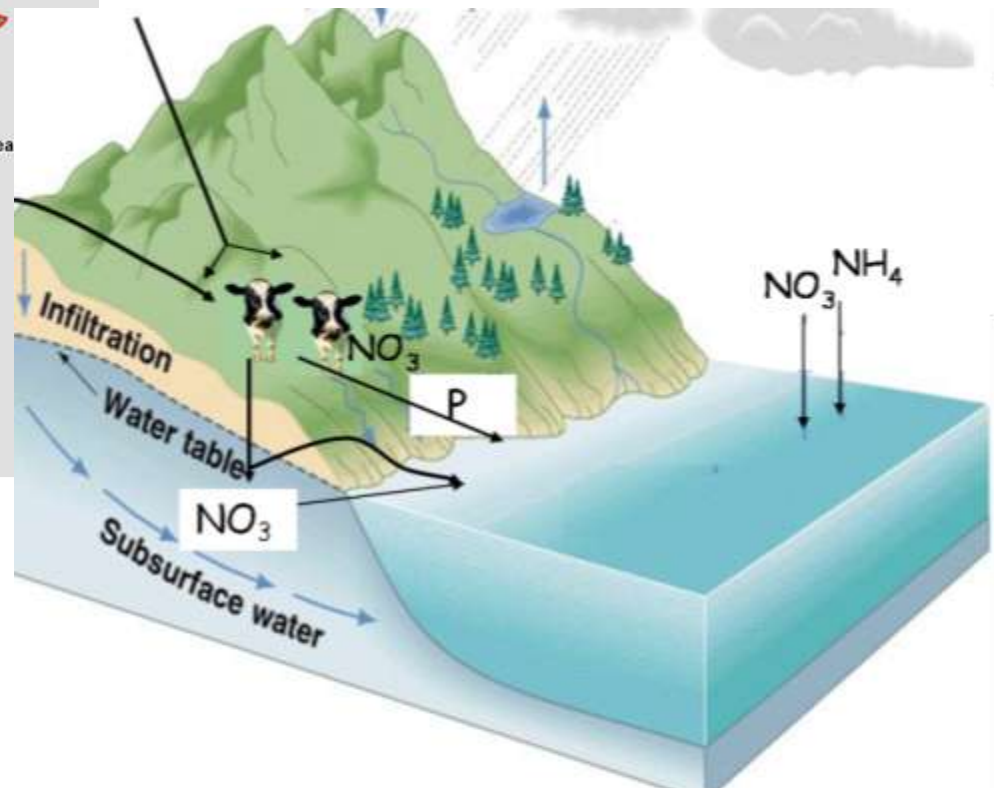


Jonathan Abell
University of Waikato

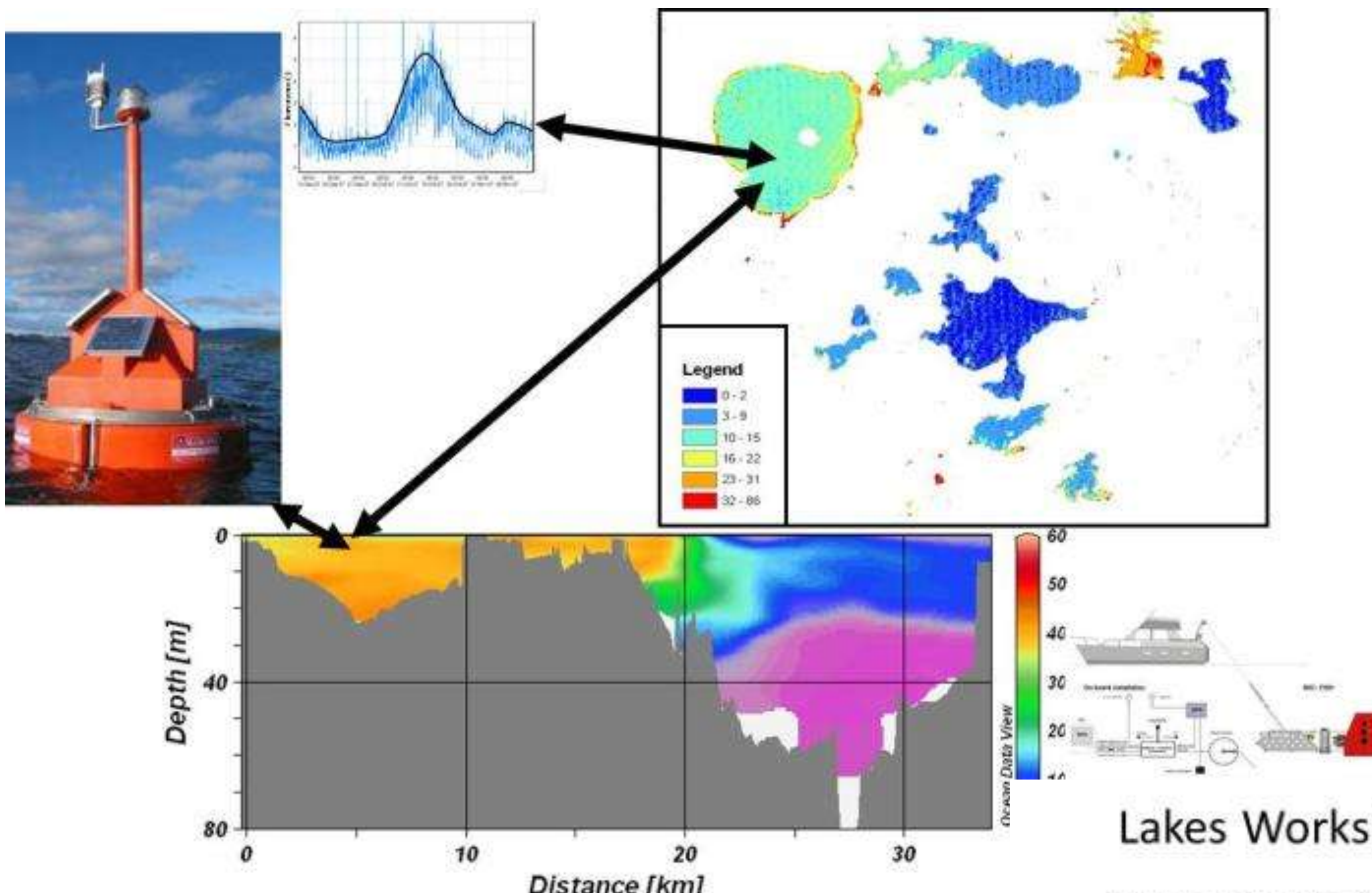
‘Old age’ groundwater to Rotorua



Hamurana 110 yr
Ngongataha 16 yr
Awahou 61 yr
Waiowhero 42 yr



Point 4. Opportunities exist to virtually revolutionise temporal and spatial coverage of lake ecosystems but require lake ecologists to adopt increasingly flexible, interdisciplinary communication linkages that may not necessarily initially be fully productive.



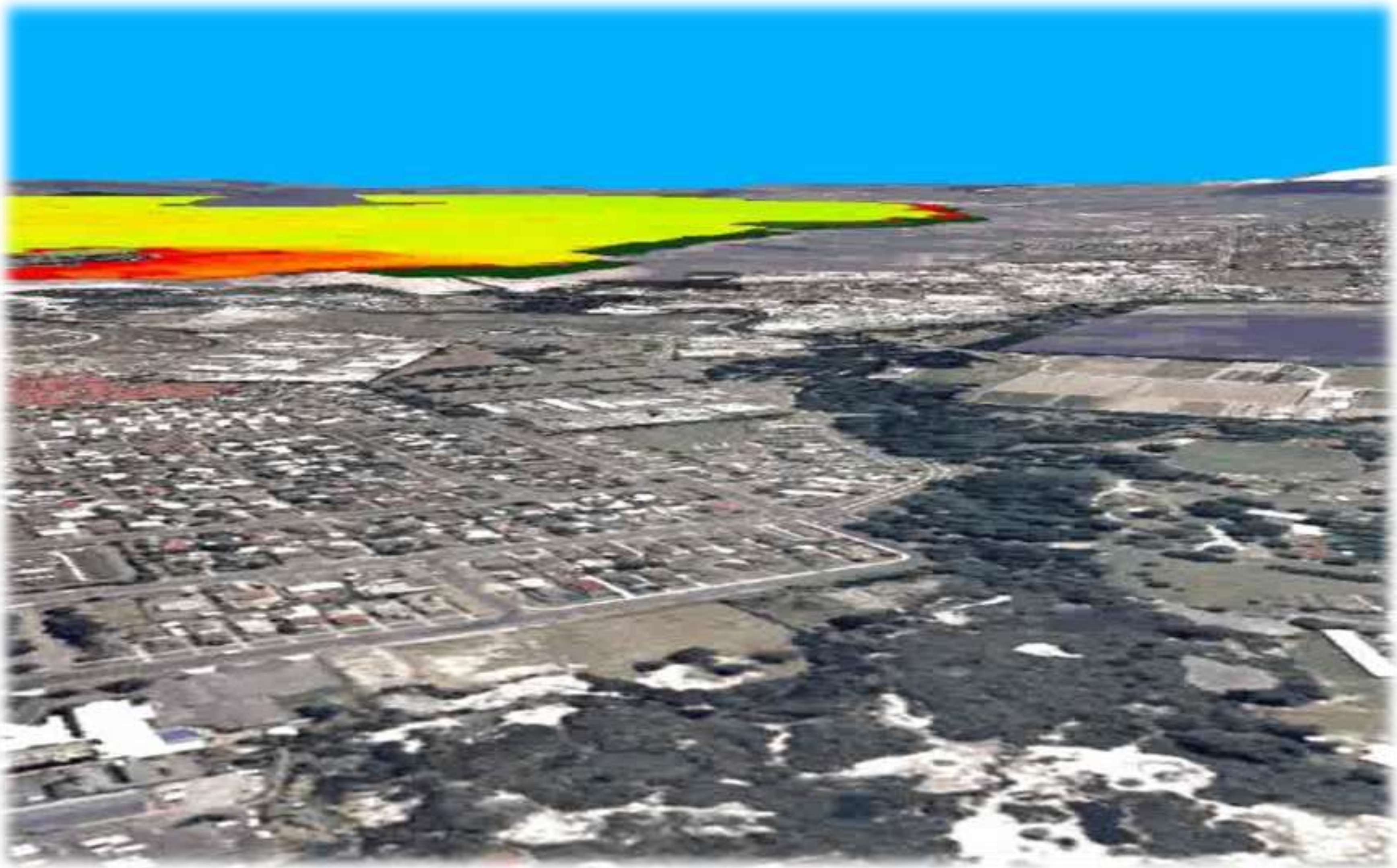
Lakes Workshop

15[th] International Conference
IWA Diffuse Pollution Specialist Group


…in the old days on Ellesmere

New tools to study lakes:

remote-sensing - high-frequency data - computer modelling



Mat Allan, Waikato University

Chalk Lakes - Explaination and Location, etc., etc., etc.

from Kinneret Pic file - Explaination and Location, etc., etc., etc.

Lake Needs to be Identified- Explaination and Location, etc., etc., etc.

Yuan Yuan Lakes - Explaination and Location, etc., etc., etc.

GLEON

global lake ecological observatory network

Further Information

lakemetabolism.org • gleon.org

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National Science Council Taiwan (KING Project)

Taiwan Forest Research Institute

Foundation for Research, Science and Technology (NZ)

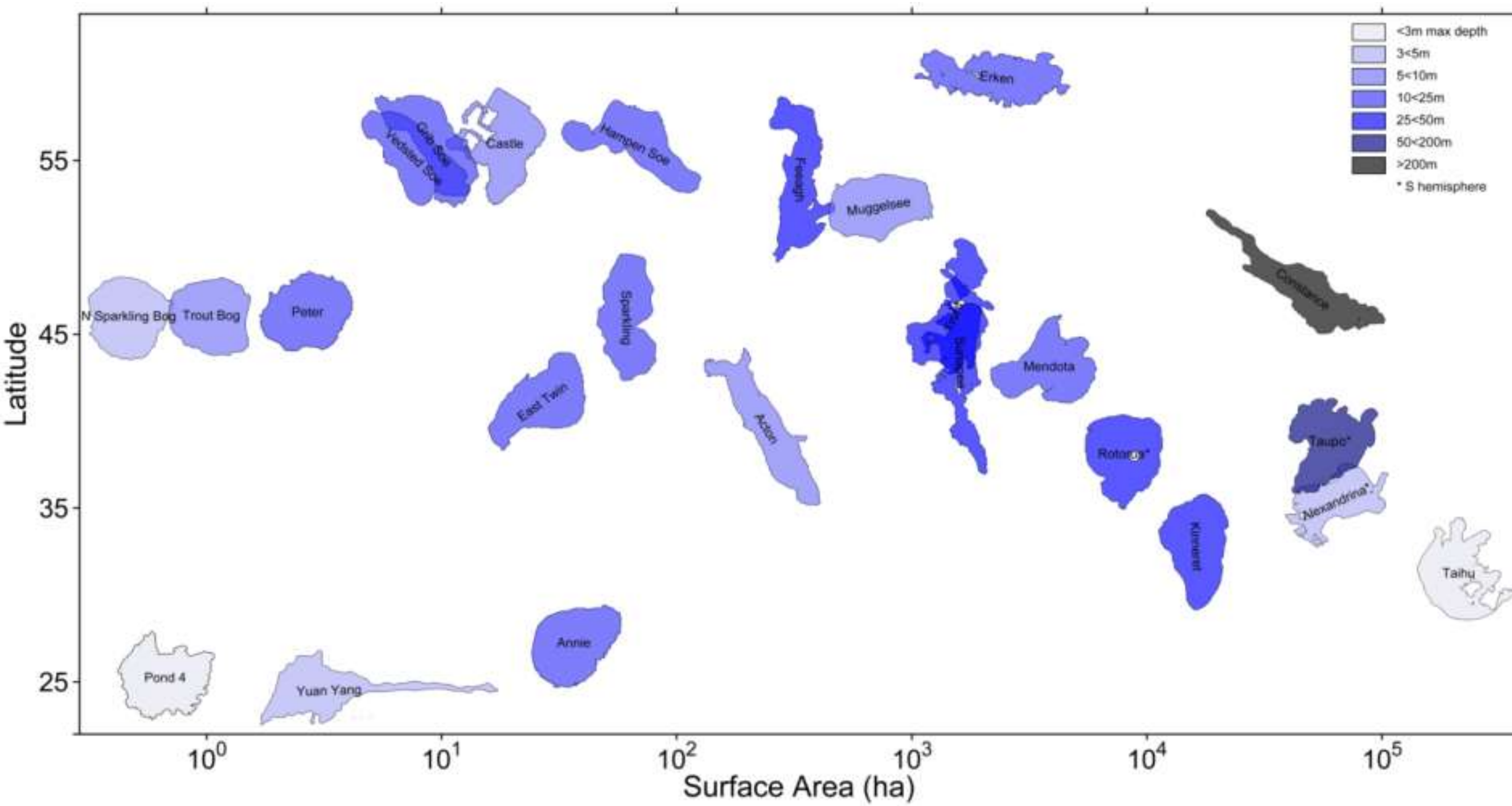
global lake ecological observatory network

GLEON

gleon.org

Current Projects: 25 lakes

Physical variability in temperate lakes: A global analysis of high-frequency instrumented buoy data from 25 temperate lakes.



Science and communication

"Scientists can be most effective if they make their results accessible to interested laypersons"

Ludwig, D. 2001. The era of management is over
Ecosystems 4: 758-764

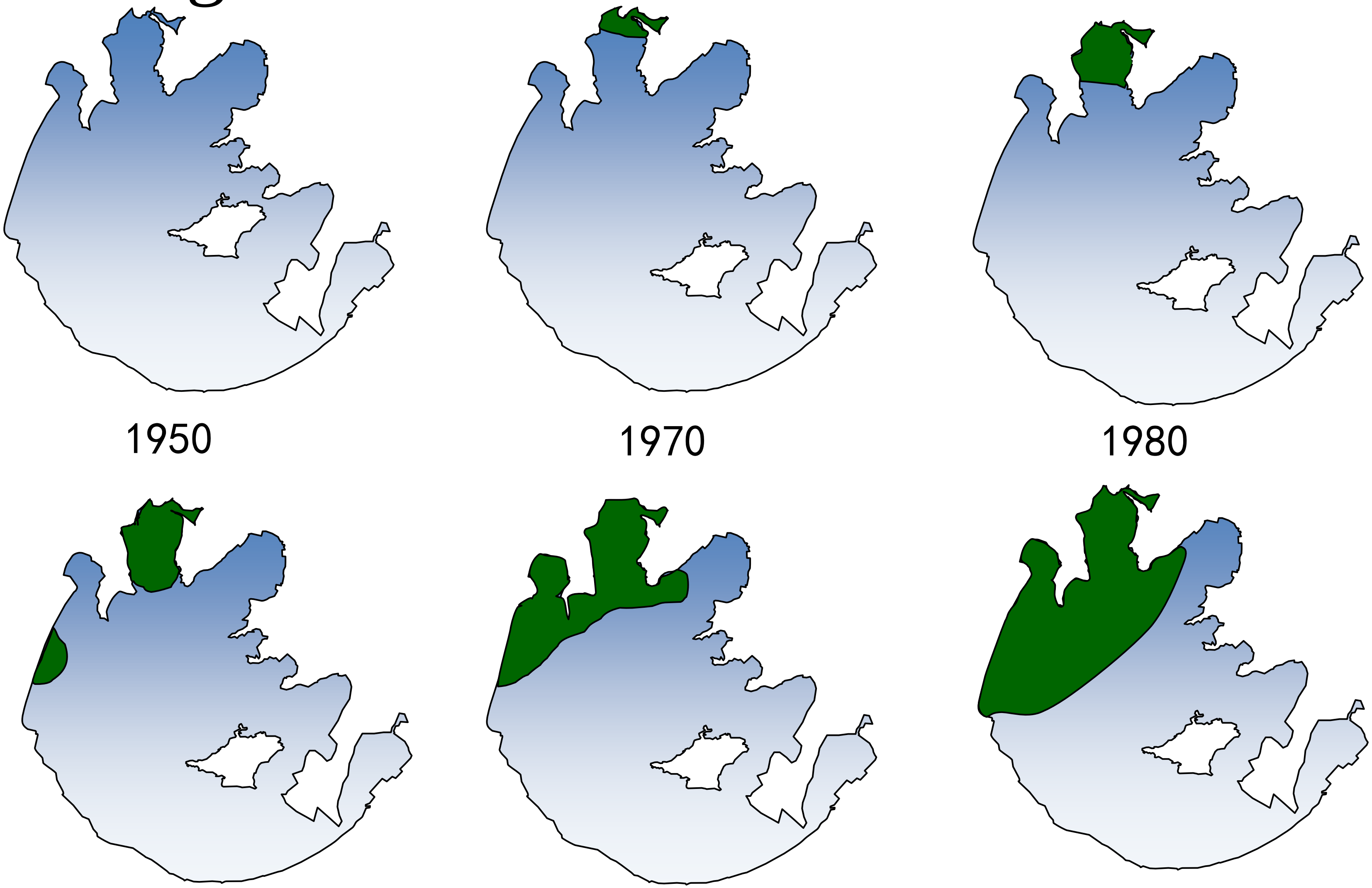
So…to lakes across the globe

Lake Taihu
P.R. China

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

NIGLAS 中国科学院 南京地理与湖泊研究所

Algal bloom evolution in Lake Taihu

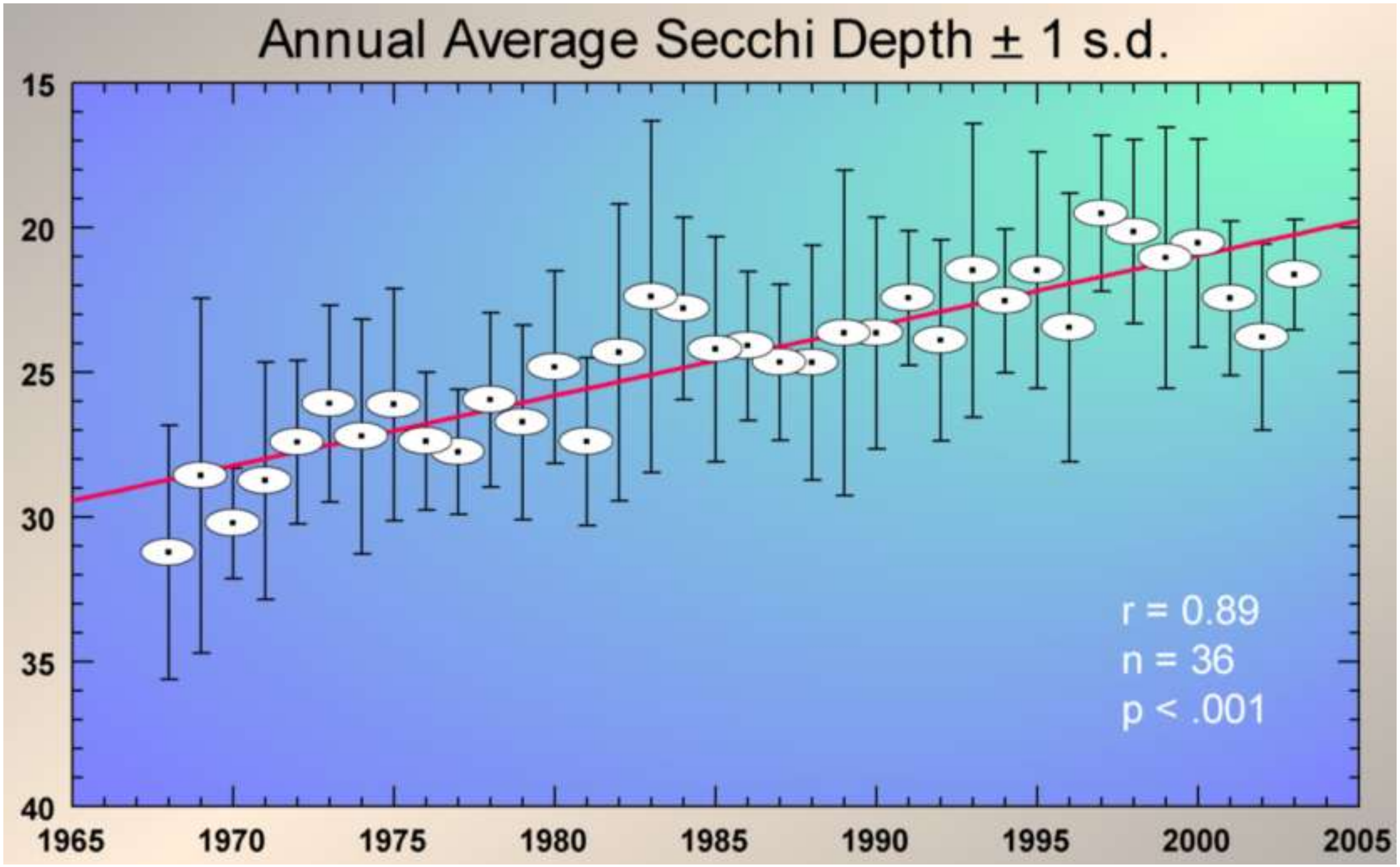



YAMAHA
115

Big problem…expensive solution?

