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Effects of intensifying catchment land-use on the water quality of Lake Taupo

B. VANT AND B. HUSER

Environment Waikato, Box 4010, Hamilton, New Zealand

ABSTRACT

Levels of the nitrogen-dependent phytoplankton in Lake Taupo are currently very low, so the clarity of the lakewater is exceptionally good. This is because loads of nitrogen to the lake from the catchment are currently low (averaging 3–4 kg N/ha/yr). Changing to more intensive land-uses is likely to increase the nitrogen input. Converting 100–250 km^2 of sheep/beef pasture to intensive dairying yielding 30 kg N/ha/yr would increase the overall nitrogen load to the lake by 20–60%. This could cause phytoplankton levels to increase by a similar proportion, so that water clarity would fall by 20–40%.

Keywords: dairying; land-use; nitrogen; water quality; Lake Taupo.

INTRODUCTION

Lake Taupo is New Zealand's largest lake (area 620 km^2, mean depth 95 m). It is highly-valued for many reasons, foremost among which is its excellent water quality. Only a few of the 165 New Zealand lakes for which Livingston *et al.* (1986) collated information have similarly high water quality (with the other excellent lakes including Lake Waikaremoana in the North Island, and several large, upland lakes in the South Island, e.g., Lakes Coleridge, Hawea, Wakatipu and Wanaka). In Lake Taupo, levels of the plant nutrients nitrogen and phosphorus, and the freely-floating microscopic plants ("phytoplankton") whose growth they support, are low (Gibbs, 1998). As a result, the water is clear and blue.

Most of the nutrient found in a lake enters in the inflowing rivers and streams. Nutrient levels in lakewaters therefore tend to reflect land-use within the catchment. Many of the lakes in the lowland areas of New Zealand that are intensively-used for agriculture are nutrient-enriched, and thus support scums and blooms of nuisance phytoplankton (Smith *et al.*, 1993).

In many lakes in the northern hemisphere, it is the availability of phosphorus that controls phytoplankton growth. Levels of nitrogen, by contrast, are often much higher than those required by phytoplankton. In many New Zealand lakes, however, large excesses of nitrogen are uncommon, and the ratio of nitrogen to phosphorus approximates that required for balanced phytoplankton growth (Pridmore, 1987). In addition, phosphorus levels are relatively high in many of the lakes of the central volcanic plateau, due to geochemical leaching of phosphorus from the pumice soils (Timperley, 1983). Phytoplankton growth is therefore often limited by the availability of nitrogen rather than phosphorus in these particular lakes. Furthermore, studies on the phytoplankton in Lake Taupo have demonstrated that their growth is indeed nitrogen-limited (White and Payne, 1977; White *et al.*, 1986).

Historically, the catchment of Lake Taupo was mostly covered in tussock grassland and native forest (Leathwick *et al.*, 1995). Since 1840, however, much of the tussock has been replaced with pine plantations and pasture (Figure 1). Concern about the erosion of pumice soils following development of the Taupo catchment in the 1960s led to the introduction of the "Lake Taupo Catchment Control Scheme" (Waikato Valley Authority, 1973). From 1976 many streams and erosion-prone hillsides were fenced to exclude stock, and in some cases riparian areas were planted with native wetland species.

Reducing nutrient runoff from farmland also became an important objective of the scheme. Removal of substantial amounts of nitrogen has been observed in protected riparian areas of the Tutaeaua Stream in the north-west part of the catchment, while removal by plants living in the channel of another stream has occurred under certain conditions (Downes *et al*., 1997). Even so, levels of nitrate in at least two of the inflowing streams and in the bottom waters of the lake have increased over the past 25 years. Furthermore, the clarity of the lakewater during the winter (approx. 14 m) has decreased slightly (by about 1 m) since the 1970s (Edgar, 1999).

Pastoral agriculture in the catchment is currently dominated by sheep and beef farming, but a shift to more-intensive dairying began recently (Ministry of Agriculture, 1997; Edgar, 1999). There are four dairy farms in the catchment at present, covering a total area of about 14 km^2 (Davidson, 1999). Elsewhere in the Waikato Region, dairying releases high loads of nitrogen to surface and groundwaters (Ledgard *et al.*, 1996; Wilcock *et al.*, 1999). Concern has therefore been expressed about the possible effects on the lake of a major shift to dairying in the catchment. This paper (1) collates information on the current nitrogen loads to the lake, (2) identifies the possible magnitude of the dairying-related increase in nitrogen load, and (3) predicts the likely effects of this increase on lakewater quality.

LAND-USE AND NITROGEN LOADS

Nutrient budget

Nutrient loads to Lake Taupo were measured in a major nutrient budget study during 1976–79 (Schouten *et al.*, 1981). Nitrogen and phosphorus levels in the rivers and streams flowing into the lake were measured at 69 sites. Stream flows were measured continuously at 18 of these sites, and were regularly gauged or estimated at many others. For this assessment we used the information from 21 key sites located on inflows which together drained an area of 2310 km^2, or about 86% of the entire catchment area (estimated to be 2673 km^2: Schouten *et al.*, 1981).

The annual load of total nitrogen entering the lake from the 21 measured inflows was 764 tonnes, giving an average yield from the catchment of 3.3 kg N/ha/yr. In addition, 164 t/yr of total nitrogen entered the lake via the Tokaanu Power Station (mean flow 38 m^3/s, about half of which was "foreign water" diverted from outside the natural catchment via the then-operational "Western Diversion"). Specific yields from individual sub-catchments varied from 0.5 kg N/ha/yr (Mangakara, area 8 km^2) to 16 kg N/ha/yr (Waikino, area 10 km^2). The largest individual source of nitrogen (158 t/yr) entered via the Tongariro River which drained 786 km^2 (29% of the lake catchment). This corresponded to an average yield of 2 kg N/ha/yr.

By way of comparison, the average yield of total nitrogen from the catchment of Lake Rotorua was about 13 kg N/ha/yr during 1976–77 (Hoare, 1980), or about four times higher than that from the Lake Taupo catchment.

Nitrogen levels in rainfall collected near the lake were measured during 1981–83 (Timperley *et al.*, 1985). From these, an average load of 2.5–3.1 kg N/ha/yr was obtained. Applying this rate to the area of the lake gives a directly deposited load of about 170 t/yr.

Nitrogen loads from different land-uses

From the land-use information given by Schouten *et al.* (1981) for each of their sites, it was possible to identify typical yields of nitrogen for the major land-use types in the catchment. These are shown in Table 1. Estimated yields ranged from 2 kg N/ha/yr for the alpine areas (i.e., bare land and tussock) to 5 kg N/ha/yr for sheep and beef pasture—values which are similar to those found elsewhere for these land-uses (e.g., Wilcock, 1986).

TABLE 1: Nitrogen budget for Lake Taupo during c. 1980–2000 (after Schouten *et al.* 1981, and Timperley *et al.*, 1985).

	Area (km^2)*	Estimated N yield (kg/ha/yr)	Nitrogen load (t/yr)
Bare & tussock land	300	2	60
Native forest	1180	2.5	300
Pine forest	600	2.5	150
Pasture	620	5	310
Turangi sewage§			<10
Tongariro PD ("foreign")†			80
Rainfall (direct deposition)			170
		Total	1080

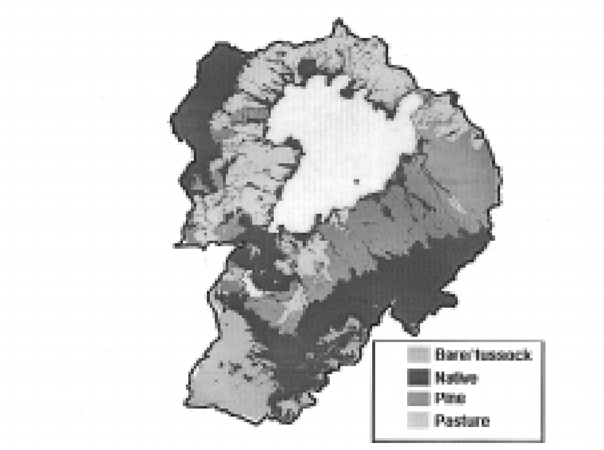
*areas (1996) based on Land Cover Database (Terralink, 1996): see Figure 1

§based on 1000 m^3/d at 12 g N/m^3 (Harrison Grierson, 1999)

†based on 28 m^3/s (see text) at 0.09 g N/m^3 (the average total N level in four Tongariro headwater streams during 1976–78: Schouten *et al.*, 1981)

Figure 1 shows the current land-use distribution within the lake catchment, with the total areas in each land-use type being listed in Table 1. Using these areas, and the corresponding nitrogen yields, the load of nitrogen from each land-use can be obtained (Table 1). Table 1 also shows an estimate of the nitrogen load entering the lake from treated sewage wastewater from Turangi (the largest settlement from which wastewater enters the lake; note that some wastewater from about 10 small settlements will also enter the lake). The table also shows the load in the "foreign water" currently diverted from outside the natural catchment via the Tongariro Power Development (average flow during 1992–99 was 28 m^3/s: Genesis Power, unpublished results [note that both the "Western" and "Eastern" Diversions operated during this period]). The total load of nitrogen to the lake from the various sources was 1080 t/yr.

FIGURE 1: Land-use in the catchment of Lake Taupo (1996). Source: Terralink (1996).

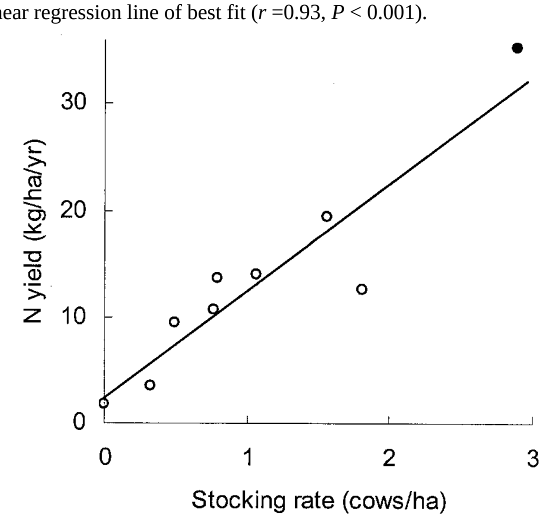


Conversion to dairying

Two estimates have recently been made of the area of sheep and beef pasture that could be converted to dairying. The first was that of Ministry of Agriculture (1997, figure 5.4.3). This identified three broad zones within the lake catchment, which, together with additional small areas that have already converted to dairying (e.g., near Kinloch), occupy an area of about 250 km^2. The second was that of Davidson (1999), which identified a smaller area of about 100 km^2.

Yields of nitrogen from dairy land in the Waikato Region have also been determined recently (Vant, 1999; Wilcock *et al.*, 1999). Figure 2 shows how nitrogen yield increases as the average stocking rate of dairy cows in the contributing catchment increases. Yields of 20–35 kg N/ha/yr are associated with dairy cow stocking rates of 2–3 cows/ha. For this assessment we assumed that the nitrogen yield from existing sheep and beef pasture in the Taupo catchment that could be converted to dairying will be 30 kg N/ha/yr.

FIGURE 2: Nitrogen yields to surface waters and average dairy cow stocking rates in nine catchments in the Waikato region. Sources: open circles, Vant (1999); closed circle, Wilcock *et al.* (1999). The line is the linear regression line of best fit (r =0.93, P < 0.001).



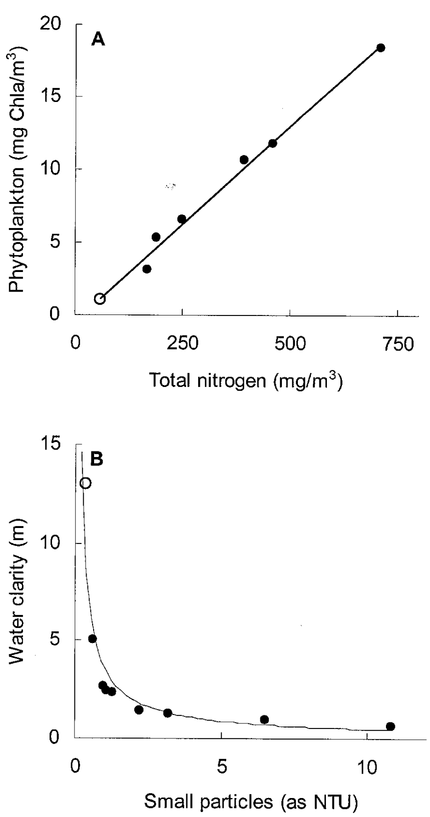
The 620 km^2 of pasture in the catchment currently produces an annual load of nitrogen of about 310 tonnes (Table 1). Converting 100 km^2 of this to dairying would result in a total annual load from pastoral land of 560 tonnes (= 100 km^2 @ 30 kg/ha/yr + [620 –100] km^2 @ 5 kg/ha/yr), an increase of 250 tonnes. The total load of nitrogen to the lake would therefore increase from 1080 t/yr (Table 1) to 1330 t/yr—a 23% increase. If 250 km^2 of pasture were to be converted, the annual load from pastoral land would be about 940 tonnes (an increase of 630 t), so the load to the lake would increase by about 60% to a total of 1710 t/yr.

EFFECTS OF ADDITIONAL NITROGEN

Nitrogen, phytoplankton and water clarity

Environment Waikato currently monitors nitrogen, phytoplankton biomass and water clarity in both Lake Taupo and the Waikato River. Figure 3A shows that phytoplankton biomass in these waters increases linearly with increasing nitrogen concentration, while Figure 3B shows that water clarity decreases approximately hyperbolically as the level of small particles present in the water increases (as often found elsewhere, e.g., Edmondson and Lehman, 1981). In Lake Taupo, the small particles that affect water clarity are mostly cells of (nitrogen-dependent) phytoplankton. So an *x*-fold increase in the nitrogen level in Lake Taupo could therefore result in an *x*-fold increase in the level of phytoplankton biomass, which in turn would cause water clarity to fall to 1/*x* of its current level (i.e., to fall by 100 ¥ [1 – 1/*x*] percent).

FIGURE 3: Water quality in Lake Taupo (open circle) and at sites in the Waikato River during 1994–97. A, Total nitrogen and phytoplankton biomass (measured as chlorophyll a, Chla); B, Water clarity (horizontal visibility) and concentration of small particles (measured as laboratory turbidity, NTU).



Reduction in water clarity

As shown above, if 100–250 km^2 of sheep and beef pasture were to be converted to dairying, the nitrogen levels in the lake would increase by about 20–60%. So would the phytoplankton levels. This would cause water clarity to fall by about 20–40%. In sheltered embayments and other nearshore areas where nitrogen-rich stream waters enter the lake, the deterioration in water quality could become apparent reasonably quickly. However, in the deeper, better-mixed waters beyond the nearshore zone it would be some time before the decline in water clarity became apparent.

This is partly because it takes about 12 years to replace the water in the lake. In addition, the water in any spring-fed streams entering the lake may be quite old, with the nutrient levels reflecting previous, rather than current, land-uses. Some preliminary work has found water in a spring in the area to be about 10 years old, while water from a groundwater bore was about 30 years old (Institute of Geological and Nuclear Sciences, unpublished results). It would thus be likely to be one or more decades before the effects of any intensification in dairying were to become fully apparent in the main body of the lake.

Note that these mechanisms also mean that current lake water quality is probably not yet in equilibrium with current land-use in the catchment. That is, regardless of any land-use changes that may occur in the future, lakewater quality may continue to slowly decline in response to the intensification which has occurred in recent decades. Even so, this decline will be much less marked than that which would be likely to follow a major intensification in land-use such as that described here for dairying.

SUMMARY AND CONCLUSIONS

- Lake Taupo currently has excellent water quality: nutrient and phytoplankton levels are low, and the water is clear and blue.
- About half of the original tussock and native forest-covered catchment has been developed since 1840—mainly for forestry and sheep and beef pasture.
- Recent records show a decline in lakewater quality.
- Conversion of some of the sheep/beef pasture to more intensive dairying has recently begun, with 100–250 km^2 (4–9%) of the catchment being potentially suitable for dairying.
- Elsewhere in the region, dairying land produces large loads of nitrogen (20–35 kg/ha/yr) to downstream waterbodies. If the potentially convertible dairying land in the Taupo catchment yielded nitrogen at rates like this, the overall nitrogen load to the lake would increase markedly—by 20–60%.
- The growth of the phytoplankton in the lake is nitrogen-limited. Increasing the nitrogen load by 20–60% could therefore cause the average quantity of phytoplankton in the lake to increase by a similar proportion.
- This increase in phytoplankton biomass would be likely to cause a 20–40% reduction in water clarity.
- The reduction in clarity may not become fully apparent for one or more decades in deeper parts of the lake, but it could occur more rapidly than this in sheltered embayments where nutrient-enriched stream waters enter.

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