Options for Reducing In-lake Nutrient Loads

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Overview:

Background: Eutrophication & lake chemistry

Describe why 'sediment capping' is used to restore lakes

Outline the advantages of using sediment capping

Outline their non-target effects if used incorrectly

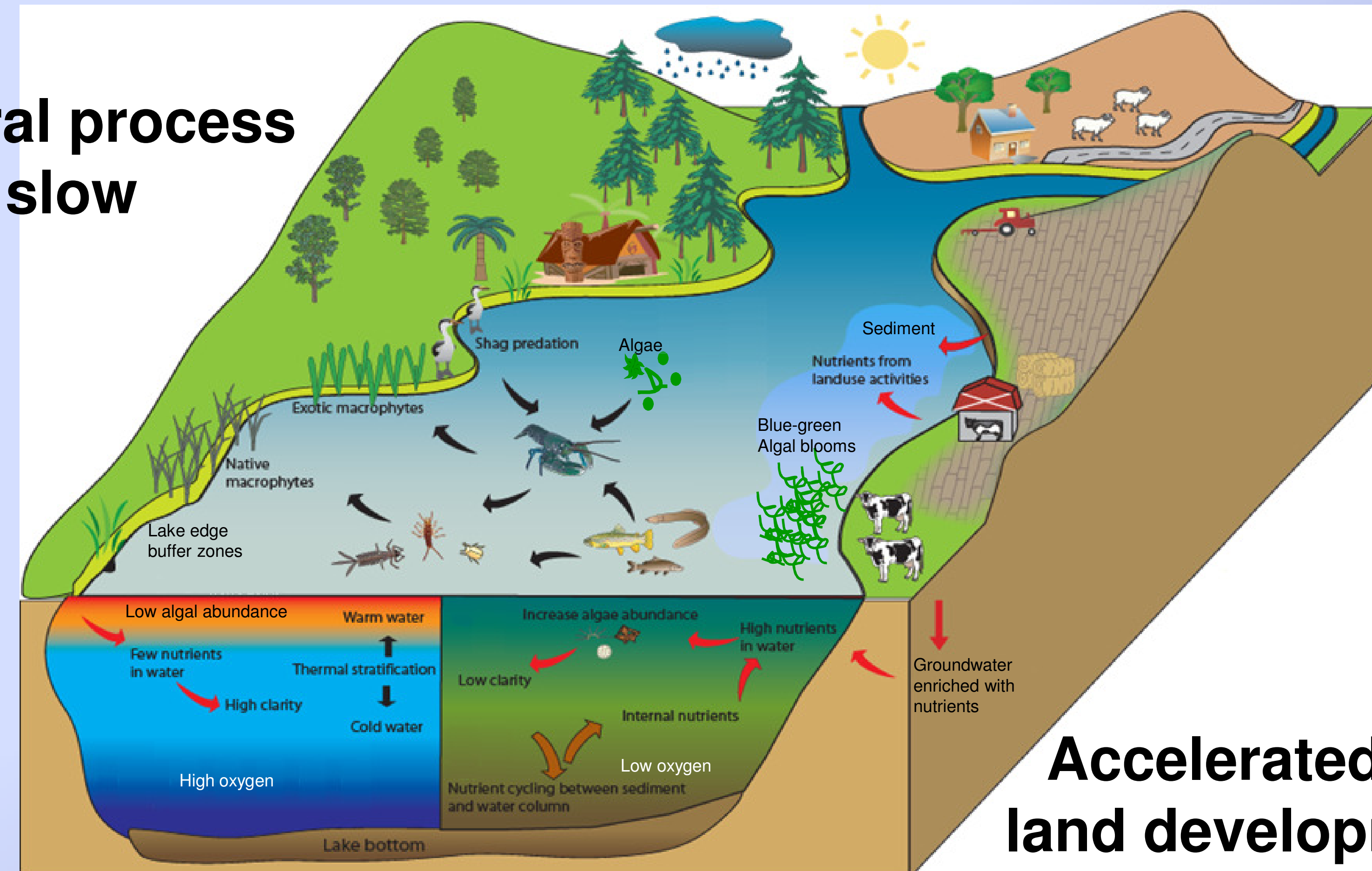
Some sediment core results for Lake Rotorua sediments

Integrated management approach

What is Eutrophication ?