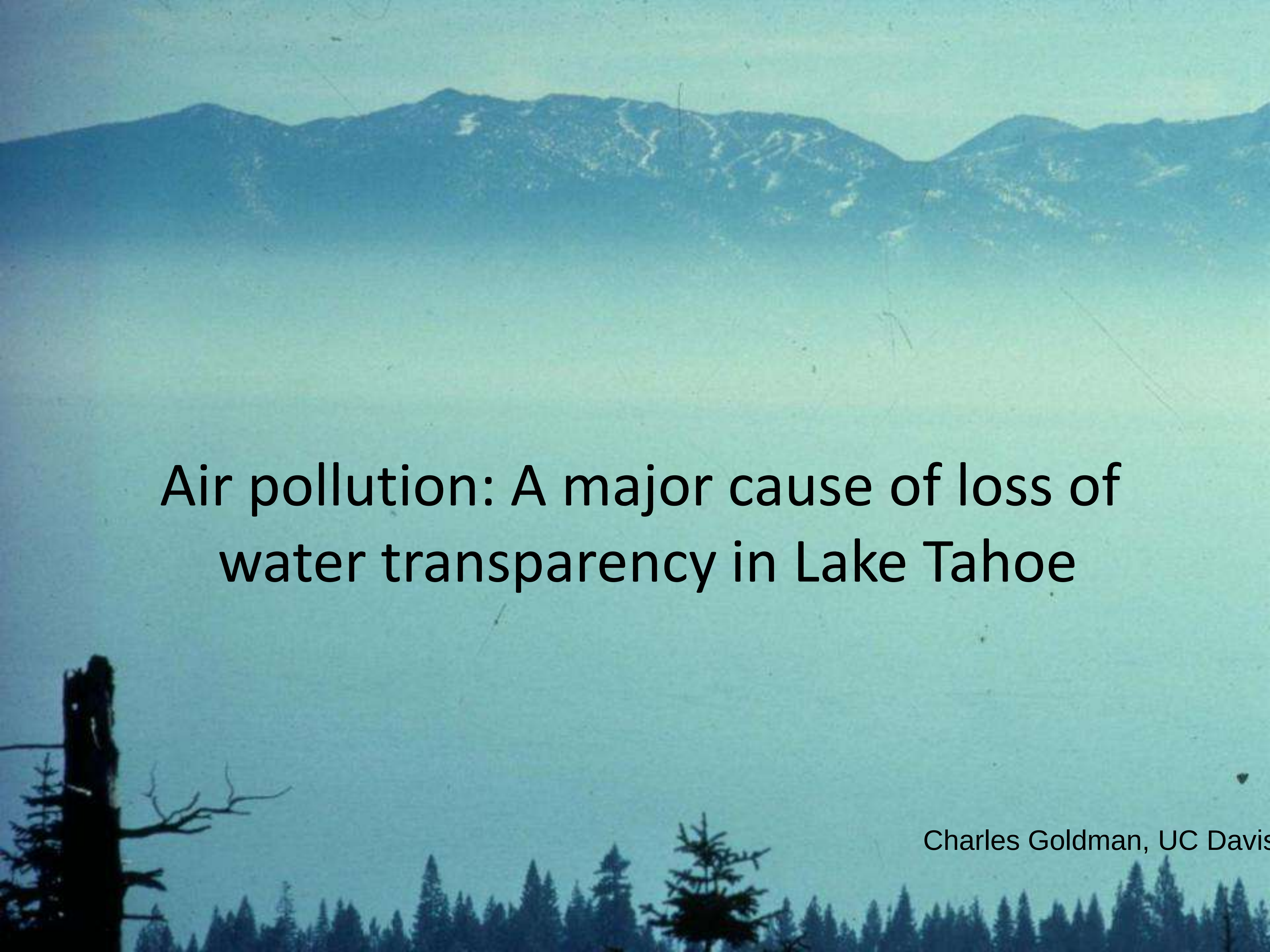
Lake Tahoe, California, USA

Transparency in Lake Tahoe
Secchi depth in m



Charles Goldman, UC Davis


Obvious culprits in
loss of transparency

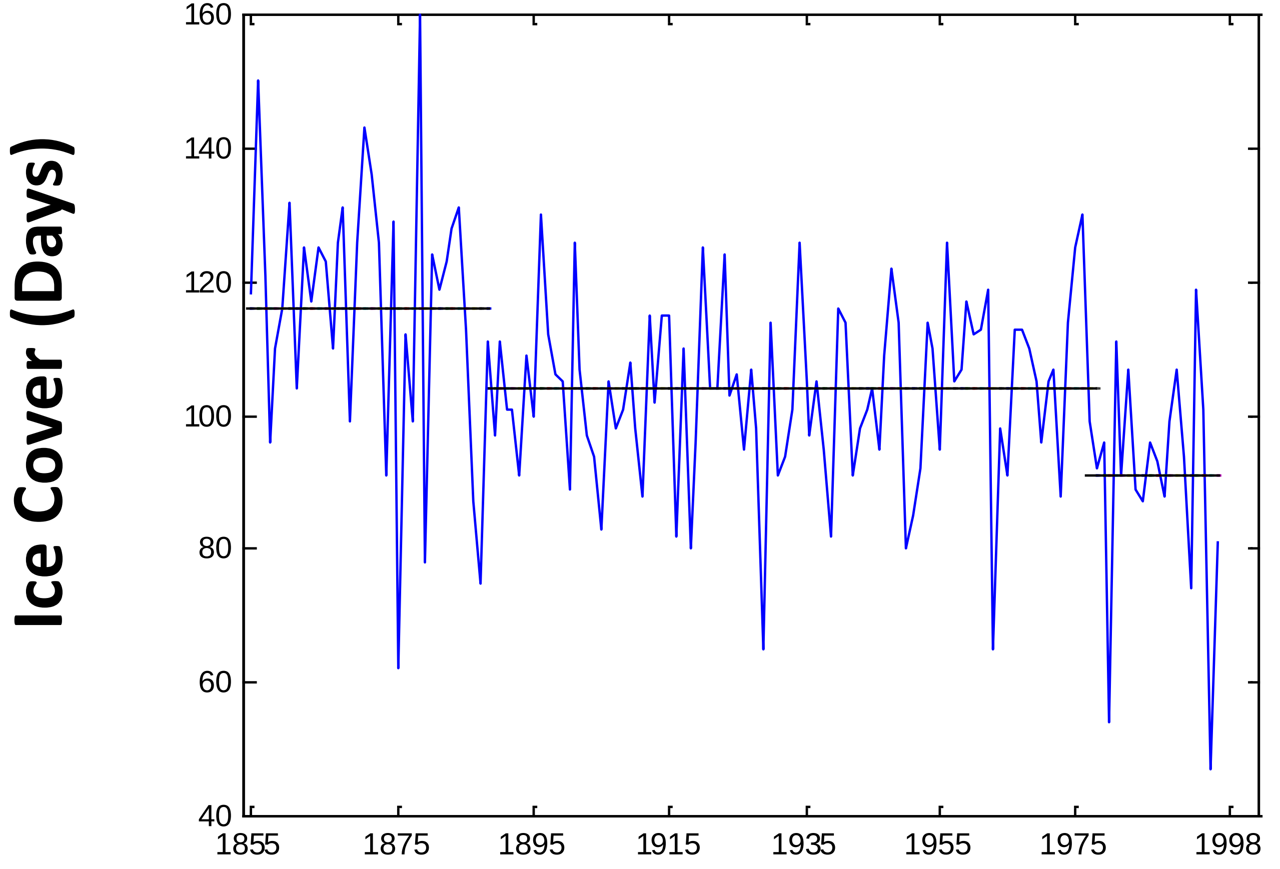


Air pollution: A major cause of loss of water transparency in Lake Tahoe

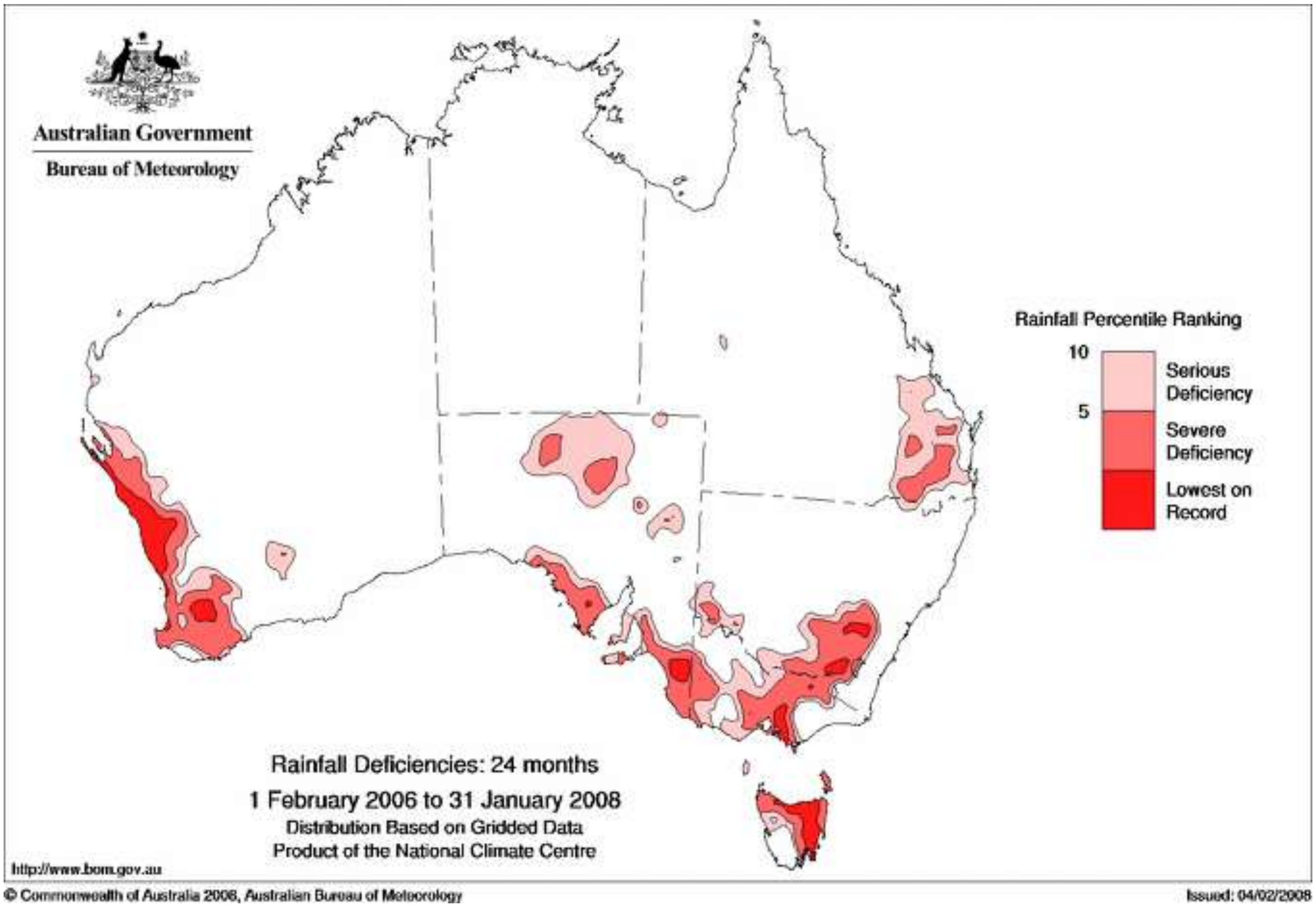
Charles Goldman, UC Davis


Lake Mendota, Madison,
Wisconsin, USA

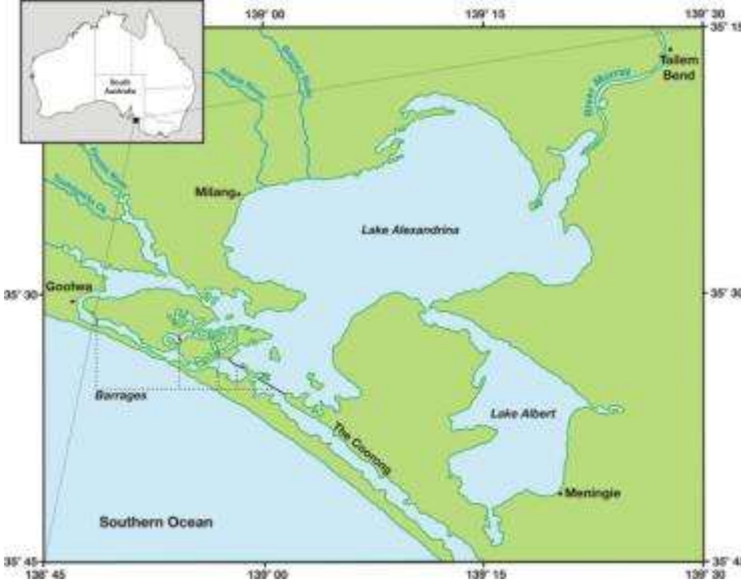
Ice cover in Lake Mendota: Characterised by discontinuities



Drought in Australia: 2008



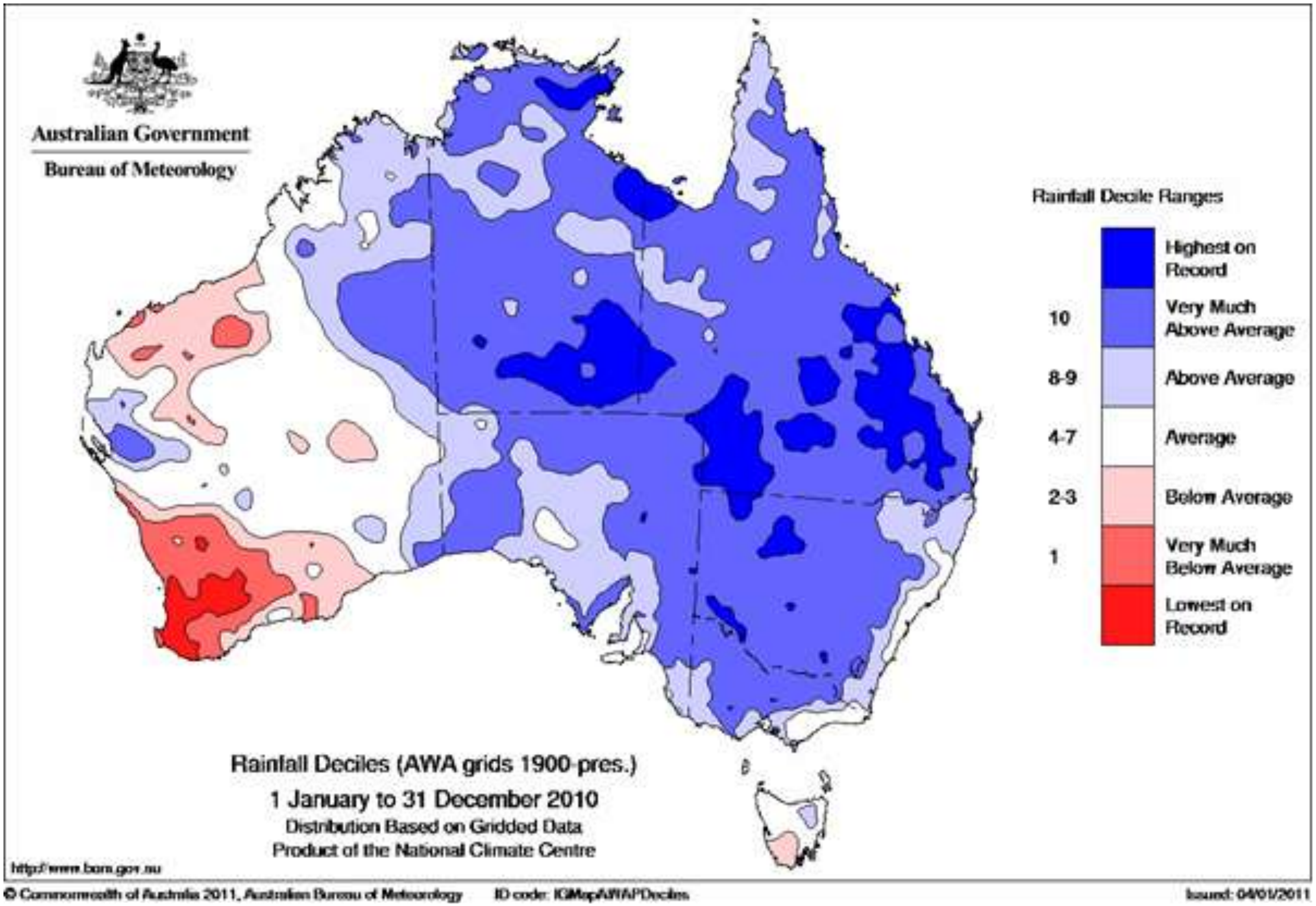
Response to drought at Milang, Lake Alexandrina



Oct 2006

Jan 2008

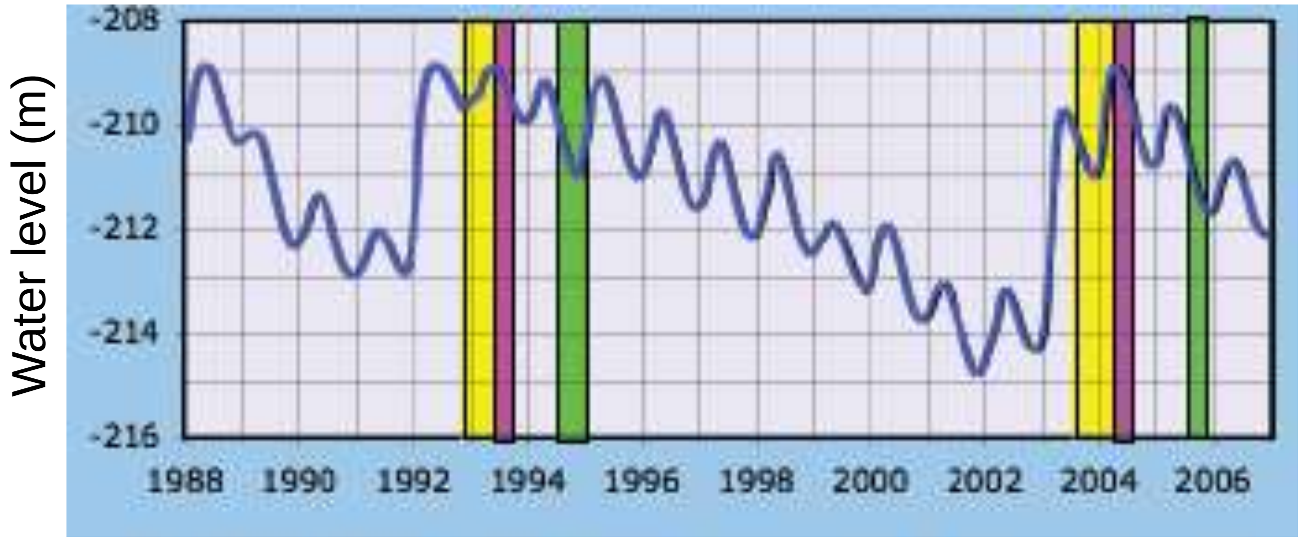
Floods and drought in Australia: 2010



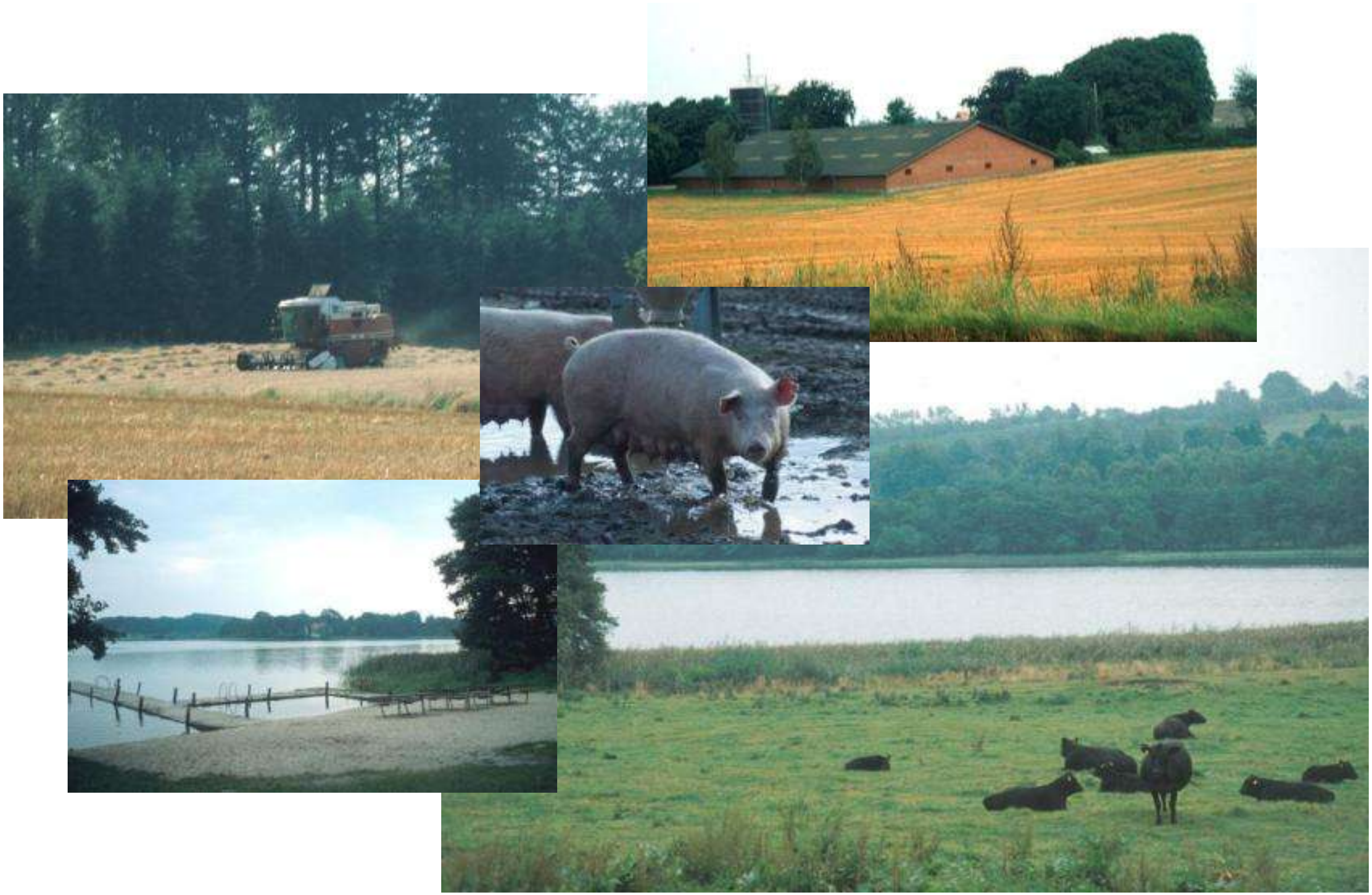
From drought to flood: unprecedented rainfall in eastern Australia

http://i.telegraph.co.uk/multimedia/archive/01797/australia-flood_1797071b.jpg

Lake Kinneret, Israel
(c. 40% of Israel's drinking water)



Denmark: the challenge of non-point source pollution



Source: Erik Jeppesen

Diffuse pollution – perhaps the most difficult case

"When an issue becomes highly controversial when it is surrounded by uncertainties and conflicting values… there are experts for the affirmative and experts for the negative. We cannot settle such issues…"

Simon HA. 1983. Reason in human affairs. Stanford University Press.

