Groundwater and Surface Water Hydrology in the Lake Rotorua Catchment, New Zealand, and Community Involvement with Lake Water Quality Restoration

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ABSTRACT.

Water quality in Lake Rotorua, New Zealand, deteriorated since the 1960s because of excessive phytoplankton growths due principally to increasing nitrogen and phosphorus in the lake waters. Nutrient concentrations in eight of the nine major streams feeding Lake Rotorua have increased since 1965.

The groundwater system has a key role in the hydrology of the Lake Rotorua catchment and the groundwater system is probably the control on the time delay between intensification of agricultural land use and response of surface water quality. All major, and many minor streams, in the catchment are fed by springs. Two lithological units are most important to groundwater flow in the Lake Rotorua catchment: Mamaku Ignimbrite, erupted in about 200,000 years ago and Huka Formation sediments which filled the caldera left by the Mamaku Ignimbrite eruption.

Rainfall recharge to groundwater in the groundwater catchment of Lake Rotorua is estimated as approximately 17300 L/s. A calibrated steady-state groundwater flow model estimates that approximately 11100 L/s of this flow discharges into streams and then into the lake and the balance travels directly to Lake Rotorua as groundwater discharge through the lake bed.

Land use has impacted on groundwater quality. Median Total Nitrogen (TN) values for shallow groundwater sites are highest for the dairy land use (5.965 mg/L). Median TN values are also relatively high for shallow sites with urban-road and cropping land uses (4.710 and 3.620 mg/L, respectively). Median TN values for all other uses are in the 1.4 to 1.5 mg/L range.

Policy development for Lake Rotorua includes defining regional policies on water and land management and setting an action plan for Lake Rotorua restoration. Aims in the action plan include: definition of the current nutrient budget for Lake Rotorua, identification of nutrient reduction targets and identification of actions to achieve targets. Current actions to restore Lake Rotorua water quality include: treatment of Tikitere geothermal nitrogen inputs to Lake Rotorua, upgrade of Rotorua City sewage plant, new sewage reticulation and alum dosing in selected streams to remove phosphorus.

1.0 INTRODUCTION

Water quality in Lake Rotorua, New Zealand, deteriorated since the 1960s because of excessive phytoplankton growths due principally to increasing nitrogen and phosphorus in the lake waters. The Trophic Level Index (an index including measurements of Chlorophyll, Seechi Depth, Total Phosphorus and Total Nitrogen) indicates that Lake Rotorua is currently eutrophic and indications of poor water quality, such as algal blooms an anoxic lake waters, are now common in summer.

Nutrient concentrations in eight of the nine major streams feeding Lake Rotorua have increased since 1965. This increase indicates a delayed response of surface water quality to intensification of agricultural land use over the last 60 years. The groundwater system is probably the control on the response time of surface water quality to intensification of agricultural land use because the groundwater system has a key role in the hydrology of the Lake Rotorua catchment. Therefore knowledge of the groundwater system is a key prerequisite to understanding of the hydrology of the Lake Rotorua catchment.

This paper reviews the groundwater and surface water of the Lake Rotorua catchment. The paper also outlines the importance of good hydrological characterisation to Lake Rotorua remediation options. Regional, and local, communities aim to restore Lake Rotorua's quality. Significant efforts will be required by these communities to restore Lake Rotorua water quality. This paper reviews regional policies relevant to Lake Rotorua restoration, reviews Lake Rotorua restoration project governance and summarises current actions.

2.0 SCIENCE REVIEW

2.1 Trends in nitrogen inputs to Lake Rotorua

Nutrient concentrations in eight of the nine major streams feeding Lake Rotorua, New Zealand, have increased consistently over the last four decades (Figure 1). Nitrogen concentrations are still quite low, certainly much lower than the drinking-water standard of 11.3 g/m^3 NO_3 –N. The increase in nitrogen concentrations over time is caused by delays in the response of surface water to land use due to residence of water in the groundwater system (Morgenstern 2003). The majority of nitrogen comes from the catchment, i.e. from agricultural land uses.

Total nitrogen entering the lake from streams is increasing (Figure 2), with an estimated 475 tonnes N/year entering the lake through streams in 1965 and an estimated 692 tonnes N/year entering the lake through streams in 2002 (Rutherford 2003).

A brief respite in total nitrogen loading occurred in 1990 (Figure 2) with the development of improved Rotorua City sewage treatment where treated wastewater was sprayed to land in the Puarenga Stream catchment. Nitrogen concentrations in Puarenga Stream catchment ('PUA' in Figure 1) have increased since 1990, partly due to increasing loading of Puarenga Stream from the Rotorua City sewage land treatment area.

