

Groundwater-Surface Water Interaction

A Lake-Modeller's Conceptual View



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Lake Water Quality

- * Defined by purpose
 - * Drinking
 - * Recreation
 - * Fishing
 - * Health of aquatic life



Poor Water Quality



Chain of cells from the cyanobacterium *Anabaena*, showing a heterocyte.
Image courtesy of Wendy Paul.

Algae blooms

Allergic reactions, asthma,
eye irritations, rashes,
gastrointestinal disorders

Can cause oxygen depletion
of the bottom waters.

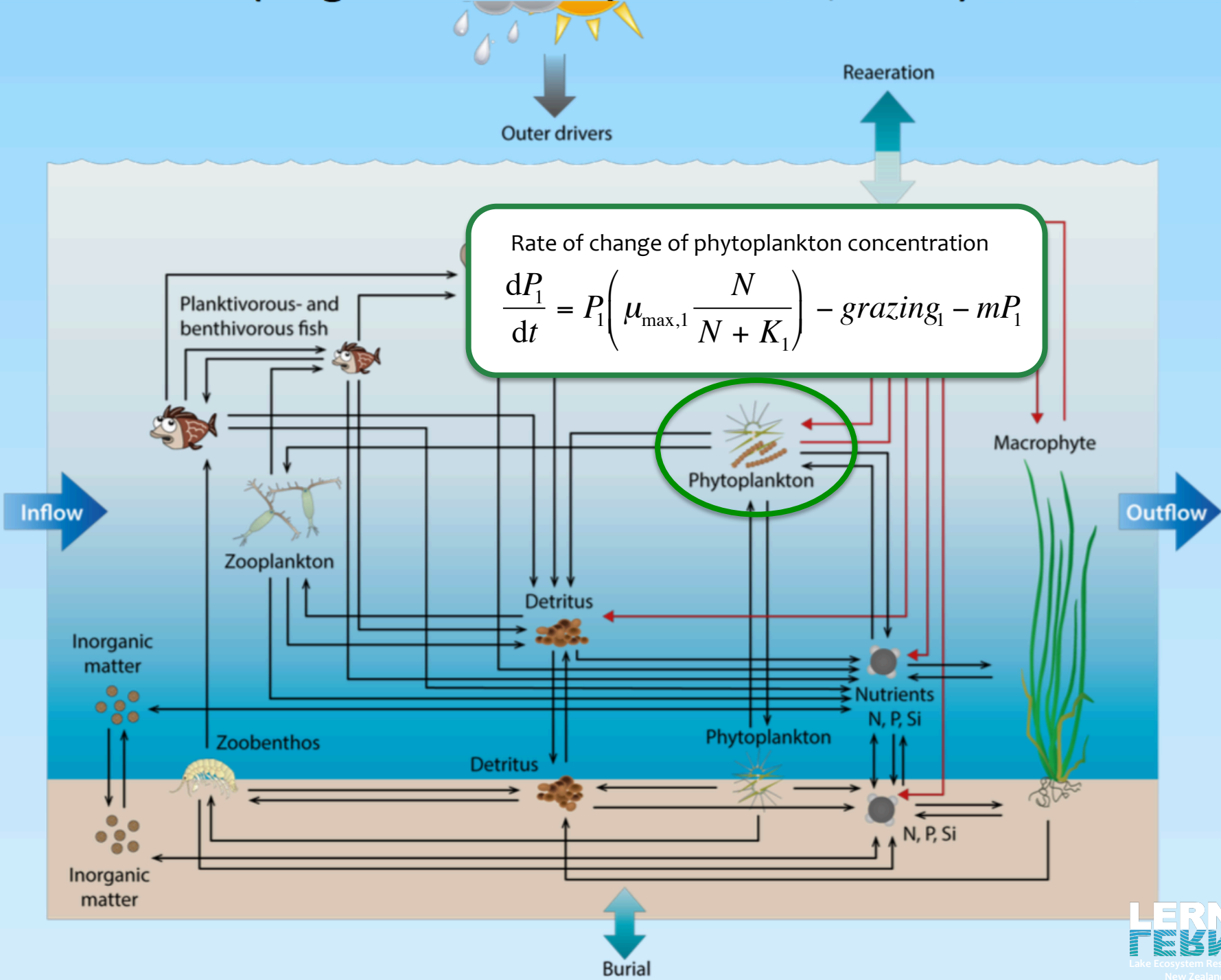
Livestock and animal
poisoning



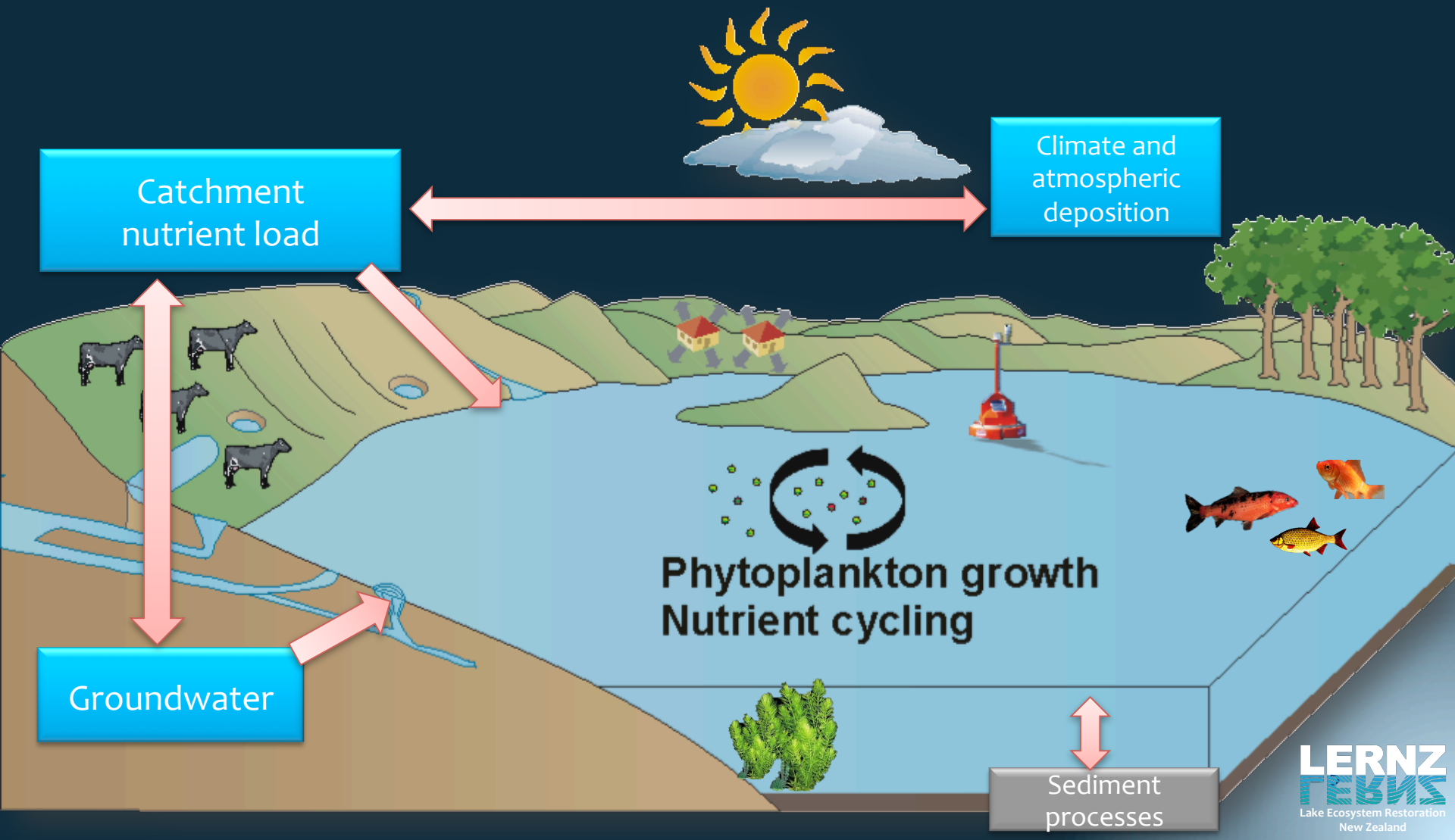
(image courtesy of Environment Bay of Plenty)



(John Clayton, NIWA)



Lake ecosystem models are linked to climate, catchment and groundwater models



Lake Science and Applications at UoW

- 3-D simulations for siting of WWTP outfall in Lake Rotorua

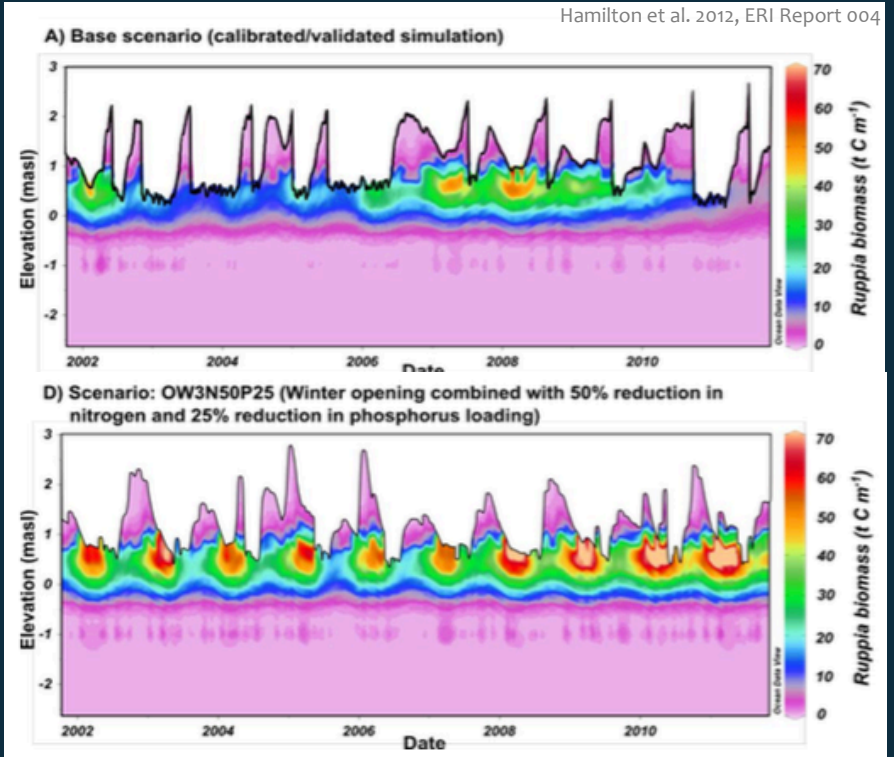


Lake Science and Applications at UoW

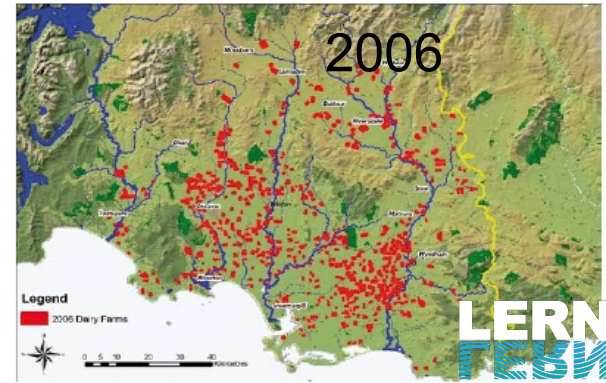
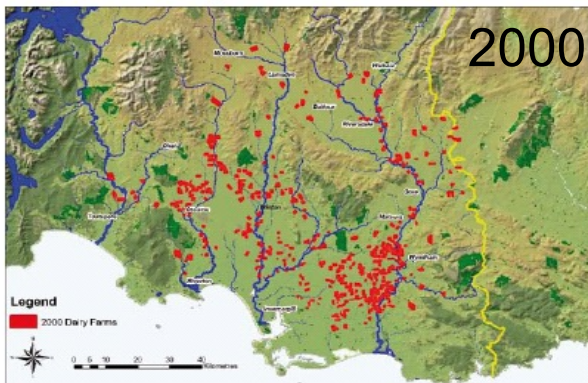
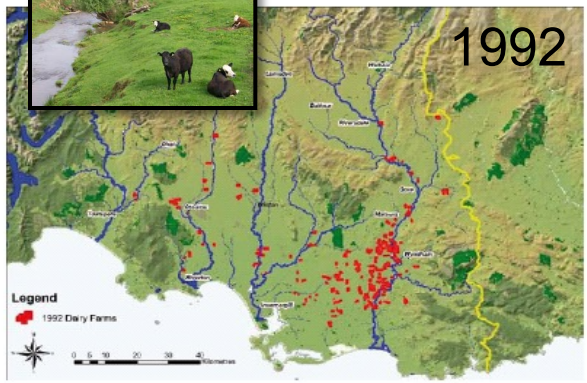
- 3-D simulations for siting of WWTP outfall in Lake Rotorua
- 1-D model of biological response to WWTP outfall
- Prediction of the effects of the Ohau channel diversion wall
- Waituna Lagoon: effects of land use and opening to ocean on macrophytes



Hamilton et al. 2012, ERI Report 004



Dairy Farms Southland



Source: Environment Southland



Lake Science and Applications at UoW

- 3-D simulations for siting of WWTP outfall in Lake Rotorua
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Addressing these *what if* questions requires a modelling approach at the right **time scale** and **space scale** (1-D, 2-D, 3-D, catchment, hydrogeology).

daily, seasonal, yearly, decades, ...

1-D, 2-D, 3-D, catchment, hydrogeology

Lake Science and Applications at UoW

	Days	Seasons	Years	Decades	Centuries
• 3-D simulations for siting of WWTP outfall in Lake Rotorua	X	X			
• 1-D model of biological response to WWTP outfall		X	X		
• Prediction of the effects of the Ohau channel diversion wall		X	X	X	
• Waituna Lagoon: effects of land use and opening to ocean on macrophytes			X	X	X

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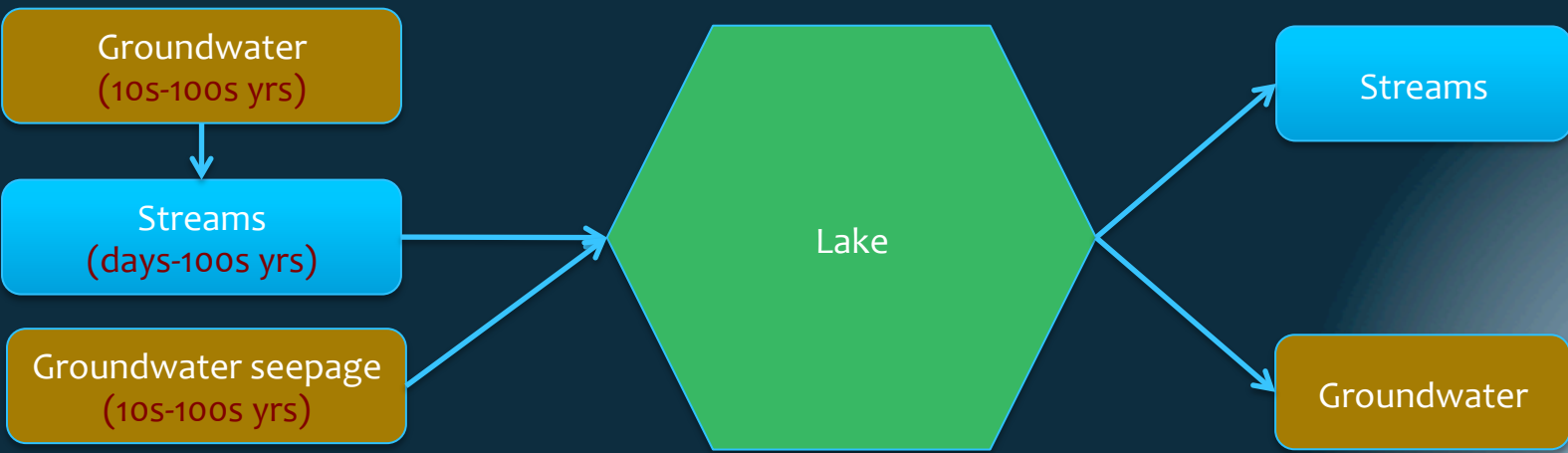
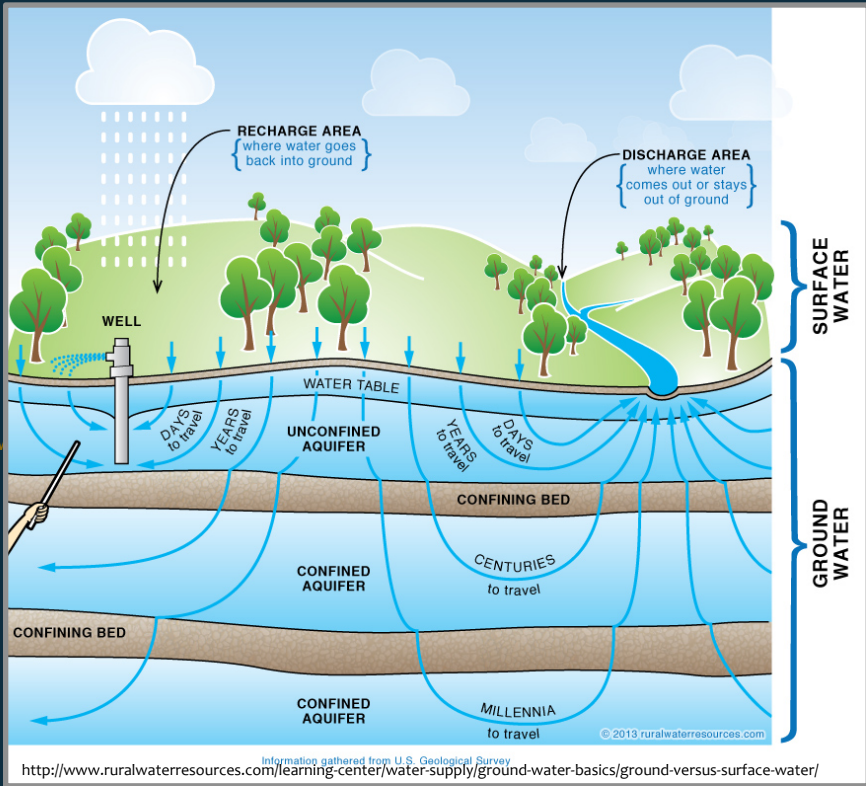
daily, seasonal, yearly, decades, ...

1-D, 2-D, 3-D, catchment, hydrogeology

* Groundwater is old, older, oldest;

* Most gw gets into lakes by river (baseflow)

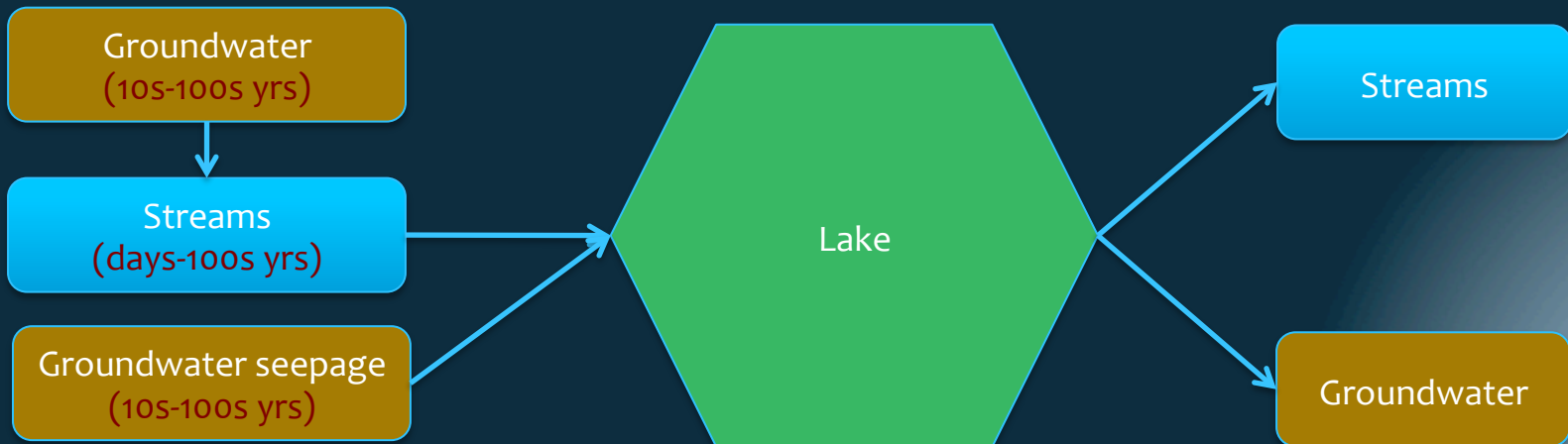
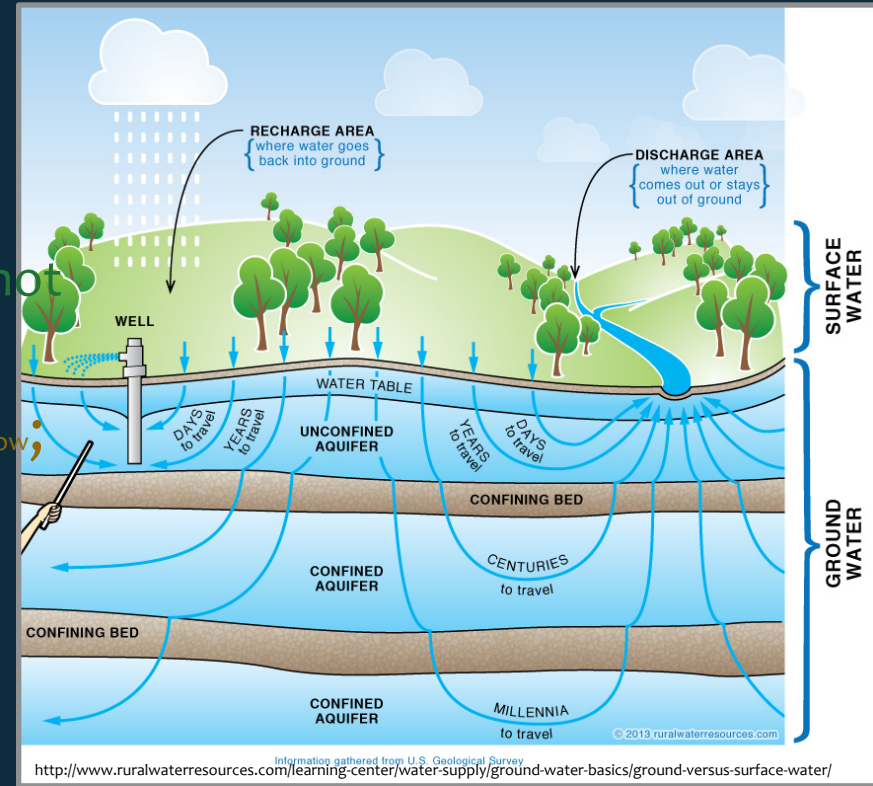
* G/w definition for lake modellers:
 groundwater = seepage (not river flow)



Admissions

of a lake modeller

- * Groundwater is old, older, oldest;
 - * Important for decadal-scale studies, not often considered
- * Most gw gets into lakes by river (baseflow);
 - * Typically measured and modelled dynamically
- * G/w definition for lake modellers: groundwater = seepage (not river flow)



G/w Seepage from Water Balance



net groundwater seepage = outflow – surface inflow – net precip

Rotorua
1967-2003
(Beyá et al. 2005)

$$2,396 \text{ l/s} = 16,459 \text{ l/s} - 14,063 \text{ l/s}$$

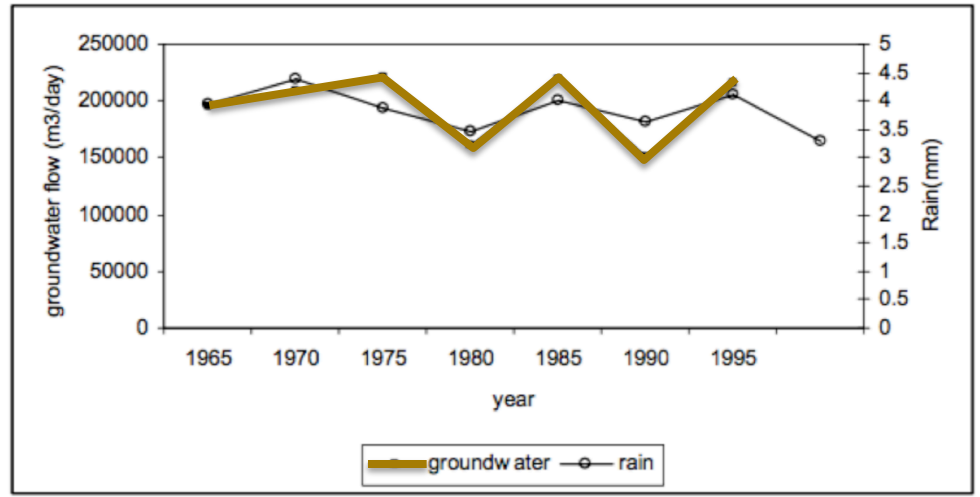


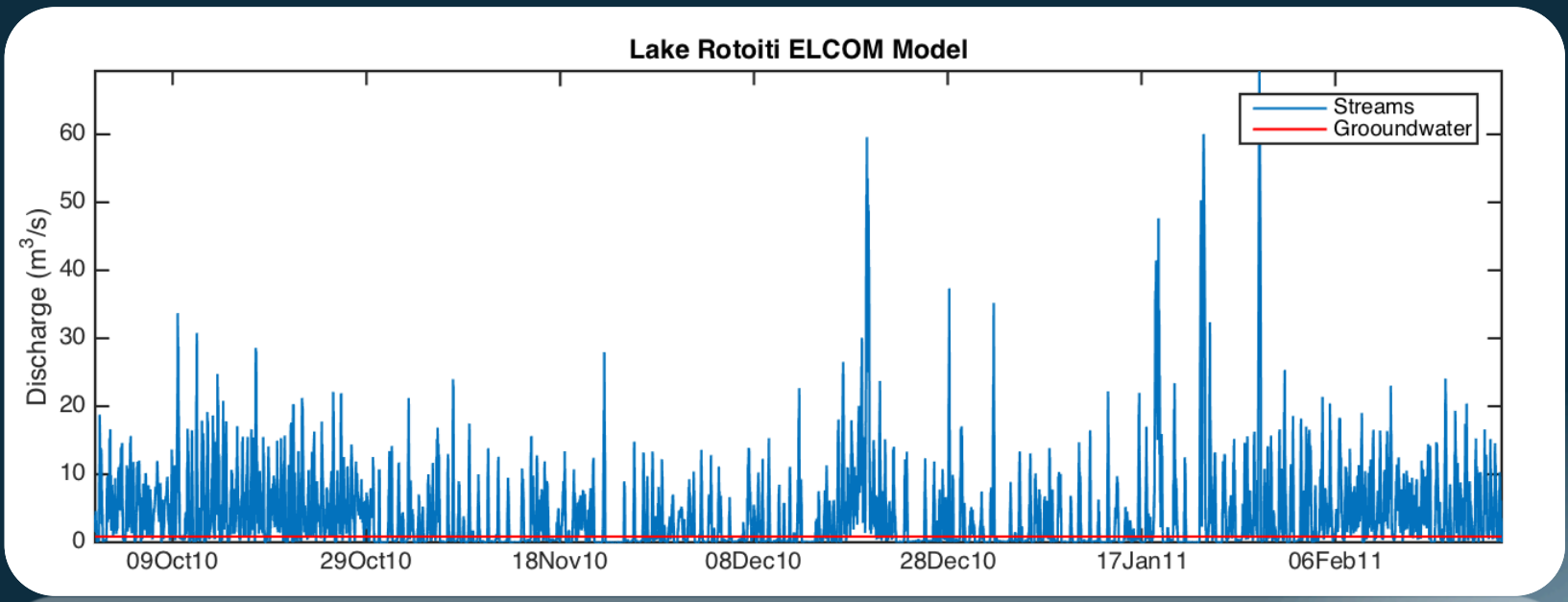
Figure 33. Net daily groundwater flow and daily rainfall. Values are means for the preceding 5 years.

Beyá et al. 2005

G/w Seepage from Water Balance



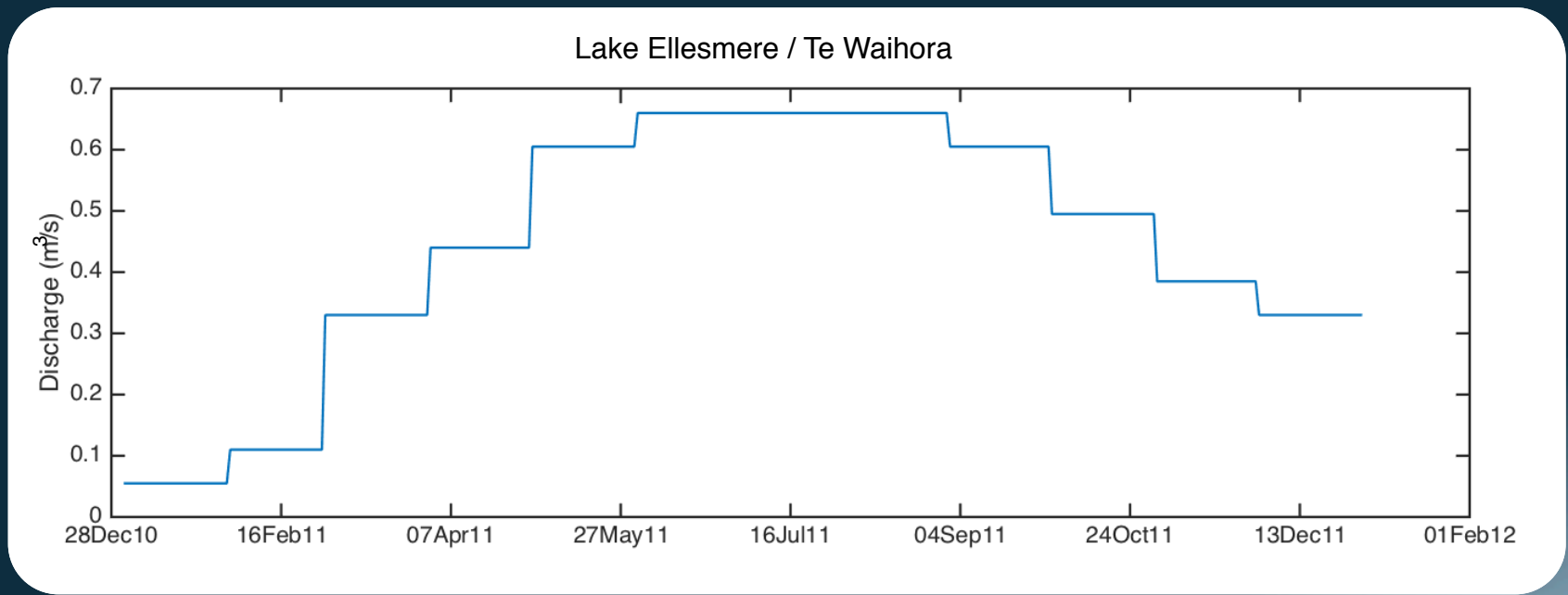
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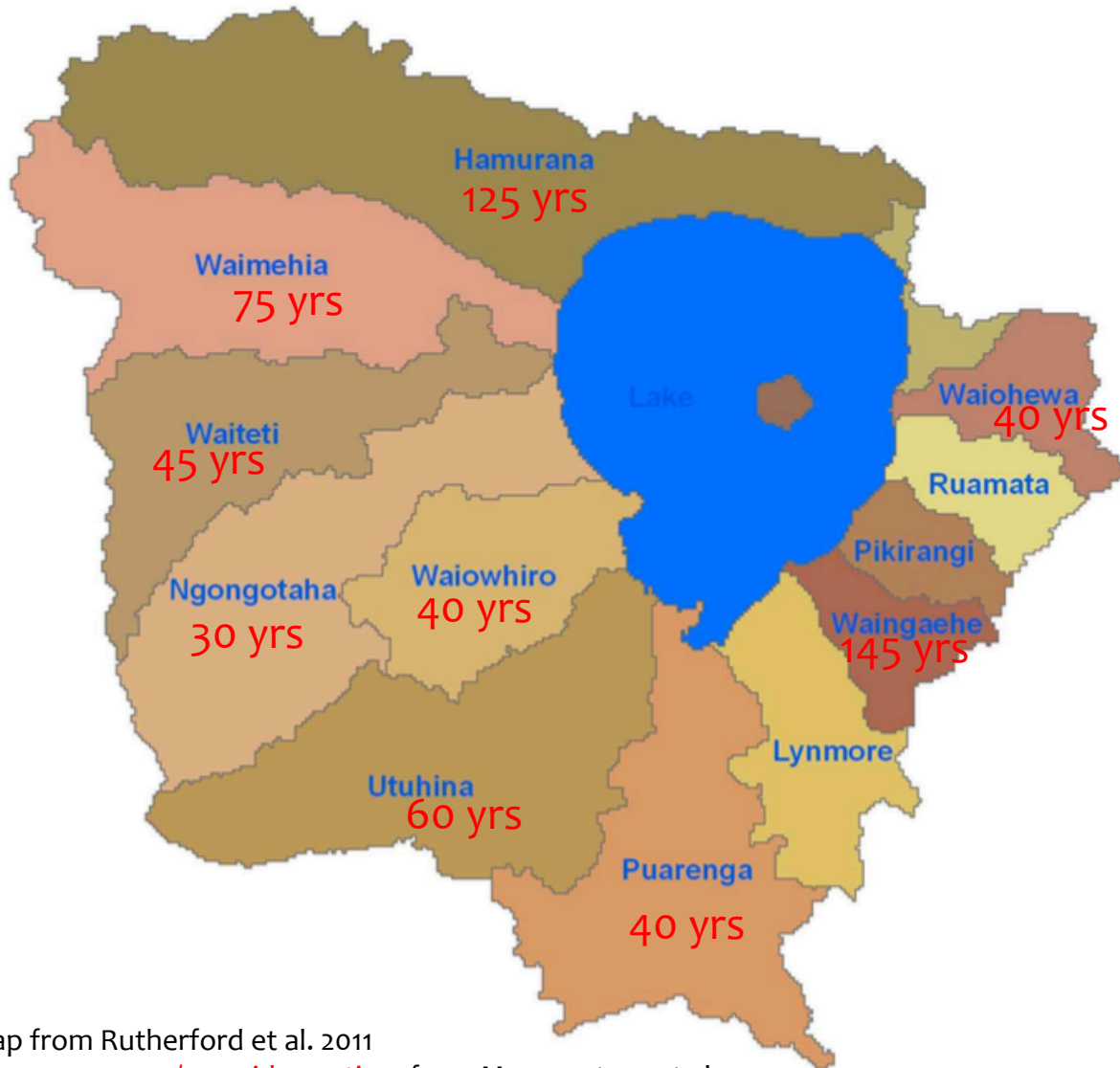
G/w Seepage from Water Balance



net groundwater seepage = outflow – surface inflow – net precip



Groundwater Age in Lk Rotorua Aquifers



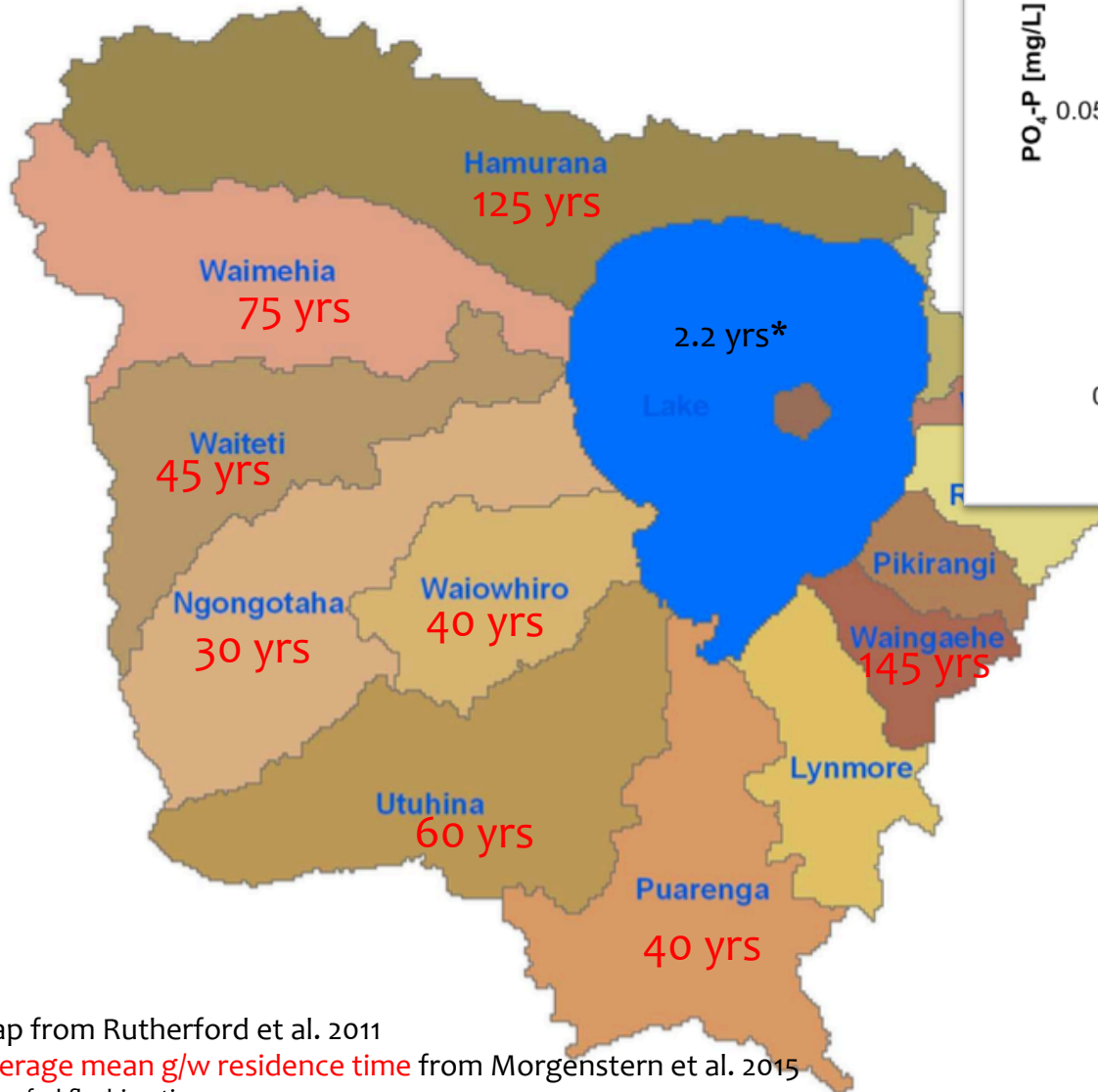
Morgenstern et al. 2015:

- Isotopic chemistry time series (Tritium) from ~100 sites
- Fit to 2-component mixing model
- Average mean residence time is weighted mean age from both components