Polarisation…

- Economism is the placing of an exceptional and inordinate emphasis upon economic values in contradistinction to all others
- Scientism is the belief that science…is inherently capable of solving almost all human problems.
- Technocracy represents an effort to achieve policy solutions by recourse to technological innovation or through what is sometimes called a "technological fix."

Caldwell LK. 1990. Between two worlds: science, the environ-mental movement and policy choice. Cambridge University Press.

And for Te Waihora…
even more difficult

- Nutrients
- Mahinga kai
- Water level regimes
- Climate change
- Wind and sediments

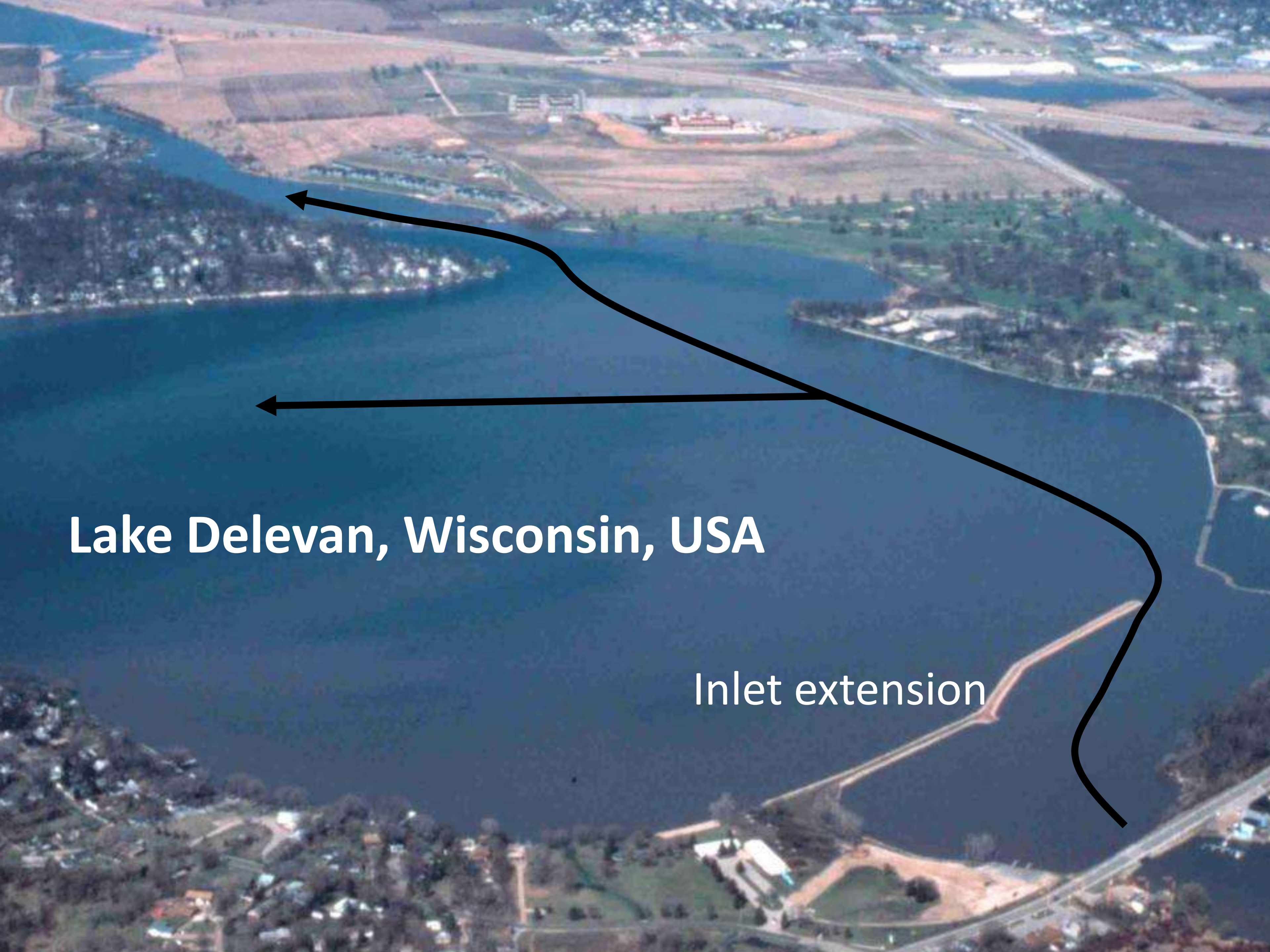
Rotorua lakes' Technical Advisory Group

"If you don't deliver then our people will be planning and writing policy without your science input"

"I need the science to record our on-ground restoration efforts"

You won't get it [the science] 100% but it will be necessary to use it for our policies and plans

Delevan Lake, Wisconsin, USA

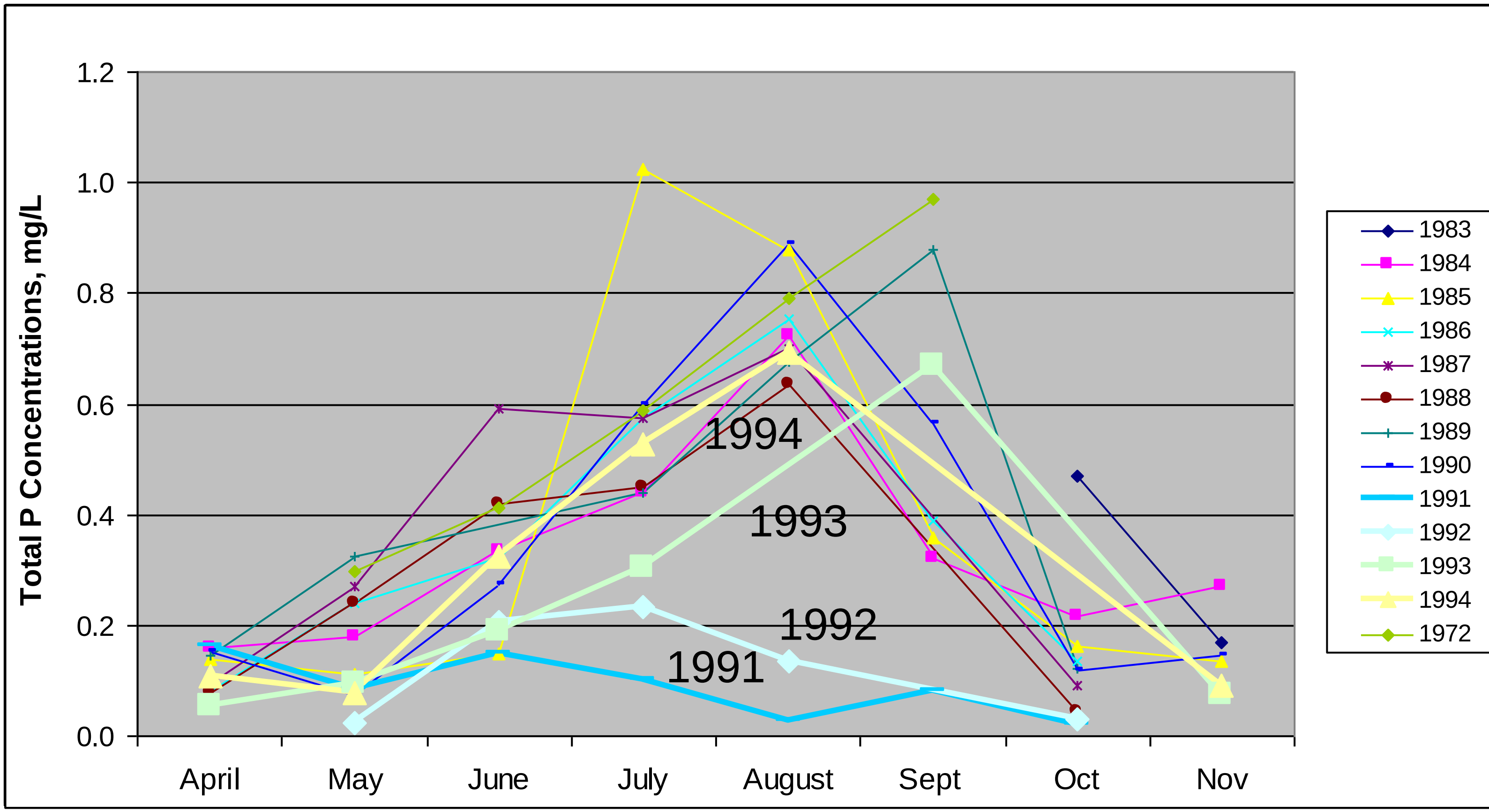

Lake Delevan, Wisconsin, USA
Inlet extension

Rotenone application, Delevan Lake

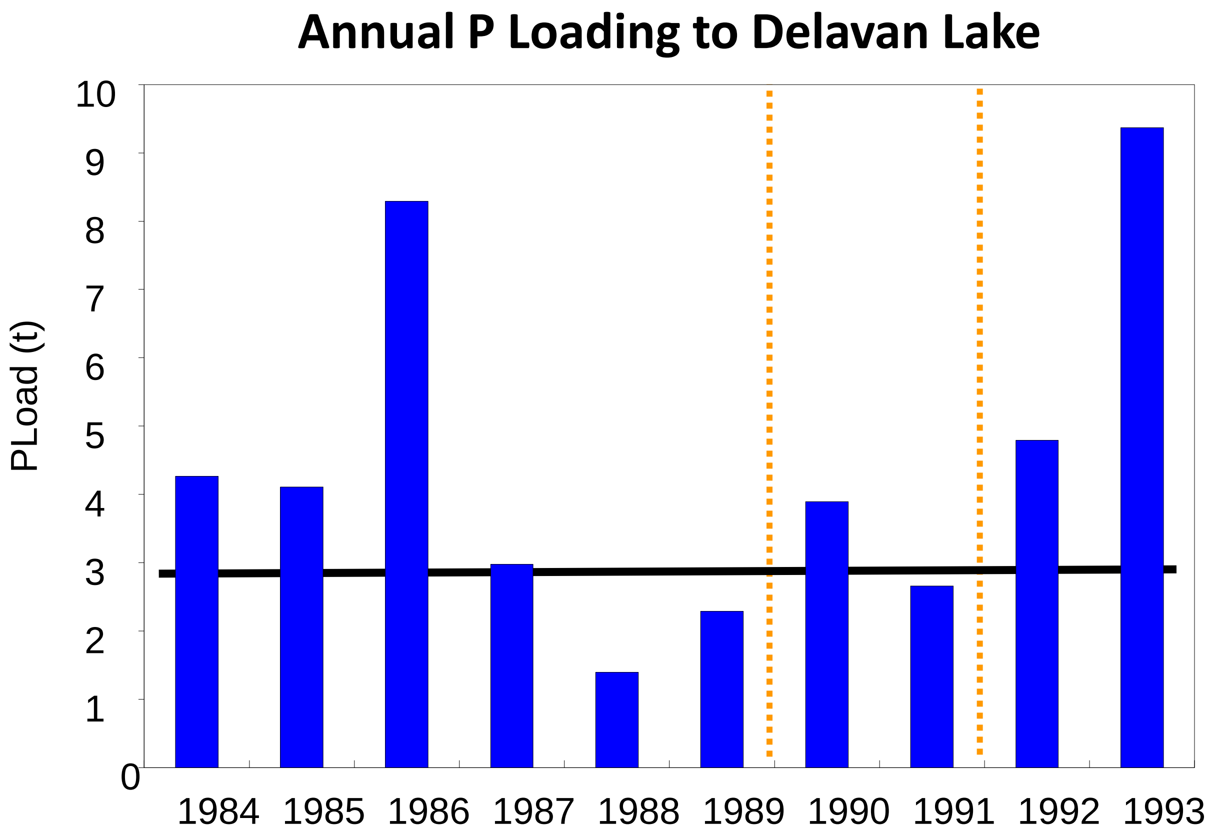
Rotenone application effects, Delevan Lake

Internal Loading

Near Bottom Total Phosphorus Concentrations



Alum application
Lake Delevan



The challenge to scientists

"...the reason we expect so little from science is that we have not yet realized that our job is to predict and not to describe. We have not yet come face-to-face with our failure to do effective ecological science"

...Rigler and Peters (1995)

The late Frank H. Rigler
and Robert H. Peters

SCIENCE AND LIMNOLOGY

Introduction (Otto Kinne)
Frank H. Rigler and Robert H. Peters: A Laudatio (Jürgen Overbeck)

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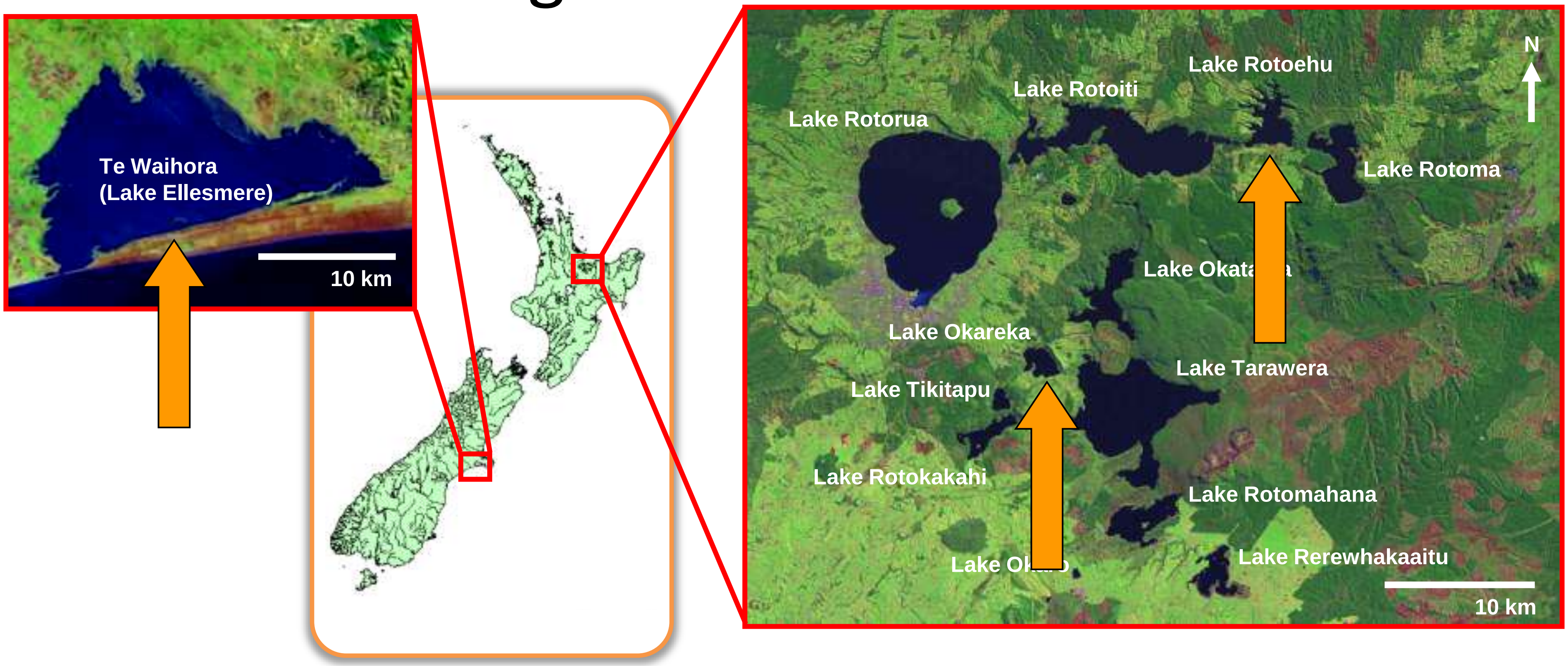
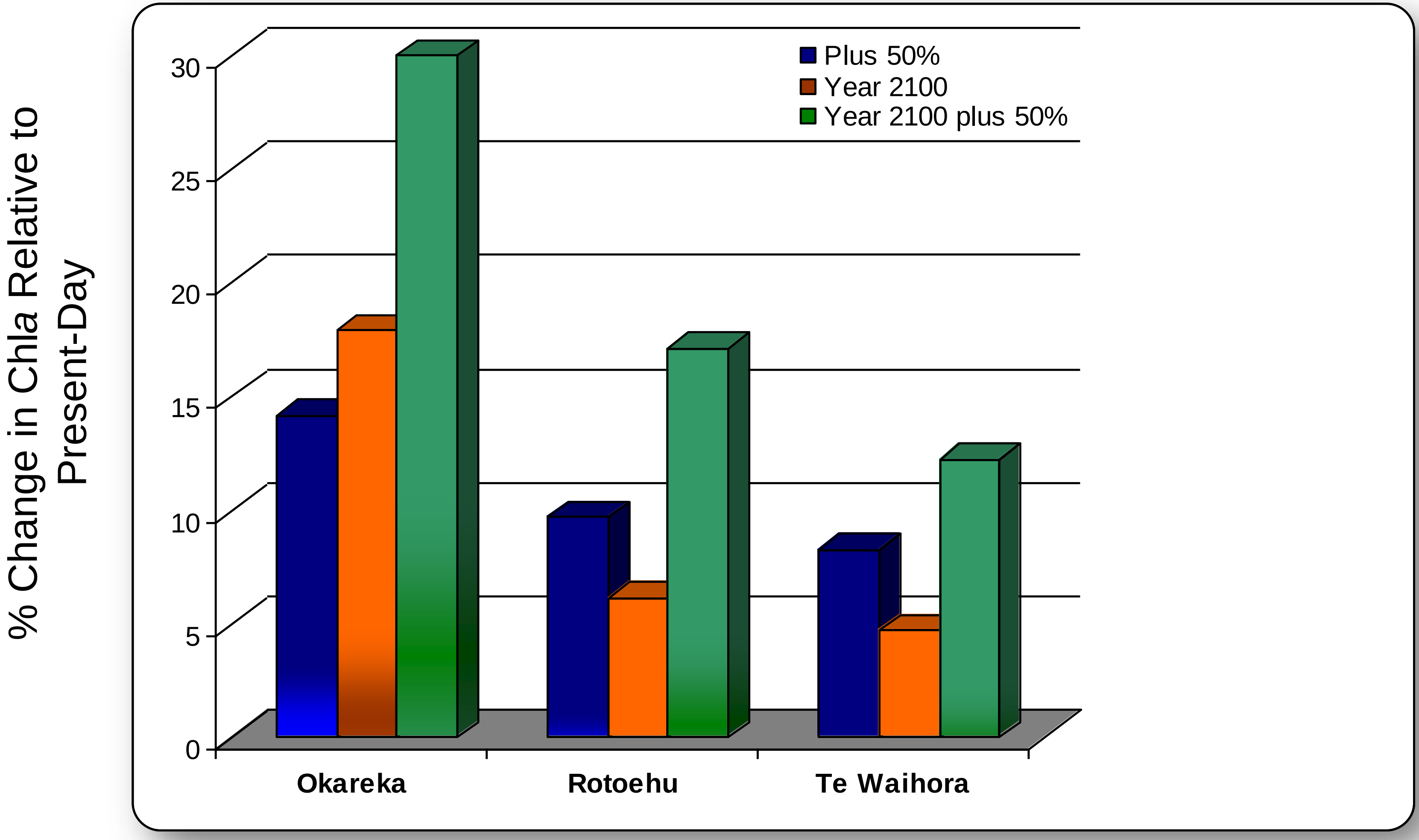
Publisher: Ecology Institute
Nordbünte 23, D-21385 Oldendorf/Luhe
Germany

Case study of potential effects of climate change on three NZ lakes



Lake	Max depth (m)	Trophic state
Okareka	33.5	Mesotrophic
Rotoehu	13.5	Eutrophic
Te Waihora (Ellesmere)	2.5	Highly eutrophic

Predicting effects of changing nutrient load and/or climate on chlorophyll *a*



Trolle, D, D. Hamilton, C. Pilditch, I. Duggan, E. Jeppesen (2011). Predicting the effects of climate change on trophic status of three morphologically varying lakes: Implications for lake restoration and management. Environmental Modelling.& Software

Managing for resilience to blooms in a changing climate

"Increasing nutrients and temperatures have a synergistic effect on cyanobacterial blooms, but only when nutrient levels are high. Ultimately nutrients are the primary factor influencing bloom formation"

Science 7 October 2011:
Vol. 334 no. 6052 pp. 46-47
DOI: 10.1126/science.1207349

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PERSPECTIVE

ECOLOGY

Resilience to Blooms

Justin D. Brookes[1], Cayelan C. Carey[2]

Author Affiliations

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Cyanobacterial blooms (see the figure) present health risks worldwide for humans and livestock that drink or use contaminated water, and also represent substantial economic costs to communities due to water treatment, lost tourism and recreation revenue, and declining property values (1). These explosive growths occur in fresh and marine water, and may be increasing globally. One recommendation is that water managers must address the effects of climate change when combating cyanobacterial blooms (2). However, recent studies suggest that controlling nutrients may be more important in increasing aquatic ecosystem resilience to these blooms.

A number of factors may potentially contribute to an increase in blooms, primarily climate change and changing land use. Most climate change modeling scenarios predict that aquatic systems will experience increases in temperature, thermal stratification (2), and water column stability, all factors that favor cyanobacteria over other phytoplankton (2, 3). Thermal stratification leads to a greater propensity for cyanobacterial blooms, as many cyanobacteria have gas-filled vesicles that enable them to rise to the water surface and form dense blooms (2, 4). In addition to climate change, deforestation, human and commercial animal waste, and agricultural fertilization have increased nutrient runoff into aquatic systems (5), also favoring cyanobacterial blooms.

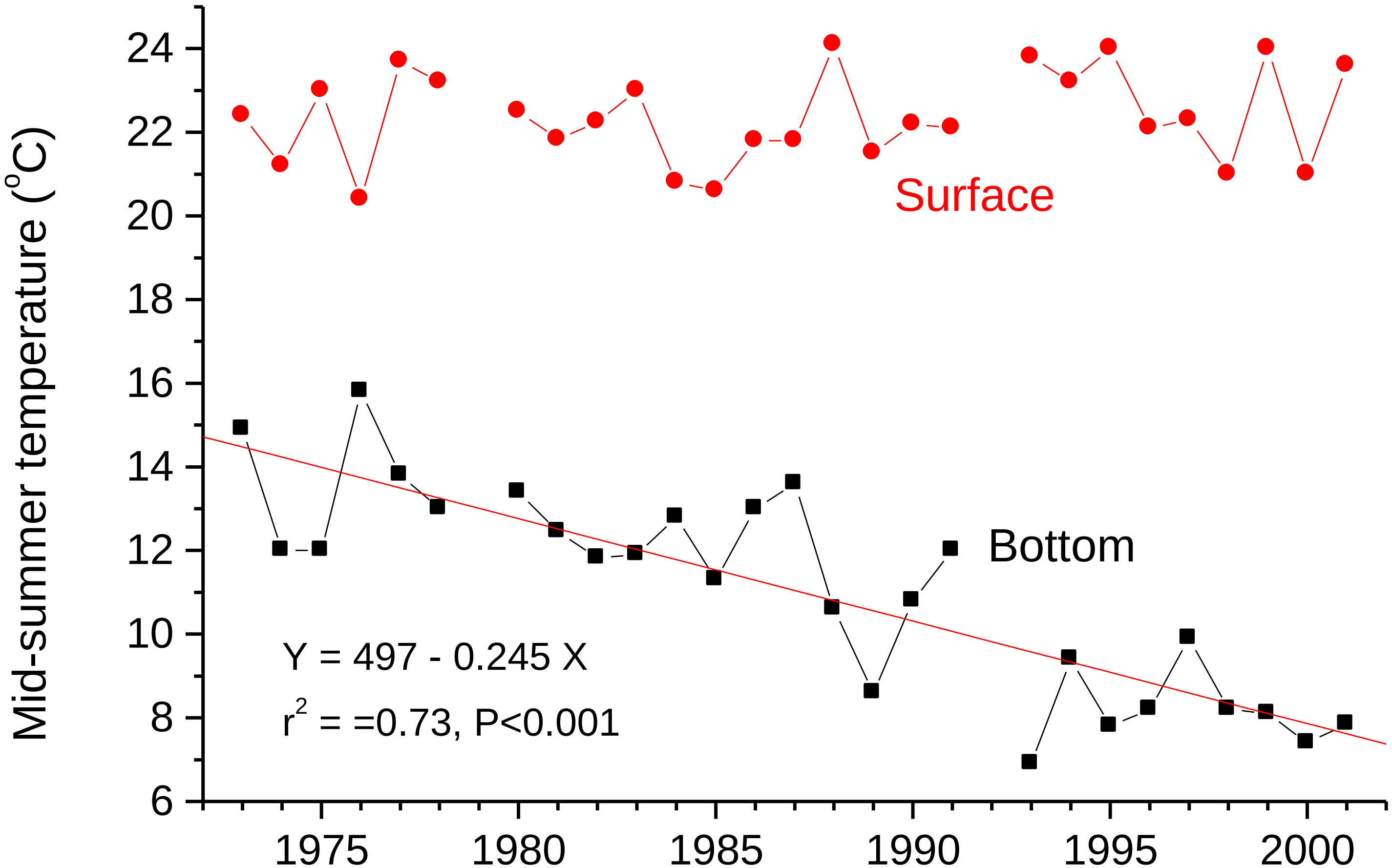
Big bloom.

A cyanobacterial bloom in Lake Windermere, England, in June 2007. See SOM text for suggested resources related to cyanobacerial blooms.

PHOTO CREDIT: LOUISE MILES/FRESHWATER BIOLOGICAL ASSOCIATION

Clearwater Lake near Sudbury, Canada

A 'reversing' temperature in Clearwater Lake



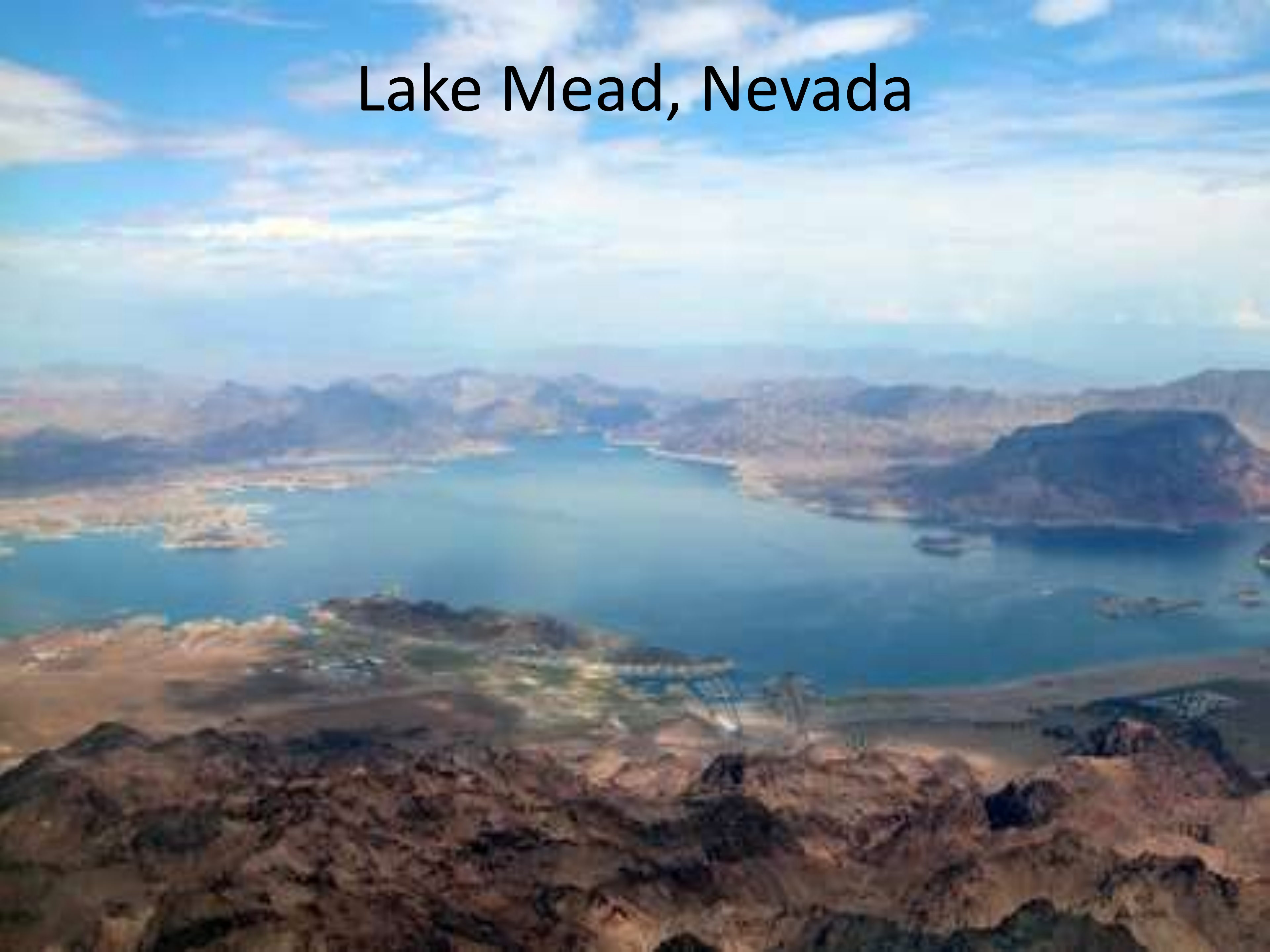
Tanentzap et al., Limnology & Oceanography

And they're using our models where?

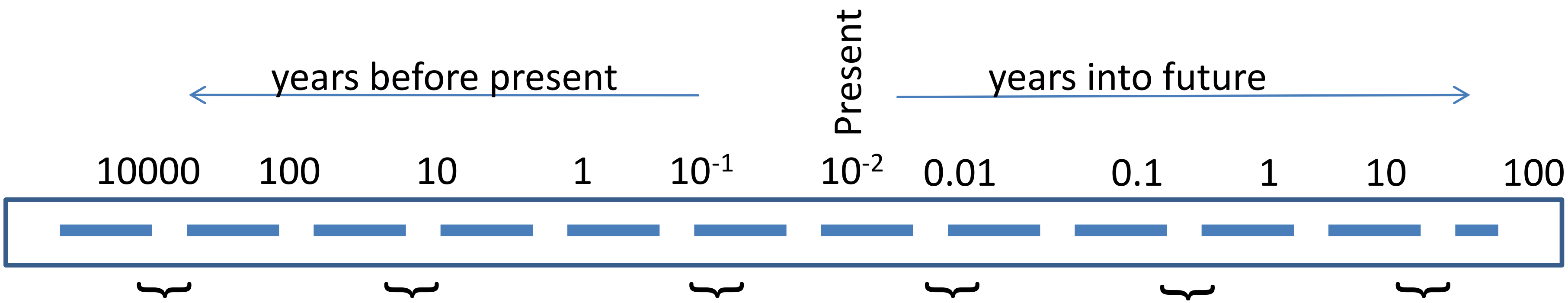
Lake Constance, Germany

Lake Wivenhoe, Queensland

Lake Mead, Nevada



Timelines for applying models



Hindcasting
- past climate
-past land-use

Hindcasting recent human disturbance:
- eutrophication,
- invasive species,
- pollutant fate

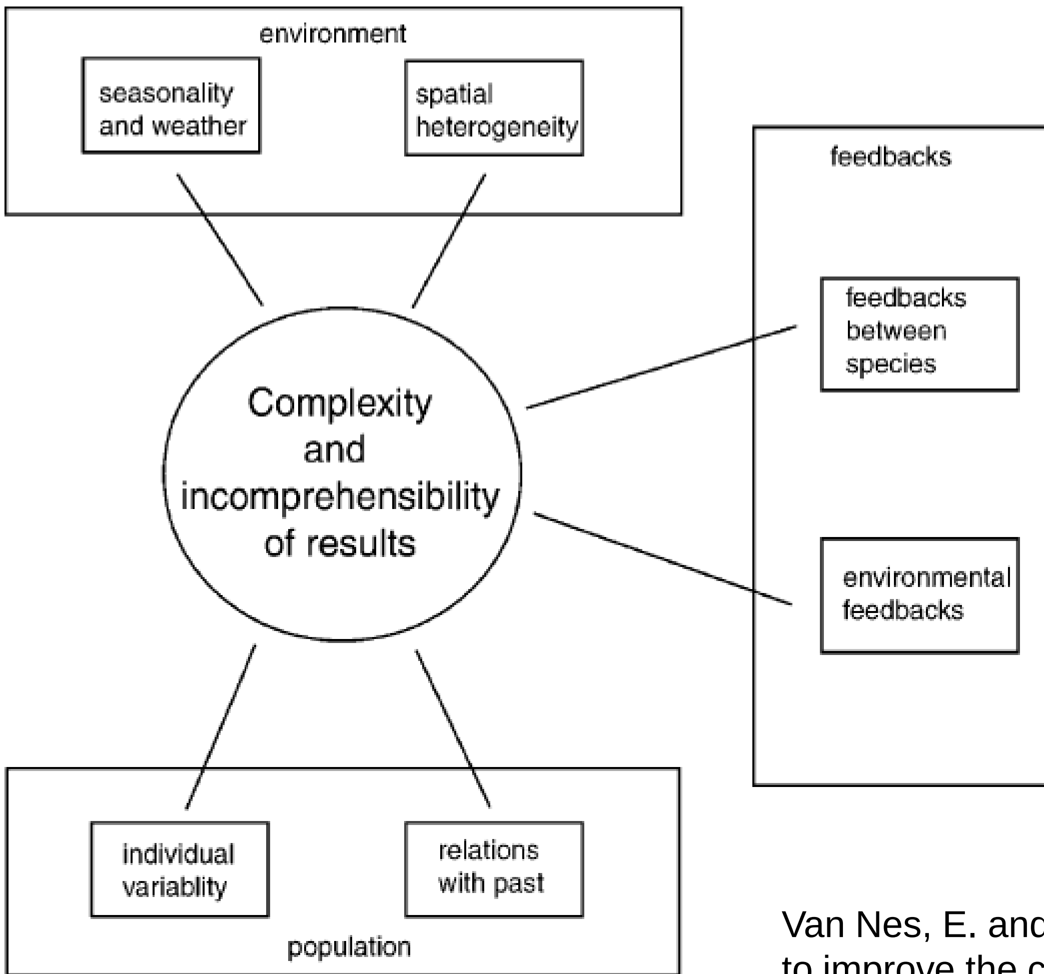
Hindcasting for detailed temporal understanding:
- material fluxes
- transport
- testing theory

Forecasting:
- response to weather forecast
- algal bloom likelihood/
-fate

Simulation:
- lake management strategies
- extreme events (weather, storms)

Prediction:
- future climate
-future land use

Levels of complexity for model applications



Van Nes, E. and M. Scheffer, 2005. A strategy to improve the contribution of complex simulation models to ecological theory. Ecological Modelling 185: 153-164.

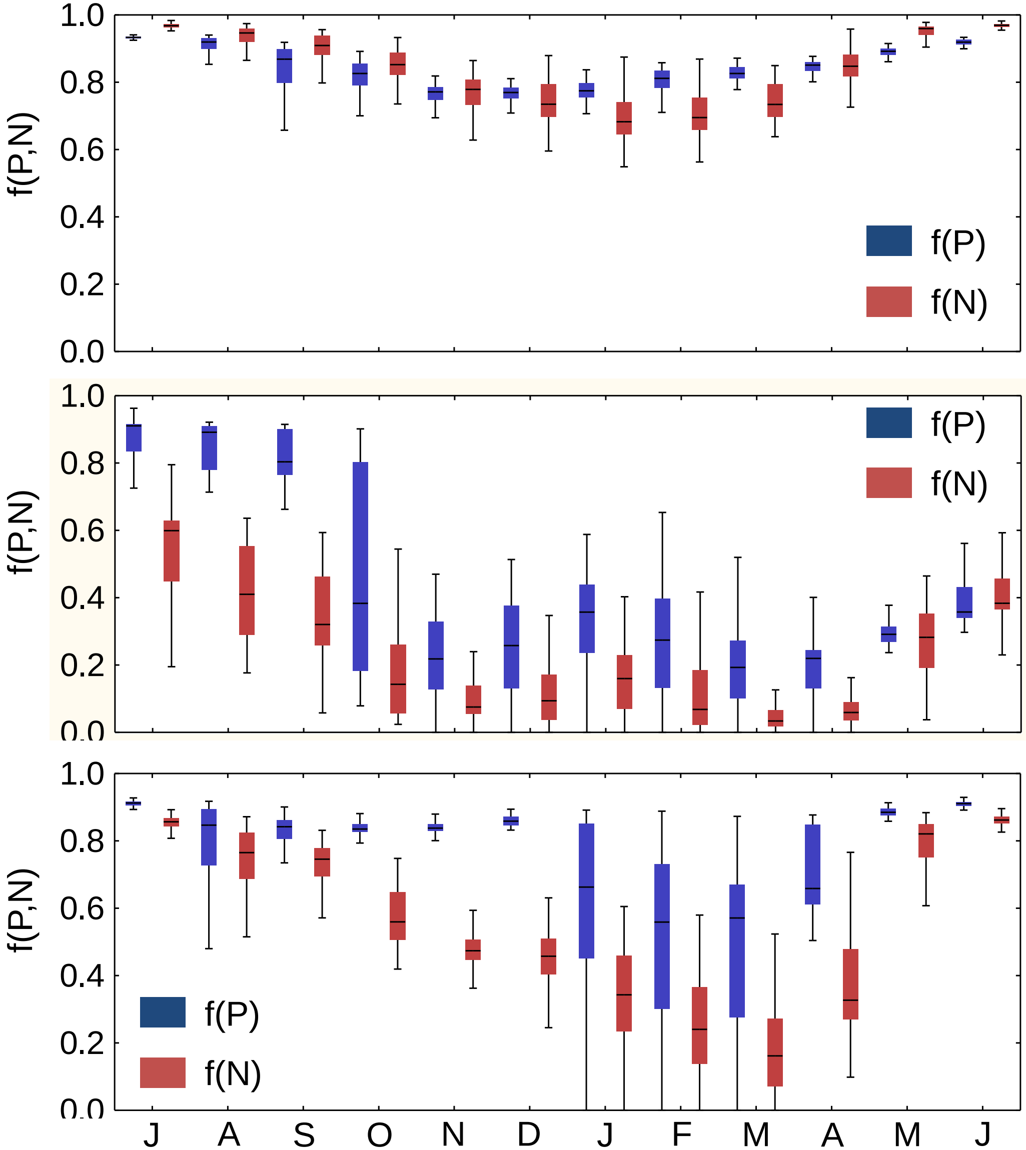
JOURNAL OF PLANKTON RESEARCH | VOLUME 27 | NUMBER 12 | PAGES 1205–1210 | 2005

Castles built on sand: dysfunctionality in plankton models and the inadequacy of dialogue between biologists and modellers

K. J. FLYNN

The science essential to assist management at the ecosystem level will be by those that connect the disciplinary science ("join the dots")

Seasonality of nutrient limitation



Cyanobacteria

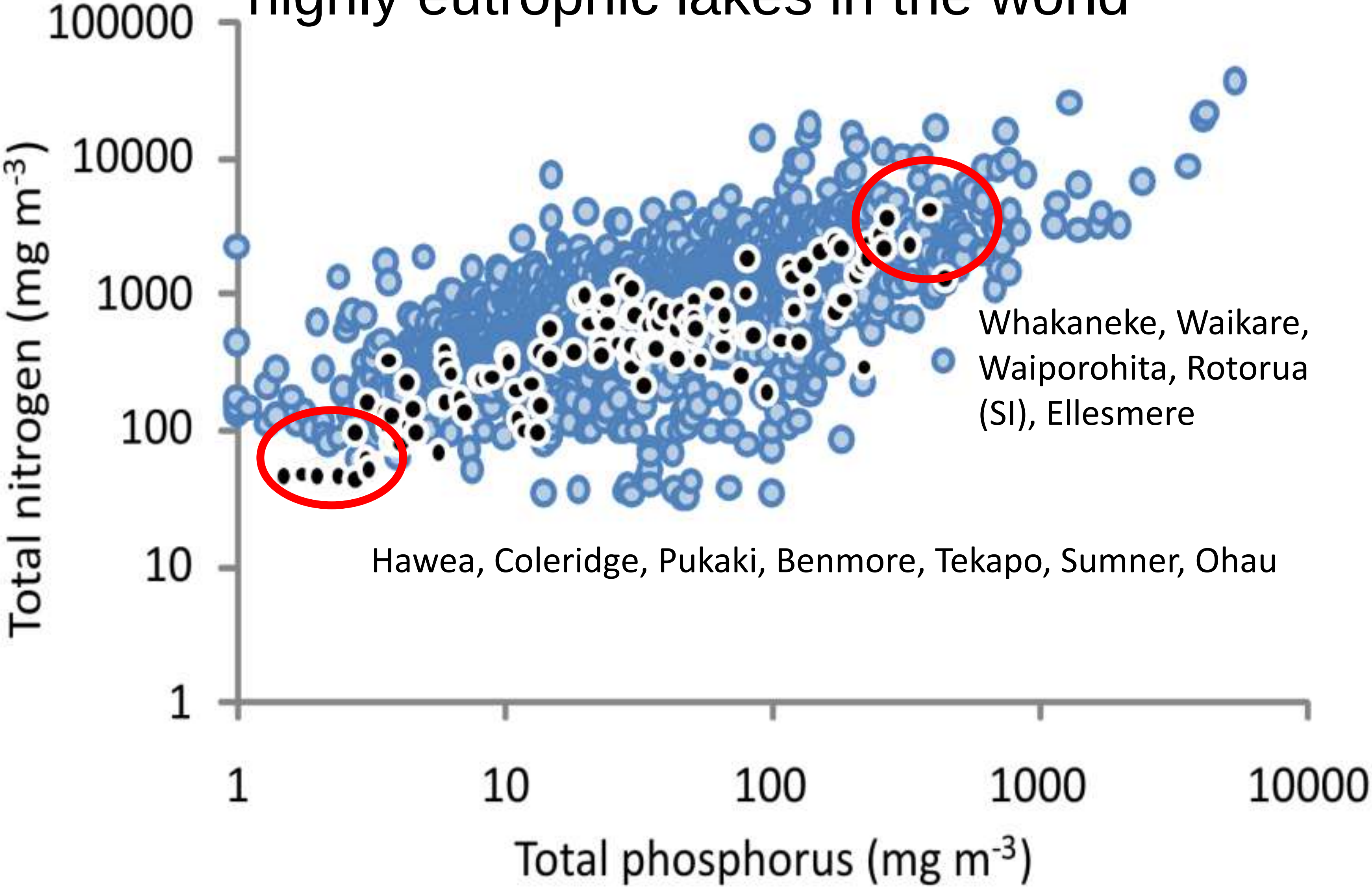
Diatoms

Chlorophytes

Source: Deniz Özkundakci

And to New Zealand lakes

NZ has some of the most ‘oligotrophic’, but also the highly eutrophic lakes in the world

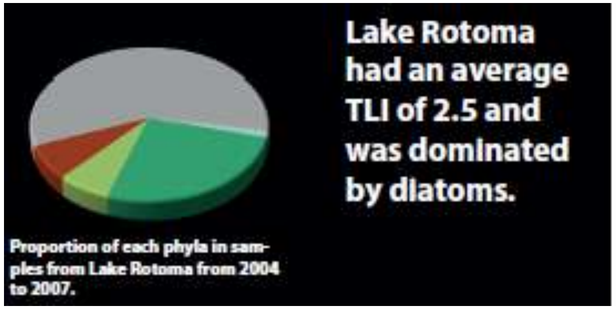


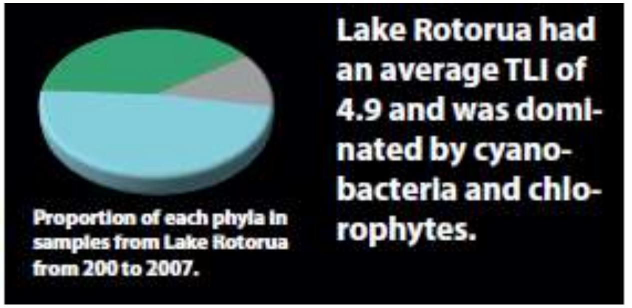
Abell, Özkundakci, Hamilton

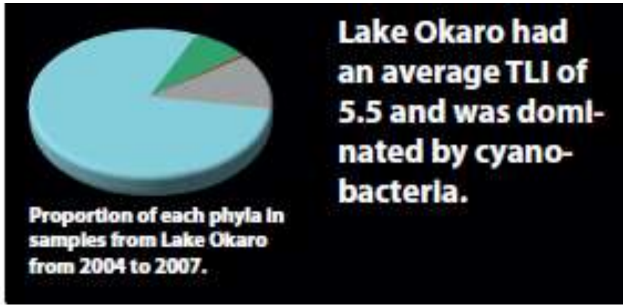
n = 2200, c. 40 countries + NZ

Lake Rotorua – a history of water quality issues

Phytoplankton species change along trophic gradients







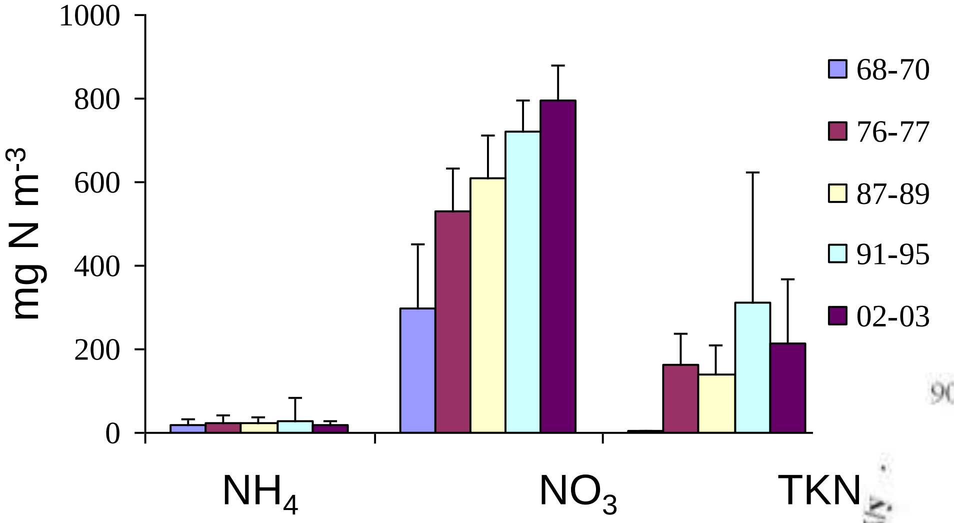
Lake Rotoma

Lake Rotorua
Photo: D. Trolle

Wendy Paul
University of Waikato

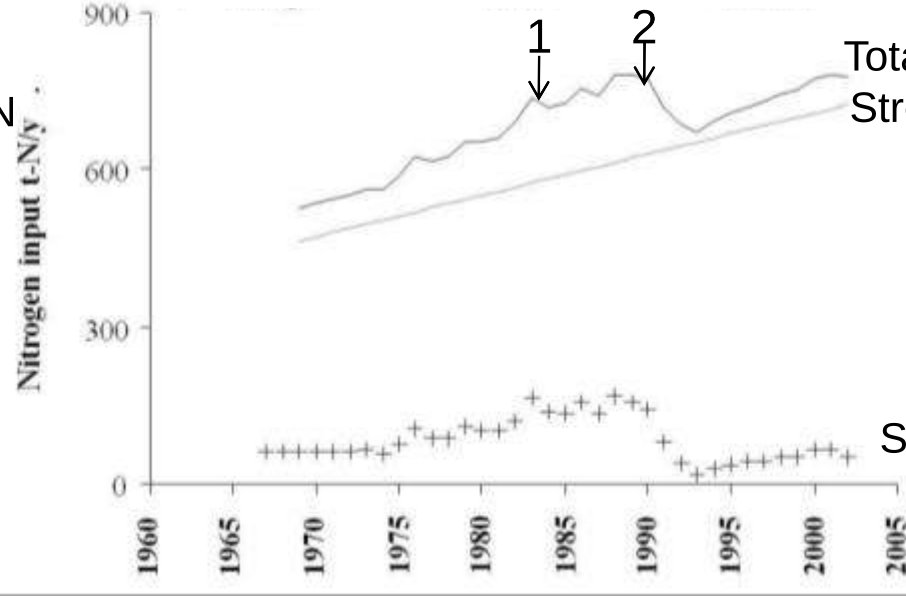
But didn't the wastewater treatment plant (1991) solve the problem?

Nitrogen concentrations, Ngongotaha



(1) Kaituna catchment control scheme

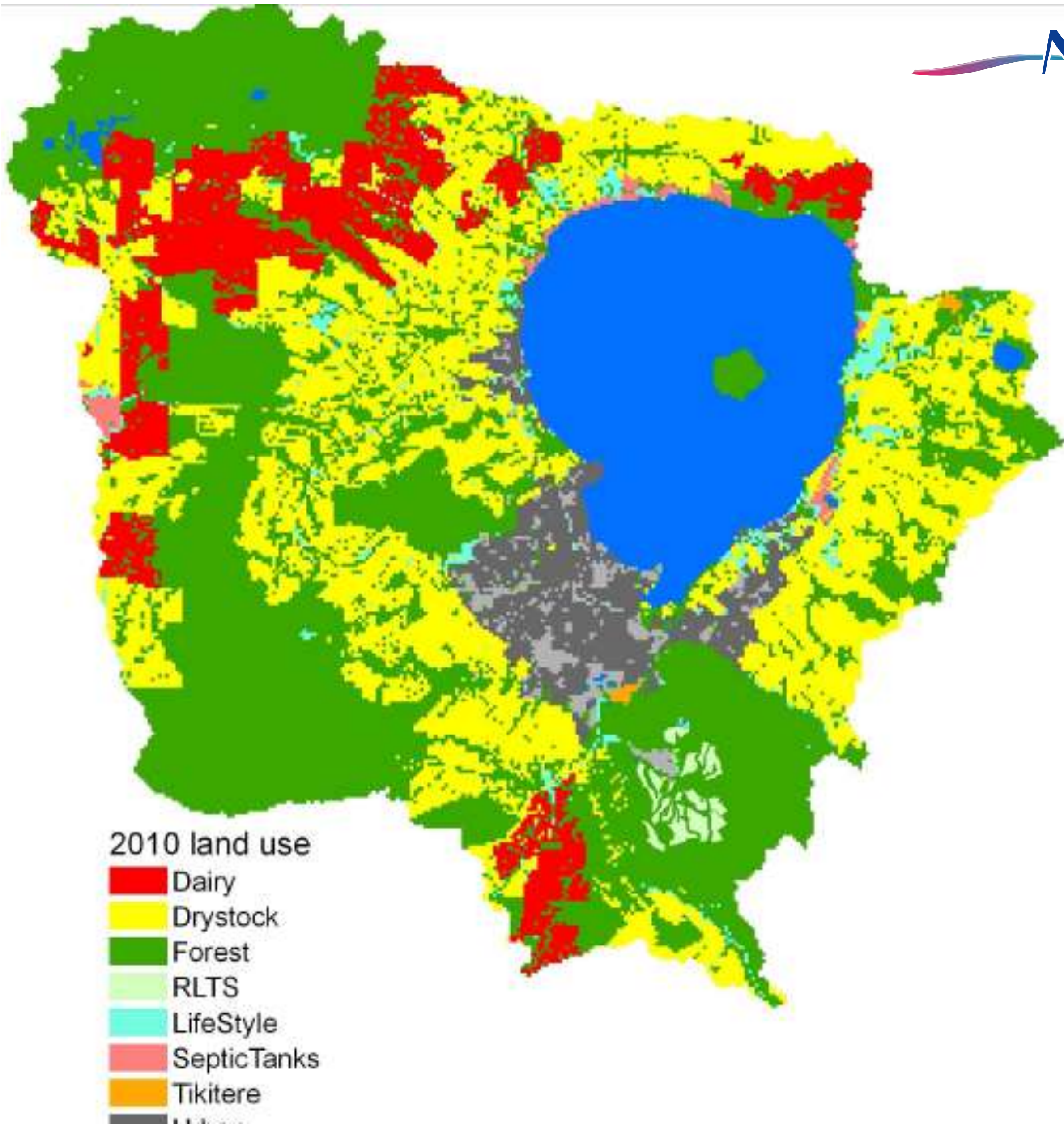
(2) Advanced WWTP land treatment



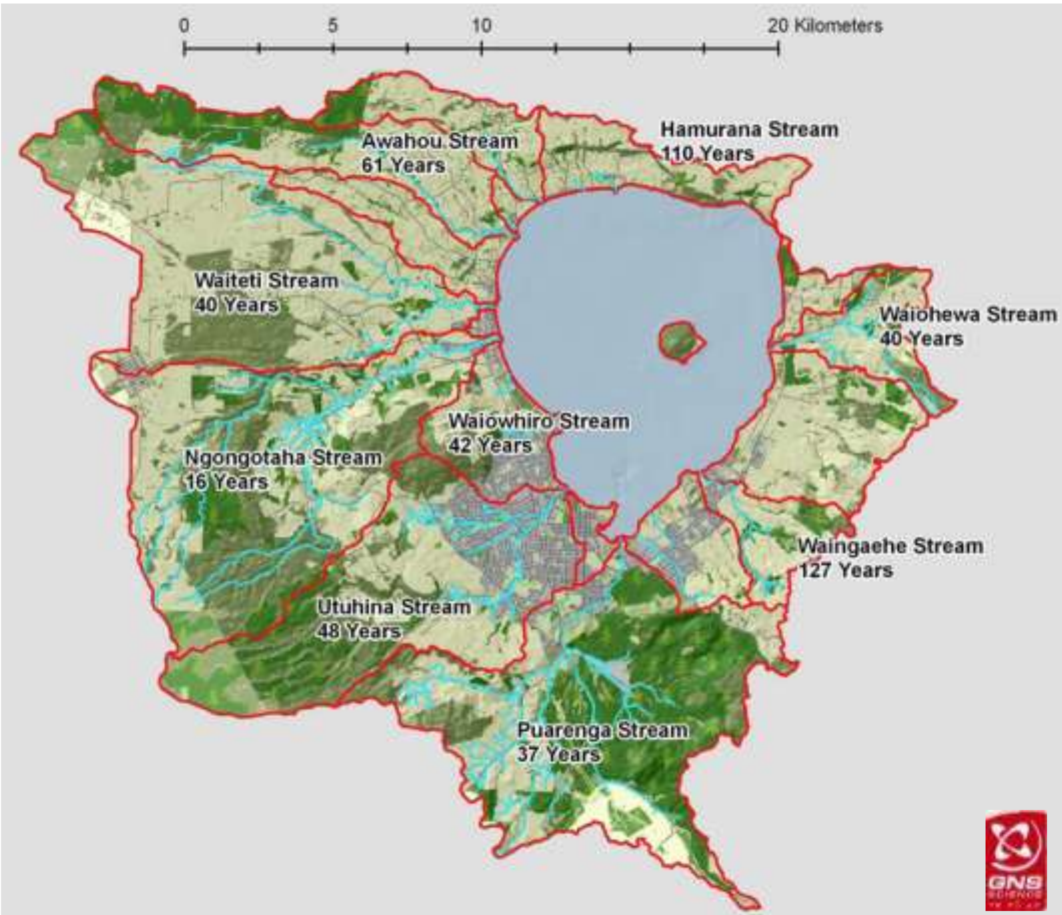
Rutherford et al. (2004)


Google Maps

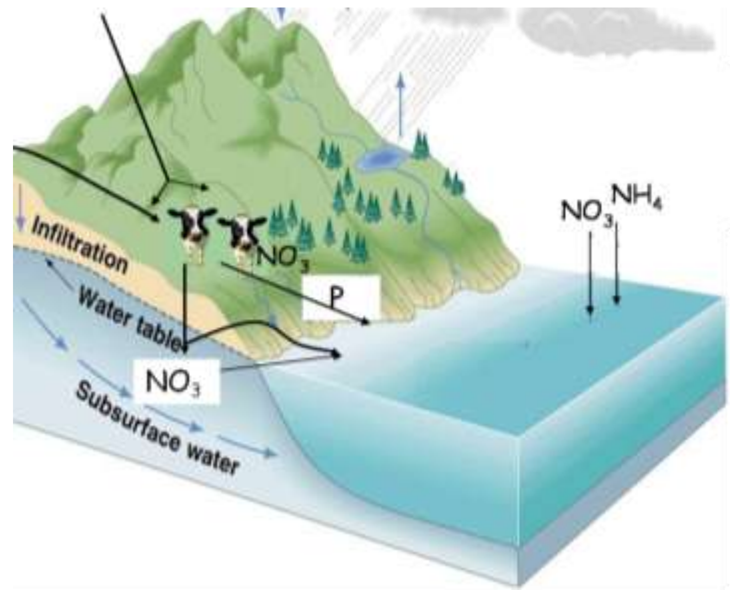
Changing land use, Lake Rotorua catchment



'Old age' groundwater to Rotorua



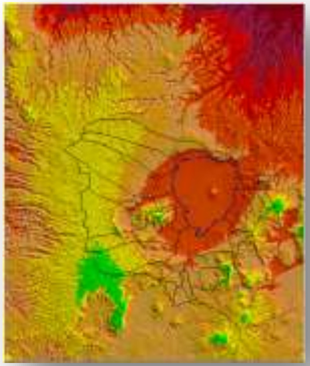
Hamurana 110 yr
Ngongataha 16 yr
Awahou 61 yr
Waiowhero 42 yr



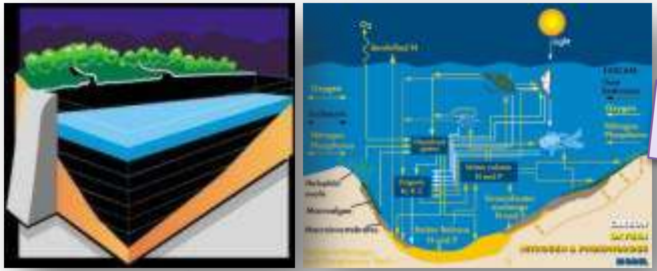
Lake Rotorua modelling as a decision support tool

ROTAN catchment model

Climate model



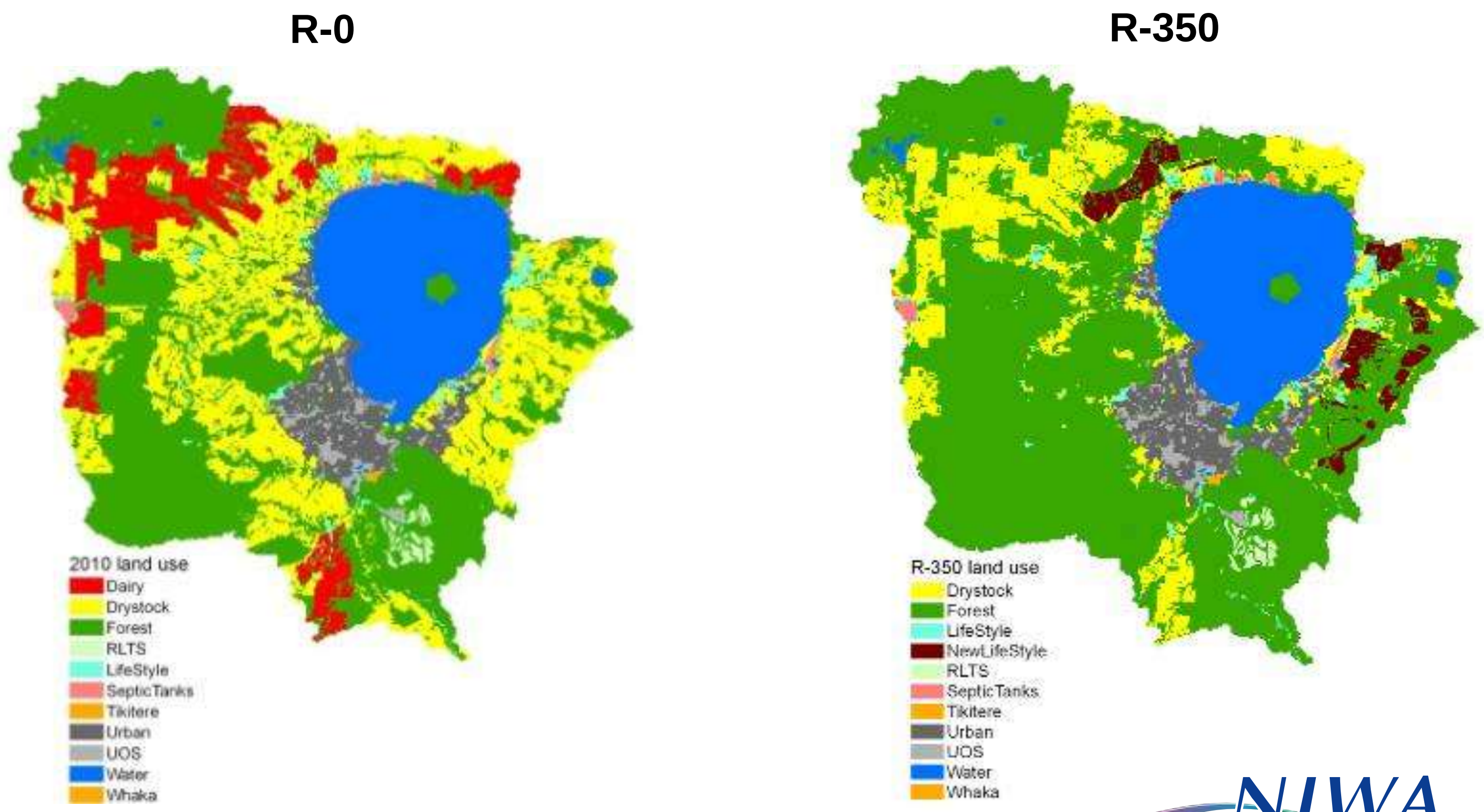
Lake model



High frequency monitoring

Inform

One scenario: 350 t N/y removed

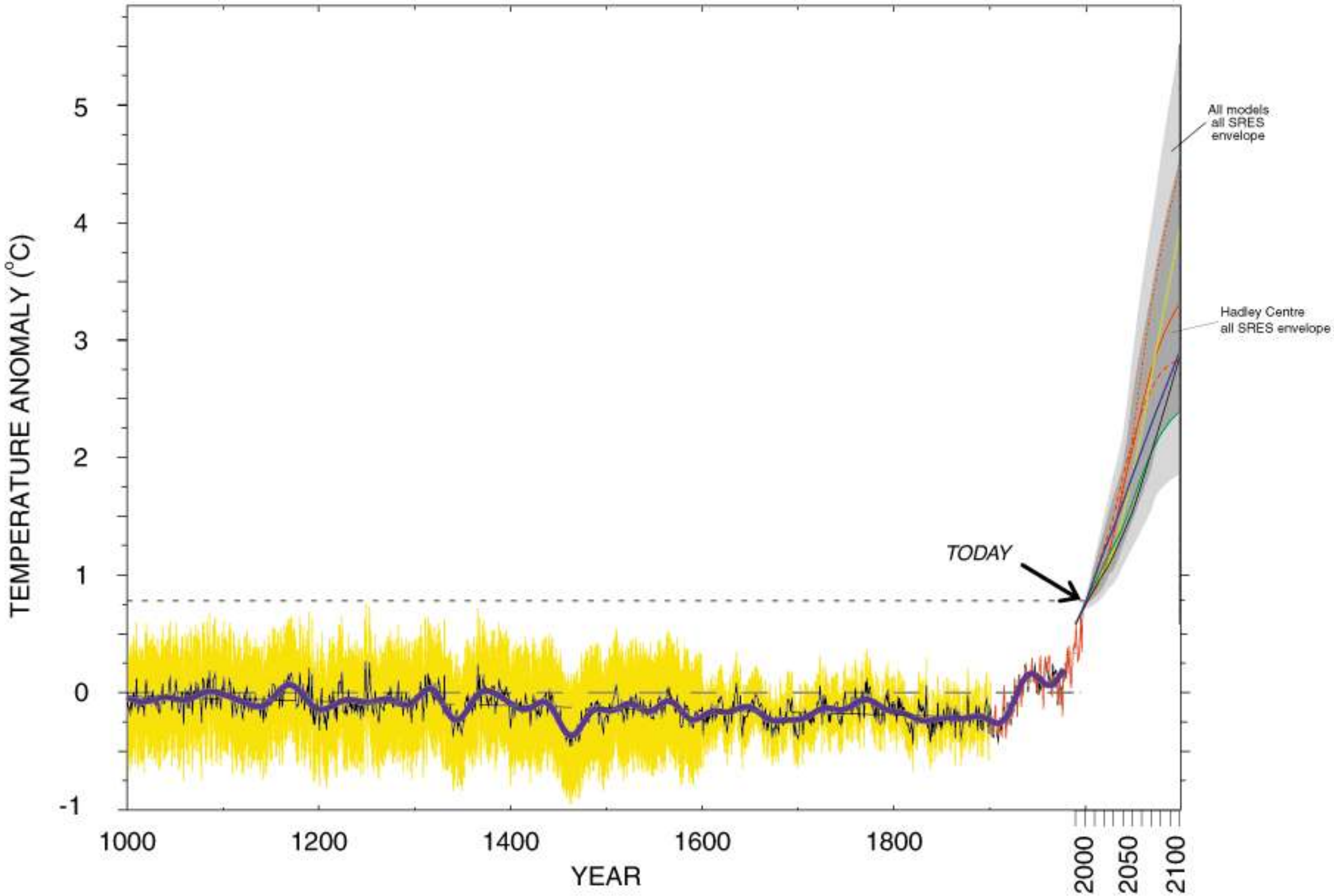


NIWA

No Dairy, less Dry Stock, more Forest, more Lifestyle

Numerous other possible scenarios with the same lake load

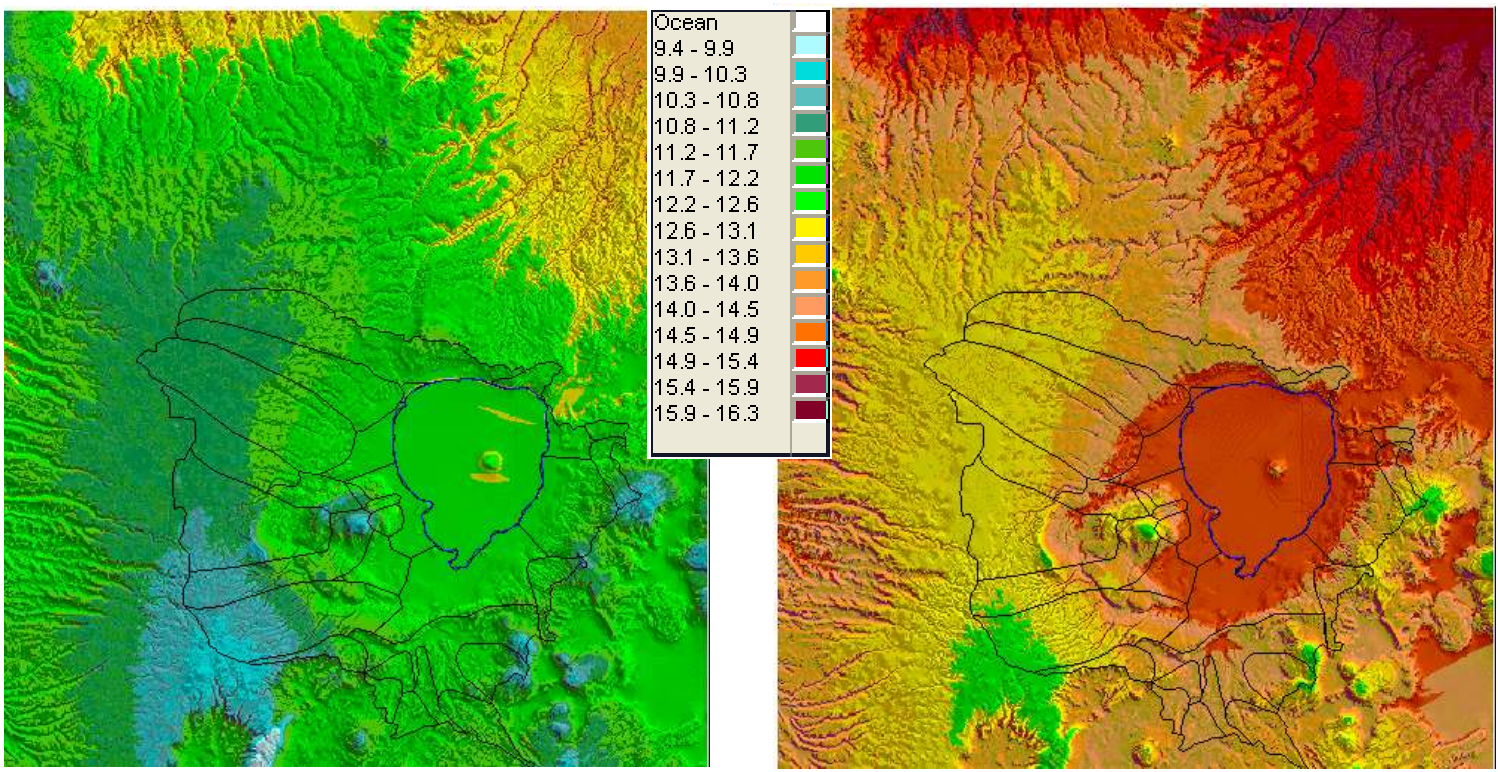
Temperature: past and future



Climate Change Scenario

Lake Rotorua annual mean temperature (^{o}C)

Baseline (1960-1991 average) | Climate change projection (2100)*

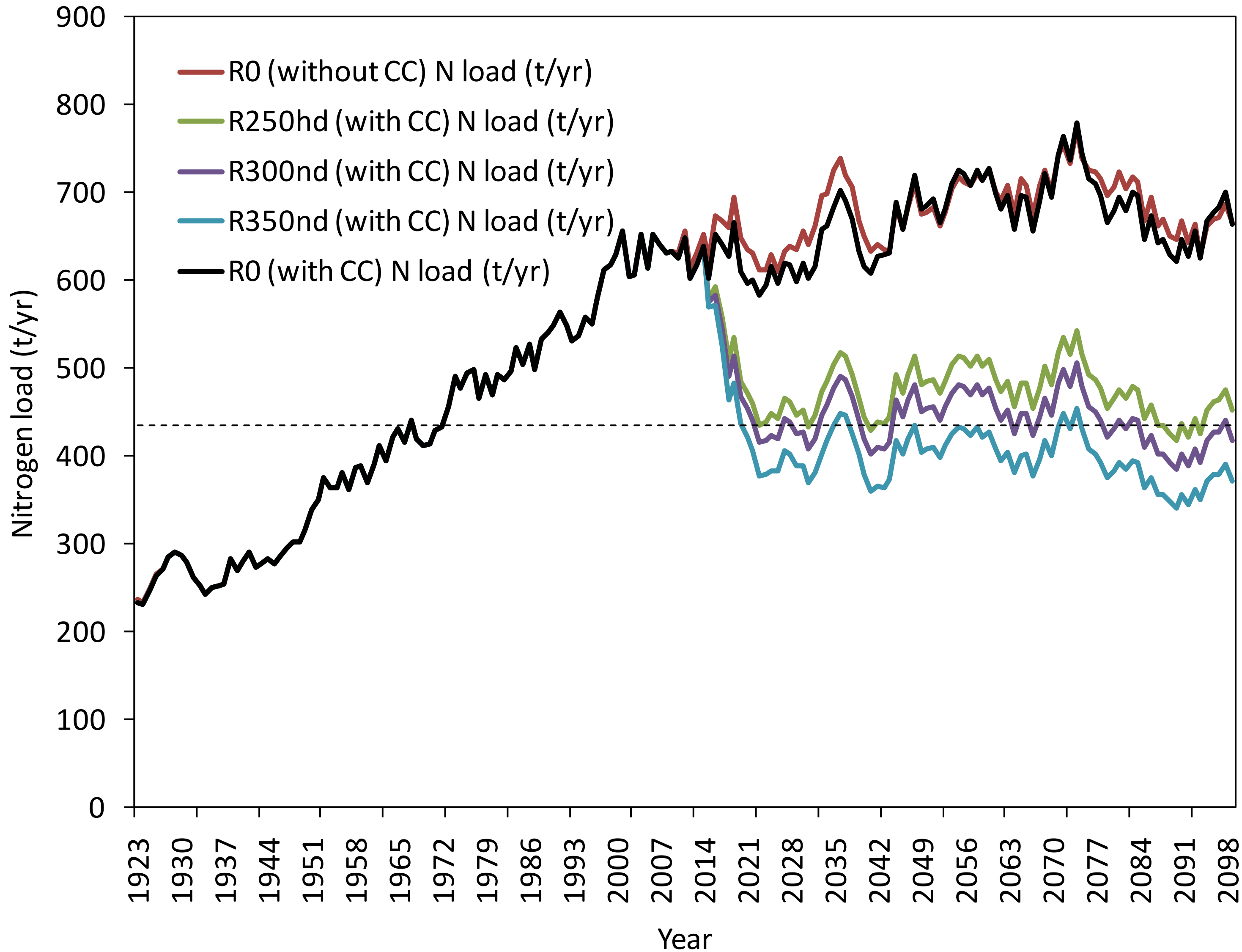


Groundwater catchment boundary

Lake boundary

Wei Ye
University of Waikato

4-year average N load



DYRESM-CAEDYM

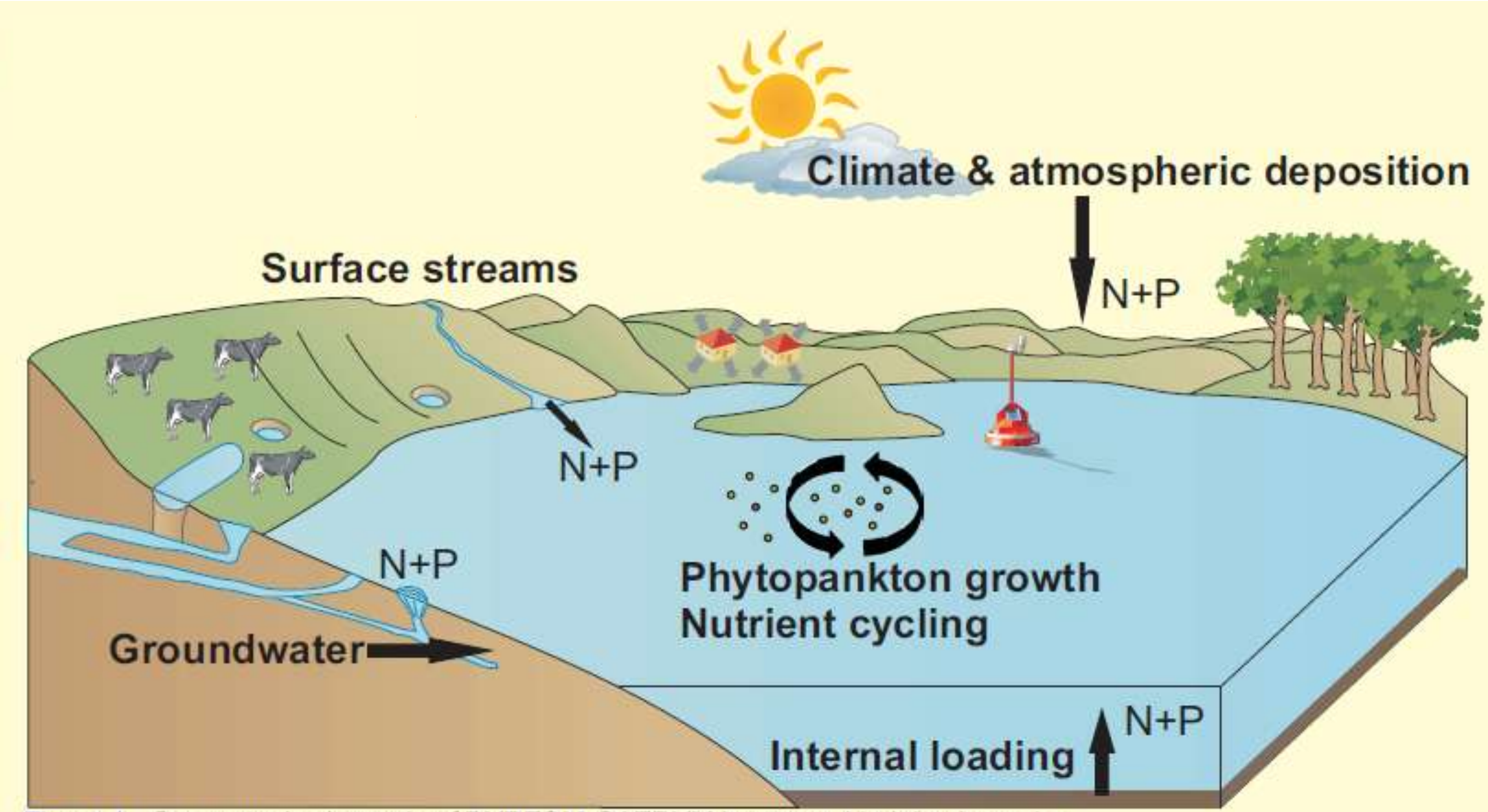
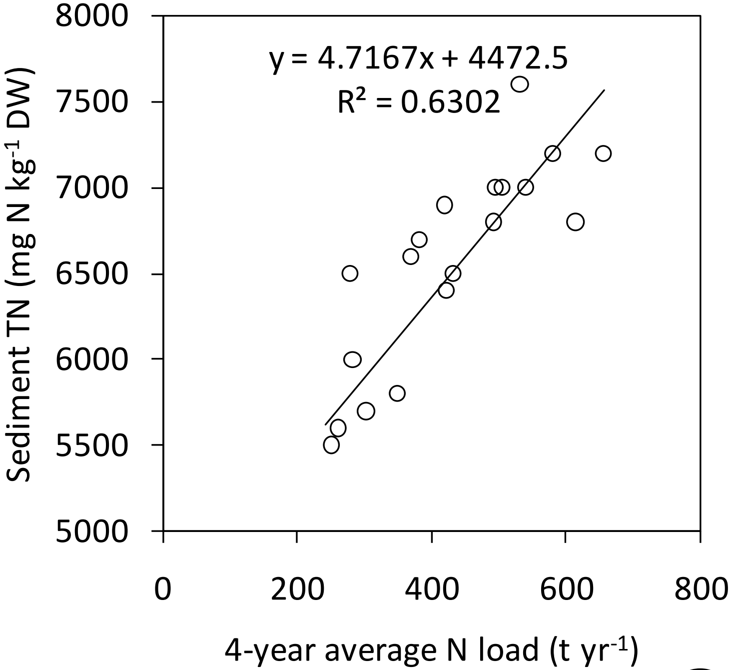
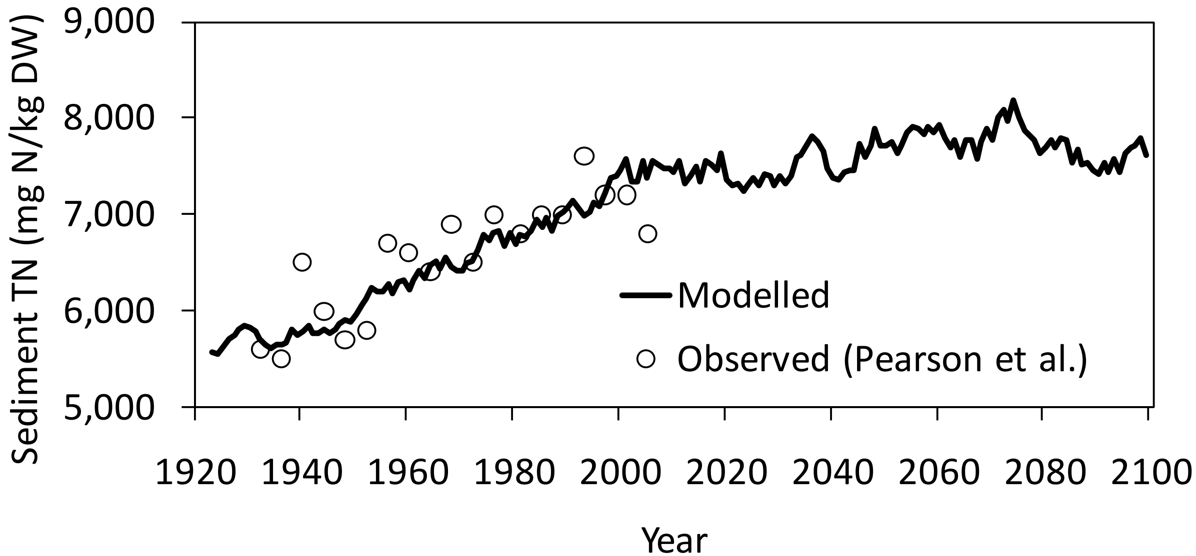


Figure 1. Conceptual schematic of DYRESM-CAEDYM inputs and in-lake dynamics.

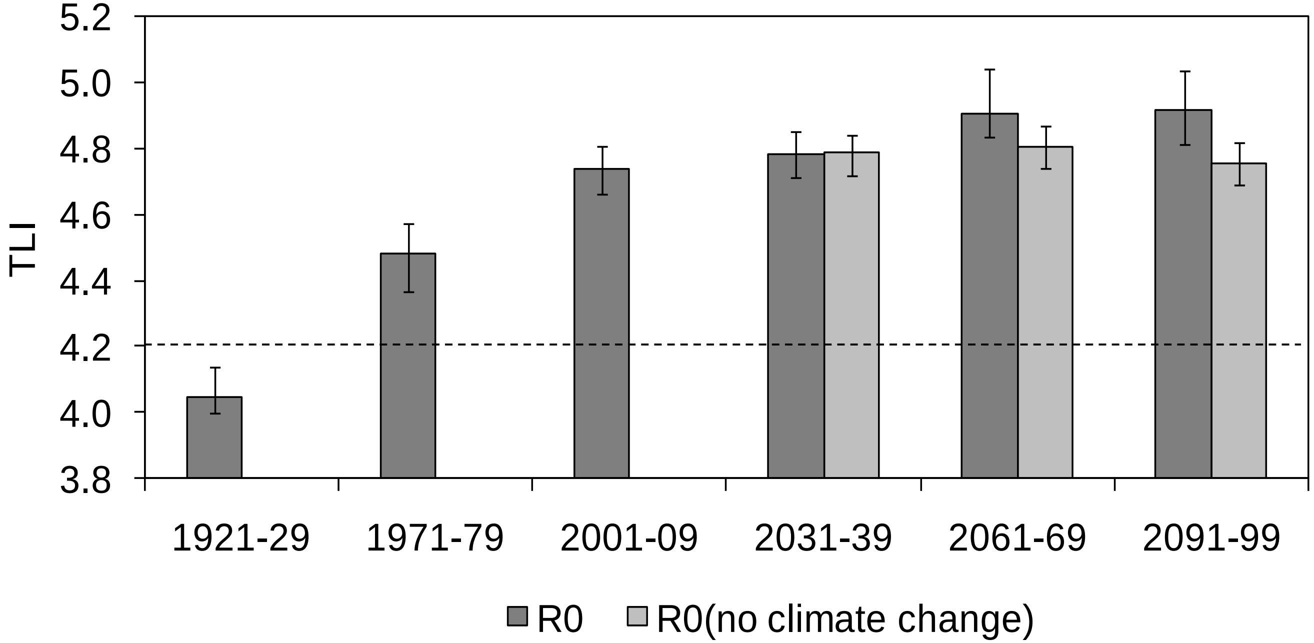
Changing 'internal' loads of nutrients



Changes in sediment composition are closely related to the increasing nutrient (nitrogen) load – a parameter for making future projections of internal nutrient loads

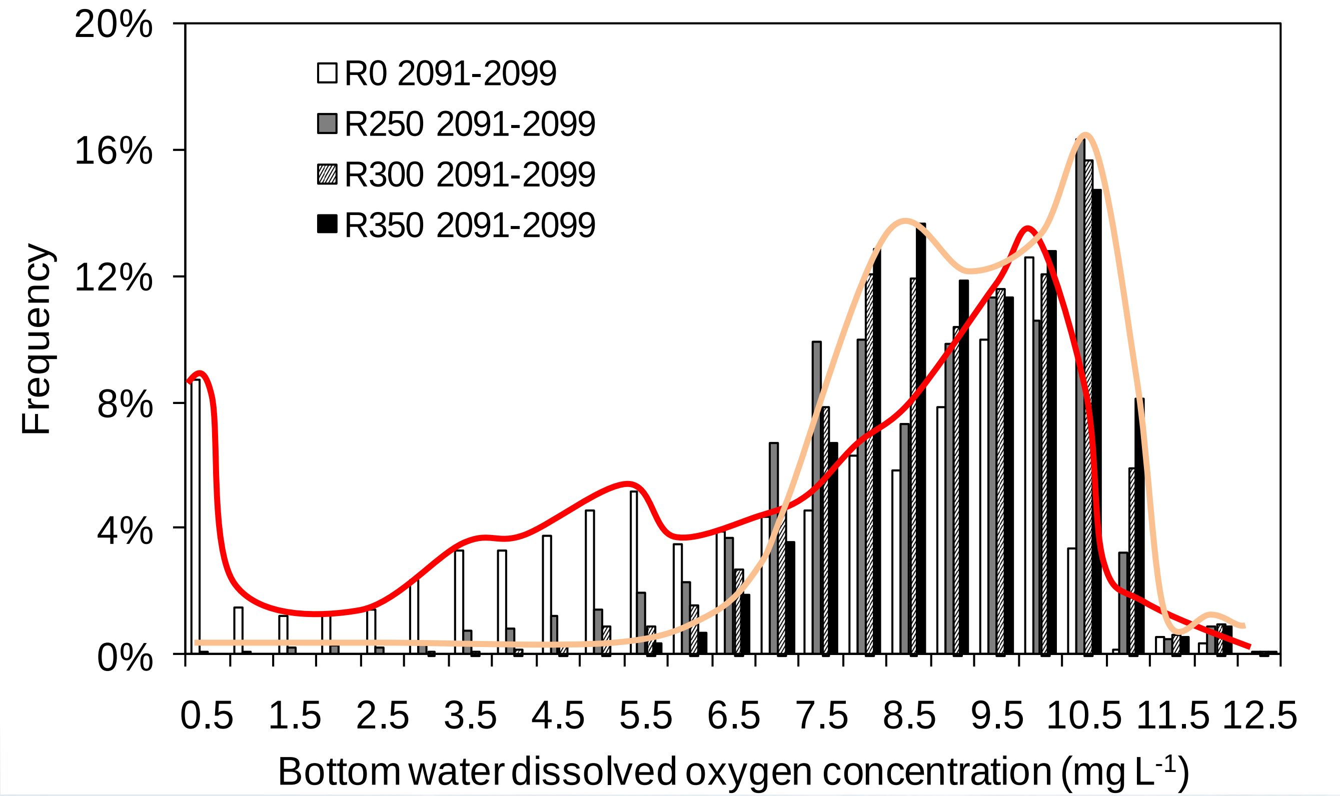


Effects of climate change on Trophic Level Index (Target TLI = 4.2)



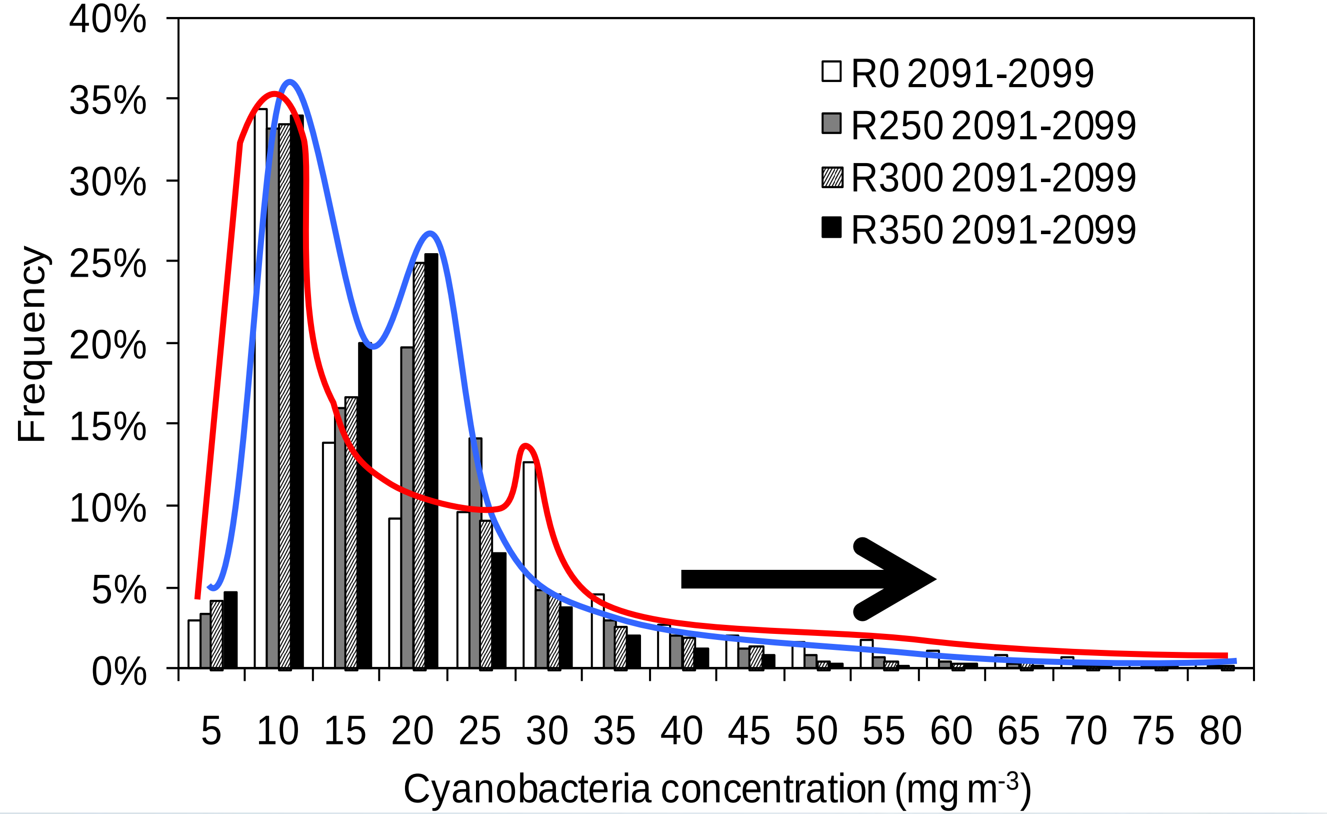
Probability distribution of bottom-water (20 m) dissolved oxygen concentrations in Lake Rotorua

for the base scenario (R0) and three other external nutrient load scenarios for 2091-2099