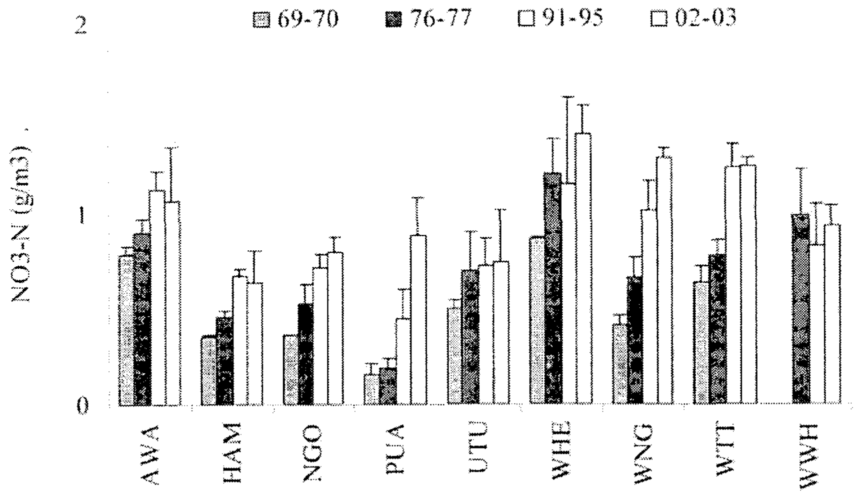

Figure 1. Concentrations of nitrogen in nine of the major streams in the Rotorua catchment (Rutherford 2003).

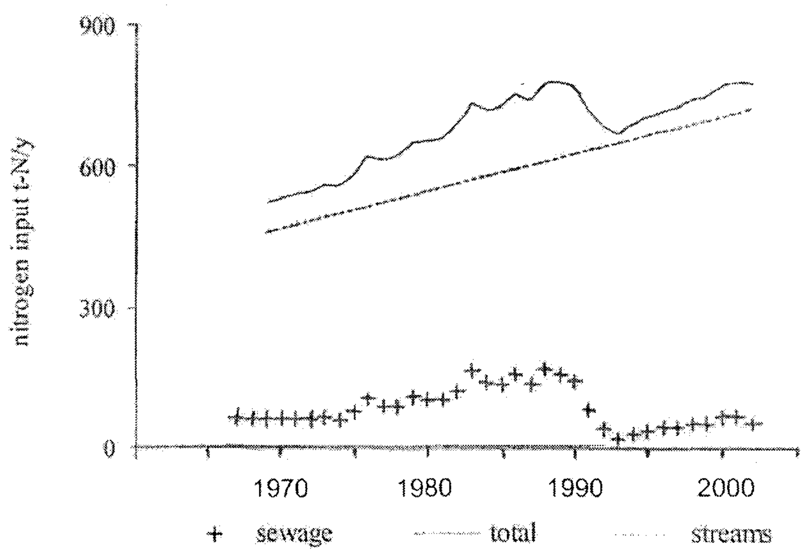

Figure 2. Total nitrogen entering Lake Rotorua from the nine major streams in the Rotorua catchment and from Rotorua City treated sewage (Rutherford 2003).

2.2 Geology

The chronology of geological history of the Lake Rotorua catchment includes: eruption of the Mamaku Ignimbrite and Lake Rotorua caldera collapse approximately 200,000 years ago; eruption of Mamaku Rhyolite domes and Young Rhyolite domes soon after the Lake Rotorua caldera collapse; deposition of Huka Formation sediments in the Lake Rotorua caldera; deposition of Holocene alluvial sediments in the Lake Rotorua caldera.

Two lithological units are most important to groundwater flow: Mamaku Ignimbrite and Huka Formation sediments. The geology of Mamaku Ignimbrite on the Mamaku Plateau includes the following sequence:

- upper – unwelded (pumice etc) ignimbrite with a thickness of approximately 5 m;
- middle, welded unit, with a thickness of approximately 60 m where groundwater flows in fractures
- lower unit – unwelded (pumice etc) ignimbrite with a thickness of approximately 45 m that is the most important aquifer for groundwater supply.

The Huka Formation consists of unconsolidated pumice and sediments.

2.3 Surface water flow

Base flow in streams is commonly supported by spring flow. Base flow in streams is estimated with surface water gaugings measured in 1973/1974, 1976/1977, 2004/2005 and 2006. In summary surface water flows total:

- 11730 L/s flow in major streams;
- 149 L/s flow in minor streams;
- 142 L/s flow in lake-front features such as swamps and drains; and
- 45 L/s flow from the Rotorua geothermal field.