Enrichment of natural waters with plant nutrients

Natural process slow

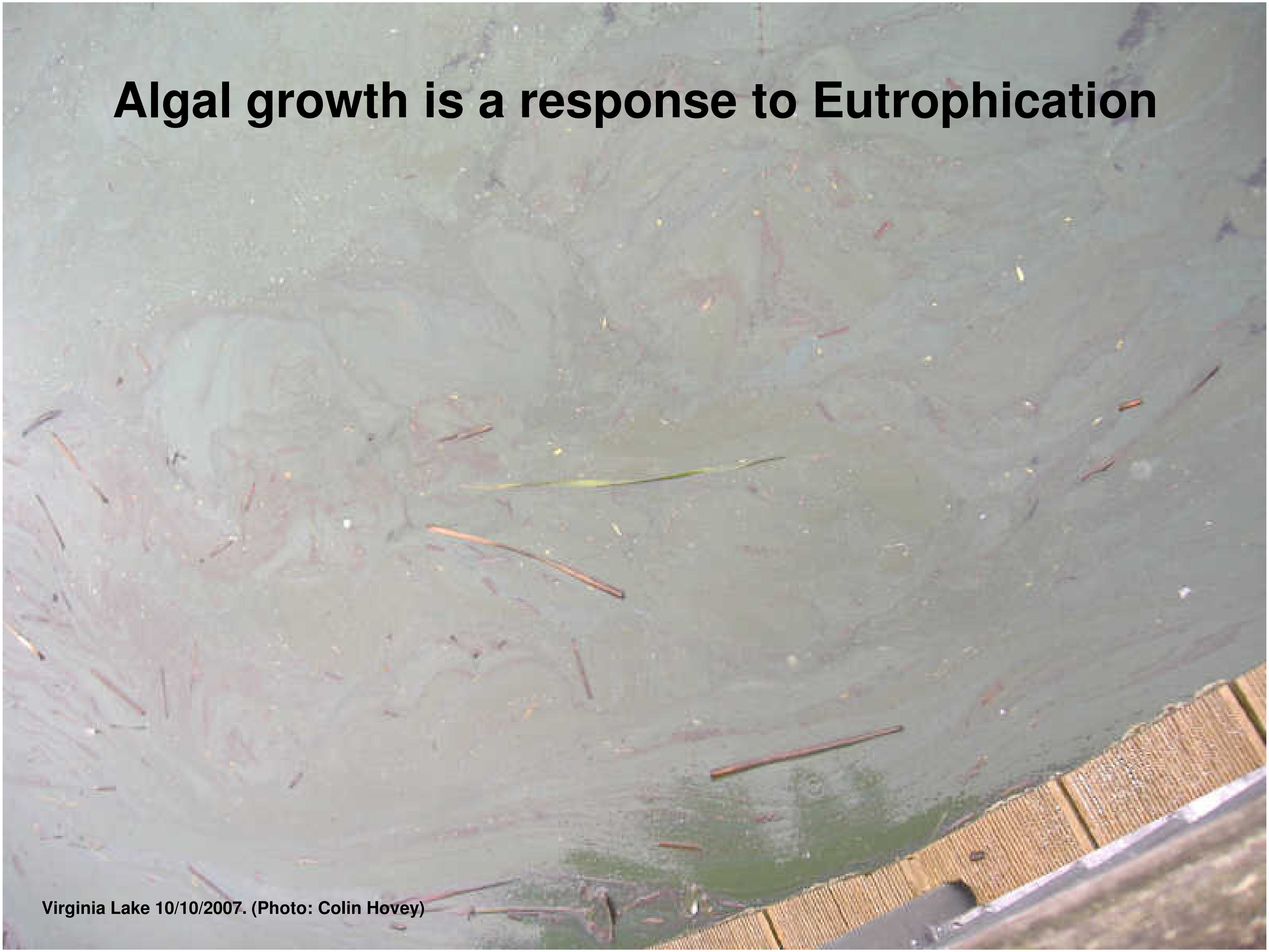


Accelerated by land development

Pristine **Eutrophic**

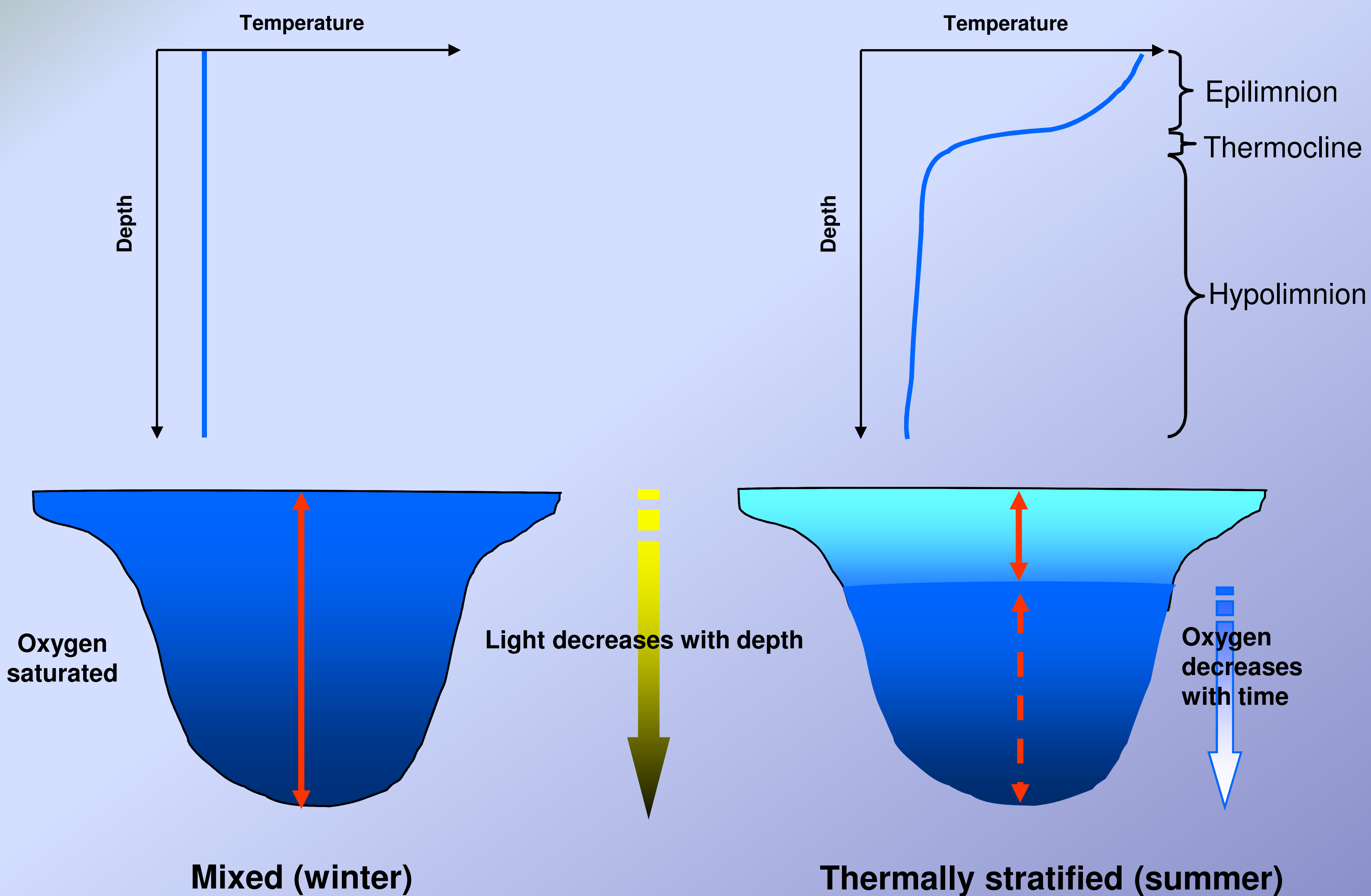
Figure from K. van Houte-Howes

Algal growth is a response to Eutrophication

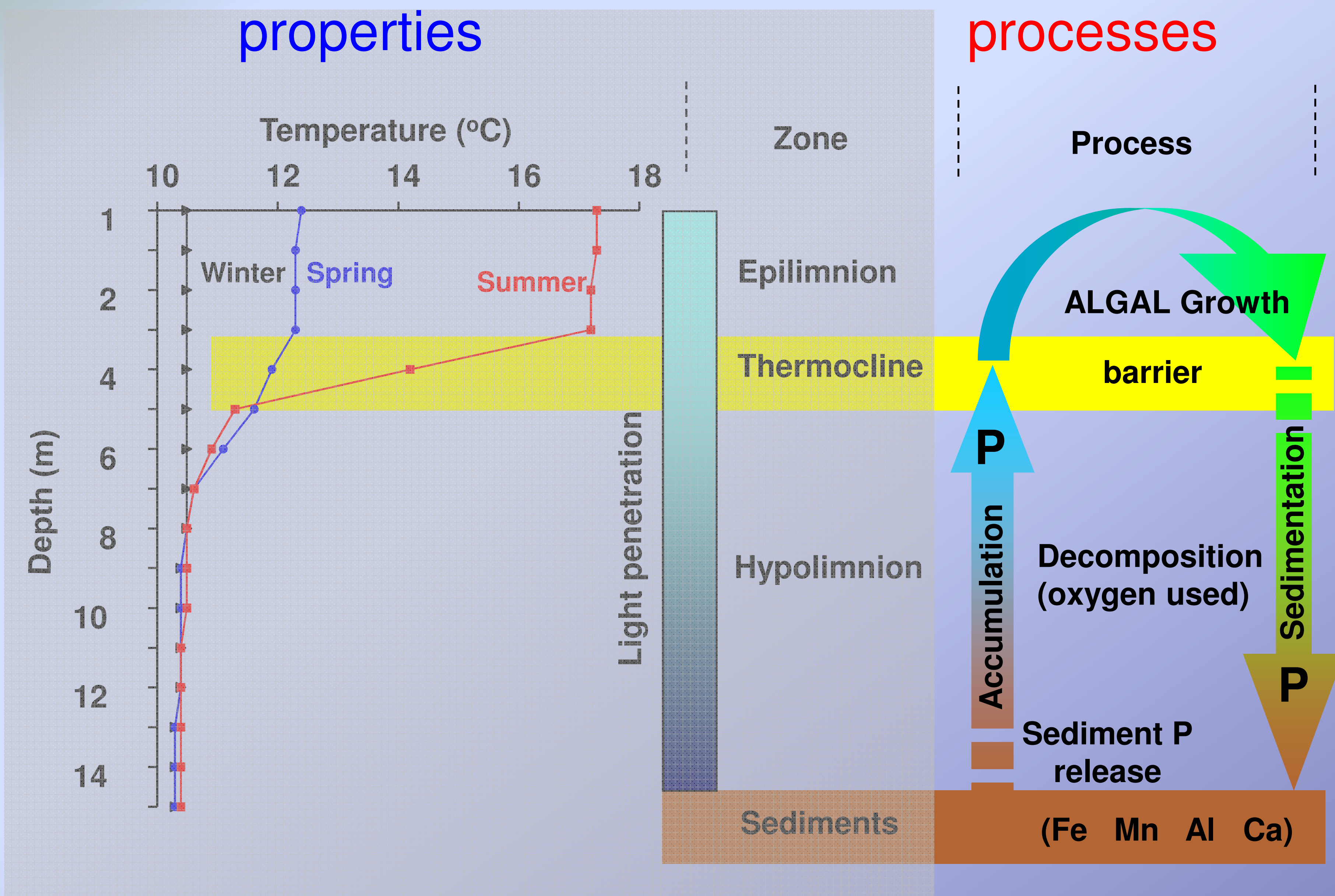


Virginia Lake 10/10/2007. (Photo: Colin Hovey)

