PHOSPHORUS VS NITROGEN – WHAT WOULD THE ENVIRONMENT CHOOSE?

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ABSTRACT

In recent times, upgrade strategies for existing municipal wastewater treatment plants and construction of new treatment plants in New Zealand that discharge to water, have focused on nutrient reduction in the discharge to protect the downstream receiving environment. Nutrient reduction strategies incur not only additional capital costs but also substantial operating costs.

A few years ago, the majority of regional councils required nitrogen removal rather than total phosphorus. However, in recent times there is a trend towards requiring both nitrogen and phosphorus removal. Do you really need both?

This paper will present the case of providing phosphorus removal, which is cheaper in capital, less complex to operate and easier to control compared to nitrogen removal involving anoxic reactors. The paper will examine the issue from a receiving environment perspective. Are we over doing it?

KEYWORDS

Phosphorus, Nitrogen, Wastewater, Nutrients,

1 INTRODUCTION

Disposal of treated municipal wastewater in New Zealand generally involves irrigation to land or a direct or indirect (often via a rock filter) discharge to surface waters (Ministry for the Environment, 2007; NIWA, 2010; van Haandel, A. and van der Lubbe, J., 2007).

In the case of land disposal, provided the strategy outlined in Figure 1 can be met, there is no benefit in nutrient stripping as mineralised nutrients in the effluent can be a resource for irrigated crops (Ministry for the Environment, 2007; Monaghan et. al., 2007; Roach et. al., 2001)

Municipal wastewater that have been treated by activated sludge systems (compared with oxidation pond systems) are generally preferable for land disposal as nutrients are in a crop-available form. Mineralised plant nutrients in secondary oxidation ponds have often been re-fixed by pond algae and are not immediately available for uptake by irrigated crops. Moreover, if these pond algae are dominated by cyanobacteria (potentially toxic blue green algae), there may be potential issues with the health and performance of both irrigated crops and grazing livestock (Pearl et. al., 2001).

Storage facilities are not generally required for secondary treated municipal wastewater being discharged to surface waters but may be required where the assimilative capacity of the receiving water varies on an episodic or seasonal basis due to changes in upstream water quality or reduced flows.

Storage facilities are generally required for all land disposal systems to prevent hydraulic overloading and effluent runoff from irrigation plots when soils are at field capacity during wet weather events. The exception is where complimentary surface water discharges are available and consented for wet weather events as is the case for Inghams Industries and the Wallace Corporation at Waitoa for example .

The storage of municipal wastewater that have been treated by activated sludge systems can also result in the availability of mineralised plant nutrients being re-fixed by algae and becoming unavailable for the immediate uptake by irrigated crops on land irrigation plots.

The strategy for discharge to land (see Figure 1) that involves "*matching seasonal nutrient load requirements / nutrient uptake potential of irrigated crop with available nutrient load in the effluent discharge*" is best achieved by sizing the irrigation plots for the late autumn winter period when the crop nutrient interception / uptake potential is at a seasonal minimum. During the spring summer period when the crop nutrient interception / uptake potential is at a seasonal maximum, a smaller area of crop may be irrigated with treated wastewater or supplementary nutrients may be provided to the irrigation plot.

Adding more nutrients to land than can be intercepted and assimilated by plants and crops on that land can result in a range of adverse groundwater effects that are not the subject of this paper (GHD, 2009A; Roach et. al., 2001; Monaghan et, al., 2005: Monaghan et. al., 2007).

The subject of this paper is the challenge of safely discharging plant nutrients associated with treated municipal wastewater to surface freshwaters that include streams, rivers and lakes.

It is clear from Figure 1 that potential enrichment or eutrophication effects of plant nutrients associated with treated municipal wastewater are only one of a suite of potentially adverse effects that need to be considered. Others include potential instream toxicity effects associated with ammonia concentrations in the discharge, potential dissolved oxygen sags due to chemical and biological oxygen demand, disease causing bacteria and other contaminants (GHD, 2009; Roach et. al., 2001).

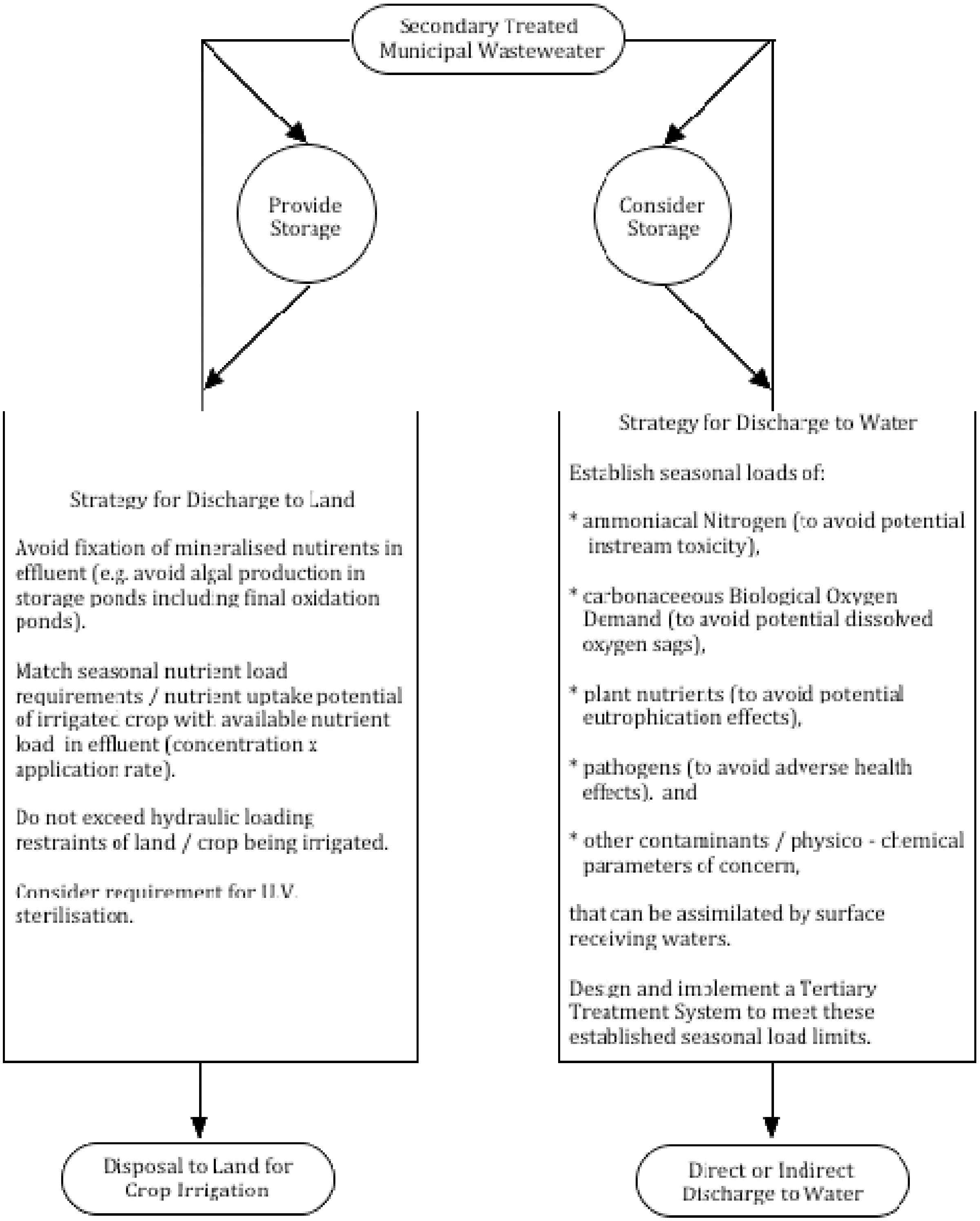

Figure 1: Stylised discharge strategies for secondary treated municipal effluent in New Zealand

2 PLANT NUTRIENTS IN AQUATIC ENVIRONS - TOO MUCH OF A GOOD THING

Surface waters containing a relatively low concentration of plant nutrients are unproductive in terms of the abundance of plants and animals they can support Fisheries values for example are improved when freshwaters contain a relatively moderate concentration of plant nutrients. Freshwaters that contain a relatively high concentration of plant nutrients can be over productive and associated with fish kills, algal blooms and other serious management issues (ANZECC and ARMICANZ, 2000; Biggs et. al., 2002; Cook et. al., 1993; Ministry for the Environment, 2007).

The thresholds at which available plant nutrients concentrations are considered to be acceptable compared to unacceptable have been well established for upland versus lowland streams and river and for lakes in New Zealand (ANZECC and ARMICANZ, 2000; Biggs et. al., 2002; Burns et. al., 2000; Collier et. al., 2010; Milne and Perrie, 2006). These thresholds have been established for nitrogen and phosphorus, which are the two elements that most frequently limit aquatic plant production (see Table 1). However, on a diurnal basis, other elements / nutrients such as carbon dioxide may also limit aquatic plant production (Cook et. al., 1993; Hutchinson, 1957; Hutchinson, 1967; Biggs et.al., 2002).

In general terms, phytoplankton and Aufwuchs including periphyton rely on dissolved nutrients in the water column for growth. Macrophytes that are rooted in the lake / riverbed also have access to nutrients in bed sediments. (Environment Waikato, 2007).

Table 1: Examples of trigger values or concentration thresholds of concern for nitrogen and phosphorus in New Zealand lowland and upland rivers (ANZECC, 2000).

Parameter	**Trigger values for lowland rivers**	**Trigger values for upland rivers**
Dissolved reactive phosphorus (mg/L)	< 0.01	< 0.009
Total phosphorus (mg/L)	< 0.033	< 0.026
Nitrate, nitrite nitrogen (mg/L)	<0.444	<0.167
Ammoniacal nitrogen (mg/L)	< 0.021	< 0.01
Total nitrogen (mg/L)	< 0.614	< 0.295

One of the reasons excess plant biomass is such an issue in aquatic environs is that an equivalent volume of water contains only some 5% of the quantity of oxygen relative to air and that the rate of diffusion of oxygen in water is several thousand times slower in water than in air (Hutchinson, 1957).

The respiratory activities of dense plant populations in water can be associated with low oxygen concentrations or even anoxia during the night / pre-dawn period (Quinn and Gilliland, 1985: Freeman, 1986; Manawatu Regional Council, 1998).

The assessment of water quality includes aquatic ecosystem values and suitability in terms of contact recreation, water supplies, aesthetic and cultural purposes. If the maintenance and enhancement of surface water quality is to be achieved there needs to be a reduction in the quantity of contaminants that impact on water quality entering lakes, rivers and streams.

3 WHAT ARE THE DRIVERS TO REDUCE NUTRIENT INPUTS TO AQUATIC ENVIRONS IN NZ?

The most recent state of the environment report (Ministry for the Environment, 2007) reviewed the changes in freshwater quality that occurred in the 10-year period between 1997 and 2007. Changes since the 1997 report include:

- there is strong evidence at both the regional level (Environment Waikato, 2004; Hamill and McBride, 2003) and nationally that the levels of nutrients in rivers increase in proportion to the levels of agricultural activity in river catchments (e.g. dairy cow numbers increased from just over 4 million to just over 5.2 million during the last decade).
- water quality is generally poorest in rivers and streams in urban and farmed catchments and reflects the impact of non-point-sources of pollution in these catchments,
- Pollution from organic waste in rivers has reduced since the late 1980s. This indicates improved management of point-source discharges of organic waste such as discharges from wastewater treatment plants,
- The median levels of nitrogen and phosphorus have increased in rivers within the national monitoring network over the past two decades
- levels of nitrogen and phosphorus in rivers have increased over the past two decades. Nitrogen levels have increased most rapidly in rivers that are already nutrient-enriched,
- on average, whilst levels of dissolved reactive phosphorus have increased in rivers of the national monitoring network, there has been a steady decrease in phosphorus in rivers with high levels of this nutrient since a peak in the mid-1990s

4 IS IT NECESSARY TO REDUCE BOTH NITROGEN AND PHOSPHORUS INPUTS TO WATERWAYS?

According to Liebig's Law or the Law of the Minimum, growth is controlled not by the total amount of resources available, but by the scarcest required resource (limiting factor). Theoretically therefore, eutrophication can be managed by driving either phosphorus or nitrogen to a concentration threshold where it will limit the growth and biomass of nuisance phytoplankton and / or periphyton in NZ waterways. It is not necessary to reduce both.

5 WHICH IS THE MOST EFFECTIVE NUTRIENT TO STRIP FROM SECONDARY TREATED MUNICIPAL EFFLUENT?

The bio-geographical recycling mechanisms for nitrogen and phosphorus are quite different and mean that phosphorus loads and concentrations can be managed in aquatic environs, but this is not necessarily the case for nitrogen. The key difference in the phosphorus and nitrogen cycles is that phosphorus is a conservative element that does not have a gas phase. If phosphorus input to a water body (lake or river) is controlled and managed, no additional load of phosphorus can enter or leave the waterbody via the air water interface in a gas phase.

This is not the case for nitrogen because of the following.

- The nutrient Nitrate-Nitrogen can be converted to N_2 gas by the process of denitrification in a lake or river and be lost to the atmosphere via the air water interface.

- Additional fixed forms of nitrogen can enter the waterbody from the atmosphere via the air water interface (e.g. washout of urea from the atmosphere during thunderstorms or washout of ammonia from the atmosphere during volcanic eruptions).
- Dissolved N_2 gas in a water body from the atmosphere can be biologically transformed from the nutrient Nitrate-Nitrogen by the process of nitrification.

Therefore, despite the effort and expense of stripping fixed forms of nitrogen from secondary treated municipal effluent before it is discharged to a lake or river, the instream biological activities of bacteria and blue green alga can increase or decrease the load and concentration of fixed nitrogen and thus thwart nitrogen-stripping initiatives.

Whilst there is generally a loss of phosphorus from a waterbody to lake / river bed sediments due to adsorption and deposition of plant and animal remains whilst the water column remains aerated, once a lake or river becomes eutrophic, it is necessary to prevent internal cycling of phosphorus (Cook et. al., 1993; Griffith et. al., 1973; Klapper, 2003; Miller, 2005; Ozktundakci and Hamilton, 2006; Ryden and Welch, 1998; Shilton et. al., 2006; Yang et. al., 2004).

The return of accumulated phosphorus from bed sediments in the hypolimnion of a lake to the water column can occur if the hypolimnion of the lake becomes anoxic during period of thermal stratification. The iron and manganese to which P is bound release the P under these anoxic conditions.

Management of a resulting situation where a lake can become locked into a eutrophic condition due to internal cycling of phosphorus, despite managing any further phosphorus loads from the catchment requires a combination of techniques such as:

- thermal de-stratification
- hypolimnetic aeration
- capping of lake bed sediments to prevent phosphorus release, and
- the use of agents such as flocculants to strip phosphorus from the water column.

The other consideration in terms of nitrogen or phosphorus stripping is the overall ratio of nitrogen to phosphorus (N:P ratio) in the final discharge. This N:P ratio is critical in determining the types of algae that will bloom in lakes reservoirs and the sluggish downstream reaches of larger rivers (Downing et. a;., 2001; Fujimoto et. al., 1997: Pearl et. al., 2001; Sheffer et. al., 1997; Takamura et. al.,1992).

Where the priority is to eliminate toxic blue-green algal blooms, the N:P ratio should be kept above 22:1, especially over late spring, summer and autumn (Environment Bay of Plenty, 2005; Hamilton et. al., 2004; Ministry for the Environment, 2007; Smith, 1983).

It is possible to manipulate the N:P ratio, by both reductions in catchment nutrient inputs and by in-situ management techniques. The most effective nutrient to strip from secondary treated municipal effluent is phosphorus.

6 WHICH IS THE MOST COST-EFFECTIVE NUTRIENT TO STRIP FROM TREATED MUNICIPAL EFFLUENT?

In terms of the capital and operating costs, it is difficult and not practical to compare costs of nutrient removal facilities from various sites due to varying factors like land, cost of labour and materials, cost of sludge disposal, requirements of associated regional councils etc. However, the Table below presents a comparison of units and components that influence the overall costs of nitrogen and phosphorus removal for retrofitting an existing activated sludge plant with nutrient removal.

Table 2: Comparison of Infrastructure Requirements for Nitrogen and Phosphorus Removal

Item	Nitrogen Removal	Chemical Phosphorus Removal
Civil Works & Tanks	Anoxic Basins,	Chemical Building
Chemical dosing	Alkalinity, carbon	Alum or ferric
Mechanical Equipment	Internal recycle pumps, anoxic zone mixers, chemical dosing plant and pumps	Chemical dosing plant and pumps,
Footprint	Higher	Lower
Operating Costs	Carbon chemical (methanol, molasses, ethanol, acetic acid) Alkalinity chemicals (soda ash) Power (Mixers and pumps) Maintenance of additional M&E equipment and dosing plant	Chemical costs (alum or ferric) Maintenance of dosing plant

Given the capital infrastructure and the operating requirements, it is apparent from Table 2 above that the overall cost of nitrogen removal is higher than chemical phosphorus removal for retrofitting an activated sludge plant without nutrient removal.

7 TOKOROA WWTP – A CASE STUDY

The discharge from the Tokoroa WWTP to the Whakauru Stream is authorised by Consent 930693 that expires this year (2011) and renewal is currently being sought. The plant has a design flow of 4,000 m^3/day for dry weather or 6,000 m^3/day for wet weather. Existing liquid stream treatment consists of primary settling, two-stage trickling filters, FAST activated sludge process, sand filter and Ultra Violet disinfection.

The treated effluent passes through a rock filter before discharging into the Whakauru stream which, by way of various other streams ultimately drains into the Waikato River. In order to avoid a water discharge, Council undertook an investigation for land disposal. This study found that land disposal is technically and economically unfeasible for Tokoroa due to: 1) unavailability of enough council owned land 2) land purchase highly cost prohibitive 3) Forestry companies unwilling to accept wastewater discharge. Therefore, the only other option for the short term is to continue discharging to the Whakauru stream.

A detailed biological survey of the stream was done in the two preceding summers. Based on the results of the survey and the Waikato Catchment Model (see Appendix 13: Water Quality of NIWA, 2010) it has been shown that the overall contribution of the municipal and industrial discharges to the total organic, solid, pathogen and nitrogen load is minor when compared to the diffuse source loads.

In our opinion, given this combination of circumstances and the type of the existing plant (i.e. activated sludge without nitrogen removal), we consider phosphorus removal as the preferred nutrient to be removed rather than nitrogen.

The purpose of this phosphorus stripping is not an effects based response because the threshold of concern for instream nutrient concentrations are already frequently exceeded in an agricultural catchment upstream of the discharge from the Tokoroa WWTP (AEE for renewal of Consent prepared by Harrison Grierson Consultants Limited, 2011). It is in recognition of the incremental contribution made to phosphorus loads in the Whakauru Stream, Pokaiwhenua Stream and Waikato River and mitigation for the cultural preference for land disposal of such discharges. We do not however, consider there is a cost effective justification for further nitrogen stripping at the plant.

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