All large springs are perennial springs and they demonstrate a relatively uniform flow rate during the year. The Hamurana Springs complex, with a flow of around 2800 L/s, has the largest spring flow in the Lake Rotorua catchment.

2.4 Groundwater system

3)A steady-state groundwater flow model is developed that aims to represent groundwater flow in the catchment including: a two-layered aquifer system comprising a shallow unconfined aquifer and a deep confined aquifer; external boundaries that are no-flow boundaries; an internal boundary representing Lake Rotorua with a constant head boundary for the shallow aquifer and a no-flow boundary for the deep aquifer.

The model includes a simulation of groundwater recharge from rainfall, discharge of groundwater to surface water and discharge of groundwater to the lake. Calibration of the model aims to represent observed spring flow and estimated stream base flow. Calibration is most difficult for streams in the northwest of the catchment where springs, for example Hamurana Springs, discharge large flows from relatively small surface catchments. Therefore springs in the northwest probably have a groundwater catchment that extends beyond the surface catchment.

Rainfall recharge to groundwater in the groundwater catchment of Lake Rotorua is estimated as approximately 17300 L/s. The calibrated groundwater flow model has approximately 11100 L/s of this flow discharging into streams, and then into the lake, with the balance discharging directly to Lake Rotorua through the lake bed.

Identification of groundwater catchments within the Lake Rotorua groundwater catchment is required for an assessment of land use options and water quality. Therefore, the boundaries of 25 groundwater catchments within the Lake Rotorua groundwater catchment are estimated with an analysis of groundwater flow directions calculated by the groundwater flow model. Groundwater catchments include catchments of springs and catchments where groundwater discharges directly to Lake Rotorua. Boundaries of proposed Lake Rotorua groundwater catchments, within the Lake Rotorua groundwater catchment, are relatively insensitive to rainfall recharge as shown by a visual comparison of groundwater flow vectors estimated for low, medium and high rainfall recharge scenarios.

2.5 Groundwater quality

Groundwater nutrient data is available for 169 sites in the Lake Rotorua catchment. Of these 169 sites, 44 are springs, five are temporary piezometers, and 120 are wells.

Relationships between Total Nitrogen (TN) and groundwater chemistry sample depth are assessed with plots of median TN concentrations sample depths, bottom of well casing or top of well screen depths, and well static water level depth. Best-fit lines to the data have negative slopes that are consistent with lower TN concentrations at depth but low coefficients of determination indicate that a straight-line relationship is not statistically significant. The highest coefficient of determination is for the correlation of bottom of well casing, or top of well screen, depths with median TN concentrations.

It would be expected that any relationship between land use and groundwater quality would be more evident with regard to the shallower groundwater wells than the deeper groundwater wells. The relationship between land use and groundwater quality is assessed by calculating median levels of TN and Total Phosphorus (TP) using only the relatively shallow well data (i.e., temporary piezometers, springs, and wells of 30 m depth or less). Median TN value for shallow sites is highest for the dairy land use (5.965 mg/L). Median TN values are also relatively high for shallow sites with urban-road and cropping land uses (4.710 and 3.620 mg/L, respectively). Median TN values for all other uses are in the 1.4 to 1.5 mg/L range. With regard to median TP, the land use with the highest value is cropping (0.099 mg/L) which is similar to forest land use (0.087 mg/L). The land use with the lowest TP value is dairy (0.038 mg/L). Other land uses cluster in the 0.05 to 0.06 mg/L range.

Summary statistics for median TN and TP levels in relation to soil type include:

- median TN values were relatively high for loamy sand and sandy loam soils (1.9 and 2.215 mg/L, respectively) and relatively low for the sand and soil classifications (1.45 and 1.33 mg/L, respectively);
- median TN values were relatively very low for the peaty loam classification (0.775 mg/L);
- with the exception of peaty loam, median TP levels were close to 0.06 mg/L (ranging from 0.053 to 0.079 mg/L). The median TP value for peaty loam was about double this level at 0.133 mg/L.

2.6 Importance of good characterisation

Remediation options for Lake Rotorua water quality include land use change. Good characterisation should allow predictions, with confidence estimates, of groundwater pathways including: groundwater that travels via streams to the lake; and groundwater that discharges directly to Lake Rotorua.

Assessment of natural denitrification of water requires a good understanding of groundwater pathways to the lake. Partial denitrification may occur in streams that take groundwater to the lake whereas denitrification may not occur in groundwater that travels directly to the lake. Therefore land remediation may have more effect on improving lake water quality, and be more cost effective, when applied to catchments where natural denitrification is less effective in reducing nutrient discharge from land to the lake.