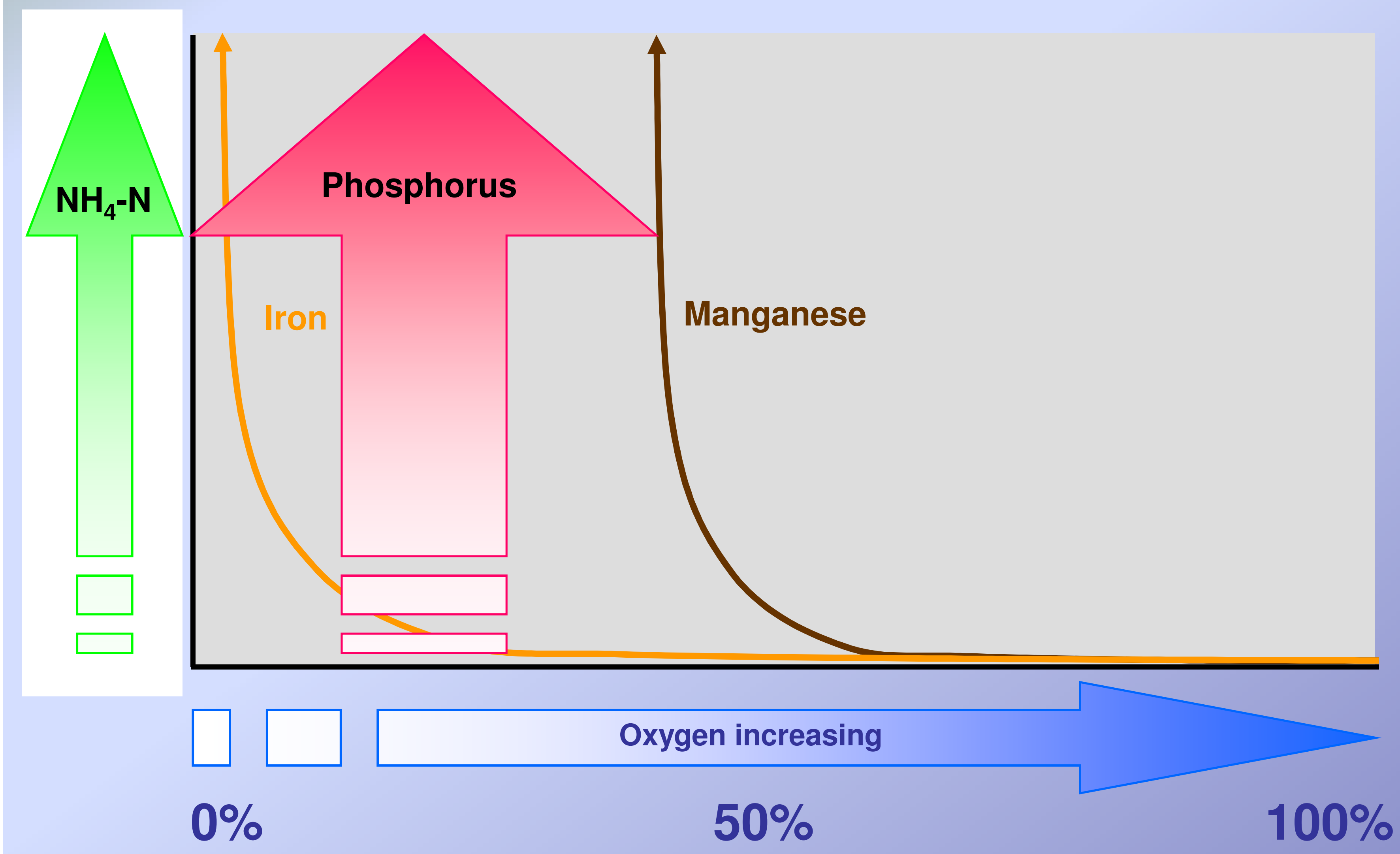
Mixing and thermal stratification



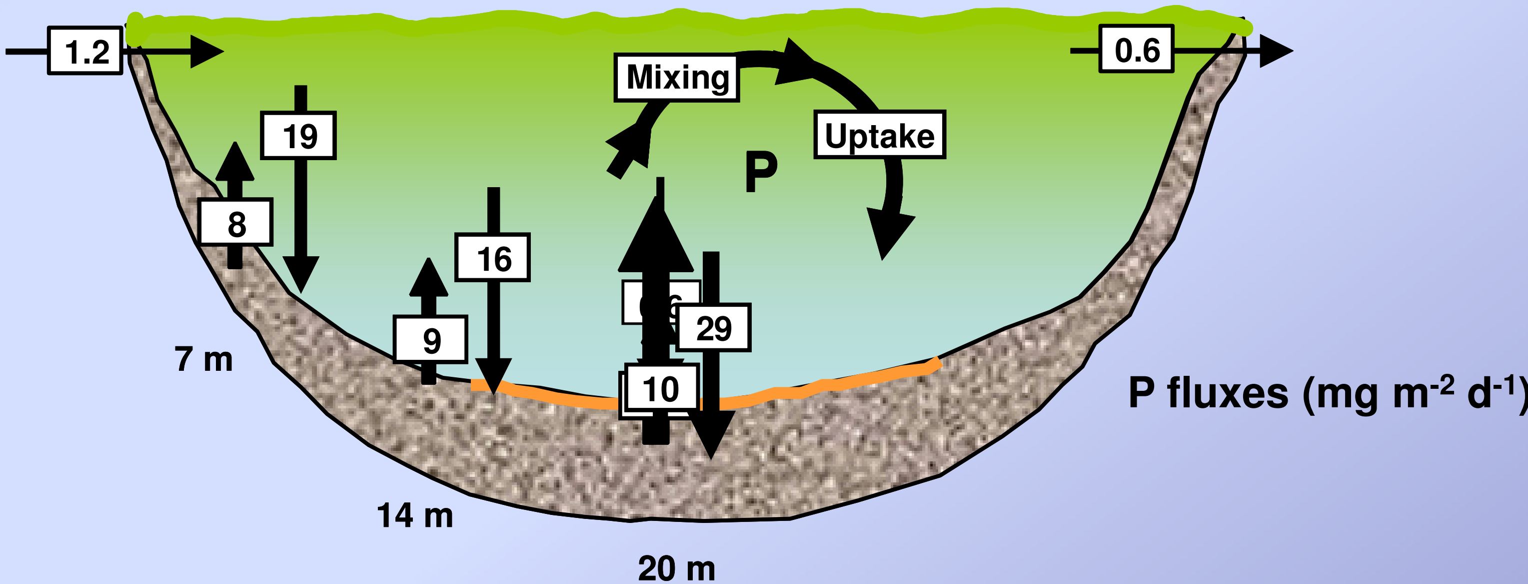
Chemical processes in a lake water column



Key chemical processes controlled by oxygen



Lake sediments are a net sink for catchment nutrients



Decomposition processes release these stored nutrients from the sediments – especially during stratification

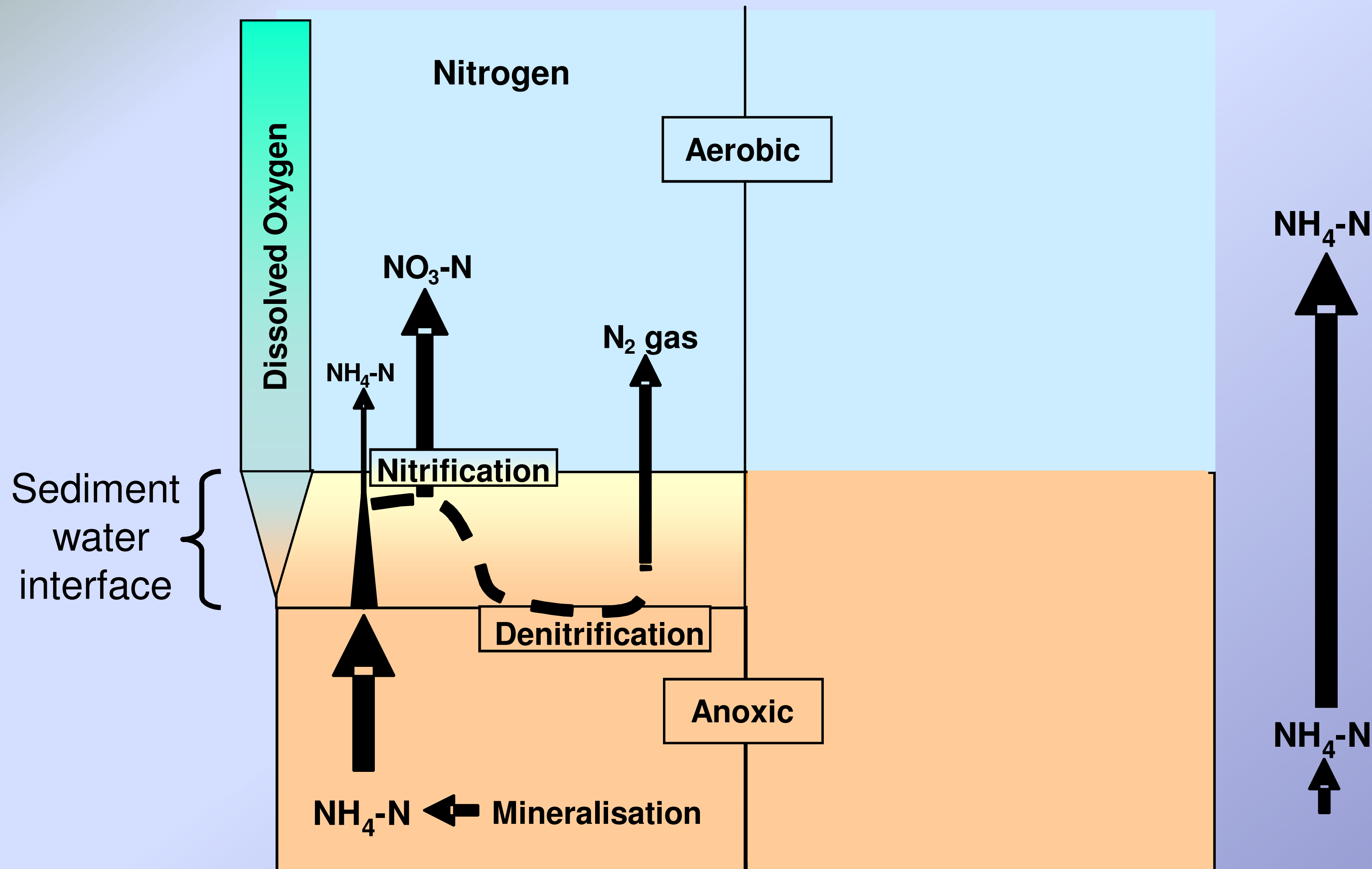
The efflux of nutrients is a function of DO concentration

When the lake mixes these nutrients drive primary production

Sedimentation of the algae returns these nutrients to the sediment

Burger et al. 2007. Benthic nutrient fluxes in a eutrophic, polymictic lake. Hydrobiologia 584:13–25.

Nitrification and denitrification can permanently remove part of the internal N load as N_2 gas



No comparable process to remove the internal P load

A practical management strategy for reducing the internal P load is the use of sediment capping

Sediment capping is the application of an active P-binding material as a thin cohesive layer, about 1-5 mm thick, across the lake bed

The amount of material used depends on the degree of P removal required relative to the cost of the material and applying it to the lake i.e., cost-benefit

Liquid capping agents are applied by boat using a spray boom
Alum application on Lake Okaro

Granular capping agents are applied from a barge using a fertilizer spreader - Modified Zeolite application on Lake Okaro

Photo SCION

Sediment capping: the pros

The loss of N causes the N:P ratio to decrease which favours the growth of cyanophytes

Sediment capping targets the internal P load which increases the N:P ratio, favouring non-cyanophytes

Sediment capping at the right time of year produces an immediate reduction in the internal P load

Sediment capping at the right dose rate can reset the internal P load to zero, limiting algal growth

The effects can be long lasting when used together with catchment remediation measures e.g., 5+ years

Sediment capping materials are easy to apply and, when used correctly, are “safe”

Sediment capping agents tested were:-

Alum – **aluminium sulphate** (flocculent)
water treatment agent commonly used to clarify water supplies, swimming pools

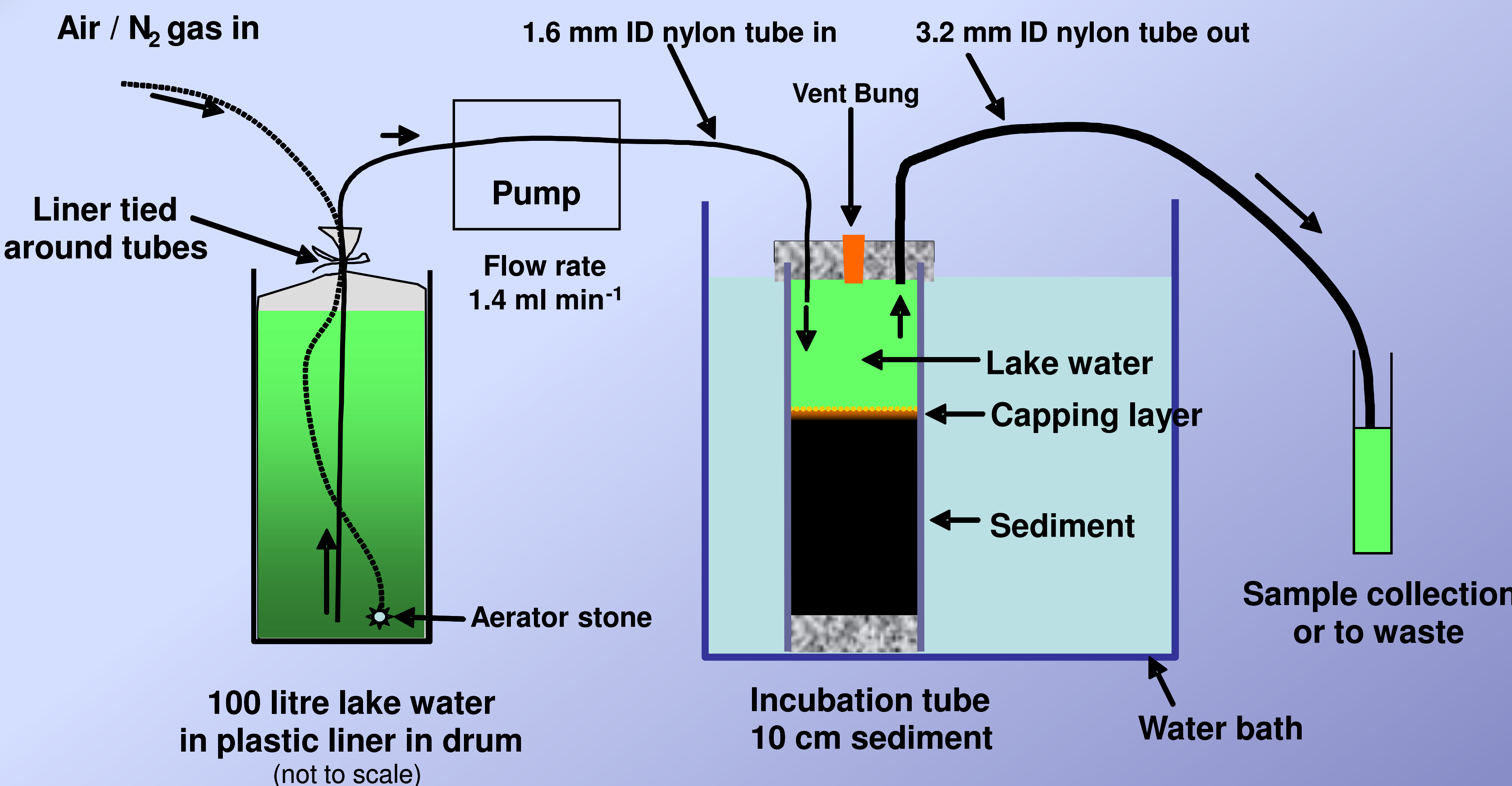
Modified Zeolite – **new product developed by SCION**
Aluminium sulphate incorporated into a zeolite carrier. Zeolite can also remove ammonium ions

Phoslock™ – **commercial P-removal agent**
Lanthanum incorporated into a bentonite clay carrier. Phoslock™ can also be used as a flocculent

Allophane – **natural volcanic clay**
Has high Al, Fe, and Si content in a crystalline structure. It can also be used as a flocculent

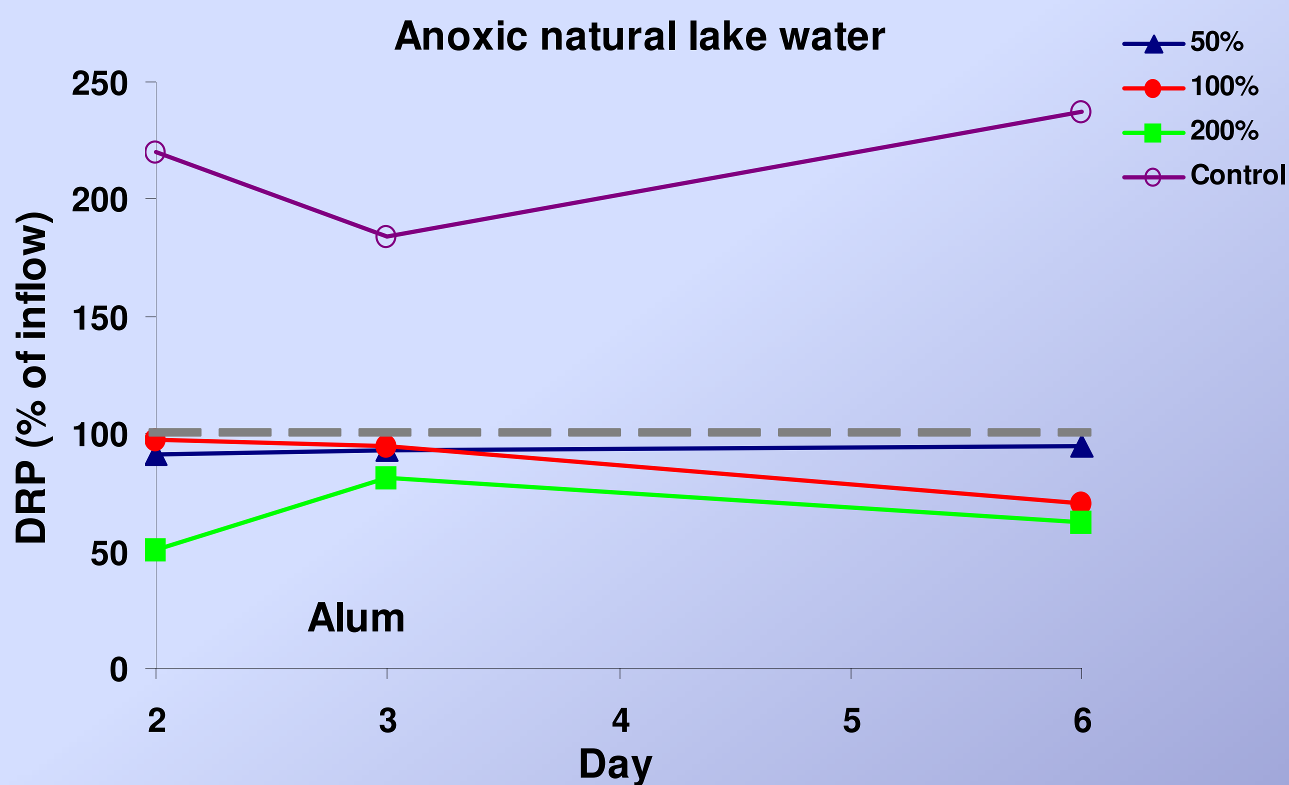
All have high affinity to P as phosphate

Testing used natural sediments in a continuous-flow incubation system with natural lake water



Continuous flow incubation system with 40 sediment cores

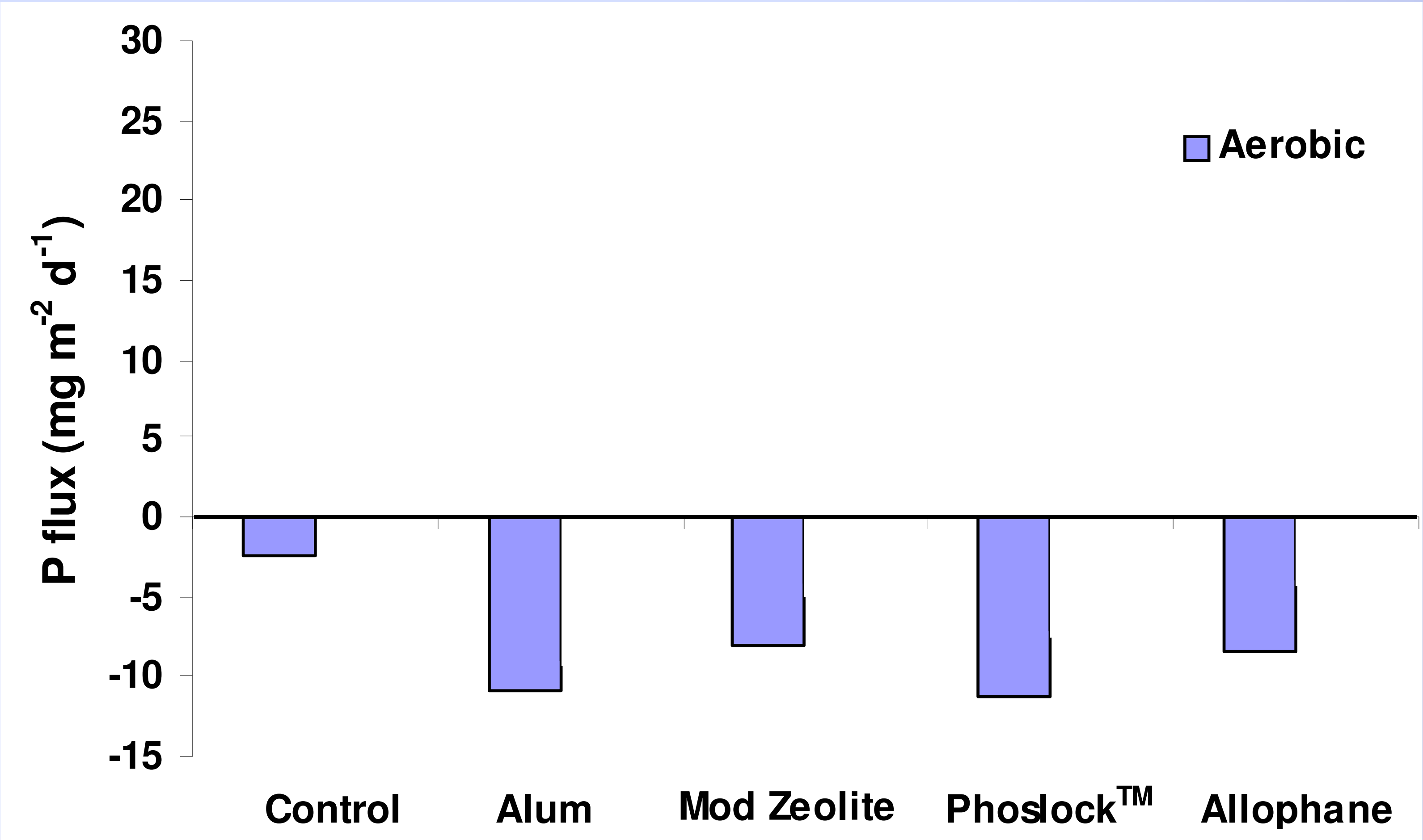
Flux rates are calculated from the difference between inflow and outflow concentrations after 4-6 days when the system has come to equilibrium



Broken line is inflow
Outflow data below line indicates removal from over-lying water
Outflow data above line indicates net release from sediments

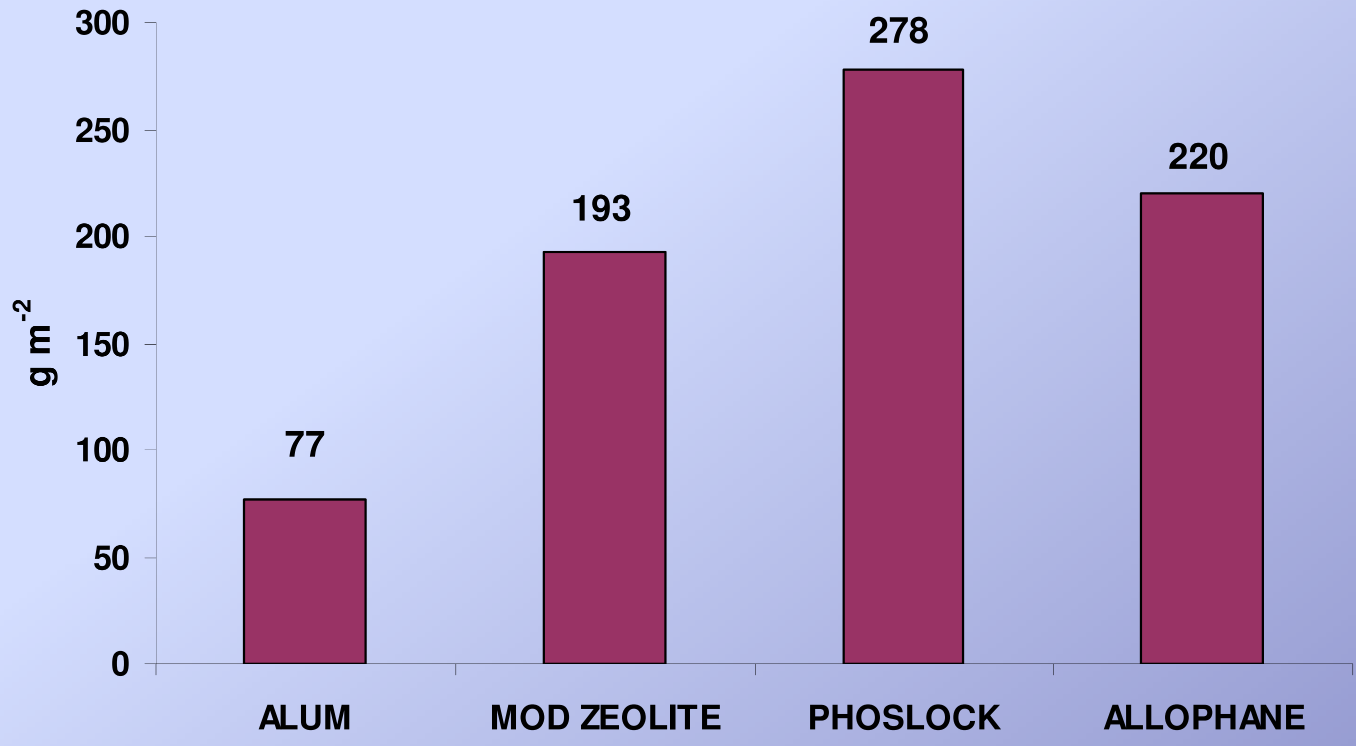
All sediment capping materials tested removed P

These data are for "P-removal efficacy" dose rates



P-removal efficacy = amount of product needed to block the release of all the available P from the top 4 cm of sediment. Units (g product m^{-2})

P-removal efficacy dose rates for Lake Rotorua

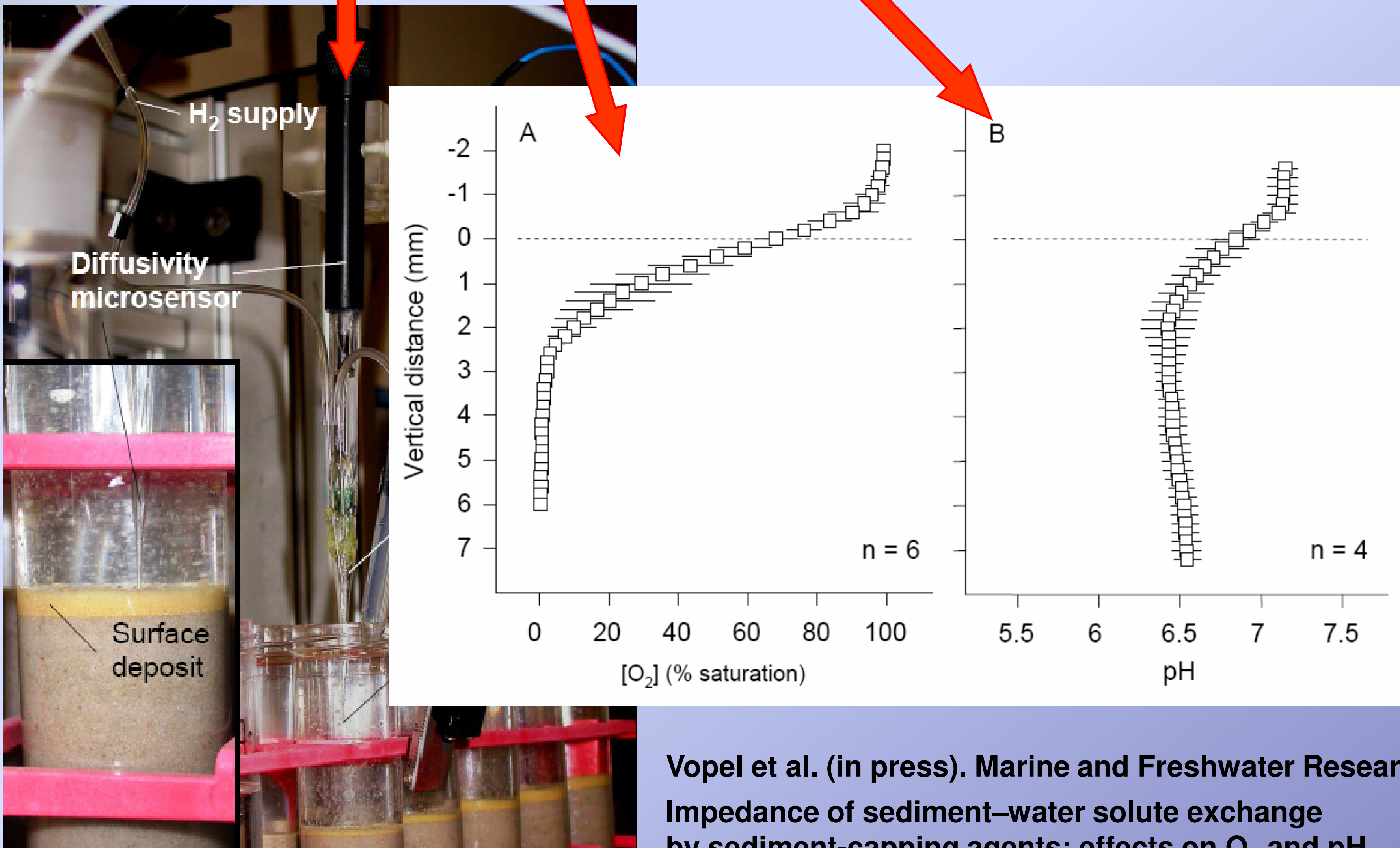


Sediment capping: the cons

They reduce the diffusion of O_2 into the sediments

This allows the near-surface sediments to go anoxic reducing habitat for benthic macrofauna

Effect on diffusivity, DO and pH were measured with micro-electrodes



Vopel et al. (in press). Marine and Freshwater Research

Impedance of sediment–water solute exchange by sediment-capping agents: effects on O_2 and pH

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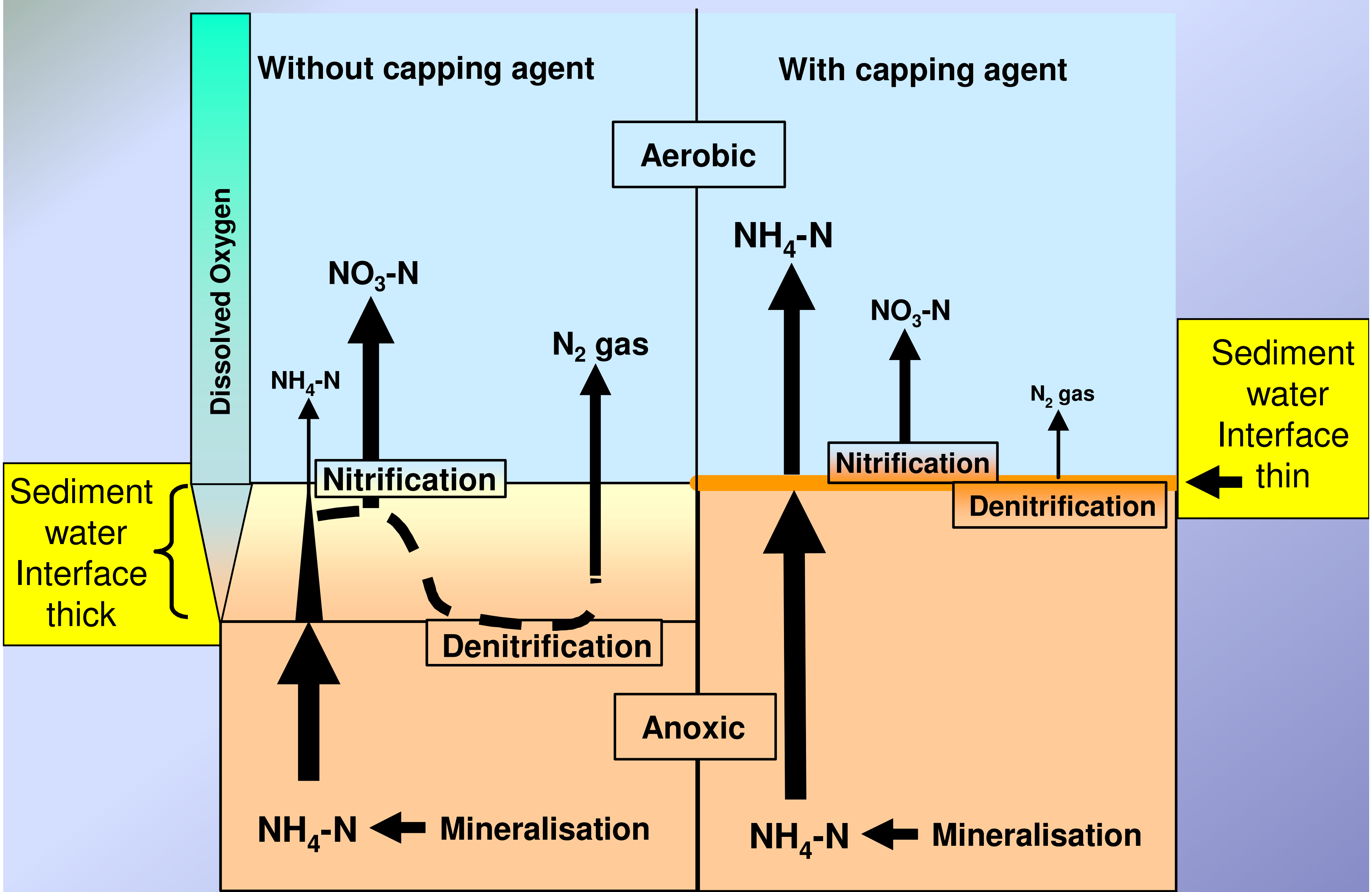
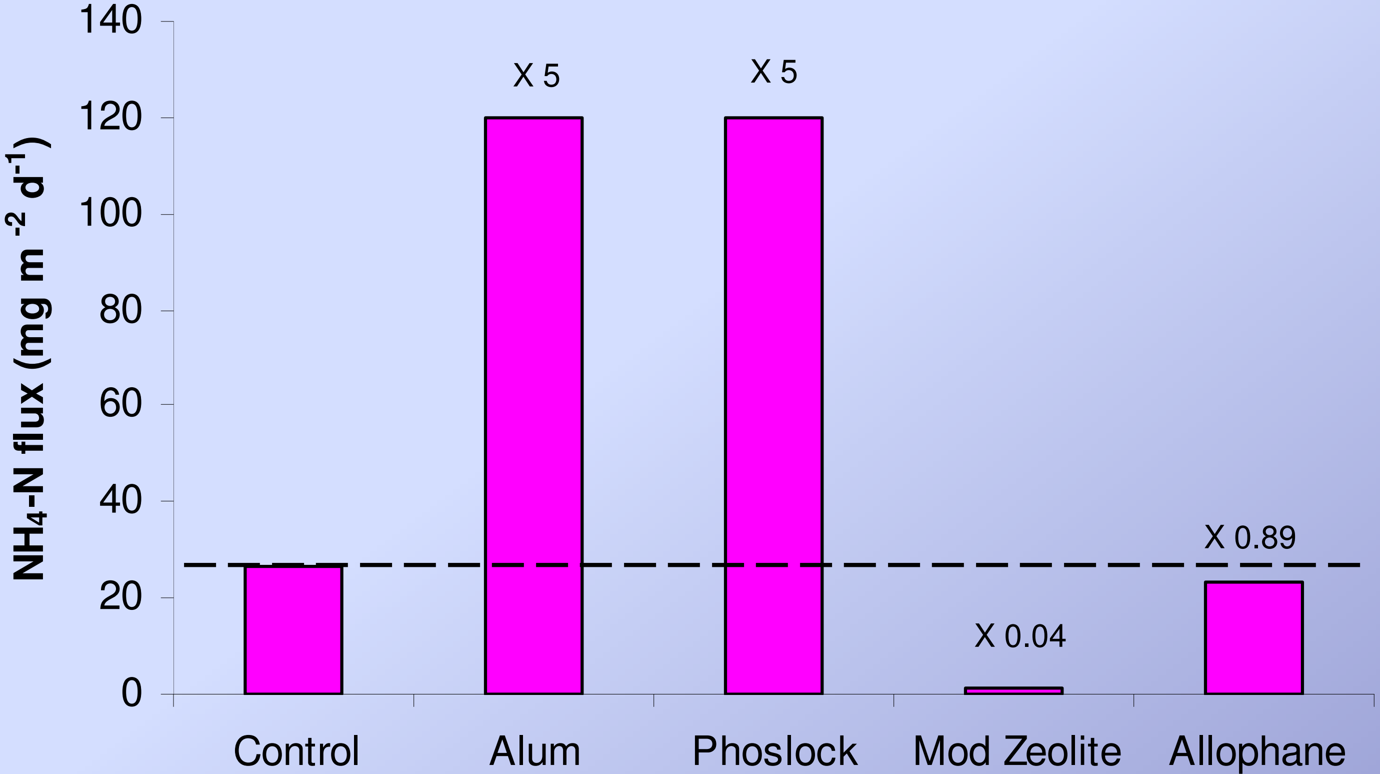
Non-target effect on nitrification and denitrification

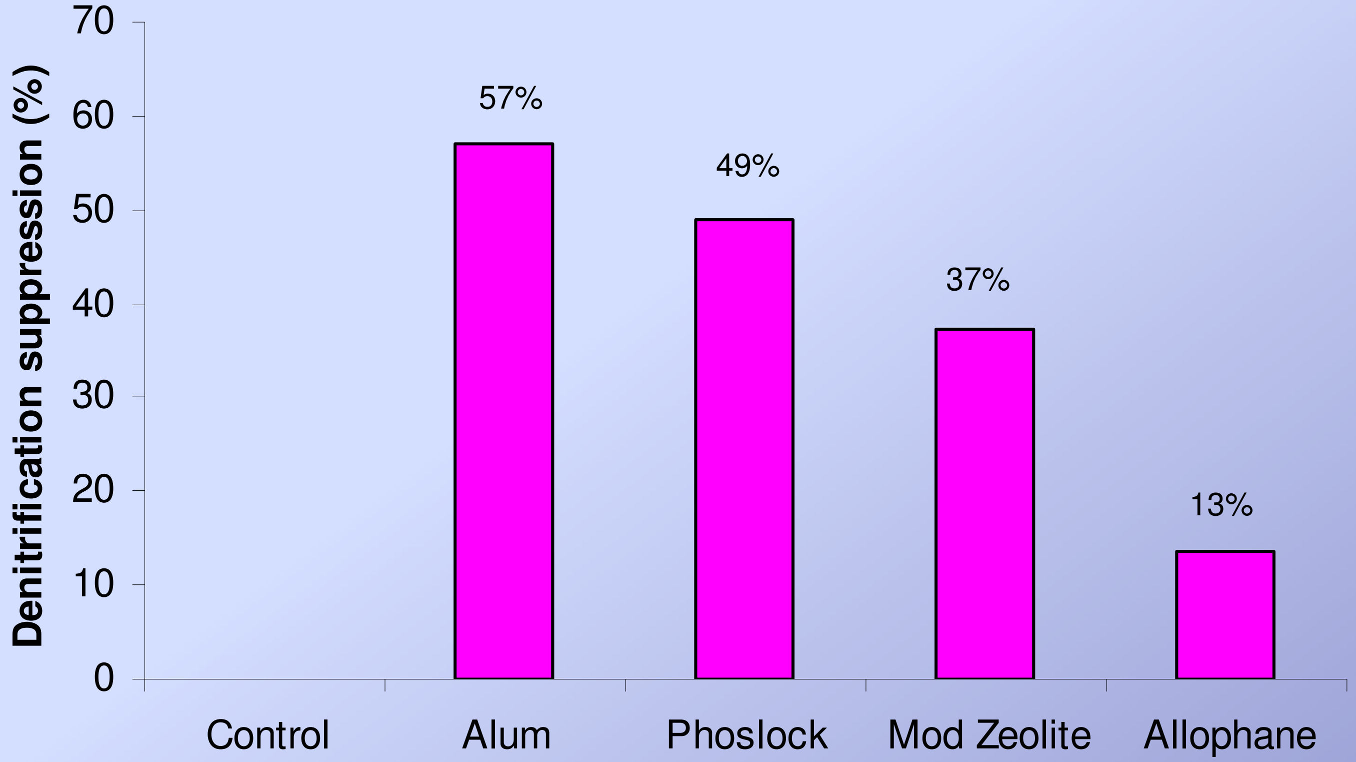


Non-target effect on nitrification increases NH_4-N release



Aerobic conditions

Non-target effect on denitrification suppresses NO_3-N loss



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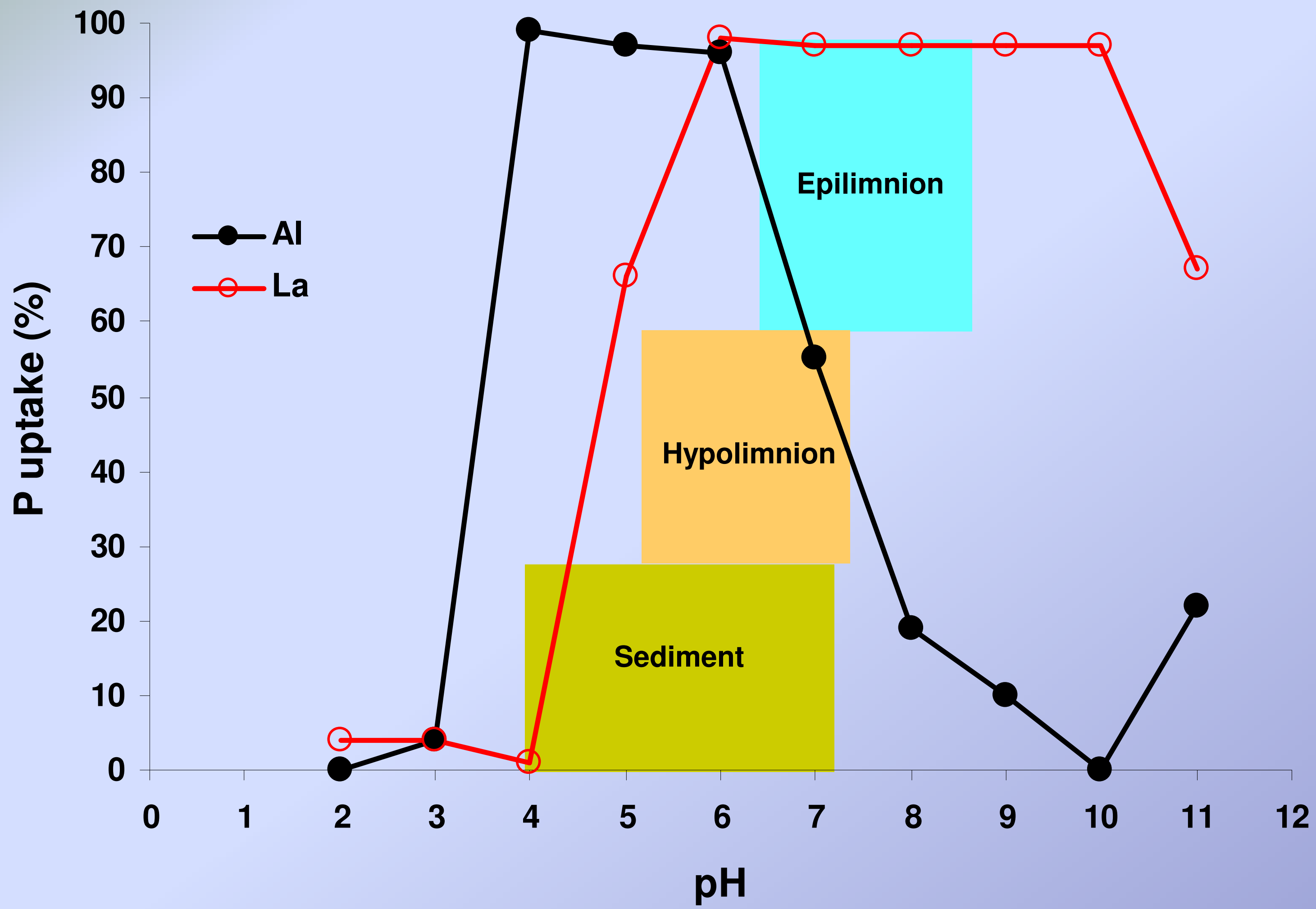
pH effects on adsorption of P onto Al and La salts



Redrawn from
Peterson et al. 1976

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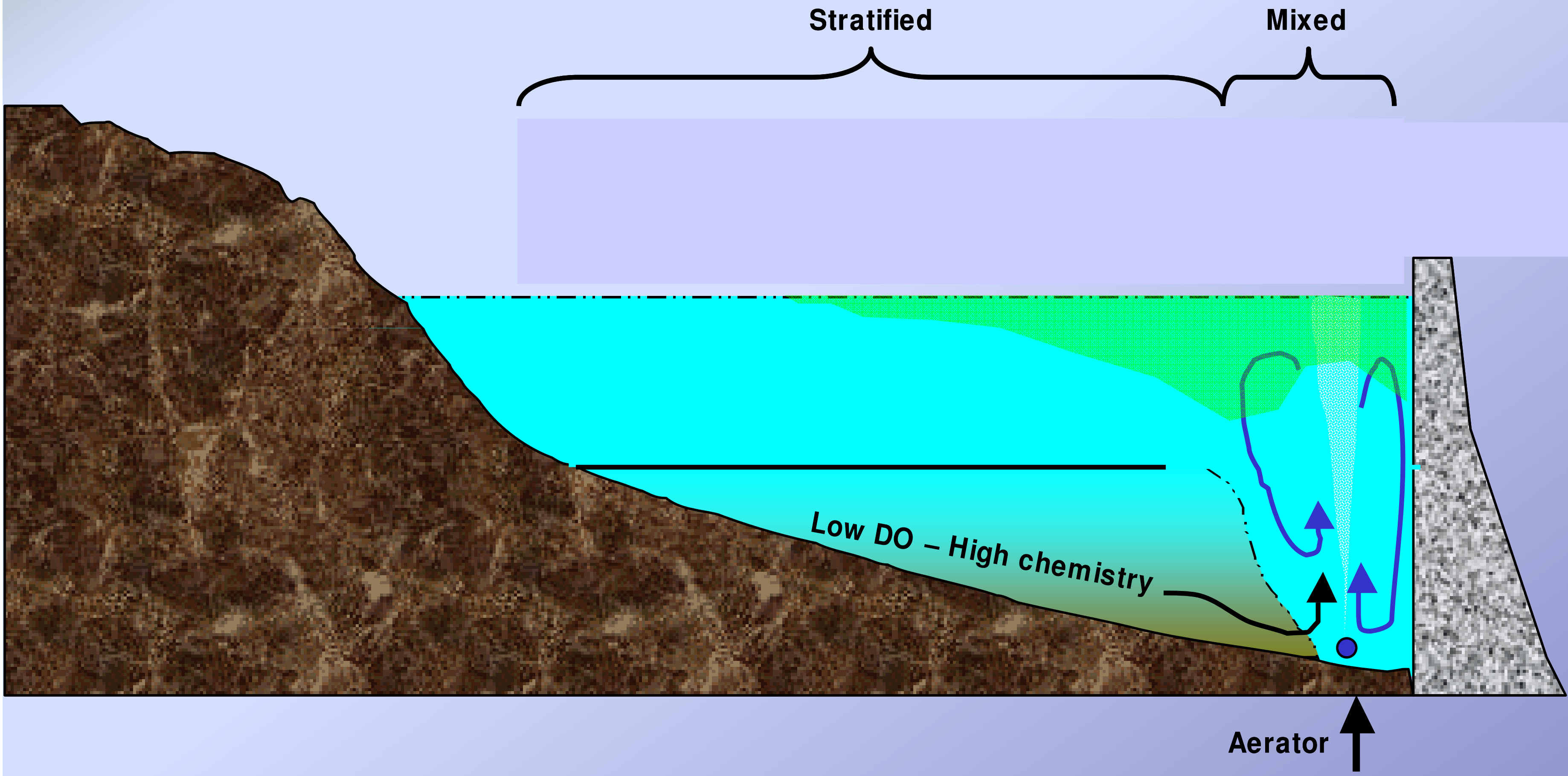
They can be buried by new sediment and the lake may need to be retreated after about 5 years

Other methods: Aeration

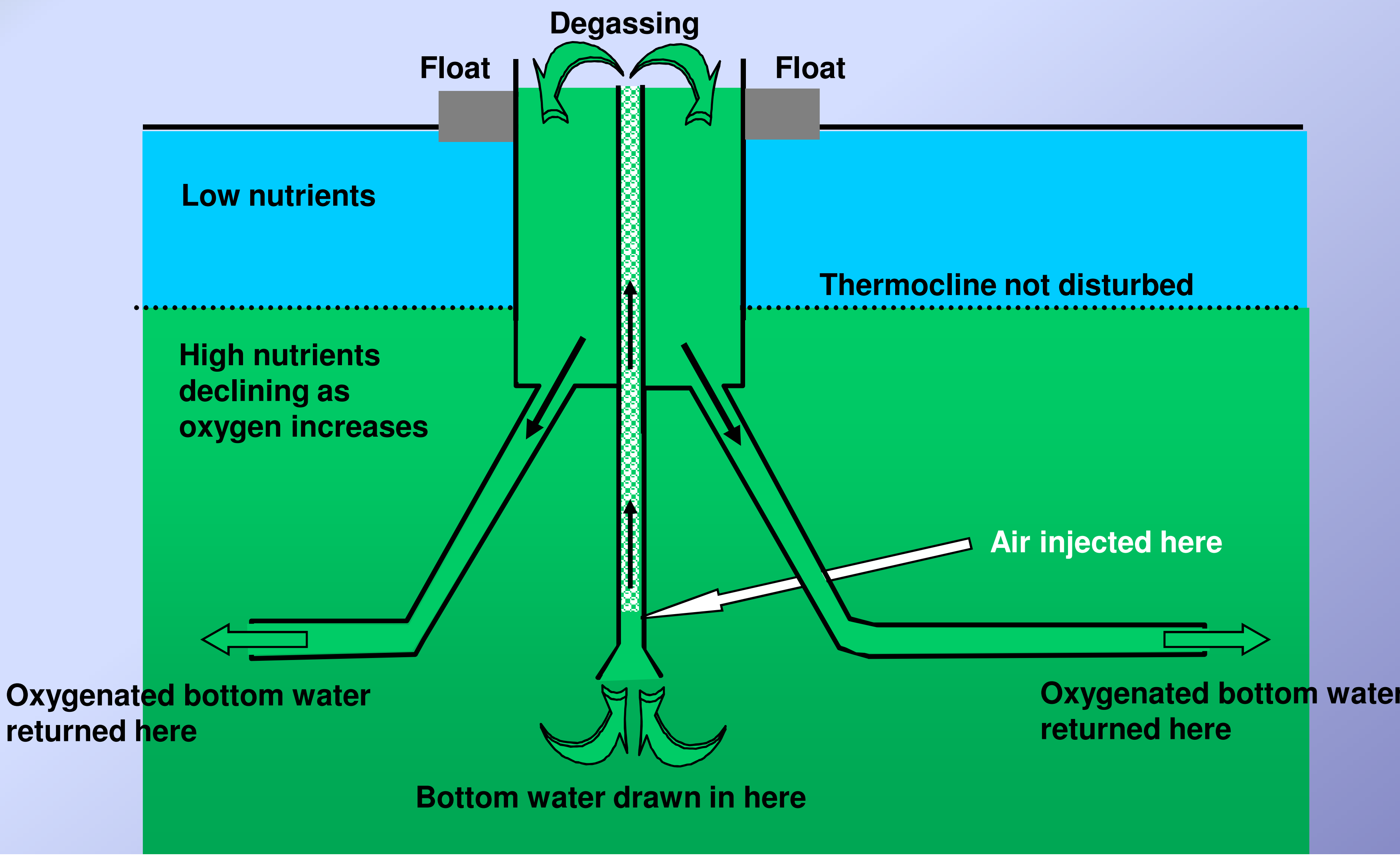
Aeration should start when the lake is still mixed …



… otherwise nutrients drawn from the bottom will cause an algal bloom immediately

Other methods: Aeration

Bottom water aeration system



Conclusions:

Sediment capping can be an effective management option for lake restoration … if used correctly

Applied at the correct dose rate for the lake, complete blocking of the internal P load can be achieved

Sediment capping should be used with catchment remediation strategies in a holistic approach

They should not be applied to the permanently aerobic littoral zones of any lake

Although there are some short-term cons, these are far out-weighed by the pros for lake restoration

Sediment capping is a potentially valuable component of an integrated management programme

For example: Three point management plan

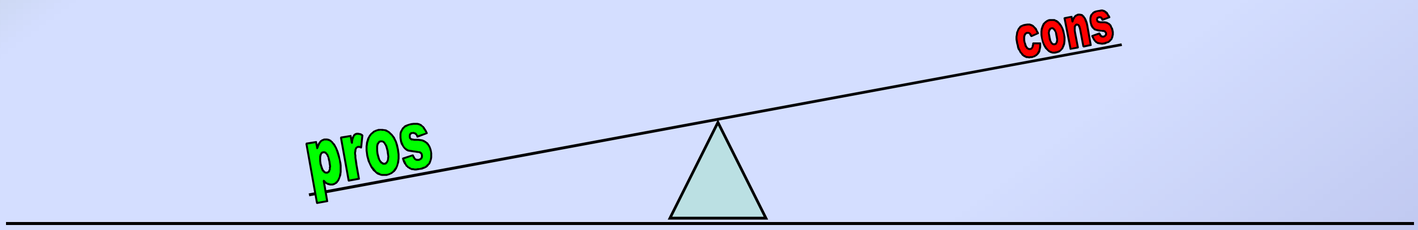
1. Restore buffer zones around the lake to reduce nutrient input loads

2. Aeration – full depth to be implemented when fully mixed in winter

3. Sediment capping – treatment to prevent nutrient release from sediments – timing is important

The success of any management plan will depend on having a good monitoring programme

Adaptive Management



Any Questions ?

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Publications and Reports:

- Gibbs M, Dudli S, Vopel K, Hickey C, Wilson P, Özkundakci D (2007) P-inactivation efficacy of Z2G1 as a capping agent on Lake Okaro sediment. BOP07215; HAM2007-112, NIWA report for Environment Bay of Plenty, Whakatane. pp 38

- Vopel K, Gibbs M, Hickey CW, Quinn JW (2008) Impedance of sediment-water solute exchange by sediment-capping agents: effects on O2 and pH. Environmental Toxicology and Chemistry (In press)

- Wright-Stow A, Parkyn S, Gibbs M (2008) Effects of modified zeolite addition on benthic fauna in Lake Okaro. BOP08207, HAM2008-037, NIWA report for Environment Bay of Plenty, Whakatane.

- Hickey CW, Gibbs M (2008) Lake sediment nutrient release management - Decision support and risk assessment framework. New Zealand Journal of Marine and Freshwater (In review)

- Kelly C (2008) Impact of flocculating products on native "seed bank" germination: implications for conservation and restoration. BIOL307-07B UOW (In review)

Alum has several issues …

In soft water lakes it must be buffered as applied to enable it to form a floc (an added cost)

This raised pH reduces its P-binding capacity but ensures that it doesn’t release toxic Al^{3+} ions

A thick layer will smother benthic invertebrates which can move up through the granular products

In an anoxic hypolimnion, low pH can release toxic Al^{3+}

Because it is a flocculent material, it is easily disturbed

Bottom line: Not recommended for large shallow lakes

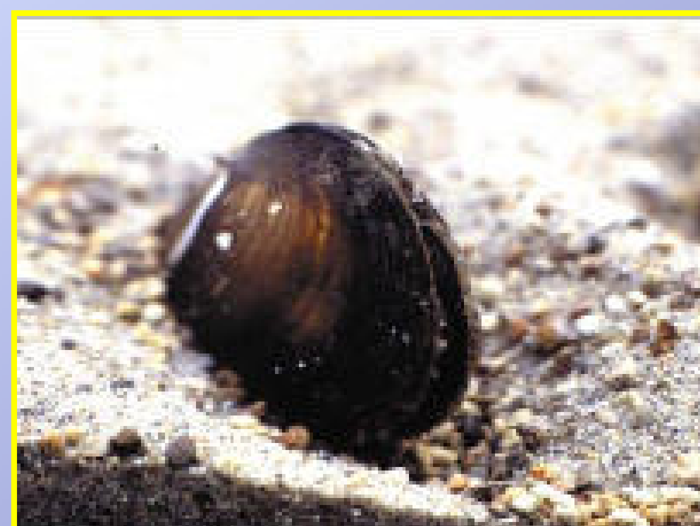
Species

Koura

Amphipod

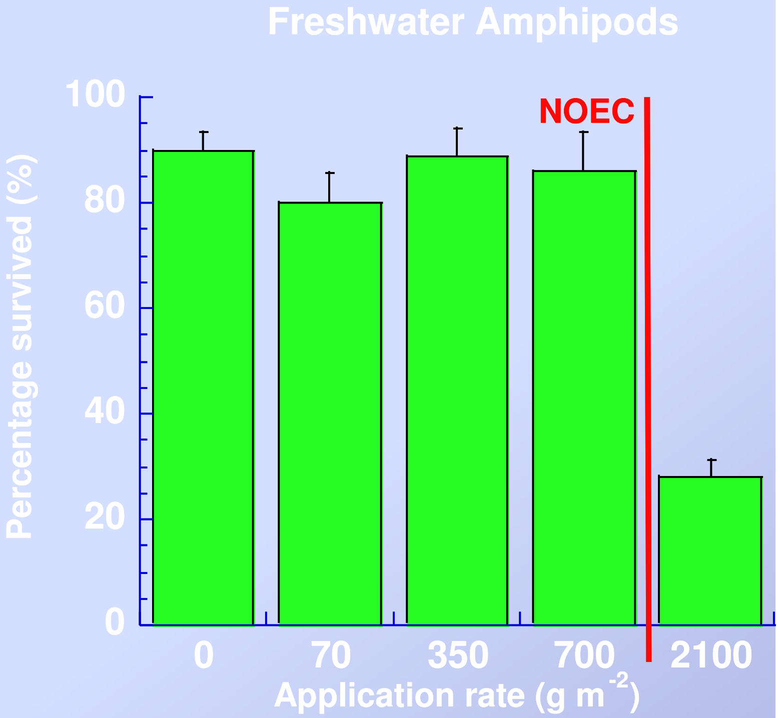
Finger-nail clams

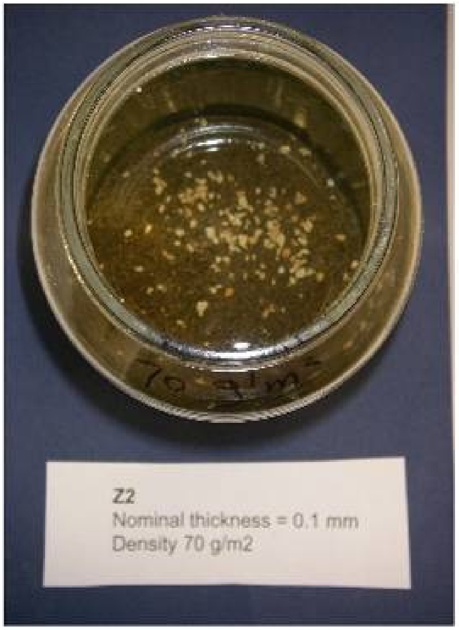
Kakahi

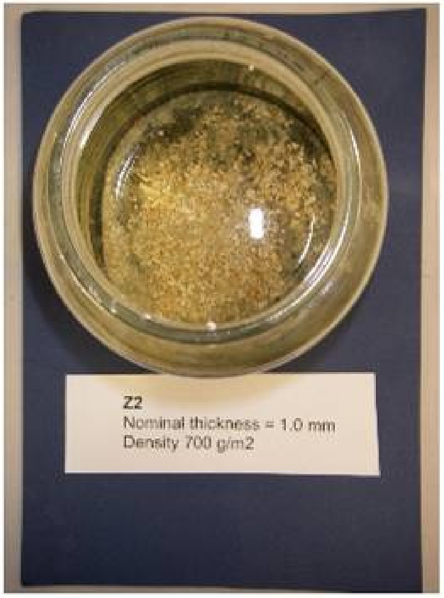


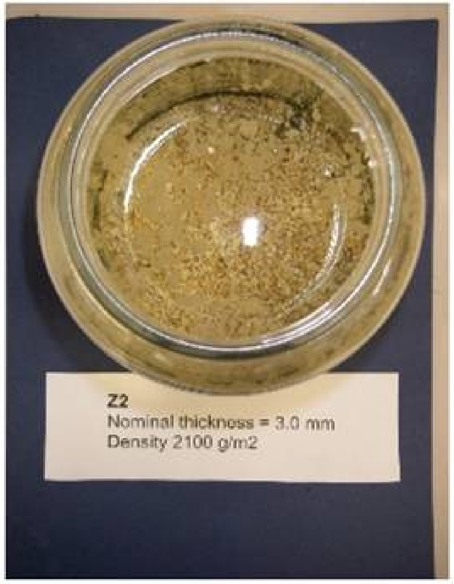
Sediment toxicity of Z2

Example plot:









In situ cages

1995 Mt Ruapehu dosed Lake Taupo with about 2 million tonnes of Allophanic ash

GNS web photo

Excessive dose produced a layer 5–30 mm thick

Allophane removed all DRP from water column and it took 3 months to reappear

Allophane suppressed nitrification and NO_3-N disappeared. It took almost 12 months for nitrifier populations to recover

Consistent with nitrifier suppression, NH_4-N concentrations rose in the water column and remained high for more than 5 years