Possible water quality issues associated with a proposed hydro-dam on the Mohaka River: brief report

NIWA Client Report: CHC2006-137
March 2007

NIWA Project: MEL06521

Possible water quality issues associated with a proposed hydro-dam on the Mohaka River: brief report

Bob Spigel

Prepared for

Merdian Energy Ltd

NIWA Client Report: CHC2006-137
March 2007
NIWA Project: MEL06521

National Institute of Water & Atmospheric Research Ltd
10 Kyle Street, Riccarton, Christchurch
P O Box 8602, Christchurch, New Zealand
Phone +64-3-348 8987, Fax +64-3-348 5548
www.niwa.co.New Zealand

Contents

Reviewed by:	*Approved for release by:*
C. Howard-Williams	Norton
Clive Howard-Williams	Ned Norton

Executive Summary

This report summarises results of a desktop study that examined available data on water quality in the Mohaka River, firstly to compare existing water quality in the Mohaka River with other rivers, and secondly to make predictions about the likely effects that creation of a reservoir on the lower Mohaka River would have on existing river water quality.

Key findings relating to existing river water quality are:

- There are two National River Water Quality (NRWQN) sites on the Mohaka River for which monthly data are available from 1989 through 2005, one in the upper catchment at Glenfalls and the other on the lower river at Raupunga. Data from Raupunga are representative of water quality for inflow to the proposed reservoir.

- Water clarity at Raupunga is lower, and turbidity higher, than national averages. The opposite is true for Glenfalls. The increase in turbidity downstream in the Mohaka River is due to an increase in fine mineral sediments transported by the river as it flows through more erodible terrain in the middle and lower catchments.

- pH is high in the Mohaka River, particularly at Raupunga, where the elevated values are attributed to photosynthetic activity of benthic algae.

- Total nitrogen and dissolved inorganic nitrogen concentrations are low (roughly half) compared to national averages. On the other hand, total phosphorus and dissolved reactive phosphorus are greater than or similar to the corresponding national averages. Agricultural land use is low (e.g., percentage pastoral land cover) in the Mohaka catchment compared to both regional and national figures.

- Mean water temperature at Raupunga is 1.0 °C warmer than the national average, while electrical conductivity (a surrogate for total dissolved solids and major ion concentrations) is approximately equal to the national mean.

- Water quality is generally "very good" in relation to recreational guidelines, although records of faecal coliform bacterial counts are not yet long enough to allow a recreation grade to be established for the river using current Ministry of Health and Ministry for the Environment guidelines.

- Upstream (Glenfalls) and downstream (Raupunga) water quality are generally comparable, with the exception of much lower clarity at Raupunga, as mentioned above. As might be

expected, water temperature at Raupunga is warmer than at Glenfalls, due to the difference in elevation between these two sites.

- Average biochemical oxygen demand (as BOD_5) is below the national level, as are the values for light absorption coefficients, indicating water with low organic content. Dissolved oxygen levels are high, and the BOD concentrations are within guidelines specified by MfE (1992) for control of undesirable biological growths.

- Overall, it can be said that water quality at Raupunga is good, with the exception of low clarity and high pH.

Key findings relating to predicted water quality in the proposed reservoir are:

- The proposed dam will back water up within a narrow, steep-sided valley for a distance of approximately 15.7 km, with a maximum water depth, just behind the dam, of approximately 40 m.

- Residence time in the proposed reservoir is approximately 7 days. Likely water quality changes include thermal stratification in summer with oxygen depletion in bottom waters, increased water clarity in surface waters, increasing phytoplankton concentrations with distance downstream toward the dam, and insertion of river inflows during summer near the level of the thermocline.

- Because of its relatively short residence time, the exact nature of the water quality changes that occur in the reservoir will depend strongly on how the outflows from the reservoir are managed, in particular on the levels within the water column at which water is drawn off. By providing for an offtake structure that has the capability of withdrawing water from multiple (e.g.,) levels within the reservoir, it should be possible to minimise and some cases avoid adverse consequences associated with hypolimnetic oxygen depletion.

- Comparison of annual loads of total nitrogen and total phosphorus into the reservoir with national statistics from Burns et al.’s (2000) study of trophic levels in New Zealand lakes indicates that the reservoir will have a trophic level index of between 3 and 4, and that the reservoir could be classified as mesotrophic to eutrophic (i.e., generally containing moderately high levels of nutrients, and having moderately high algal productivity. These predictions are of a general and indicative nature only.

- In terms of comparison with existing reservoirs, Lake Ohakuri on the Waikato River provides the best match in terms of size, residence time, maximum depth, climate, and nutrient loading.

1. Introduction

Meridian Energy Ltd requested that NIWA provide a short report on water quality issues associated with the proposed dam on the Mohaka River. The request originated from discussions with Ngati Pahauwera and specifically focused on two issues:

- What is the existing water quality in the Mohaka River? This was responded to by undertaking a summary of any available data, accompanied by general comments on how this compares to other rivers both locally and nationally.

- What are the anticipated effects of the dam on water quality, including temperature? A general discussion based on experience with similar lakes was requested rather than a detailed study.

This report makes use of data from the New Zealand National River Water Quality Network (**NRWQN**) site at Raupunga on the Mohaka River to address the first point, and a comparison with three other riverine hydropower lakes in the North Island to address the second point.

The hydrology of the Mohaka River, and the geology, vegetation cover and land use of its catchment, have been described in the Water and Soil Resource Management Plan for the Mohaka River catchment prepared by Hawke's Bay Catchment Board and Regional Water Board (**HBCB**, now Hawke's Bay Regional Council) (HBCB 1986), and in the NIWA report by Hicks et al. (2006), which was undertaken as part of the current assessment of a proposed dam on the Mohaka River. Aspects relevant to water quality will be referred to below. Related information can be found in Landcare's New Zealand Land Resource Inventory (Newsome 1992), in NIWA's River Environment Classification (**REC**) (Snelder et al. 2005) and on the Geological Map of New Zealand (Grindley 1960).

2. Available data and comparison with other rivers

2.1. Catchment and river

The Mohaka has its source in the steep greywacke ranges and pumice-infilled valleys of the central North Island east of Lake Taupo. Along its 170 km course it follows and crosses fault lines that separate its large upper and middle catchments from its narrower lower catchment (Fig. 1), cuts through steep valleys of Tertiary sandstones, siltstones and mudstones, and eventually empties into Hawke Bay (Grindley 1960, HBCB 1986, Young & Foster 1986, Hicks et al. 2006). HBCB (1986, p. 86) note that "man has had a major influence on the vegetation of the catchment", having cleared large areas for pasture and exotic forestry. Some of this land has proved too erosion-prone and/or infertile, and has been left to revert to shrubland. The remaining indigenous (primarily beech-podocarp) forest is confined to steep greywacke lands in the central catchment. A large portion of the catchment is sensitive to "practices that are likely to facilitate erosion, flooding, or deposition in water courses" (HBCB 1986, p. 11), and this includes large areas of greywacke steeplands (source of the gravel supply discussed by Hicks et al 2006), as well as virtually all of the Tertiary steeplands that supply sand, silt and clay to the lower river, making it "very turbid … during fresh flows" (HBCB 1986, p. 51).

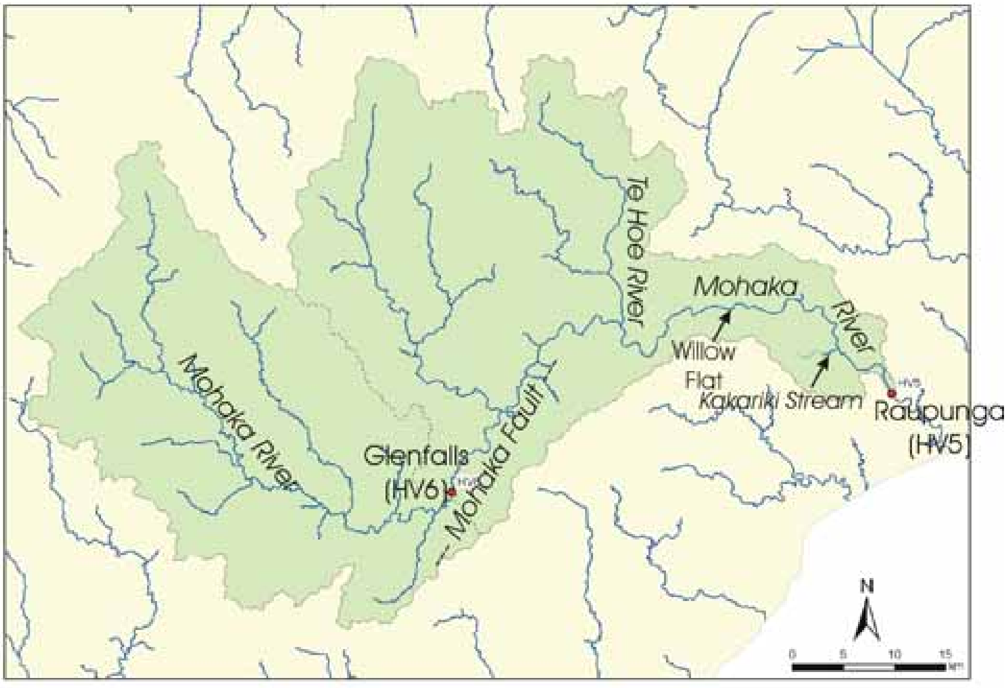

Figure 1: The Mohaka River and major tributaries, draining to Hawke Bay. Red dots show locations of NRWQN sites. The catchment above the NRWQN site at Raupunga is shaded as pale green; the upper part of the catchment that drains to Glenfalls, the second water quality monitoring site on the Mohaka River, is delineated by a dotted line. The proposed reservoir will extend from near the Kakariki Stream confluence upstream to Willow Flat, approximately 15.7 km (as indicated by arrows).

2.2. New Zealand National River Water Quality Network (NRWQN) sites

The NRWQN began operation in January 1989 at 77 sites throughout New Zealand. The network's design and objectives have been documented by Smith et al. (1989), Smith & McBride (1990), and Smith and Maasdam (1994). The parameters included in the monitoring are:

- flow; temperature; electrical conductivity (presented as specific conductance, or conductivity at 25°C);
- dissolved oxygen concentration (**DO**);
- pH;
- water clarity (200 mm black disk horizontal viewing distance);
- turbidity;
- spectrophotometric light absorbance on filtered samples at wavelengths of 340 nm, 440 nm and 740 nm, which are then used to calculate $\mathbf{g_{340}}$ and $\mathbf{g_{440}}$, the absorption coefficients at 340 nm and 440 nm (with the absorbance at 740 nm providing a correction for scattering effects);
- nutrient concentrations for ammonium ($\mathbf{NH_4}$), nitrate ($\mathbf{NO_3}$), dissolved reactive phosphorus (**DRP**), total nitrogen (**TN**) and total phosphorus (**TP**);
- biochemical oxygen demand ($\mathbf{BOD_5}$, unfiltered samples; not measured after July 2002);
- bacteriological counts (starting in February 2005) for *Escherichia coli* and total coliforms (**E Coli** and **T Coli**).

There are two NRWQN monitoring sites on the Mohaka River (Fig. 1), one in the upper catchment (at Glenfalls, site number HV6, NZMG coordinates N 6218750, E 2824030, NZ REC Reach 8017355, catchment area 1040 km^2, altitude 320 m above sea level), and one in the lower catchment at Raupunga (site number HV5, NZMG coordinates N 6228490, E 2867200, NZ REC Reach 8014348, catchment area 2371 km^2, altitude 15 m above sea level). Both sites have been monitored monthly since 1989 as part of the NRWQN; the Glenfalls record began 28 February 1989, Raupunga 6 March 1989. HBCB conducted water quality sampling at both sites prior to the establishment of the NRWQN, at Raupunga starting in 1980 and briefly at Glenfalls in 1983. Eighteen other sites scattered throughout the catchment were also sampled at various times. A complete listing of results from laboratory analyses for all earlier sampling is contained in HBCB (1986, Sec. 3.3).

This report focuses mainly on the data from Raupunga, which is close to (7 km downstream of) the proposed dam site near the Kakariki Stream confluence. Some data from Glenfalls are presented for comparison purposes. Earlier (1981-1985) sampling by HBCB on 21 occasions at Willow Flat, which marks the upstream extent of the proposed reservoir, showed that water quality at Raupunga and Willow Flat were "very similar" (HBCB 1986, p. 51). It is anticipated that the dam will back water up as far as Willow Flat (Hicks et al. 2006). Hence it is reasonable to assume that the NRWQN data from Raupunga are representative of water quality for the dominant inflow to the proposed reservoir.

NRWQN statistics for Raupunga from 6 March 1989 – 9 November 2006 are presented in Table 1; data for beyond November 2006 were not available at the time of writing. For purposes of comparison, summary statistics for all 77 NRWQN sites combined (for the years 1989-2004; the next national summary is provisionally due by the end of 2007) are included in the table, as well as means and medians for the Mohaka River at Glenfalls in the upper catchment. Graphs showing time series for all data from Raupunga and Glenfalls are contained in Appendix A, and all summary statistics for Glenfalls are given in Appendix B.

The table indicates that for the Mohaka River at Raupunga,

- discharge is lower than the national average;
- water temperature is 1 °C warmer than the national average;
- electrical conductivity (a surrogate for total dissolved solids and dissolved ionic concentrations) is similar to the national average;
- nitrogen concentrations (as ammonium, nitrate and total nitrogen) are low compared to national averages, while phosphorus concentrations (as dissolved reactive phosphorus and total phosphorus) are similar to or greater than national averages;
- water clarity is low and turbidity is high compared with national averages.

Comparisons are given below between water quality data at Raupunga with data at Glenfalls, and with water quality nationwide. The national comparisons are made in two ways – first with the statistics for all NRWQN sites combined (Table 1 and Appendix A), and secondly with results from cluster analyses that have been carried out by Maasdam and Smith (1994) to identify sites in the NRWQN with "similar

Table 1: NRWQN statistics for Mohaka River at Raupunga*

	Flow m^3/sec (see note 4)	**Temp deg C**	**Cond uS/cm @ 25 Deg C**	**DO % Sat**	**Clarity m**	**Turbidity NTU**	**Abs g340 /m**	**Abs g440 /m**
Sample size	213	213	213	208	210	213	211	211
Nat'l sample size	*14894*	*14889*	*14886*	*14787*	*14828*	*14880*	*14836*	*14836*
Mean	73.33	13.5	109	104	0.80	26.5	3.13	0.70
Glenfalls mean	34.14	11.1	81	102	2.33	2.6	2.41	0.54
Nat'l mean	*91.11*	*12.5*	*112*	*101*	*2.13*	*16.3*	*5.51*	*1.11*
Std dev	84.76	4.59	13.5	5.4	0.81	68.5	1.80	0.40
Maximum	1050.0	25.0	144	134	3.62	640	13.6	2.81
95 percentile	166.71	21.2	130	113	2.58	89.9	6.25	1.45
Nat'l 95 perc	*415.00*	*20.2*	*238*	*111*	*6.89*	*60.0*	*17.0*	*3.38*
75 percentile	82.70	17.1	119	106	1.23	27.0	3.40	0.82
Nat'l 75 perc	*87.20*	*15.8*	*124*	*103*	*2.93*	*6.80*	*7.31*	*1.48*
Median	57.43	13.2	109	103	0.47	6.60	2.58	0.57
Glenfalls median	26.36	10.8	82	101	2.30	1.00	2.00	0.46
Nat'l median	*27.31*	*12.2*	*87.4*	*101*	*1.36*	*2.30*	*3.66*	*0.75*
25 percentile	35.92	9.8	98.7	101	0.20	2.50	2.07	0.46
Nat'l 25 perc	*7.53*	*9.0*	*64.9*	*98.2*	*0.51*	*0.98*	*1.72*	*0.36*
5 percentile	20.83	6.7	86.4	97.7	0.06	0.81	1.77	0.35
Nat'l 5 perc	*1.09*	*5.3*	*44.0*	*90.4*	*0.10*	*0.36*	*0.57*	*0.12*
Minimum	10.63	5.1	76.9	94.8	0.01	0.60	1.42	0.25

Table 1 continued:

	NH4 ug/L N	**NO3 ug/L N**	**TN ug/L N**	**DRP ug/L P**	**TP ug/L P**	**TN/TP** (see note 6)	**DIN/DRP** (see note 6)	**pH**
Sample size	200	212	197	212	211	196	197	212
Nat'l sample size	*13894*	*14852*	*13832*	*14846*	*14818*			*14784*
Mean	4.9	104	208	9.2	71.0	7.1	11.0	8.24
Glenfalls mean	5.2	153	234	6.0	15.8	20.5	31.0	7.94
Nat'l mean	*11.5*	*246*	*396*	*9.8*	*48.7*			*7.67*
Std dev	3.7	82	145	4.5	273.1	3.9	8.1	0.22
Maximum	21.0	485	1177	27.1	3798	23.4	84.0	9.09
95 percentile	12.1	239	428	16.0	195	14.3	22.5	8.64
Nat'l 95 perc	*45.0*	*971*	*1289*	*33.8*	*152*			*8.31*
75 percentile	6.0	156	259	12.2	52.0	9.1	14.6	8.36
Nat'l 75 perc	*11.1*	*333*	*533*	*11.2*	*43*			*7.89*
Median	4.0	96.7	175	9.0	23.0	6.6	10.8	8.23
Glenfalls median	4.4	148.9	220	6.0	11.0	19.0	25.9	7.92
Nat'l median	*6.0*	*97*	*240*	*5.0*	*17*			*7.66*
25 percentile	2.3	34.4	119	6.0	14.0	4.1	6.4	8.11
Nat'l 25 perc	*3.2*	*27*	*97*	*2.0*	*7*			*7.42*
5 percentile	1.0	1.6	70.3	2.0	8.4	1.9	1.0	7.94
Nat'l 5 perc	*1.0*	*3*	*45*	*0.5*	*3*			*7.09*
Minimum	0.0	0.0	0.0	0.0	0.0	1.1	0.4	7.39

Table 1 continued:

	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Alk mg/L CaCO3	Cl mg/L	SO4 mg/L SO4	BOD5 mg-O/L (ceased July 02)
	(------------------------------------ceased February 1990------------------------------------)							
Sample size	12	12	12	12	12	12	12	161
Nat'l sample size	*943*	*943*	*943*	*943*	*943*	*943*	*943*	*12716*
Mean	12.9	1.57	7.61	1.10	40.1	4.45	7.04	0.45
Glenfalls mean	7.9	1.26	5.77	0.92	27.6	3.11	4.42	0.37
Nat'l mean	*9.8*	*2.00*	*8.71*	*1.31*	*32.1*	*8.13*	*7.45*	*0.54*
Std dev	1.77	0.19	1.22	0.19	3.17	0.80	2.22	0.52
Maximum	16.3	1.77	9.50	1.38	44.5	5.50	12.5	5.50
95 percentile	15.4	1.76	9.39	1.34	44.5	5.39	10.6	1.00
Nat'l 95 perc	*22.9*	*4.88*	*20.4*	*3.72*	*74.0*	*22.9*	*16.5*	*1.60*
75 percentile	14.2	1.70	8.08	1.17	42.0	5.05	8.13	0.55
Nat'l 75 perc	*10.6*	*2.38*	*9.40*	*1.60*	*35.0*	*9.90*	*7.50*	*0.65*
Median	12.7	1.64	7.60	1.13	40.3	4.70	6.50	0.35
Glenfalls median	7.8	1.24	5.80	0.92	26.3	3.05	4.25	0.30
Nat'l median	*7.70*	*1.62*	*5.90*	*0.82*	*26.5*	*5.10*	*4.50*	*0.40*
25 percentile	12.0	1.51	7.28	1.07	38.9	3.78	5.65	0.20
Nat'l 25 perc	*5.40*	*1.01*	*3.20*	*0.53*	*20.5*	*2.10*	*3.20*	*0.20*
5 percentile	10.5	1.22	5.56	0.77	34.8	3.31	4.69	0.10
Nat'l 5 perc	*3.30*	*0.60*	*1.30*	*0.35*	*12.5*	*0.50*	*1.90*	*0.05*
Minimum	9.70	1.16	5.50	0.68	34.5	3.20	4.30	0.00

* Notes:
1. Data from Raupunga are for the period 6 March 1989 – 9 November 2006, with rows containing means and medians shaded magenta.
2. Means and medians from Glenfalls (28 February 1989 – 9 November 2006), presented for comparison; rows shaded light blue.
3. Statistics for all sites in the network combined are based on the years 1989 – 2004; values are presented in blue underlined italics.
4. Mean flow in the table is the average of flows on the days samples were taken. Mean flow at Raupunga for the entire period of record 1 March 1957 – 9 January 2007 was 78.9 m^{3}s^{-1}.
5. The value of mean TP at Raupunga of 71 µg L^{-1} is influenced by two very large sample values (see Fig. A4B). Without these values the mean TP concentration at Raupunga is 49 µg L^{-1}.
6. Nitrogen:phosphorus ratios have been computed from the individual sample values, and hence represent means, medians of all the individual N:P ratios; the ratios shown in the table have not been computed from the mean or median values of TN, TP or DIN, DRP that are shown in the table.
7. BOD$_5$ is measured on unfiltered samples, light absorbance on filtered samples.

water quality". First a briefer comparison is made with guidelines for fresh water quality given by the Australian and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand (**ANZECC & ARMCANZ**) and a comment is made on bacteriological count data (only available for 2005 and 2006) in relation to microbiological water quality guidelines of the New Zealand Ministry for the Environment and Ministry of Health (**MfE & MoH**).

The general picture was concisely summarised by HBCB (1986, p. 62) following their analyses of results from a monitoring programme that they undertook in the Mohaka catchment from 1981-1985, prior to the advent of the NRWQN: "The water quality data collected on the lower Mohaka River show that at times of low and average flows the water is of good quality with low ionic strength, suitable for most uses. During and after fresh flows the water quality is greatly diminished because of a high silt load."

2.3. Comparison with ANZECC & ARMCANZ guidelines

NRWQN statistics for the Mohaka River at Raupunga (medians, means) are compared with water quality guidelines for New Zealand river ecosystems in Table 2. The guidelines for NH_4, NO_x (oxidised nitrogen), DRP, TN, TP and water clarity (black disk viewing distance) are from ANZECC & ARMCANZ (2000, Table 3.3.10, p. 3.3-17) and are "default trigger values … used to assess risk of adverse effects due to nutrients" in lowland rivers (altitude < 150 m). The guideline for conductivity is from Biggs (1988, 2000) and is based on a correlation with periphyton biomass, with a limit of 35 g m^{-2} (ash-free dry weight of periphyton per unit area of streambed) for trout habitat protection.

Table 2: NRWQN statistics (medians and means) for the Mohaka River at Raupunga (from Table 1) compared with water quality guidelines for lowland New Zealand streams.

Parameter	Guideline value	Median Raupuga	Mean Raupuga
NH_4 (mg N m^{-3})	21	4	4.9
NO_x (mg N m^{-3})	444	97	104
DRP (mg P m^{-3})	10	9	9.2
TN (mg N m^{-3})	614	175	208
TP (mg P m^{-3})	33	23	71
Clarity (m)	0.8	0.5	0.8
DO (% saturation, upper limit)	105	103	104
DO (% saturation, lower limit)	98		
pH (upper limit)	7.8	8.2	8.2
pH (lower limit)	7.2		
Sp. Cond. (µS cm^{-1})	175	109	109

Notes:

1. Guideline values for NH_4, NO_x (oxidized nitrogen), DRP, TN, TP, water clarity (black disk), DO and pH are from Table 3.3.10 of ANZECC & ARMCANZ (2000); guideline value for conductivity is from Biggs (1988, 2000)
2. Value of mean TP concentration at Raupunga (71 mg P m^{-3}) is affected by two very large values (see Fig.A4B); without these values the mean is 49 mg P m^{-3} .

The ANZECC&ARMCANZ trigger values are for “slightly disturbed” ecosystems and are intended to represent “the best currently available estimates of what are thought to be ecologically low-risk levels of these indicators for *chronic (sustained) exposures*” (ANZECC&ARMCANZ 2000, p. 3.1-21). Hence the comparisons in Table 2 are with averages, not extremes.

Except for water clarity and pH at Raupunga, all of the Mohaka River values are well below the thresholds above which management action should be taken. As discussed in Section 2.5, the low clarity and high turbidity at Raupunga is caused by high concentrations of suspended mineral particles. These do not affect specific conductance, which is controlled by dissolved ionic species and is slightly lower than the national average. The reasons for the relatively high values of pH are not known. Values at Glenfalls (median 7.93, mean 7.94) are also above the upper limit for the guideline. Close & Davies-Colley (1990, p. 326) discuss possible reasons for high pH values in some New Zealand streams, attributing them to photosynthesis by periphyton. HBCB (1986, p. 52) state: “The pH of the [Mohaka River] water is usually high, particularly at the Raupunga site where it is elevated by the photosynthetic activities of the benthic algae. The pH range occurring at both sites [Raupunga and Willow Flat] would have no detrimental effect on the fauna of the river.”

Guidelines for the various nitrogen (N) and phosphorus (P) species are related to the fact that N and P are the most important nutrients required for plant growth in aquatic ecosystems. The nutrient-related water quality issue that is usually of greatest concern is whether enough N and P are present to allow excessive or nuisance plant growth. This depends not only on total concentrations but also on whether the N and P are present in balanced amounts and in forms that plants can readily utilise. Three forms of nitrogen and two forms of phosphorus are monitored for the NRWQN database (as listed at the start of Section 2.2). Total amounts TN and TP include all forms – dissolved inorganic, dissolved organic, and particulate (which includes N and P incorporated in dead and living cells as well as P in suspended mineral particles) – whereas the dissolved inorganic species NO_3, NH_4 and DRP are the forms most readily available to plants. Furthermore, plants do not require N and P in equal amounts. Planktonic organic matter contains a ratio of N:P of roughly 7.2:1 by weight (this is a form of what is known as the “Redfield ratio”, see Wetzel 2001, p. 278). Generally, if the ratio of *available* N:P present in water differs greatly from this ratio, plant growth will likely be limited by the nutrient that is in relatively short supply. Close & Davies-Colley (1990, p. 326) have suggested a value of $(NO_3+NH_4)/DRP = 10$ as being in balance for optimal algal growth (i.e., neither nutrient acting alone to limit growth). This is also the value suggested by Wetzel (2001, p.278) as the ratio of TN/TP above which a relative lack of phosphorus acts to limit growth.

Because of the number of forms in which N and P are found and the dynamic nature of their transformations, interrelations and relative balance, interpretation of specific concentration values in terms of possible water quality problems is not straightforward. The difficulty is compounded by the fact that nutrients are not the only factors that control plant growth; among others are sunlight, temperature, pH, trace elements and dissolved oxygen concentrations. Nevertheless it seems reasonable to conclude from Table 2 that nutrient enrichment is not currently a problem in the Mohaka River at Raupunga. N values are well below ANZECC&ARMCANZ (2000) trigger values and DRP values are slightly less than trigger values. While the value for mean TP exceeds the guideline, this does not seem to be a cause for concern. Two points can be noted. First, it is possible that much of the TP is associated with the high suspended mineral sediment load sometimes present in the river at Raupunga, and has nothing to do with living or dead plant matter. Secondly, the mean TP value is strongly influenced by two very high values that occurred at very high flows (see note below Table 2).

These issues will be discussed further in the comparison between Glenfalls and Raupunga in Section 2.5.

2.4. Comparison with MfE & MoH guidelines for freshwater recreational sites

NRWQN bacterial count data for the Mohaka River are available only for 2005 and 2006, and are shown in Figure 2. Such statistics are generally of interest for purposes of establishing grades of suitability for recreation and/or water supply. If neither of these uses is of concern for the proposed reservoir, then there is little point in discussing the bacterial count data further. However, to put the measurements into a national perspective, the data can be provisionally related to Ministry of Health guidelines for recreational water use by following procedures outlined in MfE&MoH (2003) for establishing a "suitability for recreation grade" (SFRG; the guideline specifies that a minimum of 5 years data be collected before a recreation grade is established for a water body). The process of establishing a grade is somewhat involved – there is no single number against which to compare, for example, median bacterial counts, as was the case in the previous guideline (MfE&MoH 2002). However, a preliminary comparison is given as an example of how a grade might be established and to put the data in perspective. This involves evaluation of two measures – a "sanitary inspection category" (SIC) and a "microbiological assessment category" (MAC).

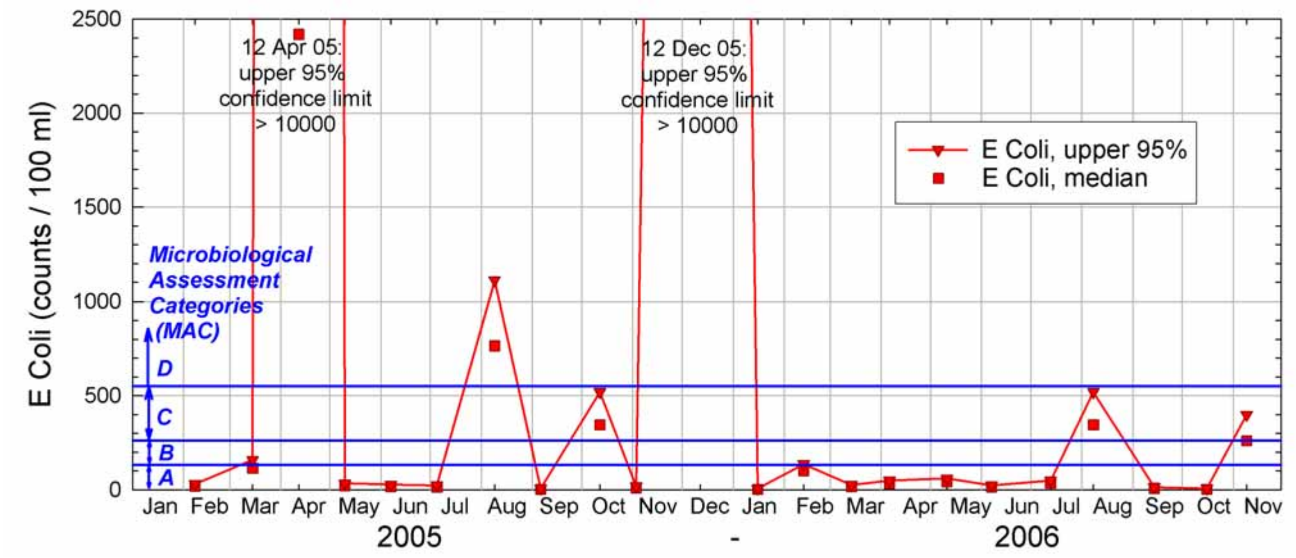

Figure 2: Bacteriological counts at Raupunga for *Escherichia coli* (E Coli); medians and upper 95% confidence intervals are shown. The values for microbiological assessment categories (MAC) apply to 95% confidence interval upper limits.

The SIC is a measure of a water body's susceptibility and exposure to possible faecal contamination and is designated as one of five classes: very low, low, moderate, high, or very high [MfE&MoH 2003, p. E6 and note H(iii)]. In order to specify an SIC for the purposes of this example, a number of assumptions need to be made regarding the presence or absence in the catchment of various pollution-related factors. Reasonable assumptions are that runoff to the river network comes from a catchment with low intensity agricultural and urban land use, that no sewage effluent is discharged to the river, there are no combined sewer overflows and no urban stormwater. Then the SIC would be low. These assumptions are consistent with Landcare's New Zealand Land Resource Inventory (LRI) listing of the percentage of the catchment above Raupunga that is devoted to pastoral land use as 14 %. This can be compared with a regional figure for Hawkes Bay of 56%, and a North Island figure of 52% (MAF 2007). The LRI states that there is no urban land use in the catchment above Raupunga. Then if the upper 95% confidence limits (+95% c.l.) for *Escherichia coli* counts are less than or equal to 130/100 ml (which they were on fourteen of the twenty-two sampling occasions in 2005 – 2006), the MAC would be A (Fig. 2). An MAC of "A" combined with an SIC of "low" implies (MfE&MoH 2003, Table E2) that the SFRG is "very good", which is the highest possible category. For the two occasions (15 March 2005, 13 February 2006) when the count's +95% c.l. was between 130 and 260, the SFRG would be "good", and for the three occasions (12 October 2005, 8 August 2006, 9 November 2006) when the count's +95% c.l. was between 260 and 550, the SFRG would be "fair". This also assumes that the occasions when the count's +95% c.l exceeded 550 (12 April 2005, 9 August 2005, 12 December 2005) represented "exceptional circumstances", and such occurrences would need to be followed up if regular recreational use were of concern.

2.5. Comparison of Raupunga and Glenfalls data

Flows at Glenfalls are roughly half those at Raupunga, with (Glenfalls flow)/ (Raupunga flow) = 0.45 and 0.47 for mean and median flows, respectively. For all practical purposes these flow ratios are the same as the ratio of catchment areas, (Glenfalls area) / (Raupunga area) =0.44. Water temperatures are slightly cooler at Glenfalls, as would be expected from the difference in elevation between the two sites (Glenfalls is 320 m above sea level, Raupunga 15 m above sea level). Relative ionic composition is similar between the two sites, although with generally lower concentrations at Glenfalls, 65% - 75% those at Raupunga. The downstream increase in dissolved solids concentrations is reflected in a downstream increase in conductivity, Glenfalls conductivity being on average 74% that at Raupunga.

Daytime dissolved oxygen levels are high (never far below saturation) at both Raupunga and Glenfalls, with low biochemical oxygen demand (see DO and BOD_5, Table 1, and further discussion in the following section). This is consistent with the low values for light absorption coefficients for filtered water at wavelengths of 340 nm and 440 nm (g_{340} and g_{440}, Table 1) These absorption coefficients are used as indices for the amount of dissolved organic matter ("yellow substance") present in the water (Davies-Colley et al 1993, pp. 28-29), and their low values indicate low concentrations of dissolved organic matter.

In terms of nutrients, we note that nitrogen and phosphorus concentrations at both Raupunga and Glenfalls are below the ANZECC&ARMCANZ (2000) guidelines discussed in Section 2.2 in connection with Table 2 (with the exception of the mean concentration of TP at Raupunga, also discussed in Section 2.2). Hence nutrient concentrations are not an issue in the existing river so far as the possibility of excessive or nuisance plant growths at either Raupunga or Glenfalls is concerned.

There are differences in N:P ratios between Glenfalls and Raupunga. Nitrogen concentrations are lower at Raupunga than at Glenfalls, while the opposite is true for phosphorus. In other words, nitrogen concentrations decrease downstream while phosphorus concentrations *increase* downstream. The reason for the downstream increase in P is probably related to the mineralogy and greater erodibility of the middle and lower catchment. There is a strong correlation at Raupunga between flow and both turbidity and TP (see Fig. A2B & Fig. A4B), and the coincidence of the two very high values of TP recorded at Rupunga with flood flows (Fig. A4B) has been mentioned in Section 2.2.

Implications of N:P ratios for plant growth were discussed in Section 2.2. The ratio for DIN/DRP at Raupunga of 10.9 (Table 1) closely matches the value of 10 suggested by Close & Davies-Colley (1990, p. 326) as being in balance for optimal algal growth (i.e., neither nutrient acting alone to limit growth). At Glenfalls the ratio is greater, DIN/DRP = 31. According to these criteria, algal growth at Glenfalls could be limited by availability of phosphorus, whereas at Raupunga any nutrient limitation would be due to a combination of nutrients. It is true that TN/TP values at Raupunga (mean 7.0, median 6.6) are slightly less than 10, although they closely match the N:P Redfield ratio of 7.2 for planktonic organic matter (see Section 2.2 and Wetzel 2001, p. 278). Questions about the how absolute values of nutrient concentrations might affect trophic status of a future reservoir are considered in Section 3. There it will be seen that the classification system for trophic levels in lakes, developed by Burns et al. (2000) for MfE, does permit a possible interpretation of nitrogen limitation for the Raupunga data.

The major difference between Raupunga and Glenfalls water quality is in terms of clarity. Water at Raupunga has very low values of clarity (measured as the horizontal viewing distance for a 200 mm black disk; Davies-Colley 1988a) and very high levels of turbidity, both in comparison with water at Glenfalls and in comparison with other rivers nationwide in the water quality network (Table 1). The downstream decrease in clarity is due to a downstream increase in suspended fine mineral sediments transported by the river – clays, silts and fine sands, as opposed to organic particulate matter or dissolved humic substances – most notably after the river and its tributaries leave the upper greywacke-dominated catchment and flow through more erodible tertiary terrain in the middle and lower catchments. HBCB (1986, p. 63) state that “the long term discolouration of the lower Mohaka River is due mainly to the input of silt from the Te Hoe River and the resuspension of silt in the middle reaches of the Mohaka River (between Glenfalls and Willow Flat)”.

2.6. Comparison of Raupunga and combined national network statistics

While the Mohaka River’s mean flow is considerably lower than the national mean (for rivers included in the NRWQN), its median flow is considerably larger than the national median. Comparison of the percentiles shows that the Mohaka’s flow distribution is more compact than that for all network rivers combined, and in fact the standard deviation of Mohaka flow is only half that for all sites combined (173 $m^3 s^{-1}$, not shown in Table 1). Note, however, that the maximum recorded flow in the Mohaka of 2204 m^3 s^{-1} occurred on 15 March 1985 and is not included in the NRWQN's time span.

Conductivity of Mohaka River water (an index of total dissolved solids concentration) is slightly lower in the mean than that for all sites combined, but somewhat higher in terms in terms of the median. This is also true generally for ionic content.

Levels of BOD_5 (unfiltered water) and values of the light absorption coefficients (for filtered water) g_{340} and g_{440} are below national values. As noted in the previous section, low values of BOD_5 and of the light absorption coefficients g_{340} and g_{440} indicate low levels of organic matter, both dissolved and particulate. HBCB (1986, p. 151) noted that all of the BOD measurements they made on samples from Raupunga were less than 2.0 g m^{-3}, "indicating water of low organic content which will not detrimentally affect the river's dissolved oxygen levels." Note, however, that while the 95 percentile BOD_5 in Table 1 is less than 2.0 g m^{-3}, the maximum observed BOD_5 from 1989-2005 was 5.5 g m^{-3}. Snelder and Scarsbrook (2005) suggest a guideline of 1 g m^{-3} for mean BOD_5, based on MfE (1992) guidelines for control of undesirable biological growths in waters; the Raupunga mean of 0.45 g m^{-3} meets this standard. Dissolved oxygen concentrations measured during the daytime at Raupunga are slightly above the national mean (in terms of % saturation) and never far below complete saturation.

Values for pH at Raupunga are high compared with national statistics. Possible reasons for this and the significance for in-stream fauna were discussed in Section 2.3.

In terms of nutrients, concentrations of phosphorus (both as DRP and TP) are higher than the corresponding national statistics, while concentrations of nitrogen (as NH_4, NO_3, and TN) are generally lower than the corresponding national statistics. Nevertheless, as noted in Section 2.5, ratios for both TN/TP and DIN/DRP at Raupunga closely match the value of 10 suggested by Close & Davies-Colley (1990, p. 326) and Wetzel (2001, p.278) as being in balance for optimal algal growth (i.e., neither nutrient acting alone to limit growth). Questions about the how absolute and relative values of nutrient concentrations might affect trophic status of a future reservoir are considered in Section 3.

As in the Raupunga – Glenfalls comparison, the most distinctive difference between Raupunga water quality statistics and corresponding national values is in terms of water clarity. As noted in Section 2.5, water at Raupunga has very low values of clarity (measured as the horizontal viewing distance for a 200 mm black disk; Davies-Colley 1988a) and very high levels of turbidity, in comparison with other rivers nationwide in the water quality network (Table 1). Clarity in the lower reaches of the Mohaka is much lower than in the upper reaches. Comments in Section 2.5 regarding downstream increase in suspended fine mineral sediments transported by the river apply here and the reader is referred to that section.

2.7. Raupunga data and results from the site cluster analysis of Maasdam & Smith (1994)

Using the first 2 years' data from all 77 sites in the NRWQN, Maasdam & Smith (1994) grouped sites of "similar water quality", and then sought relationships between the groups and several environmental factors related to hydrology, geology, vegetation cover and land use. For the purposes of this report it is of interest to see how the Raupunga data fit into the "similar water quality" groupings. Maasdam & Smith (1994) identified nine "clusters" of sites, each cluster consisting of similar sites and mainly differentiated from other clusters by concentrations of "P-species" (TP and DRP) and "organics" (BOD_5 and NH_4), with water quality generally declining with increasing cluster number (the highest water quality associated with cluster 1 and the lowest with clusters 8 and 9). Clusters 1 to 4 have good water quality and accounted for 65 sites of the 77 sites in the entire network. Raupunga is in cluster 3, and most of the median values of the Raupunga data fall within the range of median values from clusters 2 to 4. The most notable exceptions are for in clarity and pH, where the Raupunga values match those of waters with poorer water quality. Raupunga median turbidity falls between the medians for clusters 6 and 7, and Raupunga median black disk viewing distance is close to that for cluster 8. Raupunga median pH matches that of cluster 9. In contrast, median Raupunga NH_4 concentration is lower than that for cluster 1, and median BOD_5 is between those of clusters 1 and 2.

3. Water quality in the proposed reservoir – trophic status and comparison with existing reservoirs

3.1. Introductory comments

Section 2 of this report has described water quality in the the Mohaka River and how it compares with water quality of rivers locally and nationally. This section (Section 3) addresses the question of what changes can be expected if the relatively shallow and swift-flowing character of the river were to be transformed into that of reservoir with much deeper, slower-moving flow, weaker but more complex currents, and a seasonal thermal regime that often exerts a dominant influence on oxygen and nutrient dynamics in the lake, and thus ultimately on algal productivity and water quality in general. These are complex issues, as they involve the interaction of many factors. Like a river, nutrient load is one of the most important determinants of trophic status of the water body. Unlike a river, where energetics and character of the downstream flow dominate most processes of the in-stream ecosystem, in a lake, influences of climate, inflows, thermal stratification, mixing, water clarity and oxygen dynamics all interact with chemical and biological factors to affect ultimate water quality. An extra degree of freedom exists in a reservoir in terms of the ability to control not only the magnitude of outflows, but also (providing there is a variable-level offtake structure) the depth from which the outflows are drawn. This obviously influences water quality downstream of the reservoir, but in reservoirs with short residence times it can also influence stratification and mixing (and hence water quality) within the lake itself (Spigel and Ogilvie 1985).

This report addresses these questions, in a general and preliminary fashion, firstly, by referring to a classification scheme developed for New Zealand lakes by Burns et al. (2000) for the New Zealand Ministry for the Environment, based on the concept of the trophic state of a lake, and, secondly, by referring to experience in existing New Zealand reservoirs that possess varying degrees of similarity to the proposed reservoir.

3.2. Proposed reservoir morphometry and residence time

This report follows Hicks et al (2006, p. 1) in assuming that the proposed dam will be near the confluence with Kakariki Stream, approximately 20.5 km upstream from the coast and 7 km upstream from Raupunga, and will back water up within a narrow, steep-sided valley for a distance of approximately 15.7 km to Willow Flat (locations are shown in Fig. 1). The maximum water depth, just behind the dam, will be approximately 40 m, and reservoir water volume will be approximately 50×10^6 m^3 (Hicks et al 2006). Mean flow in the Mohaka River at Raupunga, since the start of records in March 1957 up to July 2006, was 78.9 $m^3 s^{-1}$ (Walter 2000), giving a mean hydraulic residence time (water volume divided by through-flow) for the proposed reservoir of 7.3 days.

An alternative dam site has also been mentioned, located farther downstream at Raupunga. This would result in a larger, deeper reservoir with longer residence time, but the differences would probably not be great enough to alter the general conclusions stated below regarding thermal stratification, oxygen depletion, nutrient availability and trophic status.

3.3. Trophic status: MfE classification (Burns et al. 2000)

Before describing possible implications of the Burns et al (2000) study for water quality in the proposed reservoir, it may be helpful to discuss some of the terminology associated with classification of lakes based on their trophic status. Such classifications generally attempt to define lake water quality in terms of its biological productivity and on the availability of nutrients to support primary production. The classification is usually established with reference to measures of algal biomass, nutrient concentrations and water clarity. The chief indicator variables are usually concentrations of chlorophyll-a, TP and TN; and Secchi disk depth. Sometimes the rate or extent of oxygen depletion is included. Algal growth depends on many factors besides availability of N and P, including solar radiation, water temperature, mixing and circulation patterns, and a host of other organic and inorganic nutrients and micronutrients. Hence trophic-state classifications have been criticised because of the inevitable simplifications and imprecision they involve, not only in general (e.g. Likens 1972 and other papers in that volume), but also in regard to their applicability to New Zealand waters (White 1983). Ironically, it probably because of their simplifications and imprecision that such schemes retain popularity and prove useful in describing the general character of aquatic systems.

The terms “oligotrophic”, “mesotrophic” and “eutrophic” were introduced into the limnological literature by Einar Naumann (1919) to classify water types in terms of their nutrient content and their ability to support poor, intermediate or rich communities of phytoplankton. Other water quality characteristics such as water clarity, extent of oxygen depletion, and suitability for recreational use have since come to be associated with these terms, with water quality generally declining from the clear, oxygenated, nutrient-poor waters of oligtrophic lakes to the more turbid, nutrient-rich waters, with algal blooms and hypolimnetic (bottom water) oxygen depletion, of eutrophic lakes. Hutchinson (1969) and Rodhe (1969) give interesting historical perspectives on the evolution of these concepts, while Ryding & Rast (1989, Chapter 4) give an overview of present-day applications, methods and limitations of trophic classification schemes in OECD countries.

Burns et al. (2000) used data collected in the 1990’s from 23 New Zealand lakes over periods of two to four years to develop their classification scheme. They wanted to assess the condition of “some of New Zealand’s more important lakes and to use the database to develop a sensitive, cost-effective Lakes Monitoring Protocol for detecting small changes in the trophic status of lakes” (Burns et al. 2000, p. v). Although their report for MfE focuses on the condition of existing lakes, and on how to monitor changes in the existing lakes, the scheme does provide a New Zealand – based framework that allows the data presented in Section 2 to be put into the perspective of lake trophic status. Burns et al. (2000) found a three-tier classification (oligotrophic-mesotrophic-eutrophic) too imprecise for their purposes and introduced four further categories, as well as a method for combining measures of chlorophyll-a concentration, TN and TP concentrations, and Secchi disk depth into a single value called a trophic level index (**TLI**).

Table 3 below, based on Table 1.4 in Burns et al. (2000, p.10), sets out the seven trophic levels of the classification scheme and the values of TLI that define boundaries for each level. Values are also given for ranges of TN, TP, Chl-a and Secchi disk depth that correspond to the various trophic levels. The (yellow) shaded cells show where the median and mean values for TN, TP for the Mohaka River at Raupunga (from Table 1) fit in (TN_{mean} = 206 mg m^{-3}, TN_{median} = 175 mg m^{-3}, TP_{mean} = 71.4 mg m^{-3}, TP_{median} = 23.4 mg m^{-3}). A number of comments should be made before an interpretation is given.

Table 3: Trophic levels and values of trophic level index that separate them, from Table 1.4 (p. 10) in Burns et al. (2000). Concentrations of total nitrogen (TN), total phosphorus (TP), chlorophyll-a (Chl-a) and Secchi disk depth that correspond to boundaries of different trophic levels are based on data from 23 lakes used to develop TLI's. Highlighted cells indicate where median and mean Mohaka River data from Raupunga for TN and TP (see Table 1) fit into the ranges for trophic classes.

Lake type	Trophic level index (TLI)	TN (mg N m^{-3})	TP (mg P m^{-3})	Chl-a (mg m^{-3})	Secchi disk (m)
Ultra-microtrophic	0 – 1	16 – 34	0.84 – 1.8	0.13 – 0.33	33 – 25
Microtrophic	1 – 2	34 – 73	1.8 – 4.1	0.33 – 0.82	25 - 15
Oligotrophic	2 – 3	73 – 157	4.1 – 9.0	0.82 – 2.0	15 - 7
Mesotrophic	3 – 4	157 – 337	9.0 – 20.0	2.0 – 5.0	7 – 2.8
Eutrophic	4 – 5	337 – 725	20 – 43	5.0 12.0	2.8 – 1.1
Supertrophic	5 – 6	725 – 1558	43 – 96	Dec-31	1.1 – 0.4
Hyptertrophic	7 – 8	> 1558	> 96	> 31	< 0.4

Firstly, the use of the TLI system for a residence time of only 7.3 days is open to question. At the end of their publication, after applying the scheme to Lake Rotorangi as an example of their method, Burns et al. (2000, p. 106) state: "The TLI system for lake classification can apparently be used on reservoir data to describe the nature of the reservoir water if it has resided in the reservoir for more than 130 days" [the value of residence time calculated using the median rather than the mean flow]. They leave open the question of what the limiting residence time is for application of their method.

Secondly, the TLI scheme uses annual means of four variables – TN, TP, Chl-a, Secchi disk depth (SD) – measured by prescribed methods in a lake to evaluate four TLI's, one for each variable, according to the following empirical equations:

$$TL_C = 2.22 + 2.54 \log_{10}(Chla) \quad (1)$$
$$TL_S = 5.10 + 2.27 \log_{10}(1/SD - 1/40) \quad (2)$$
$$TL_P = 0.218 + 2.92 \log_{10}(TP) \quad (3)$$
$$TL_N = -3.61 + 3.01 \log_{10}(TN) \quad (4)$$

The TLI for the lake is then calculated as the average of the four individual TLI's for the four different variables:

$$TLI = (TL_C + TL_S + TL_P + TL_N)/4 \quad (5)$$

Application of this scheme to the proposed reservoir is not completely straightforward since only two of the four variables are available, and the values of these variables represent TN, TP in the existing river, not necessarily the values that would occur in the proposed lake. Regarding the first point, the best that can be done is to take an average of the TLI's computed from TP and TN, to give some indication of overall TLI. Using mean values for TP, TN from Table 1 gives TL_p = 5.6 and TL_N = 3.4, with an average for TLI of 4.5; i.e., in the middle of the eutrophic range in Table 3.

Regarding the latter point, it is reasonable to assume that the river concentrations of the *dissolved inorganic fractions* of TN and TP (i.e., DIN and DRP) are representative of concentrations in a future reservoir, because the short residence time (less than two weeks) will not allow for significant retention or sedimentation of nitrogen or phosphorus in the lake via uptake by phytoplankton (Pridmore & McBride 1984). However, much of the TP seems to be bound with the suspended sediment load of the river, and therefore not in dissolved forms that are available to plants. Size distributions for the suspended sediment load given in Hicks et al (2006; their Fig. A2.2 and Table A2.1) indicates that some of the suspended sediment will settle to the bottom before reaching the dam. Hence TP levels in the water column will likely be lower than the high values indicated in Table 1 for the river. But the difference will not be great enough to alter the conclusion that the reservoir will have a character that is mesotrophic to eutrophic. In any case, it is the dissolved inorganic fractions DIN, DRP that are most relevant for the likely trophic status of the proposed reservoir.

An alternative method for using the classification scheme of Table 3 would be to assume that when different trophic levels are predicted by different variables, as is the case here (mesotrophic for TN, supertrophic for TP), it is the variable that predicts the lowest trophic level that will control the outcome for overall water quality, since it will act to limit productivity. In this sense, the classification predicts a mesotrophic water body. Note, however, that there is a slight inconsistency between this interpretation and that given in Sections 2.5 and 2.6 concerning nitrogen:phosphorus ratios being generally in balance.

In spite of the problems associated with applying the TLI scheme to the proposed reservoir, the general conclusion that the reservoir will have a character that is mesotrophic to eutrophic seems reasonable and is consistent with the comparisons with existing reservoirs given in the next section. Although a TLI has been calculated that in some sense synthesizes predicted effects of nutrient fluxes to the proposed reservoir, the imprecise and descriptive nature of the result needs to be borne in mind, as the discussion at the beginning of this section indicated. The overall conclusion is that that the lake will have moderately high algal productivity sustained by moderately high levels of nutrients. There will probably be moderately low water clarity, except during floods when the water will contain high concentrations of suspended sediment and the clarity will be very low. Some anoxia in bottom waters can be expected during periods of summer stratification, as discussed in more detail below.

3.4. Comparison with existing reservoirs

Most New Zealand lakes and reservoirs that are deeper than 20-30 m undergo a seasonal mixing and thermal regime that is termed “warm monomictic” – they are thermally stratified from late spring through summer and much of autumn, and mix completely during winter (Green et al. 1987). Thermal stratification tends to create a kind of layered structure in which warmer surface waters overlie cooler deeper waters. This layering inhibits vertical mixing, so that vertical mixing by wind and by surface cooling at night becomes restricted to the upper layers, while deeper waters remain relatively quiescent. The supply of dissolved oxygen to bottom waters is generally greatly diminished, and dissolved oxygen concentrations in bottom waters generally decline over the stratified period as a result of microbiological respiration processes. Depending on the strength of these microbiological processes, oxygen may become completely depleted in bottom waters for an extended period of time, only to be replenished when the lake mixes to the bottom in winter. Such anoxia is a common feature of nutrient-rich, highly productive (i.e., eutrophic) lakes that undergo seasonal thermal stratification (e.g., Wetzel 2001, p. 155).

Given the size of the proposed reservoir, it is almost certain that its waters will be thermally stratified for a considerable part of the year (Green et al. 1987, Davies-Colley 1988b). But, given the relatively short residence time of the lake, the nature and strength of stratification will be strongly influenced by the way the outflows from the lake are controlled and the levels from which they are drawn (e.g., Spigel & Farrant 1984, Spigel & Ogilvie 1985). The strength and duration of stratification will influence the degree of oxygen depletion in bottom waters during summer, which in turn will influence nutrient release from sediments and submerged vegetation, and subsequent nutrient cycling (Vant 1987). An interesting example of these processes, described by Spigel & Ogilvie (1985) and summarised below, indicates that problems associated with deoxygenation could be minimised, perhaps even avoided altogether, by providing an offtake structure that has the capability of withdrawing water from more than one level within the reservoir.

Upper Huia Reservoir is located in a protected, native-bush catchment in the Waitakere Ranges north of Auckland and is operated by the Auckland Regional Council for water supply purposes. The reservoir's surface area is 0.2145 km^2, volume is 2.436 x 10^6 m^3, and maximum depth is 38 m (all at top water level). Although outflows from Upper Huia Reservoir are much smaller (generally less than 0.5 m^3 s^{-1}) than in the proposed Mohaka reservoir (mean river flow 78.9 m^3 s^{-1}), and hence its residence time much longer than the 7.3 days predicted for the Mohaka reservoir, the residence time of Upper Huia Reservoir is still shorter than the period of summer thermal stratification (September to May) and the duration of anoxia in bottom waters (February to May), and is therefore capable of influencing thermal stratification and anoxia in the reservoir. The reservoir has an offtake tower with inlet valves at three elevations – 3.8 m, 16.0 m and 28.2 m above the scour pipe in the base of the dam. Prior to 1983, withdrawals from the reservoir were taken mainly from the mid-level offtake, and the reservoir became thermally stratified every summer, with a strong thermocline near the level of the offtake. Anoxia below the thermocline accompanied stratification from February to overturn (generally in May), resulting in release of dissolved iron and manganese from the bottom sediments. In a trial operation organised by David Ogilvie of the (then) Auckland Regional Authority, withdrawals for the summer of 1983-1984 were taken only from the bottom offtake. There was a dramatic effect on stratification, deoxygenation and release of dissolved iron and manganese from the sediments. Although a shallow thermocline formed in surface waters, bottom waters were flushed by river inflows throughout the summer and neither deoxygenation nor sediment release of dissolved manganese or iron occurred. The effect of outflow operations on thermal stratification was very accurately predicted by DYRESM, a one-dimensional (in the vertical) hydrodynamic computer model.

When waters are thermally stratified in the proposed Mohaka reservoir, and in the absence of withdrawal of outflows from a bottom offtake, it is likely that river inflows will form insertions around the thermocline that separates warmer upper waters from cooler bottom waters. During winter, Mohaka River temperatures are cold enough that inflows will form underflows that penetrate to the bottom of the lake (see, for example, Gibbs 1992). But in summer, reoxygenation of bottom waters by river inflows is not likely unless outflows are persistently drawn from bottom waters, as described in the previous praragraph. Insertion of more turbid river water at mid-depth in summer during periods of normal flow also means that surface waters will likely become clearer than river water is at present, allowing sunlight to penetrate upper layers, in turn allowing algae to grow. Large floods may, however, discolour the reservoir for periods of the order of one to two residence times (i.e., until the fine suspended sediment fractions are flushed out), and if large enough may even break down stratification and cause complete mixing. This is not a cause for concern from a water quality point of view, any more than the occurrence of turbid water during floods is in the river at present. On the contrary, it would have the benefit of replacing any dissolved oxygen in bottom water that may have become depleted prior to the flood. However, sedimentation within the reservoir may be an issue in terms of reducing reservoir volume; this is not discussed in this report.

In Table 4, data for the proposed reservoir are compared with three other North Island reservoirs with somewhat similar shapes and sizes, chosen after conferring with Clive Howard-Williams, Jacques Boubee and Marty Bonnett. The reservoirs are Lake Ohakuri, the largest of the Waikato hydropower lakes, Lake Rotorangi on the Patea River in Taranaki (“the longest reservoir of its type in New Zealand” according to TRC 2004), and Lake Matahina on the Rangitaiki River approximately 22.5 km south of the Rangitaiki River mouth on the Bay of Plenty.

Very little information is available about water quality or thermal stratification in Lake Matahina. Hence the comparison will focus on Lake Ohakuri and Lake Rotorangi. Of these two it is felt that Lake Ohakuri is the more relevant because of the much closer similarity of its residence time and inputs of TN and TP to those of the proposed Mohaka River reservoir. Both Lake Ohakuri and Lake Rotorangi change in character as one moves from their most upstream extent to the dams, becoming gradually more lake-like and more eutrophic in character as current speeds decrease, the water column stratifies, oxygen declines in bottom waters (with anoxic conditions lasting for much of summer and autumn), and phytoplankton grow in surface waters. Lake Ohakuri has only one outlet for routine operations, at approximately 6 m below the water surface, used to supply water to a penstock and the power station. There is a spillway for passing flood flows, and a diversion tunnel for augmenting the spillway or for emptying the reservoir, but there is no option for routine withdrawal from deeper waters. Lake Ohakuri has been characterised as eutrophic by Coulter et al. 1983. Lake Rotorangi has been described as predominantly mesotrophic by Burns et al. (2000) and mesotrophic to eutrophic by TRC (2006).

Table 4: Comparison of some predicted aspects of the proposed lake with three other existing hydro lakes. Numbers in parentheses refer to data sources: (1) Hicks et al. 2006; (2) Coulter et al. 1983; (3) Freestone 1992; (4) TCB 1988; (5) TRC 2006; (6) Burns et al. 2000; (7) Phillips & Nelson 1981; (8) Pridmore & McBride 1984; (9) Walter 2000.

	Mohaka River near Kakariki	**Lake Ohakuri (2) (Waikato River)**	**Lake Rotorangi (Patea River)**	**Lake Matahina (Rangitaiki River)**
Date operational		1961	1984	1966
Volume (10^6 m^3)	50 (1)	106 (entire lake) 95.4 (excluding Whirinaki arm)	175 (4)	33 (3)
Surface area (km^2)		8.0 (entire lake) 6.7 (excluding Whirinaki arm)	6.17 (4)	2.5 (7)
Maximum depth (m)	40 (1)	37.5	56 (5)	50 (7)
Approx length (km)	15.7 (1)	7.5	46 (4)	5.4 (7)
Mean flow (m^3 s^{-1})	78.9 (9) (1957 – 2006)	161 (1969-1978)	24.5 (5) (2003-2004)	74 (7)
Mean hydraulic residence time, volume/flow (days)	7.3	6.9 (main basin, excluding Whirinaki arm)	83 [Note: 130 days listed in (6) based on median flow]	5.2
Thermal stratification	[Likely]	Yes	Yes (5)	?
Oxygen depletion	[Likely]	Yes	Yes (5)	?
Trophic status	[Mesotrophic – eutrophic]	Eutrophic	Mesotrophic – eutrophic (5,6)	? [Eutrophic, based on limited chl-a and TP data in (8)]
TN (mean, mg N m^{-3})	208 (Table 1)	193 (summer 1978-79)	580 (6)	?
TP (mean, mg P m^{-3})	71 (Table 1)	31 (summer 1978-79)	15.1 (6)	48 (8) (March 1984)

Lake Ohakuri experiences maximum phytoplankton concentrations in summer and autumn, concerning which Coulter et al. (1983, p. 182) comment: “Although summer phytoplankton biomass (mean chlorophyll *a* concentration 9.3 mg m^3, mean secchi value 3.2 in 1978) is equivalent only to a mildly eutrophic condition (Wetzel 1975, OECD 1982), the amount of phytoplankton generated and lost from the lake over the period is equivalent to production in a lake of much higher trophic status in a closed basin.” Coulter et al. (1983, p. 181) also note that the toxin-producing cyanobacterium *Anabaena oscillaroides* is prominent in the plankton in summer.

Exotic rooted aquatic plants are present in the littoral areas of Lake Ohakuri, including the nuisance species *Ceratophyllum demersum* (hornwort), which caused closure of the Ohakuri power station in 1965 (NIWA 2001).

3.5. Decay of submerged vegetation

Decay of submerged vegetation in newly formed reservoirs can cause water quality problems in two ways, first through depletion of dissolved oxygen by microbiological respiration processes associated with the decay of the vegetation itself, and secondly by the release of dissolved organic compounds that are subject to further transformations that consume oxygen, including mineralization to inorganic nutrients that can support algal growth. Very little research has been published that would allow reliable predictions of the duration or intensity of these effects. Both duration and intensity depend on type and amount of submerged vegetation, submerged soil characteristics, basin morphometry, flushing rate, inflow and outflow dynamics, and the nature of thermal stratification, including temperature of bottom waters. The problems seem most common and severe in tropical reservoirs (Gregoire & Sandrine 2006), but experience with Lake Opuha in South Canterbury (Hawes & Spigel 1999) shows that significant problems can occur in New Zealand for a period of several years, and that design of the offtake structure for provision of bottom draw-off capabilities is desirable. As Gregoire & Sandrine (2006) point out, however, the problems can be reduced significantly by removal of vegetation prior to filling the reservoir. This was not done in Lake Opuha.

3.6. Summary of main points relating to the proposed reservoir

- Use of a trophic state classification system based on data from existing New Zealand lakes indicates that the proposed Mohaka reservoir would be mesotrophic to eutrophic. That is, it would have moderately high algal productivity sustained by moderately high levels of nutrients. There will probably be moderately low water clarity, except during floods when the water will contain high concentrations of suspended sediment and the clarity will be very low. Some anoxia in bottom waters can be expected during periods of summer stratification, as discussed in more detail below.

- Provision of an offtake structure with the capability of withdrawing water from more than one level would give operators some control over the quality of water released downstream. It would also have beneficial effects on stratification (and hence oxygen levels and water quality) within the lake itself, allowing problems associated with deoxygenation to be minimised, possibly avoided.

- Comparison of projected reservoir bathymetry, inflow volumes and nutrient loads indicates that the reservoir may have a character similar to that of the hydropower Lake Ohakuri on the Waikato River, which has similar residence time, nutrient loading and bathymetry.

- Decay of submerged vegetation may exacerbate water quality problems during the initial years after the reservoir is filled; these could be minimised by clearing vegetation prior to filling.

4. Conclusions

Available data from two New Zealand National River Water Quality (NRWQN) sites on the Mohaka River (1985-2005) have been used firstly to compare existing water quality in the Mohaka River with other rivers, locally and nationally, and secondly to make general, descriptive predictions about the likely effects that creation of a reservoir on the lower Mohaka River would have on existing river water quality. One NRWQN sites is at Glenfalls in the upper catchment and the other is on the lower river at Raupunga. Data from Raupunga are representative of water quality for the inflow to the proposed reservoir.

With the exception of clarity, water quality at Raupunga is good. Concentrations of particulate and dissolved organic matter are low, resulting in low biochemical oxygen demand and fully-saturated concentrations of dissolved oxygen. Phosphorus and nitrogen levels are in the middle range of the good water quality sites, with slightly higher values for phosphorus and lower values for nitrogen, but all well below default trigger values for management action suggested by ANZECC&ARMCANZ (2000). Turbidity is high and clarity (black disk viewing distance) is low at Raupunga, compared with the Glenfalls site and with other rivers nationwide. Poor clarity is caused by high suspended sediment concentrations, especially during periods of high flow, carried to the river mainly by tributaries draining erodible sandstone-siltstone-mudstone terrain of the middle and lower catchment. Values of pH are also high, but not enough to cause concern (HBCB 1986, p.52). Not enough bacterial count data are available yet to allow a suitability-for-recreation grade to be established, but a preliminary comparison of data from 2005 has been made with MfE&MoH (2003) guidelines. Most of the time the bacterial counts satisfied conditions for a grade of good or very good, but there were three occasions when counts were very high.

It was assumed that the proposed reservoir will have a maximum depth of approximately 40 m, a water volume of approximately 50 million m^3, and extend approximately 15.7 km upstream from the dam site, near the Kakariki Stream confluence, to Willow Flat. The reservoir will be confined for most of its length within a narrow, steep valley. With a mean annual flow (1957-2006, Raupunga) through the reservoir of 78.9 $m^3 s^{-1}$, the hydraulic residence time would be 7.3 days. Location of the dam at an alternative site 7 km downstream at Raupunga would make the reservoir somewhat larger and deeper, but the general conclusions given in the report about its likely thermal and oxygen regimes and its trophic status would not change.

The proposed reservoir's trophic level index, based on total nitrogen and total phosphorus loading and following the MfE calculation methods outlined by Burns et al. (2000), indicated that the reservoir will be eutrophic or mesotrophic-eutrophic. It was assumed that total nitrogen and total phosphorus in the reservoir would be similar to those in the existing river, which is reasonable for a reservoir with a residence time of less than two weeks and with a single major inflow. Comparison with existing reservoirs in the North Island were consistent with this prediction and suggested that thermal stratification in summer, accompanied by depletion of oxygen in bottom waters, are likely to be features of the proposed reservoir. Lake Ohakuri, the largest of the Waikato River hydropower lakes, with a maximum depth of 37.5 m, a residence time of 6.9 days and somewhat lower levels of total nitrogen and total phosphorus at its outlet than those at Raupunga, was felt to provide the closest match to the conditions specified for the proposed reservoir. Lake Ohakuri is eutrophic and stratifies thermally from October to May. Its waters are anoxic below about 20 m for most of the summer. It supports a variety of algal communities over the course of the year, including the cyanobacterium *Anabaena oscillaroides* during summer, as well as macrophyte beds in littoral areas.

Attention was drawn to the desirability of providing an offtake structure for the reservoir that has the capability of withdrawing water from more than one level. This not only gives operators some control over the quality of water released downstream, but can, in reservoirs with short residence times, also have effects on stratification (and hence oxygen levels and water quality) within the lake itself that would be beneficial in terms of water quality. This could be particularly important during the first few years of operation when decay of submerged vegetation may increase oxygen demand in bottom waters and concentrations of dissolved organic matter, as occurred in Lake Opuha in South Canterbury (Hawes & Spigel 1999).

It is difficult to predict quantitatively what changes can be expected when the relatively shallow and swift-flowing character of a river is transformed into that of reservoir with much deeper, slower-moving flow, weaker but more complex currents, and a seasonal thermal regime that can exert a dominant influence on oxygen, nutrient and algal dynamics. This report addressed these questions in a general, descriptive and preliminary fashion, mainly by referring to experience in existing reservoirs that possess varying degrees of similarity to the proposed reservoir. Computer modelling could be used to make the predictions more precise. Models exist that have been applied successfully to New Zealand lakes and reservoirs that simulate interactions of climate, inflows, outflows, thermal stratification, mixing, water clarity and oxygen dynamics with chemical and biological factors (Spigel & Ogilvie 1985, Spigel et al 2003).

5. References

ANZECC & ARMCANZ (2000). Australian and New Zealand guidelines for fresh and marine water quality. Volume 1. The guidelines. Canberra, Australia and New Zealand Environment and Conservation Council for Agriculture and Resource Management Council of Australia and New Zealand.

Biggs, B.J.F. (1988). Algal proliferations in New Zealand's shallow stony foothills-fed rivers: toward a predictive model. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 23*: 1405-1411.

Biggs, B.J.F. (2000). New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams. Wellington, Ministry for the Environment. 122 p.

Coffey, B.T. (1975). Macrophyte distribution in the Waikato lakes. Chapter 18 (pp. 263-270) *in*: Jolly, V.H.; Brown, J.M.A., *New Zealand Lakes*, Auckland, Auckland University Press and Oxford University Press. 388 p.

Coulter, G.W.; Davies, J.; Pickmere, S. (1983). Seasonal limnological change and phytoplankton production in Ohakuri, a hydro-electric lake on the Waikato River, *New Zealand Journal of Marine and Freshwater Research 17*: 169-183.

Close, M.E.; Davies-Colley, R.J. (1990). Baseflow chemistry in New Zealand rivers 1. Characterisation. *New Zealand Journal of Marine and Freshwater Research 24*: 319-341.

Davies-Colley, R.J. (1988a). Measuring water clarity with a black disk. *Limnology and Oceanography 33*(4): 616-623.

Davies-Colley, R.J. (1988b). Mixing depths in New Zealand Lakes. *New Zealand Journal of Marine and Freshwater Research 22*: 517-527.

Davies-Colley, R.J.; Vant, W.N.; Smith, D.G. (1993). Colour and clarity of natural waters. New York, Ellis-Horwood. 310 p.

Freestone, H.J. (1992). Hydrology and large water projects. Chapter 21 (pp. 409-421) in: Mosley, M.P. (Ed.), *Waters of New Zealand*. Wellington, New Zealand Hydrological Society. 431 p.

Gibbs, M.M. (1992). Influence of hypolimnetic stirring and underflow on the limnology of Lake Rotoiti, New Zealand. *New Zealand Journal of Marine and Freshwater Research 26*: 253-263.

Green, J.D.; Viner, A.B.; Lowe, D.J. (1987). The effect of climate on lake mixing patterns and temperatures. Chapter 2 (pp. 65-95) in: Viner, A.B. (Ed.), Inland Waters of New Zealand, DSIR Bulletin 241, Wellington, Department of Scientific and Industrial Research. 494 p.

Gregoire, A.; Richard, S. (2006). How flooded biomass affects water quality after reservoir impounding. *HRW 14*(6): 28-31. (HCI Publications, Kansas City).

Grindley, G.W. (1960). Geological Map of New Zealand 1:250,000, Sheet 8 Taupo, Wellington, Department of Scientific and Industrial Research.

Hawes, I.; Spigel, B. (1999). Report on water quality in Opuha Dam. NIWA Client Report CHC99/12, prepared for Opuha Dam Company, NIWA Project CRC90510. Chiristchurch, National Institute of Water and Atmospherioc Research. 31 p.

HBCB (1986). The Mohaka catchment water and soil resource management plan. Napier, Hawke’s Bay Catchment Board & Regional Water Board (now Hawke’s Bay Regional Council). 123 p.

Hicks, D.M.; Walsh, J.; McKerchar, A. (2006). Sedimentation effects of a proposed hydro-dam on the Mohaka River near Kakariki. NIWA Client Report CHC2006-119, NIWA Project MEL06506, prepared for Meridian Energy Ltd. National Institute of Water and Atmospheric Research, Christchurch. 53 p.

Hutchinson, G.E. (1969). Eutrophication, past and present. Pages 17-26 in: U.S. National Academy of Sciences, Eutrophication: causes, consequences, correctives, Washington D.C., National Academy of Sciences. 661 p.

Larned, S.T.; Scarsbrook, M.R.; Snelder, T.H.; Norton, N.J.; Biggs, B.J.F. (2004). Water quality in low-elevation streams and rivers of New Zealand: recent state and trends in contrasting land-cover classes. *New Zealand Journal of Marine and Freshwater Research 38*: 347-366.

Likens, G.E. (1972). Eutrophication and aquatic ecosystems. Pages 3-13 in: Likens, G.E. (Ed.), Nutrients and eutrophication: the limiting nutrient controversy, Special Symposia Volume 1, American Society of Limnology and Oceanography. Lawrence, Kansas, Allen Press. 328 p.

Maasdam, R.; Smith, D.G. (1994). New Zealand's National River Water Quality Network 2. Relationships between physico-chemical data and environmental factors. *New Zealand Journal of Marine and Freshwater Research 28*: 37-54.

MAF (2007). Land Cover Data Base: Hawke's Bay and New Zealand. http://www.maf.govt.nz/statistics/primaryindustries/regions/tables/landcover/lc-hawk.htm (for Hawke's Bay) and http://www.maf.govt.nz/statistics/primaryindustries/landcover/tables/11-lc-nz.htm (for New Zealand); based on satellite imagery acquired 1996-1997.

MfE (1992). Water quality guidelines no. 1, Guidelines for the control of undesirable biological growths in water. Wellington, Ministry for the Environment. 60 p.

MfE & MoH (2002). Microbiological water quality guidelines for marine and freshwater recreational areas. Wellington, Ministry for the Environment and Ministry of Health. 121 p.

MfE & MoH (2003). Microbiological water quality guidelines for marine and freshwater recreational areas. Wellington, Ministry for the Environment and Ministry of Health. 159 p.

Naumann, E. (1919). Några synpunkter angående planktons ökologi. Med särskild hänsyn till fytoplankton. *Svensk Botanisk Tidskrift 13*: 129-158.

Newsome, P.F.J. (1992). New Zealand Land Resource Inventory ARC/INFO Data Manual, DSIR Land Resources Technical Record 81. Lower Hutt, Department of Scientific and Industrial Research. 64 p. Also see: http://www.landcareresearch.co.nz/databases/nzlri.asp

NIWA (2001). *Aniwaniwa*, *Issue No. 18*. Hamilton, National Institute of Water and Atmospheric Research. 8 p.

OECD (1982). *Eutrophication of waters*. Paris, OECD. 154 p.

Phillips, C.J.; Nelson, C.S. (1981). Sedimentation in an artificial lake – Lake Matahina, Bay of Plenty. *New Zealand Journal of Marine and Freshwater Research 15*: 459-473.

Pridmore, R.D.; McBride, G.B. (1984). Prediction of chlorophyll-a concentrations in impoundments of short hydraulic retention time. *Journal of Environmental management 19*: 343-350.

Rodhe, W. (1969). Crystallization of eutrophication concepts in Northern Europe. Pages 50-64 in: U.S. National Academy of Sciences, Eutrophication: causes, consequences, correctives, Washington D.C., National Academy of Sciences. 661 p.

Ryding, S.-O.; Rast, W. (Eds.) (1989). *The control of eutrophication of lakes and reservoirs*, Man and the Biosphere Series, Volume 1. Paris, UNESCO and Carnforth, U.K., The Parthenon Publishing Group. 314 p.

Smith, D.G.; Maasdam, R. (1994). New Zealand's National River Water Quality Network 1. Design and physico-chemical characterization. *New Zealand Journal of Marine and Freshwater Research 28*: 19-35.

Smith, D.G.; McBride, G.B.; Bryers, G.G.; Davies-Colley, R.J.; Quinn, J.M.; Vant, W.M. (1989). A national water quality network for New Zealand. DSIR Consultancy Report 8016/2. Department of Scientific and Industrial Research, Hamilton. 147 p.

Smith, D.G.; McBride, G.B. (1990). New Zealand's national water quality monitoring network – design and first year's operation. *Water Resources Bulletin 26*(5): 767-775.

Snelder, T.; Scarsbrook, M. (2005). Spatial patterns in state and trends of environmental quality in New Zealand rivers: an analysis for State of Environment reporting. