THE LINK BETWEEN EROSION, PHOSPHORUS AND WATER QUALITY

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Max was trained as an analytical chemist and has worked for NIWA (and its predecessor, DSIR) for 50 years, initially in the field of pesticides and forensic analysis and subsequently studying eutrophication in freshwater. For the last 42 years, Max has worked on lakes around most of New Zealand, primarily on Lake Taupo and the restoration of Lake Rotorua, and Lake Horowhenua. He was instrumental in the identification of the hydraulic coupling between Lake Rotorua and Lake Rotoiti, which eventually lead to the installation of the diversion wall. He has used his experience of iron cycling, obtained as a fellow at Edinburgh University and the Lake District in 1980, to help in the understanding of phosphorus interactions across the sediment-water interface in New Zealand lakes. He was awarded an Honorary Doctorate of the University of Waikato in 2010 for his work with lake restoration and the assistance and mentoring of students. Recently Max developed an internationally acclaimed forensic stable isotope technique that enables the identification and apportionment of sediment sources by land use in the catchment and he has extensive knowledge of the linkages between erosion and the impacts of fine sediment in lakes, rivers and estuaries.

ABSTRACT
In lakes, the solubility of phosphorus (P) in water, and therefore its availability to aquatic plants (macrophytes and algae) for growth, is controlled by oxygen and pH. The supply of dissolved reactive P (DRP) to the lake water column is mostly from sediment release from decomposing plant material and iron oxides during periods of low oxygen, although in Lake Rotorua and most of the other lakes on the central volcanic plateau, spring-fed streams carry relatively high concentrations of DRP into the lakes. The mechanism for releasing iron-bound DRP from the sediment focusses around the oxidation state iron (Fe) and manganese (Mn). In well oxygenated conditions iron exists in the oxidised state as ferric ions which form ferric oxides that are insoluble in water. These oxides sequester DRP as they precipitate and remove it from the water column. When the oxygen concentration falls to zero (anoxic conditions) iron exists in the reduced state as ferrous ions, which are soluble in water. As the ferric form reduces to the ferrous form it dissolves and the DRP bound to the iron is released into the water column where it is used by algae for growth. The algae eventually senesce and die, returning the P to the sediment as particulate P, where it can be recycled during the next period of anoxia.

Apart from recycling of algal biomass, P also comes from the catchment, bound to the iron oxides in soil particles. The P content of the soil is greatest in the finest soil particles, which are the first to be eroded by rainfall and do not settle until they reach the calm waters of a lake. There they augment the P load from the senescing algal biomass, thereby increasing the amount of DRP that can be released during the next anoxic event. Because of the high background concentration of dissolved inorganic nitrogen in the lake water, the addition of any DRP will stimulate algal growth and thus result in a deterioration of lake water quality. Land management strategies to reduce soil erosion include changes to the way land is farmed and the interception and retention of fine sediment using detention bunds.

TRANSCRIPT
Sediment from land erosion is the largest contaminant of water and costs over $US500 billion per year. This is due to sediment costs for potable water and the treatment required cleaning it up. Sediment from land erosion represents threats to sustainable food production and the loss through soil from arable land and of course sediment can adversely affect the aquatic ecosystem affecting biodiversity and the water quality in the lakes.

My talk today examines the link between erosion, phosphorus and water quality. The previous speakers have talked about the cause of sediments, of landslides, bank erosion, flood events, etc. I am going to focus on fine sediment; the particle size is typically less than 20 microns, i.e. the clays, silts and muds, all very fine material.

Unlike an estuary where fine sediment flocs when it meets the sea water and settles, fine sediment entering a lake remains as a suspension of fine particles for extended periods. These suspended solids affect water clarity by reducing light penetration and cause light limitation for aquatic plants, native species and exotic species alike. In Okataina there could be weed beds smothered because fine sediment is coming into the water. Over time the fine sediment eventually settles to the lake bed and lake currents cause it to move into the deeper parts of the lake, a process called sediment focusing. As Theodore Knodonu referred, the sediment eventually gets to the bottom of the lake. The deeper parts of the lake may become anoxic below the summer thermocline due to decomposition of organic matter from weeds and algae.

Common factor: Bare soil washes away in rainfall events

Erosion is a process destabilising soil and causing it to move. Wind driven erosion (Aeolian) is common in the dry parts of the world. Water driven erosion is the most common form in New Zealand. If you take plants off the ridges and put in place grasslands, they cannot hold the soil on the steep slopes. If you have forests which are removed by clear felling the period of clear felling leaves exposed land which is not going to stop rain from eroding the soil. If you have farmers that cultivate the land right to the edge of the streams, in fact run their ploughs almost into the streams, nothing will stop sediment getting into the system. The common factor here is that bare soil washes away in rainfall events.