Poor characterisation of the hydrological system is one reason why the legal system commonly struggles with resource allocation decisions. Characterisation of the hydrological system, to a high standard, is of vital importance in Lake Rotorua restoration. For example we need to know the detail of agricultural impacts on water: where does water go from a farm - via surface water or via groundwater, or both?; what are the time scales of response by surface water and groundwater to land use change?; what are the options, costs and benefits of changing the intensity of land use.

3.0 ENVIRONMENT BAY OF PLENTY POLICIES ON LAKE RESTORATION

Policy development is a two-stage process. Firstly regional policies are set on water and land management and secondly an action plan for Lake Rotorua restoration is developed.

Water quality science in Lake Rotorua indicates that nitrogen is driving phytoplankton productivity and therefore nitrogen discharge from the catchment needs to be targeted if the community is to see improvements in lake water quality in the medium term (10 – 20 yrs). This requires policies for water and land management in the catchment of Lake Rotorua. The primary objective of policies is to reduce both nitrogen and phosphorus in the lake to limit productivity of phytoplankton. The secondary objective of policies is to stop the algal population being dominated by undesirable blue-green algae by maintaining a high nitrogen-to-phosphorus ratio.

Recent Environment Bay of Plenty regional policy includes 'Rule 11' to cap nutrient loss from land use change. An action plan to manage water and land management in Lake Rotorua is currently under development by a community-based working party. The development of the action plan is a four-step process including: risk assessment and problem evaluation; project prioritization; development of actions and targets; implementation and monitoring of the action plan.

The action plan aims to: define the current nutrient budget for Lake Rotorua; determine the level of nutrient inputs that is sustainable; identify nutrient reduction targets; determine actions to achieve targets; take a holistic approach to planning, including sewerage, landscape, climate change, land use change, land-use management change and economics; reach agreement on the understanding of the science.

The plan aims to reduce current nutrient inputs to Lake Rotorua by 150 tonnes nitrogen per year, from the catchment, and by 10 tonnes phosphorus per year, from the catchment and from sediments. Current actions in the short term (2-3 years) include research and engineering to consider:

- diversion of the Ohau Channel;
- treatment of Tikitere geothermal nitrogen inputs to Lake Rotorua
- diversion of Hamurana Stream;
- upgrade Rotorua City sewage plant;
- new sewage reticulation;
- alum dosing in selected streams to remove phosphorus;
- in-lake flocculation and sealing of sediments.

Actions in the long term (3-15 years) include assessment of:

- land use change options;
- land use management change options;
- ongoing catchment management including: riparian control, nutrient loss control, wetland creation and wetland enhancement;
- new technologies.

For example an agricultural land use and nutrient discharge model (OVERSEER in combination with a mitigation model NPLAS) is currently used to estimate nutrient leaching from farms. Nutrient leaching from each farm will be 'benchmarked' for the 3 years 1 July 2001 – 30 June 2004. Farmers may increase production in the future if their land use change is consistent with the aim of maintaining the nutrient cap. Reductions in the cap are necessary to meet the reduced lake nutrient input target. This will be achieved by the implementation of best management practices and with the use of incentives to reduce the nutrient cap of individual farmers.

4.0 LAKE ROTORUA RETORATION AND THE COMMUNITY

The Lake Rotorua restoration project is led by the local and regional communities. Lake Rotorua restoration is a significant political issue amongst the local and regional communities because many people are passionately concerned about Lake Rotorua water quality. The project is lead by a Joint Strategy Committee. The Joint Strategy Committee consists of the leaders of:

- Environment Bay of Plenty who represent regional ratepayers;
- Rotorua District Council who represent local ratepayers;
- Te Arawa Lakes Trust Board who represent Maori groups around the lake and who own the bed of Lake Rotorua.

The Joint Strategy Committee interacts with central government through the Ministry of Environment. The Joint Strategy Committee leads the 'Action Plan Working Party', the 'Stakeholder Forum' and a project coordinator. Action Plan Working Party members include: strategic partners, Maori groups, community groups and stake holders (such as farmer groups, fishermen's organisations and environmental groups). The Stakeholder Forum allows open dialogue between the Joint Strategy Committee and the local community.

Lake Rotorua restoration is a significant technical challenge for the community. The project coordinator leads two technical advisory groups that include experts from across New Zealand who bring scientific advice to the project. The technical advisory group on water aims to assess lake, and catchment, science on water quantity and water quality. Bi-monthly meetings of this group are held to review research results, assess monitoring results and discuss ideas for new research. The technical advisory group on land aims to assess research on land use, land management and land-based remediation options.

5.0 REFERENCES

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