Map from Rutherford et al. 2011

Average mean g/w residence time from Morgenstern et al. 2015

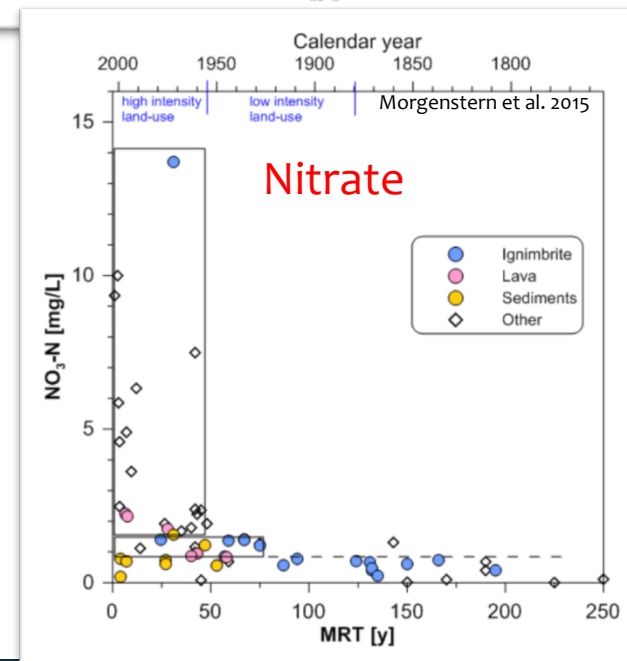
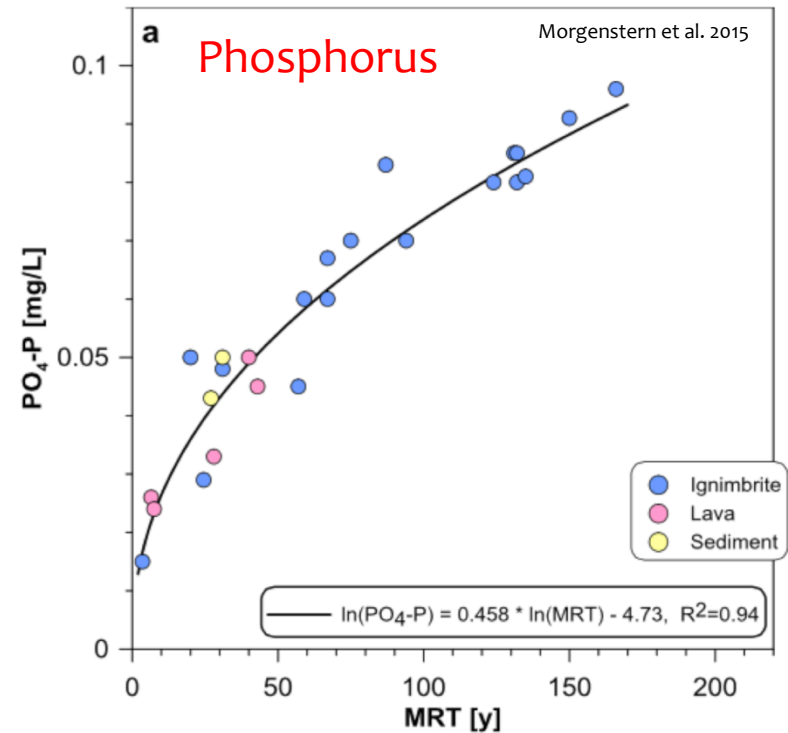
Nutrient concentration in g/w is why ecosystems care about age



Map from Rutherford et al. 2011

Average mean g/w residence time from Morgenstern et al. 2015

*g/w-fed flushing time



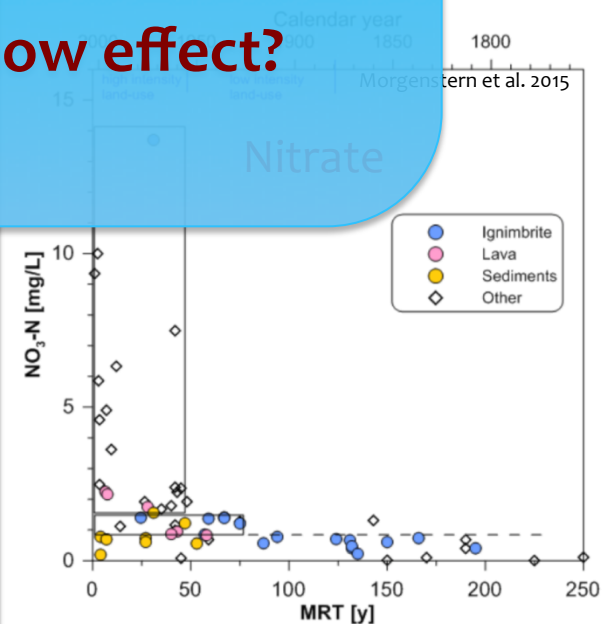
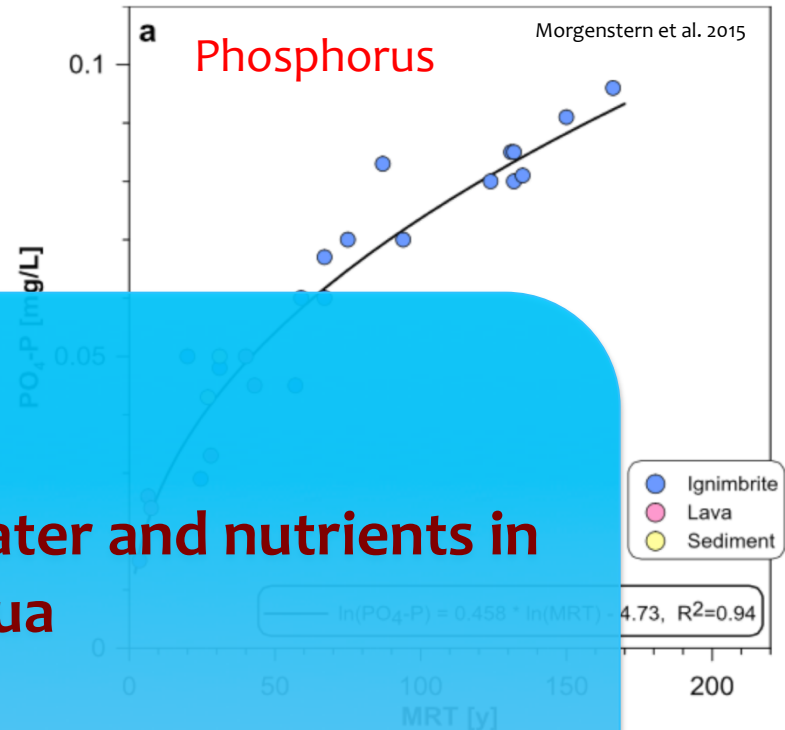
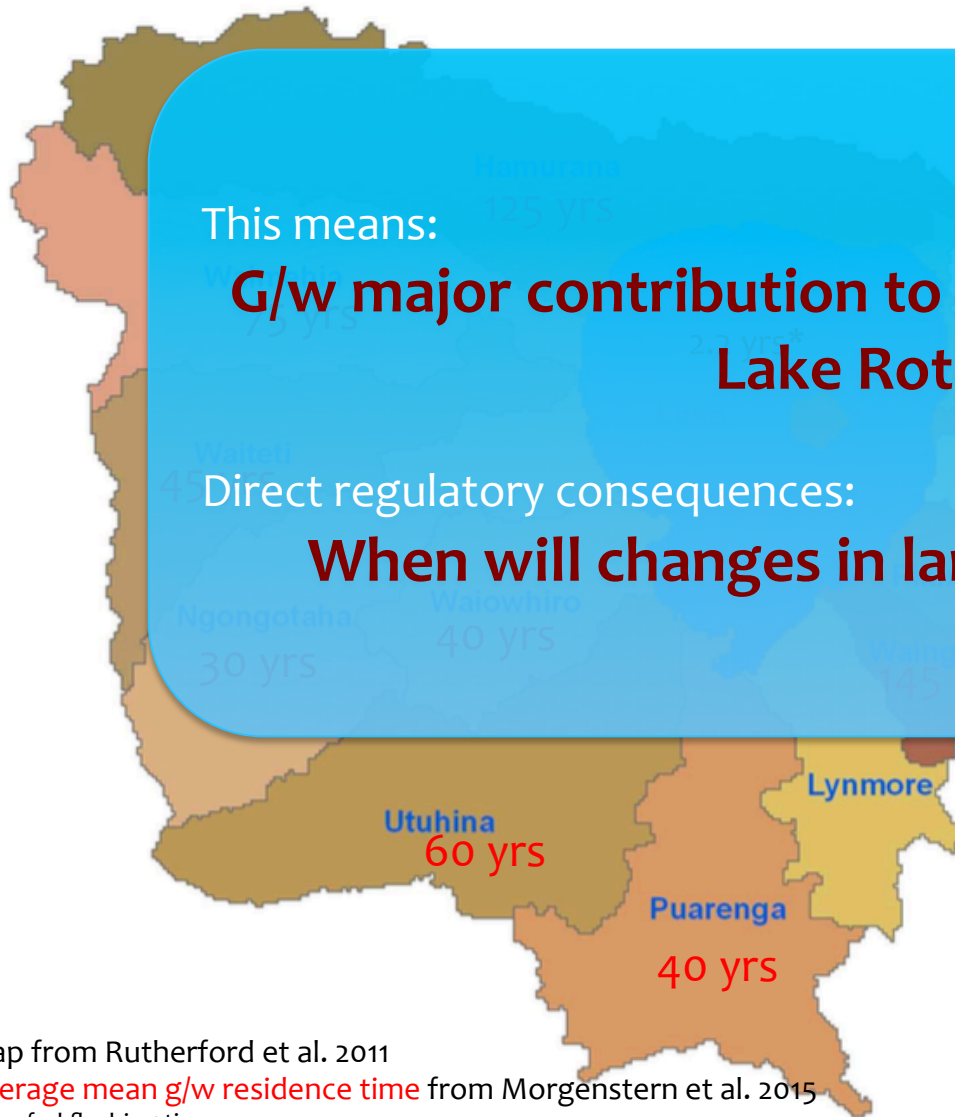
Nutrient concentration in g/w is why ecosystems care about age

This means:

G/w major contribution to water and nutrients in Lake Rotorua

Direct regulatory consequences:

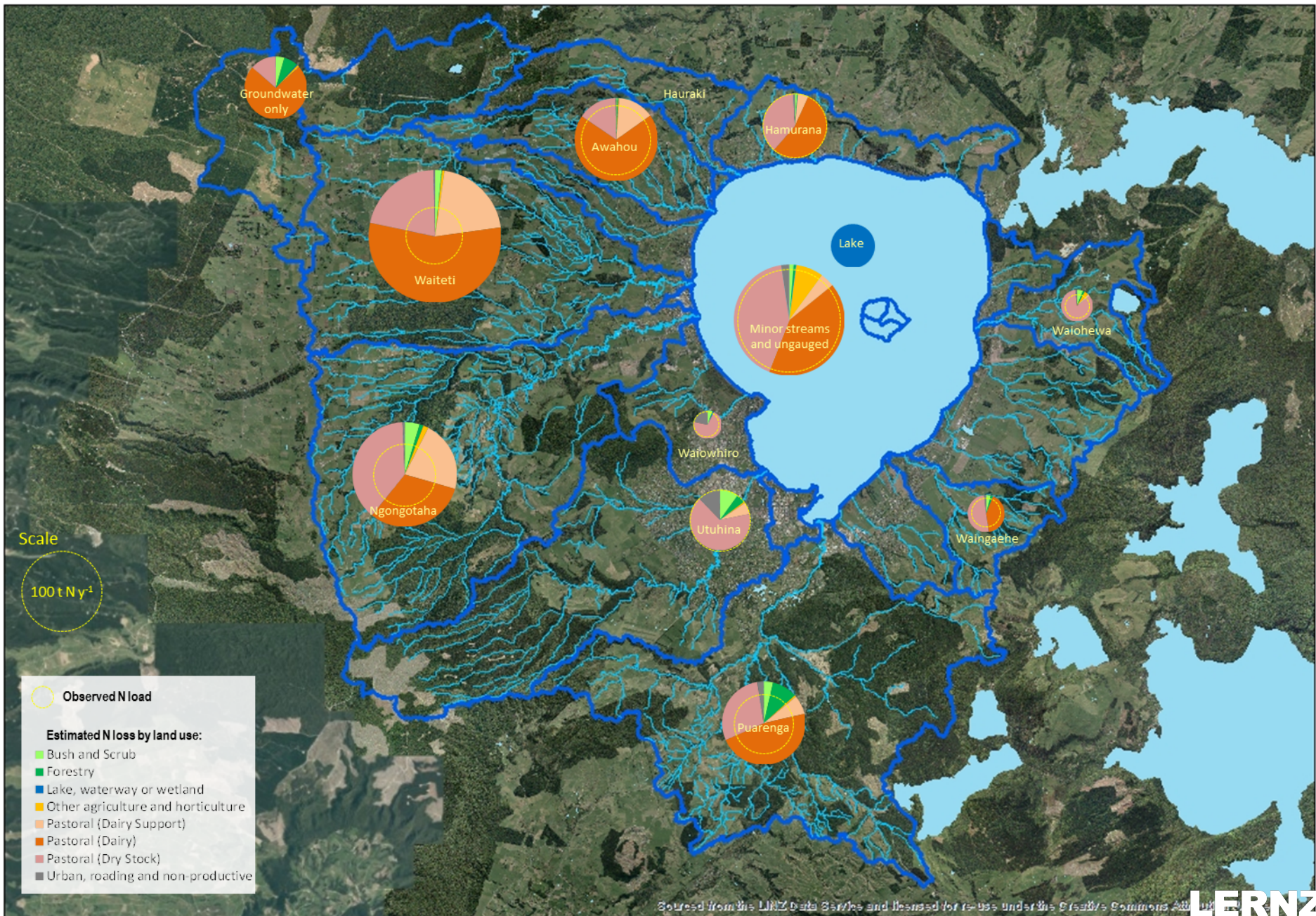
When will changes in land-use show effect?



Map from Rutherford et al. 2011

Average mean g/w residence time from Morgenstern et al. 2015

*g/w-fed flushing time



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McBride CG, MacCormick A, and Hamilton DP (in prep). Catchment and subcatchment nitrogen loads to Lake Rotorua. ERI report.

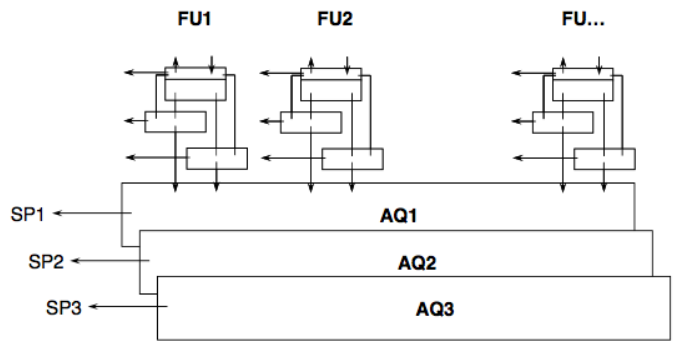
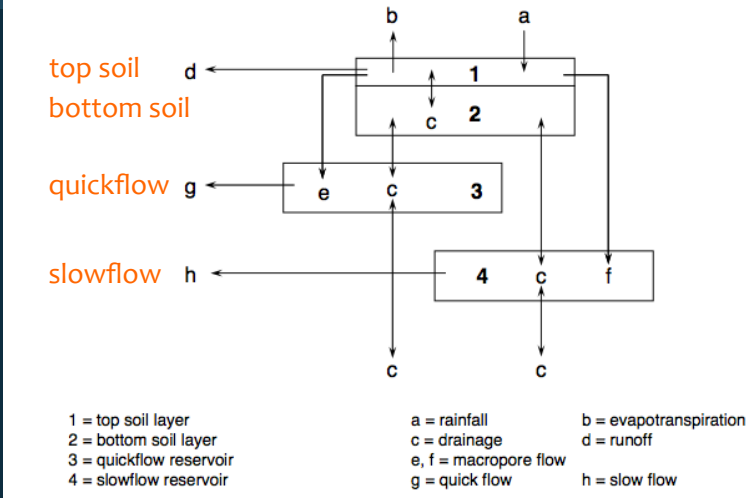
ROTAN

ROtorua and TAupo Nitrogen model

- ROTAN is a daily time-step, conceptual rainfall-runoff-groundwater model
- land use layer of functional units (FU), each assigned a nitrogen export rate ($N\ ha^{-1}\ yr^{-1}$) from Overseer®
 - 1 aquifer layer (3 possible).



Aquifers used in the ROTAN-1 model. Lines show the groundwater flow connections. 'S' denotes where the groundwater emerges as spring-flow which then joins stream flow in the surface catchment (see Figure 1 for the surface catchments).
Rutherford et al. 2011



AQ1, AQ2, AQ3 = aquifers
FU1, FU2, FU... = functional units
SP1, SP2, SP3 = spring flows

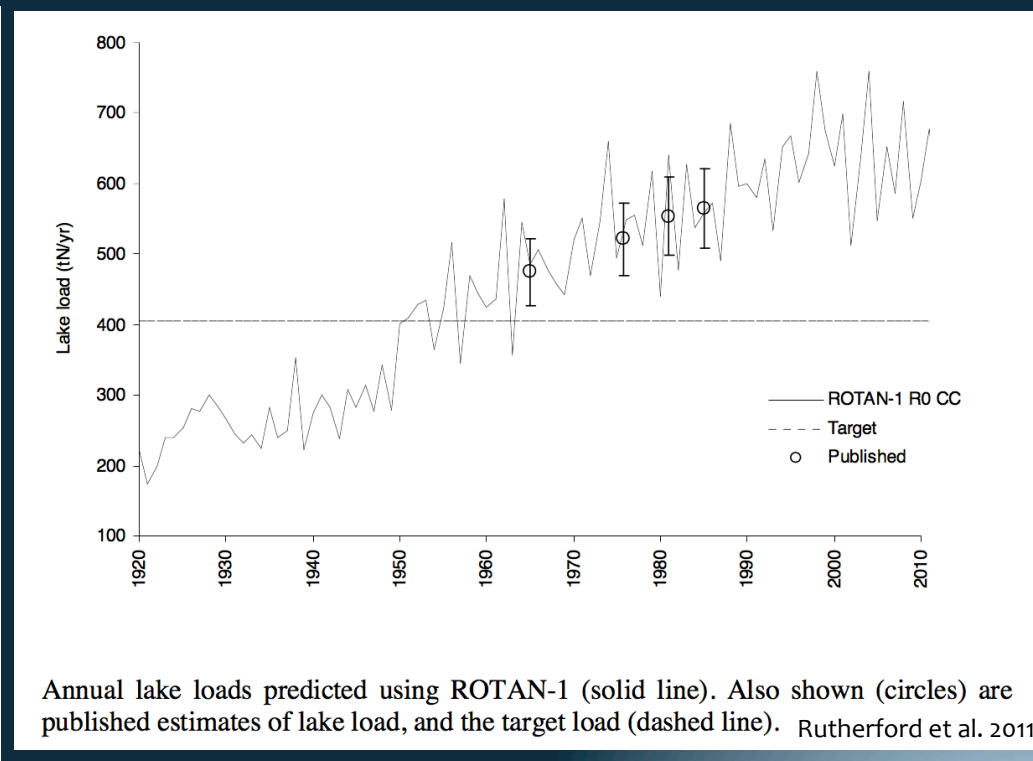
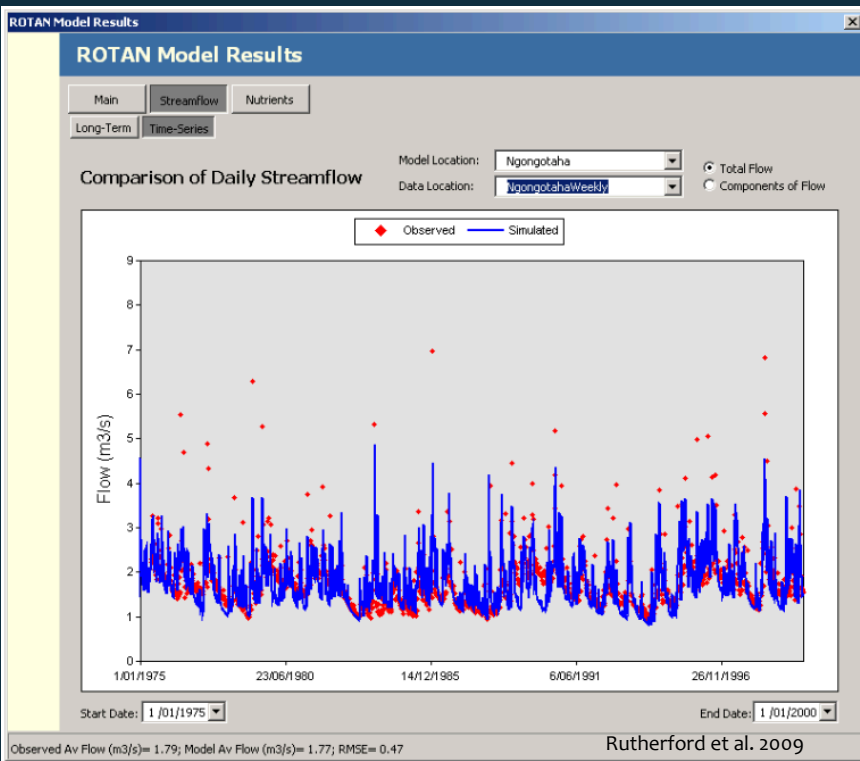
Rutherford et al. 2009

ROTAN

Results for Rotorua

Daily streamflow

Annual lake nitrogen loads



ROTAN provides a valuable tool to generate flows and loads for future scenarios of land-use and climate change at desired time scales

Ongoing GW-SW Studies at



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Question:

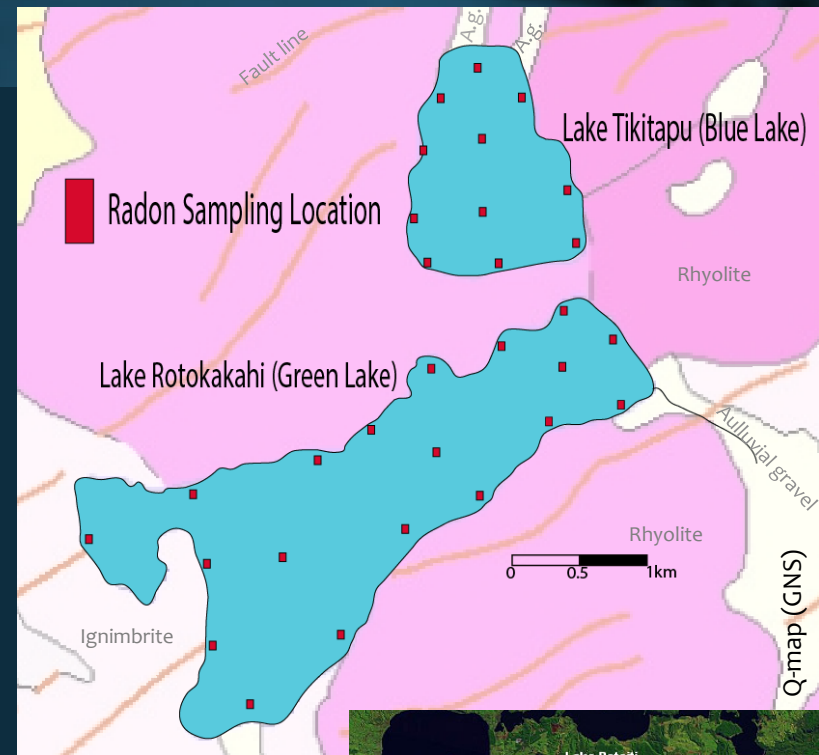
What is the effect of groundwater discharge on

- *water balance,
- *nutrient budgets, and
- *water quality?

GW-Nutrient Dynamics Lakes Rotokakahi and Tikitapu

Katie Noakes (M.Sc. Research)

- * Both lakes largely gw-fed, but not enough data to know for sure;
- * ^{222}Rn survey in lake and surrounding boreholes for water budget; and
- * Concurrent nutrient samples to quantify gw nutrient input to lakes.



Coastal Ocean

The work of Karin Bryan et al.

- * Estuaries and mud flats:
- * Highly productive environments; and
- * Cycling of nutrients and organic matter;
- * Submarine groundwater discharge (SGD) enhances fluxes



Coastal Ocean

The work of Karin Bryan et al.

Santos et al. 2014

- Rn often enriched in g/w or porewater relative to surface water;
- Combined Rn and nutrient budgets suggest that g/w is source for nutrients in mud-flat surface water (Tauranga Harbour)

- * Estuaries and mud flats:
 - * Highly productive environments; and
 - * Cycling of nutrients and organic matter;
- * Submarine groundwater discharge (SGD) enhances fluxes

Future Work

(Ben Stewart's PhD project):

- Use Radium (Ra) as tracer (more isotopes with different λ);
- Spatial survey for g/w hotspots
- Combine with hydrodynamic modelling

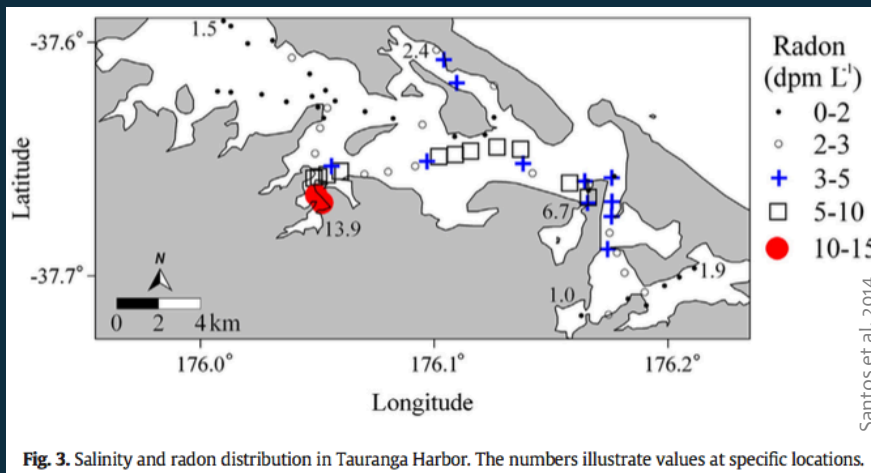
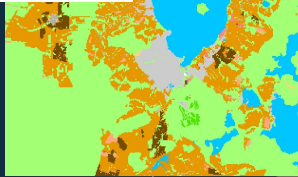
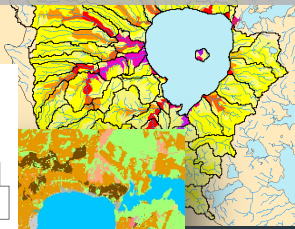
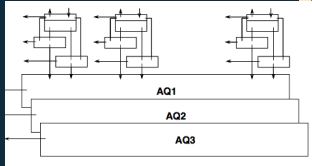


Fig. 3. Salinity and radon distribution in Tauranga Harbour. The numbers illustrate values at specific locations.

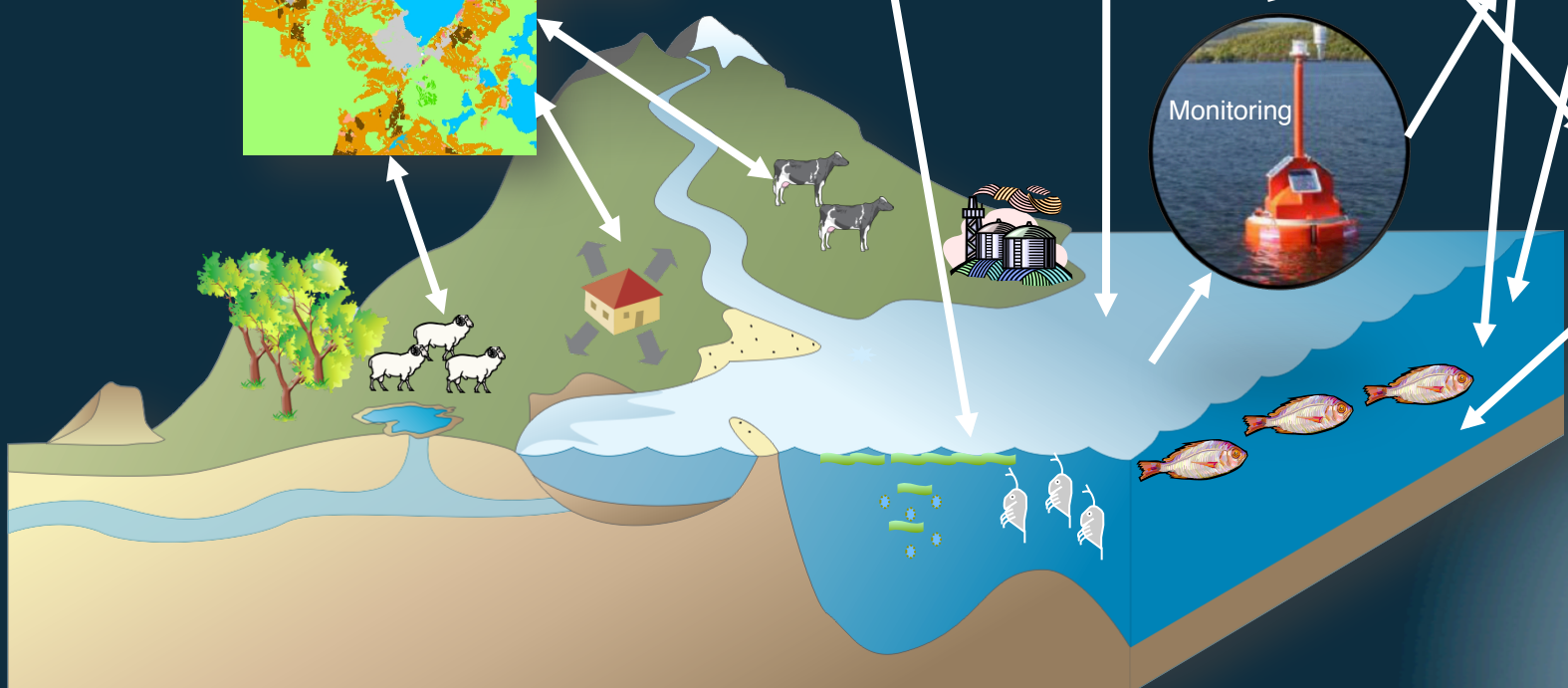
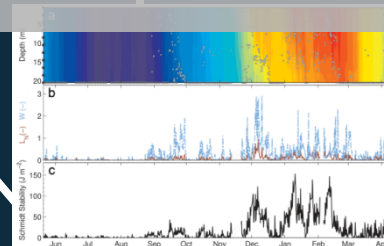
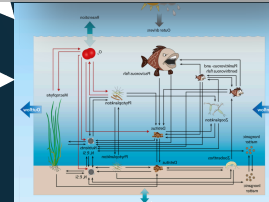
Conclusions

* Aquatic ecosystem models are part of a toolbox for environmental monitoring and prediction;

Catchment and groundwater modelling



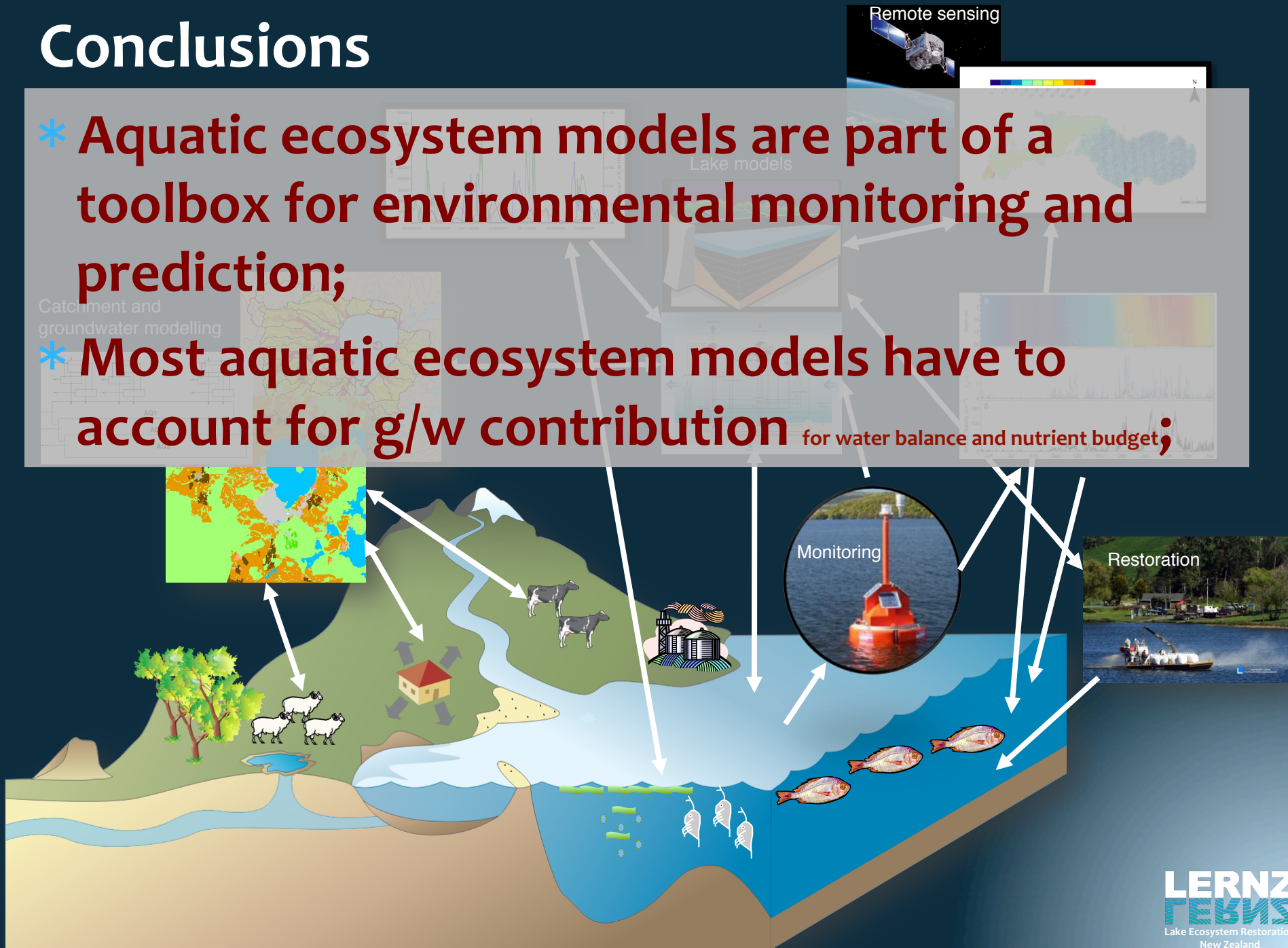
Lake models



Conclusions

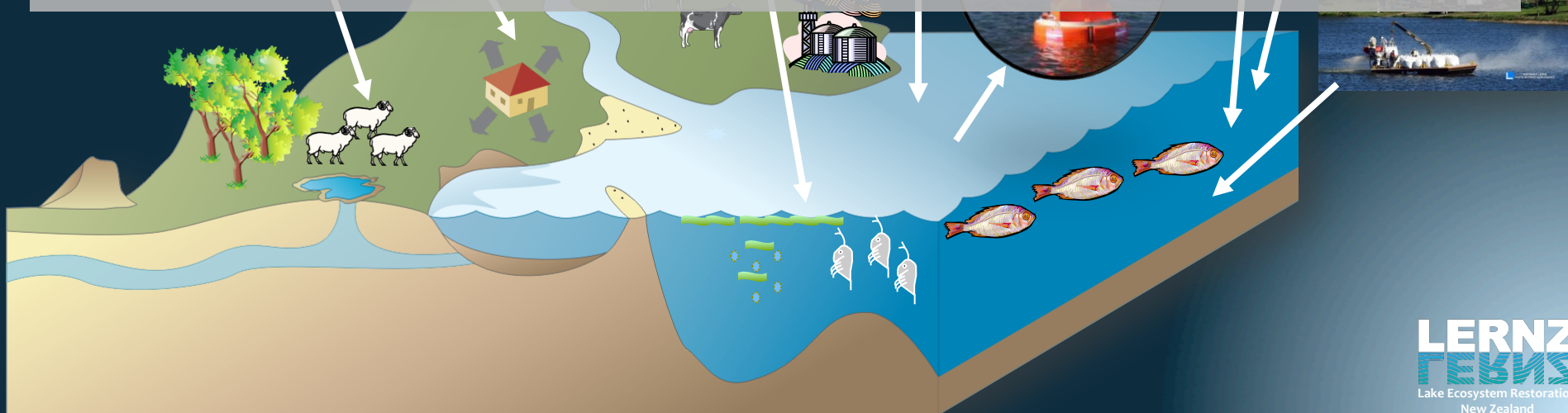
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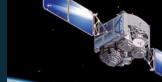
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- * Most aquatic ecosystem models have to account for g/w contribution for water balance and nutrient budget;
- * Time-scale (of question) dictates how g/w has to be treated; and



Conclusions

- * Aquatic ecosystem models are part of a toolbox for environmental monitoring and prediction;
- * Most aquatic ecosystem models have to account for g/w contribution for water balance and nutrient budget;
- * Time-scale (of question) dictates how g/w has to be treated; and
- * Really interesting questions (e.g., land-use changes, climate effects) require solid g/w models because of long time scales.

Remote sensing



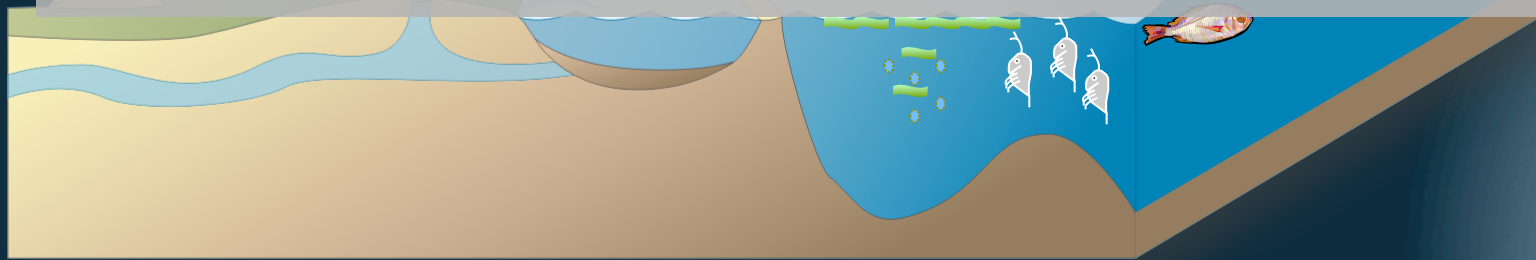
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Lake models

Catchment and groundwater modelling

Monitoring

Restoration





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Environmental Research Institute
University of Waikato

Thank You!