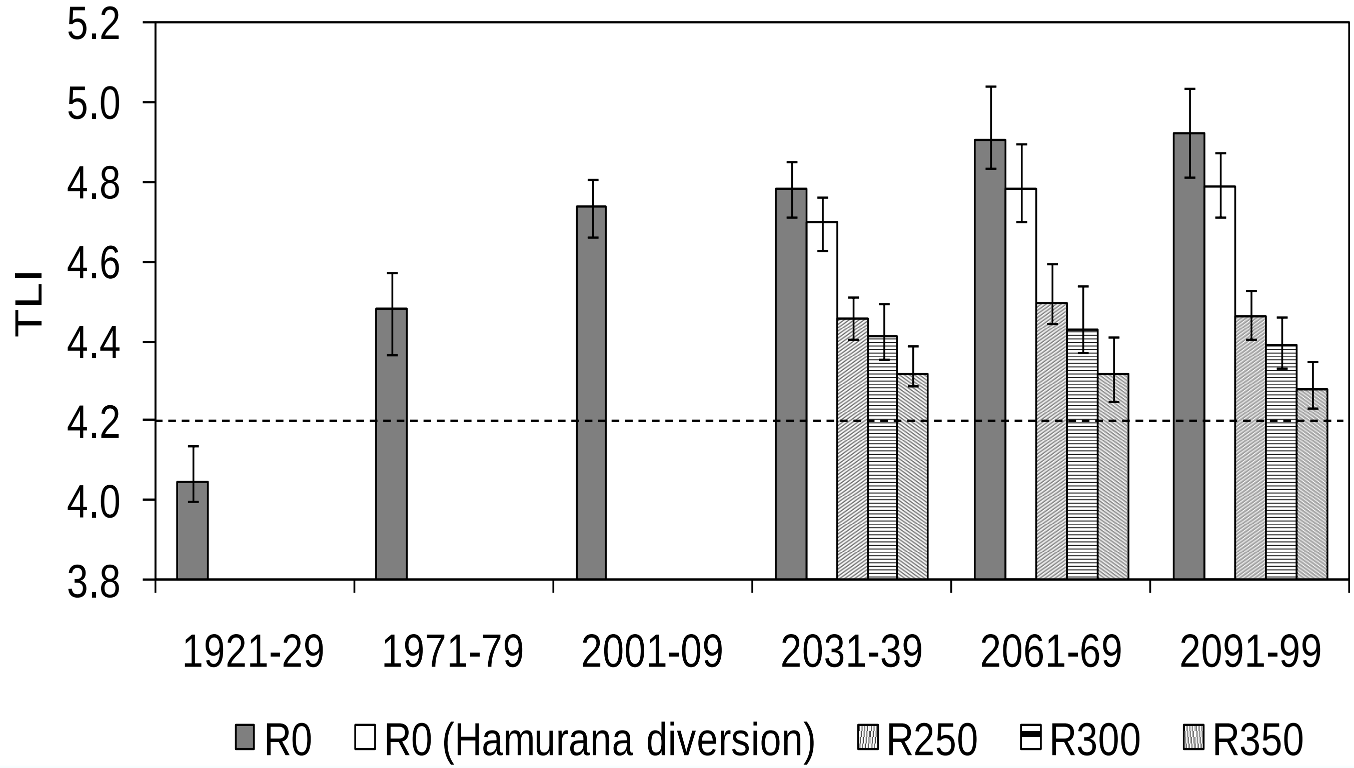


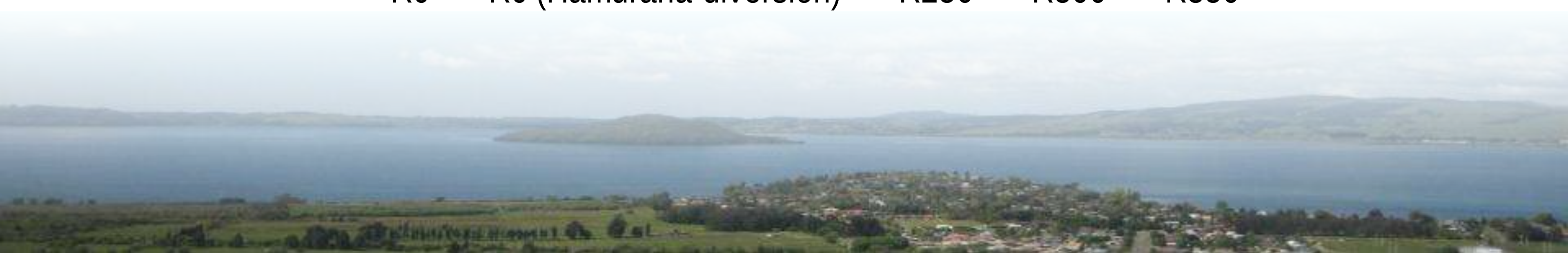
Probability distribution of cyanobacteria concentrations in Lake Rotorua

for the base scenario (R0) and three other external nutrient load scenarios for 2091-2099 (includes climate change)



Effects of land use change and inflow diversion on Trophic Level Index (Target TLI = 4.2)



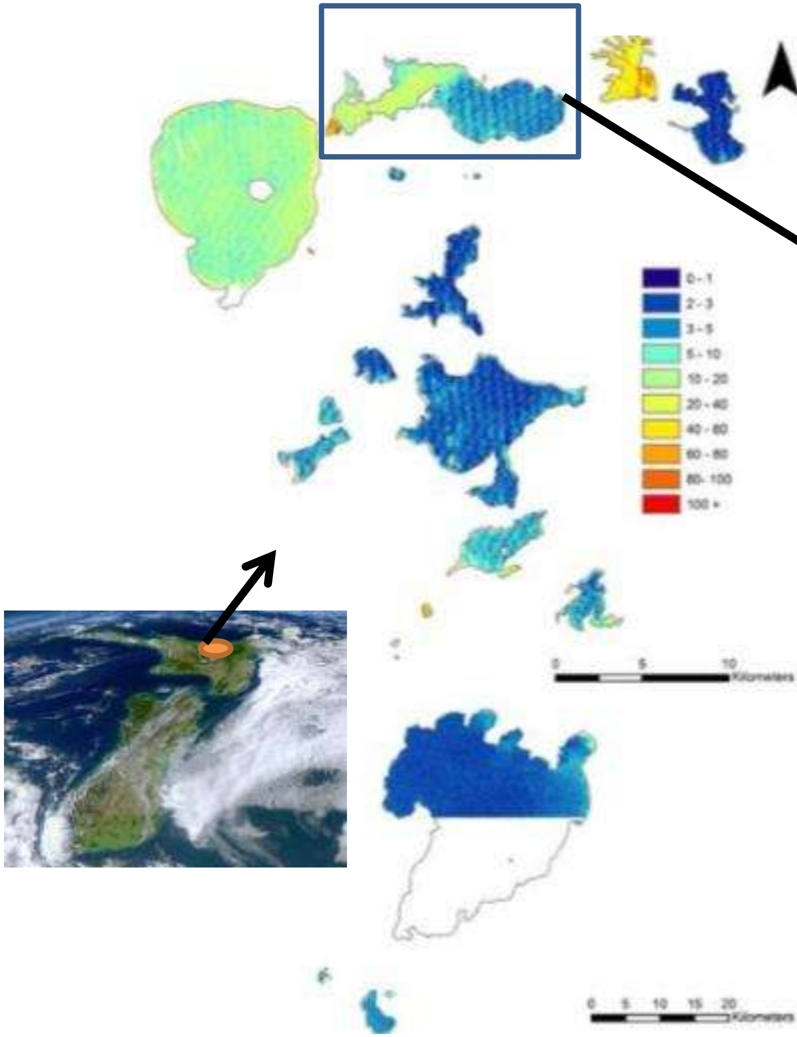


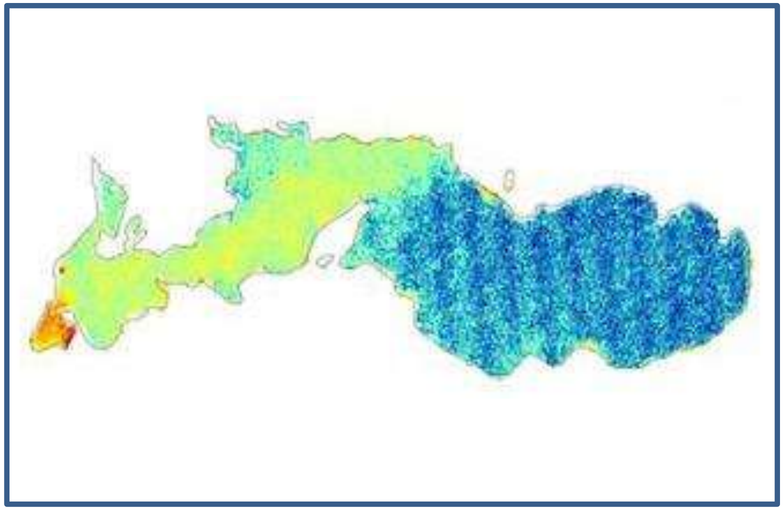
Impacts of climate and nutrient load reductions on cyanobacteria concentrations

Relative change of days with cyanobacteria concentration > 20 mg m^{-3}					
Period	R0	R0 (noCC)	R250	R300	R350
1921-1929	0%	0%	0%	0%	0%
1971-1979	0%	0%	0%	0%	0%
2001-2009	0%	0%	0%	0%	0%
2031-2039	0%	-7%	-22%	-39%	-61%
2061-2069	0%	-3%	-14%	-37%	-56%
2091-2099	0%	-6%	-30%	-47%	-60%

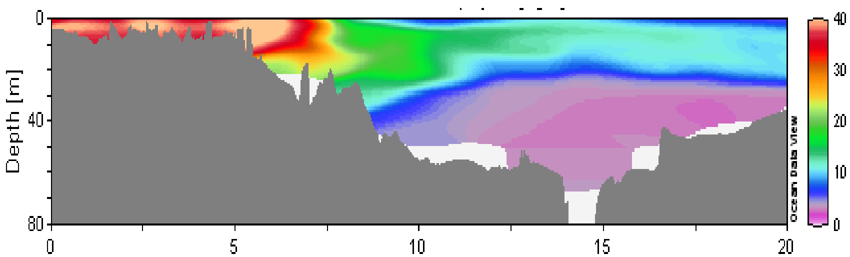
Inflows and outflows for Lake Rotoiti: Historical case

Landsat-derived chlorophyll *a* for Rotorua lakes





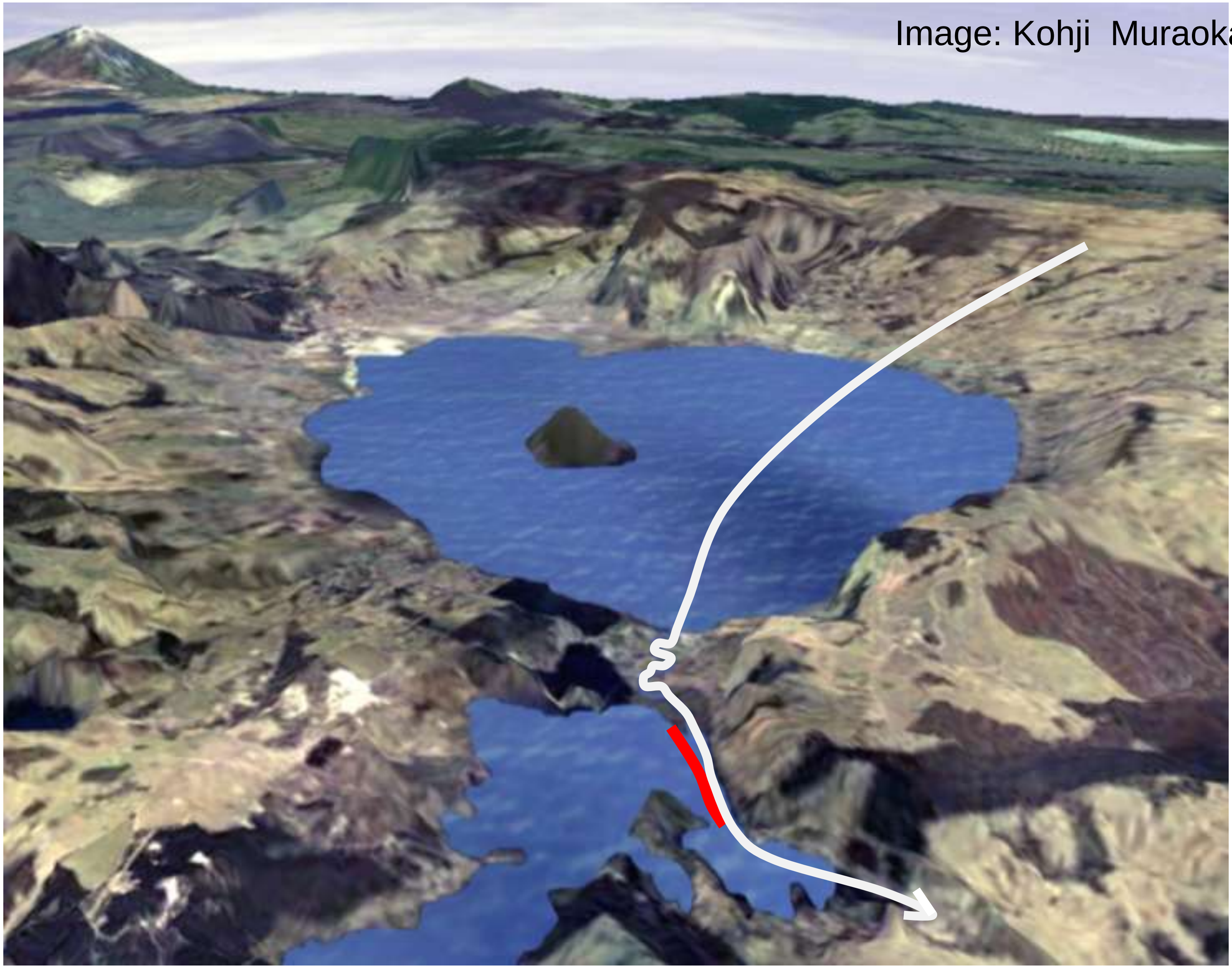
Allan et al. (2010). Int. J. Remote Sensing



Hamilton et al. (2010). Aquat. Sci.

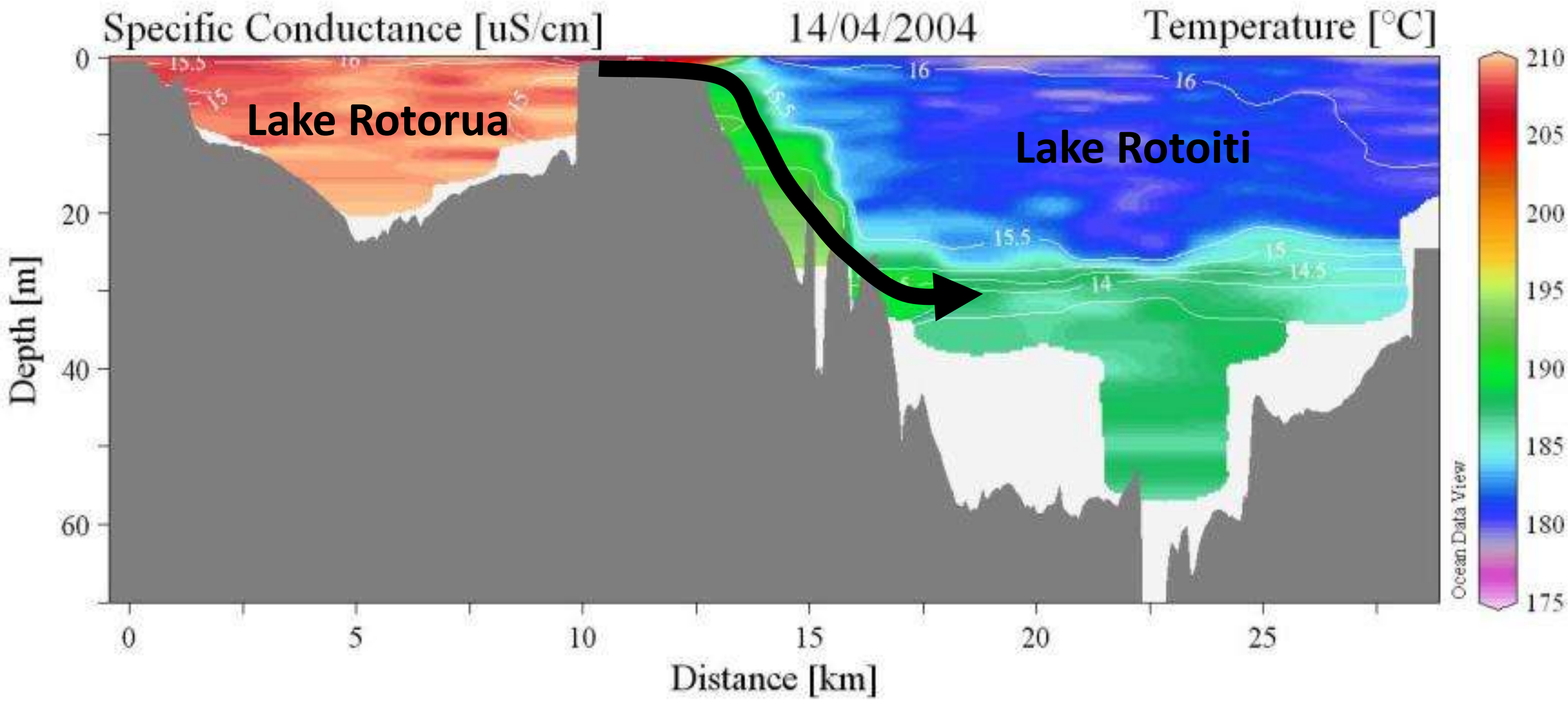
Strong vertical and horizontal gradients necessitate the application of highly spatially resolved models

Implications beyond Lake Rotorua: Ohau Channel diversion wall



Inflows and outflows for Lake Rotoiti: Diversion case

Lake Rotorua – Rotoiti connection



Percentage of current Ohau Channel inflow versus cyanobacteria (as µg chl-a L^{-1}) in Lake Rotoiti

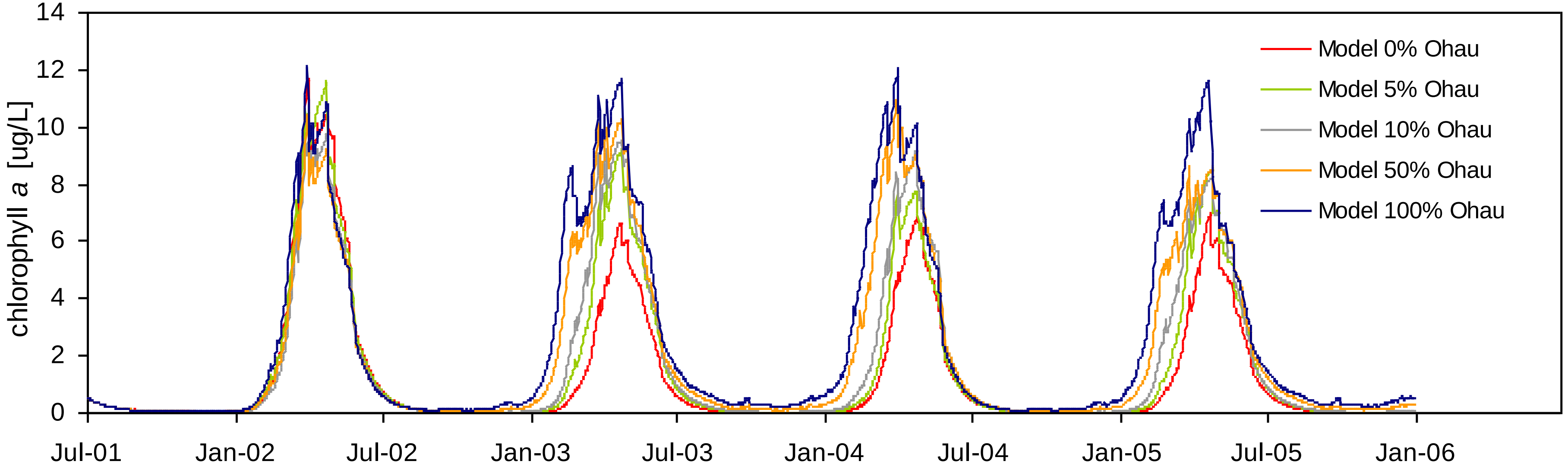
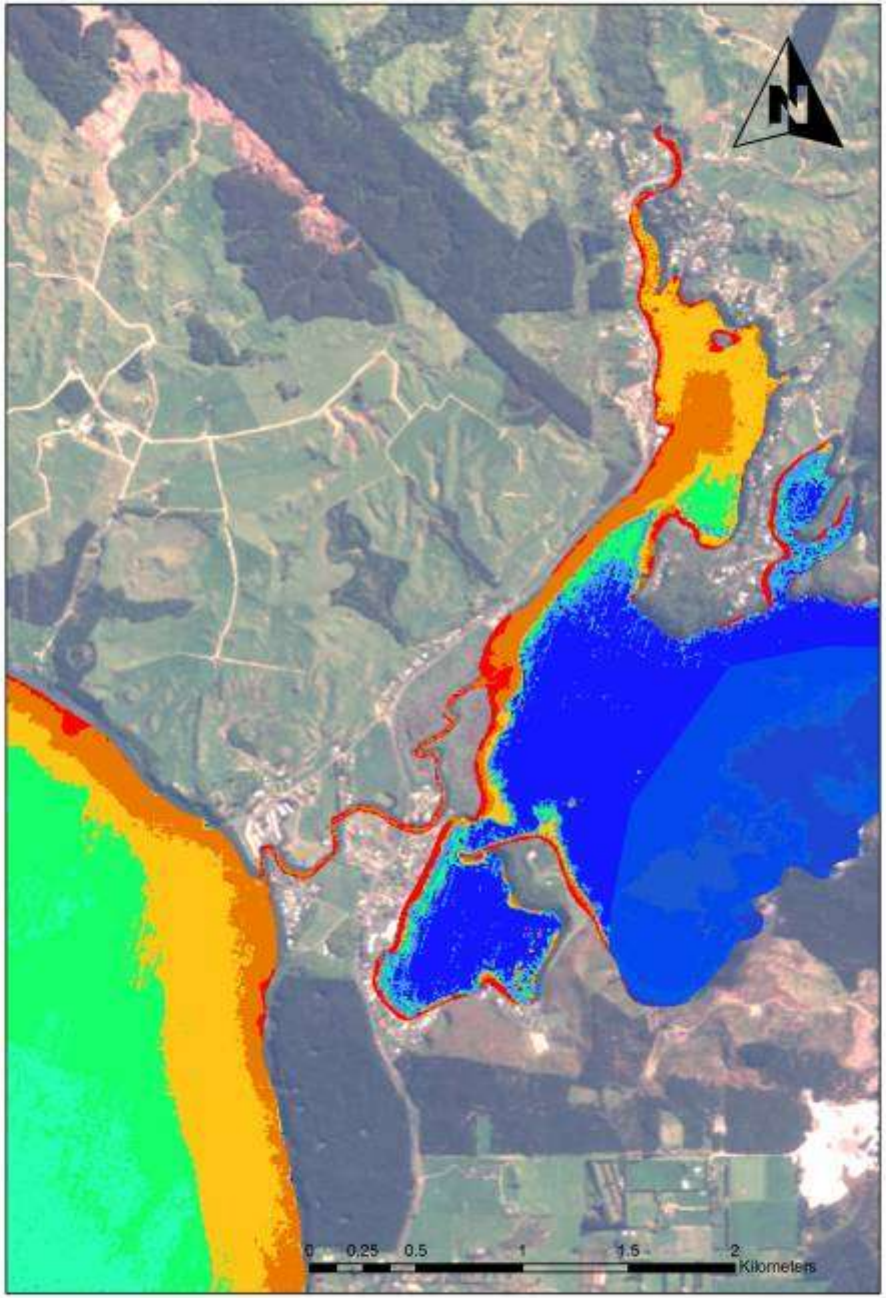
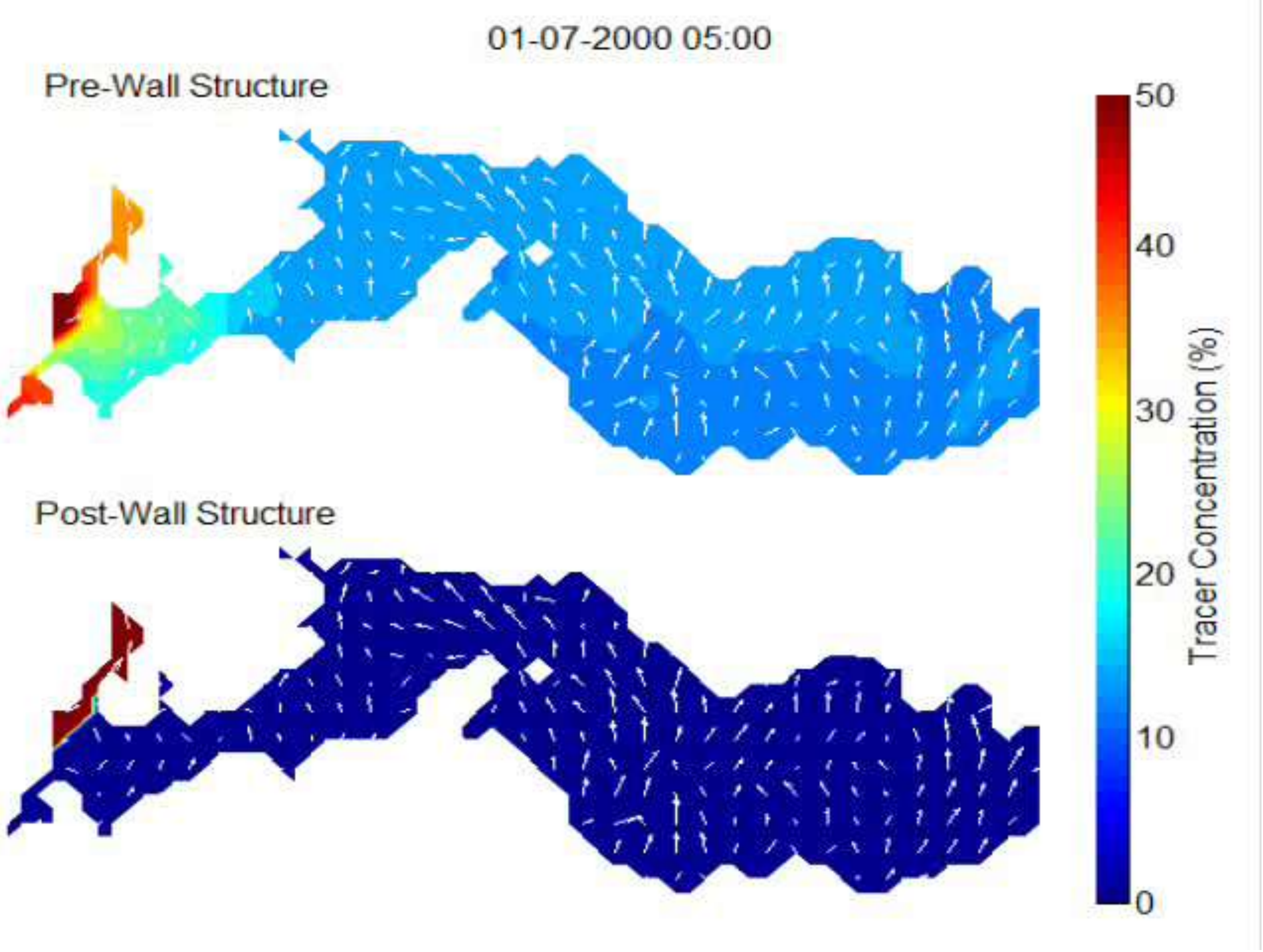



Photo: Andy Bruere, BOPRC

Satellite/aerial views of diversion wall, Lake Rotoiti



Lake Rotoiti – pre and post-wall



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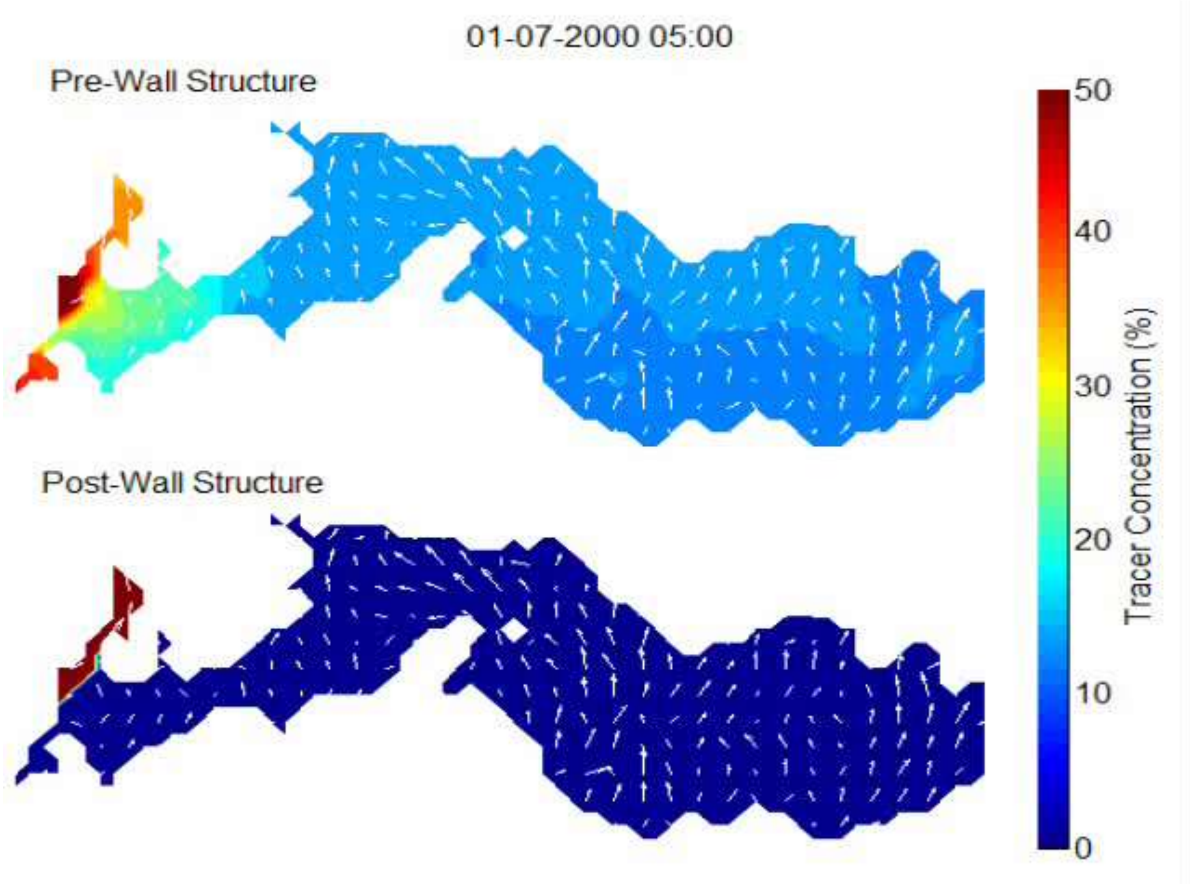
Numerical Lake Modelling

Kohji Muraoka (km112@waikato.ac.nz)

Lake Ecosystem Restoration New Zealand

3D model: The Estuary and Lake Computer Model (ELCOM)

Centre for Water Research, University of Western Australia



Modified zeolite application, Lake Okaro, September 2009

Photo A. Bruere, EBoP

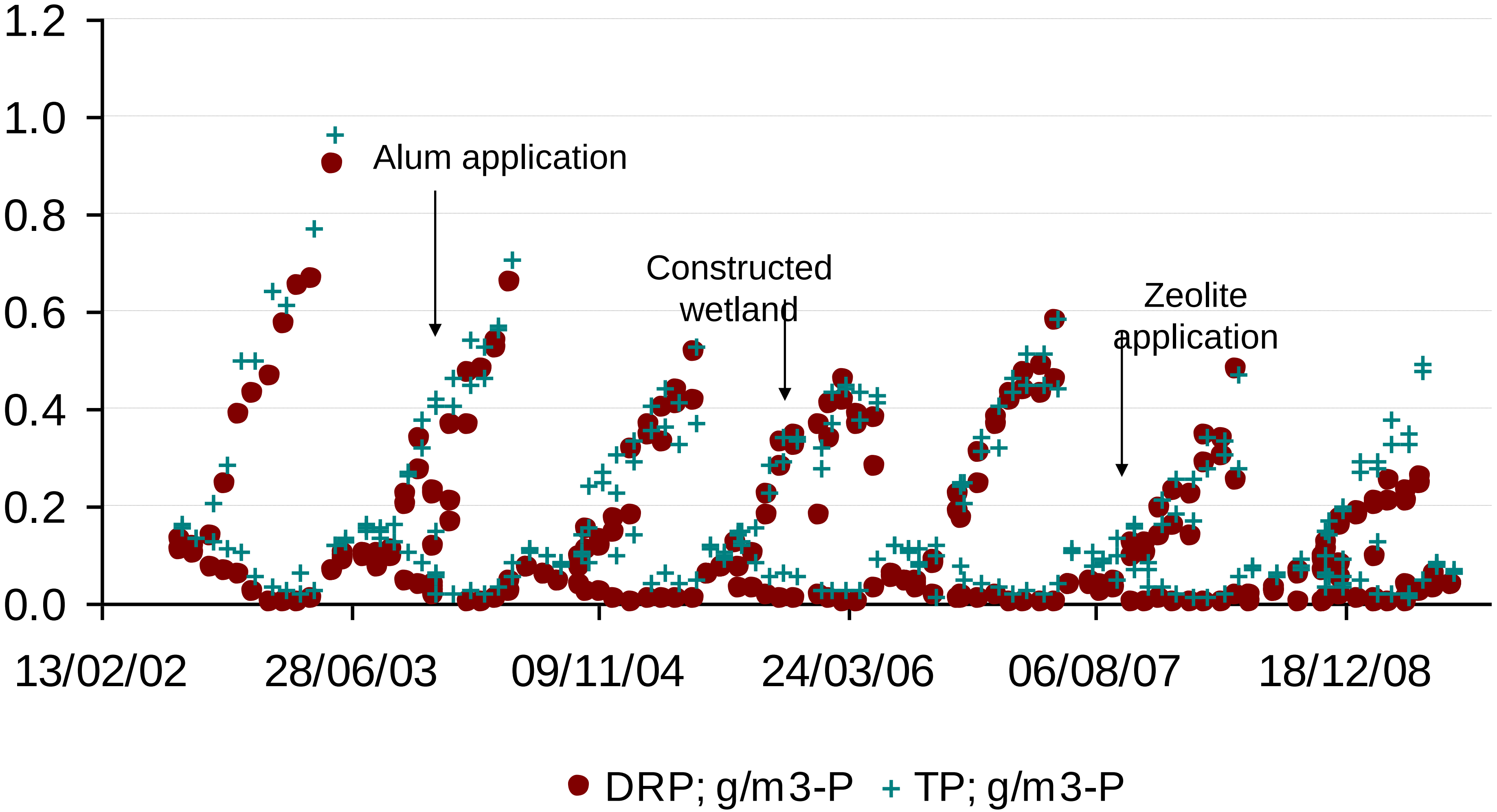

Lake Okaro constructed wetland
Photo A. Bruere, EBoP

Potential to apply models to major lake ecosystem perturbations: Modified zeolite application to Lake Okaro

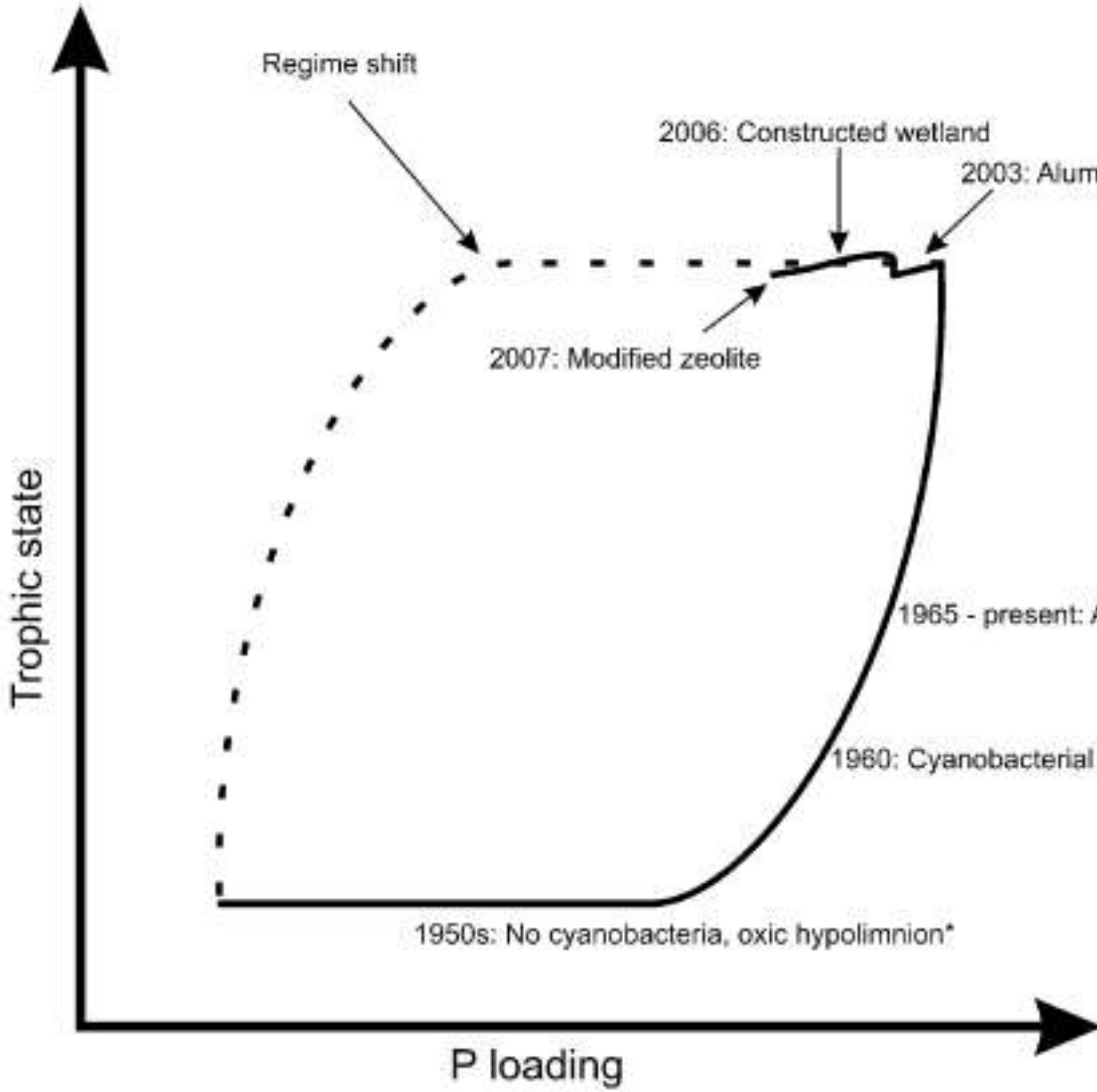
Modified zeolite application to Lake Okaro, September 2009

Photo M.Gibbs, NIWA

Phosphorus concentrations in bottom waters of Lake Okaro



Regime shift in a eutrophic Rotorua lake



Ozkundakci et al. (2010), Ecological Engineering

The Rotorua lakes – trends in water quality

Mann-Kendall non-parametric test for trend (seasonally adjusted time series)

Total nitrogen

Lake	Kendall tau	p-level	
Okareka	0.286	0.001	X
Ōkaro	-0.088	0.276	
Okataina	0.278	0.001	X
Rerewhakaaitu	0.452	0.000	X
Rotoehu	-0.087	0.281	
Rotoiti	-0.374	0.000	√
Rotoma	0.208	0.009	X
Rotomahana	0.209	0.009	X
Rotorua	-0.061	0.454	
Tarawera	0.181	0.025	X
Tikitapu	-0.013	0.869	

Total phosphorus

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Rerewhakaaitu	0.079	0.325	
Rotoehu	0.182	0.024	X
Rotoiti	-0.392	0.000	√
Rotoma	0.187	0.020	X
Rotomahana	0.345	0.000	X
Rotorua	-0.379	0.000	√
Tarawera	0.039	0.631	
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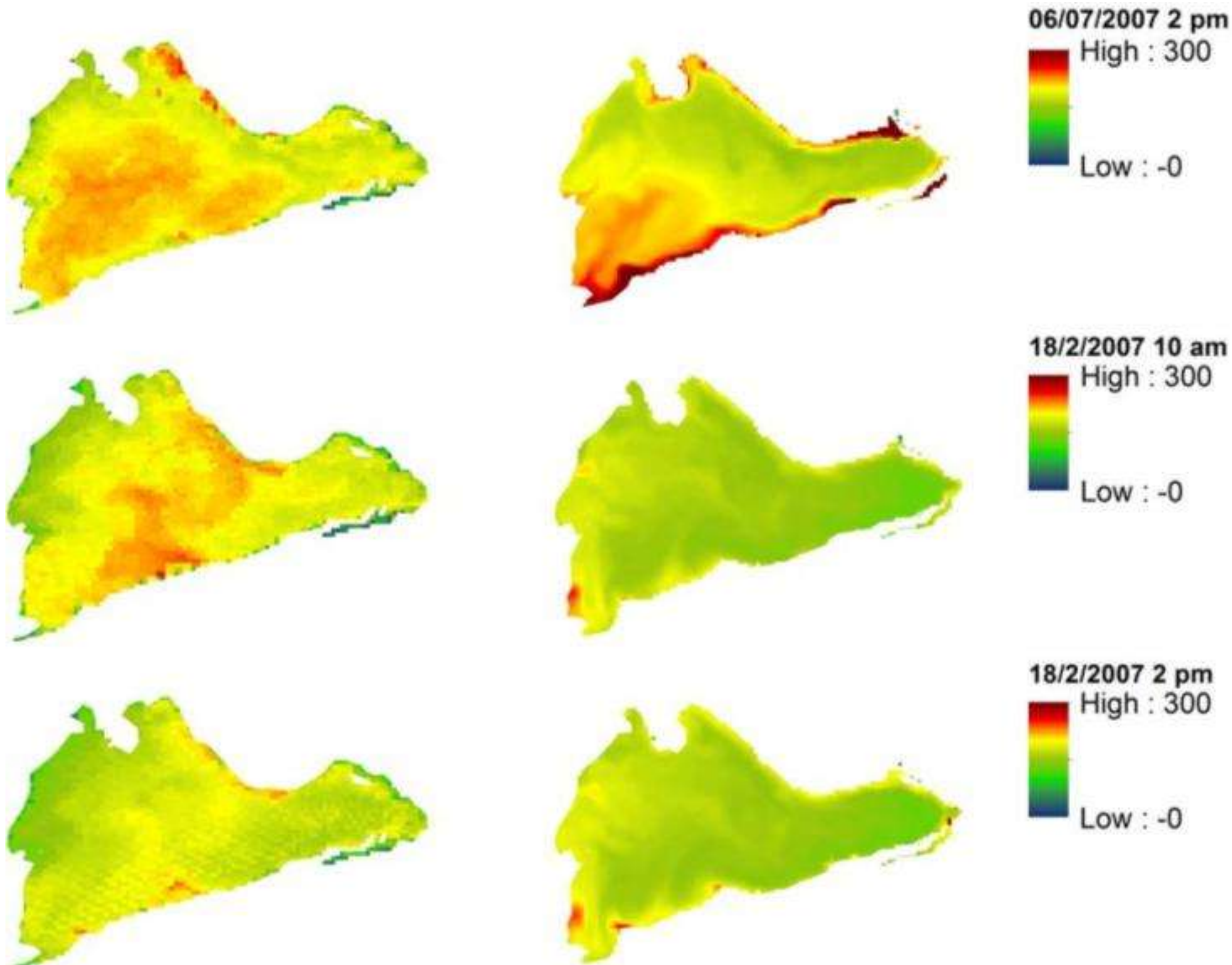
And to Te Waihora

Suspended sediment concentrations (mg L^{-1})



Landsat Model

Conclusions

– The balance of economism, scientism and technocracy?

– Many models but some common features:

– "If you don't provide us with the results the planners will make decisions in the absence of knowledge of environmental outcomes"