Sediment can come from land slips and we have already seen these. Willy Shaw showed close ups of slips in Okataina. We see bank erosion in Okataina and around other lakes. Theodore referred to the denudation of the forest understorey by animal grazing and the effects of wallaby in the Okataina catchment.

Sediment can come from land slips

Or bank erosion

Or denudation of forest understory by animal grazing

Erosion occurs at all stages of rainfall events with different parts of the landscape being affected depending on the previous rainfall history and intensity. In most cases it is the surface soil that is eroded first with the very fine particles moving even with light rain. The slip faces that came down in a big event continue to leach fine sediment with fine rain washing off that surface all the time.

The fine sediment in surface runoff may not be considered important. For example, in the Okataina water quality Background Information 2012 there is a surprising statement that says –

‘There are small areas of bare ground and built areas in the Lake Okataina catchment, but it is thought that only a trace amount of nutrient input, (10 grams of phosphorus and 110 grams of nitrogen a year) is generated from these.’

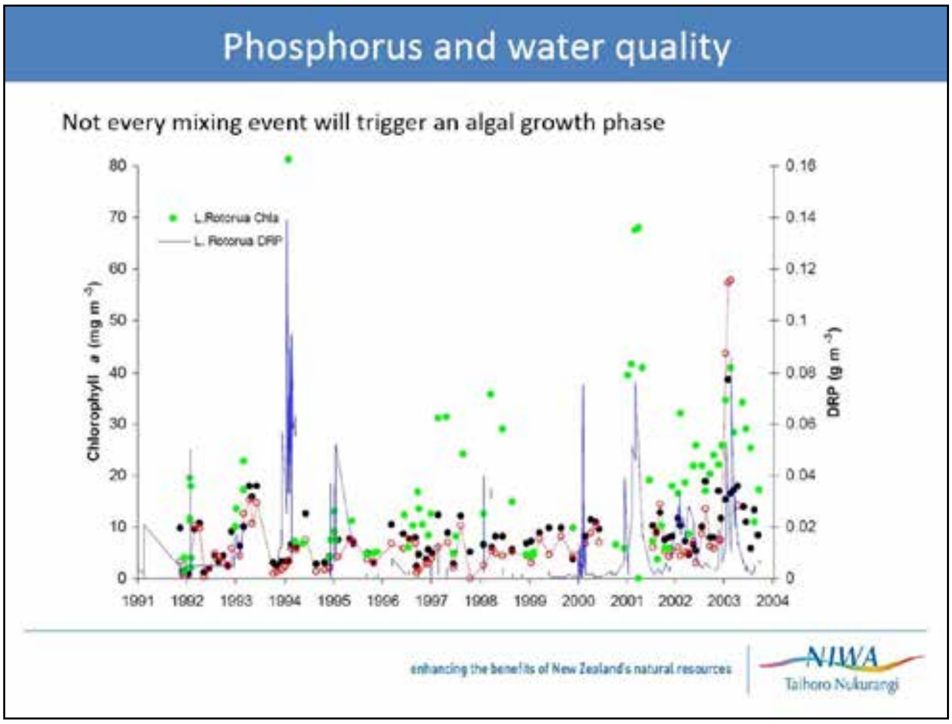
Where does the P come from? Fine sediment has the highest concentration of phosphorus P of any sediment. Pumice soil is naturally high in phosphorus and that is due to the feldspars that are in the pumice. Elsewhere farm fertiliser application and animal waste applied to land can be a major source.

Phosphorus as dissolved reactive phosphorus (DRP) is rarely found in abundance in freshwater streams or lakes. The exceptions are the natural spring waters of the central volcanic plateau. Theodore referred to these as the mineralisation leaking from the rocks. Lakes are thermally stratified with anoxic bottom waters which also produce phosphorus. Phosphorus concentrations are controlled by dissolved oxygen (DO) concentrations in the water. With high DO concentrations minerals, such as iron, form insoluble oxy hydroxides or oxides which sequester the phosphorus to their surface, in other words iron binding. These remove the phosphorus particles from availability to algal plants in the water column. With zero oxygen, in other words anoxia, the insoluble iron oxide dissolves and releases the phosphorus as DRP into the water column where they are available for algal growth.

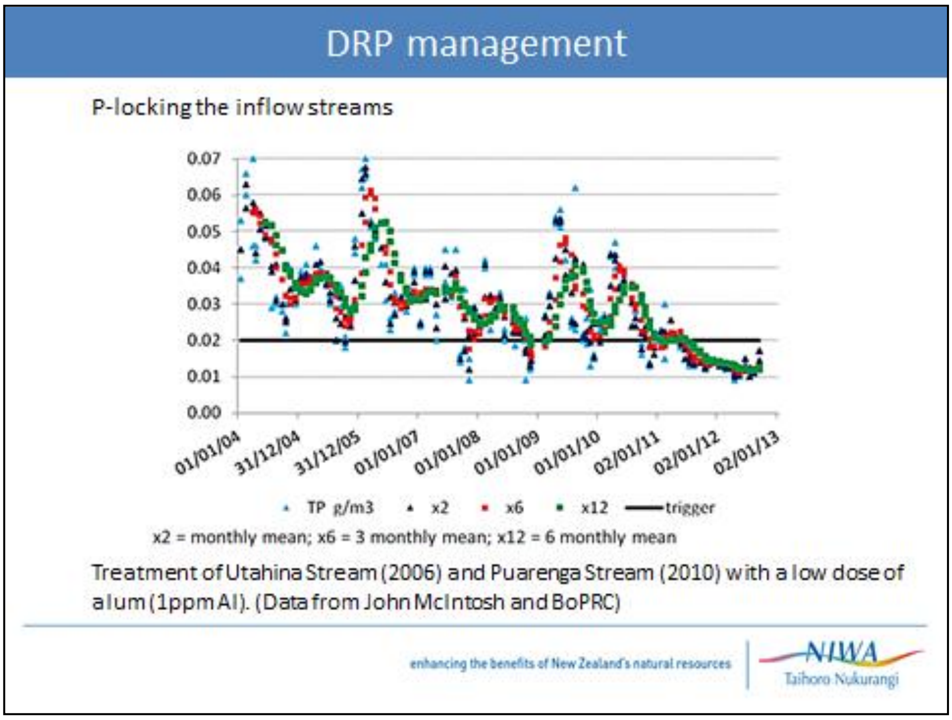
What is so special about phosphorus? All plants need phosphorus and nitrogen for growth, typically in a mass ratio of N : P of 7.2 : 1. These are as dissolved inorganic nitrogen (DIN) and phosphate, i.e. DRP, not total phosphorus or total nitrogen. If either DIN or DRP are in short supply plant growth may be limited. In most New Zealand lakes there is an elevated concentration of dissolved organic nitrogen and low concentrations of phosphorus. This implies that phosphorus is the nutrient most likely to limit algal growth in lakes. It also implies that if phosphorus is added algae are likely to grow and sometimes quite rapidly. Consequently after thermal stratification with bottom water anoxia (DPR) phosphorus concentrations will increase in the lake when the lake mixes and algae will grow.

Lake Rotorua is polymictic; it thermally stratifies and then mixes. Historically it has produced high phosphorus concentrations when stratifying and these are released into the overlying water column when it mixes. In **Slide 1** the data set ranges from 1991 to 2004 and we can see events where the blue line is phosphorus; the green spots are the chlorophyll concentrations. Phosphorus release chlorophyll. Not every mixing event will trigger an algal growth phase. We have situations here where there is phosphorus release but no algal growth. I do not know why, it just happens that way. We saw in previous talks yesterday the way of managing phosphorus in a lake. If you treat the streams you can reduce the phosphorus entering the lake from the streams. **(Slide 2)**

Slide 1



Slide 2



Fine sediment is a bit more difficult to manage because it comes off farm land, slips and other sources. The Bay of Plenty Regional Council has developed detention bunds which are stretched across an ephemeral channel in a paddock. **(Slide 3)**

Slide 3

Slide 4 looks downstream in a paddock towards an ephemeral detention bund.

Slide 4

The device in **Slide 5** is the outlet for the water level control for the detention bund. They hold water with fine sediment eroded by rain allowing most of the sediment to settle in the

Slide 5

paddock. A surprising amount of fine sediment is washed off pasture. It does not look like a major source but 80 to 90% of the catchment in pasture produces a tremendous amount of very fine sediment with very high concentrations of phosphorus.

In conclusion, the link between erosion, phosphorus and water quality is fine sediment. Fine sediment is eroded from the land even with light rain, so just a light shower and phosphorus is moving. Fine sediment carries the highest concentration of iron-bound phosphorus. It is the vector for inorganic phosphorus from land to the streams and lakes. The fine sediment is very slow to settle making this a one step process. It does not move down a bit and wait for the next rainfall; it goes with the rain the full distance. Fine sediment is focussed into the deeper parts of the lake by lake currents and the bottom waters are more likely to become anoxic in summer. Anoxia releases iron-bound phosphorus which may stimulate algal growth when the lake mixes. An excess of dissolved reactive phosphorus in a lake favours the growth of cyanobacteria and there goes your water quality.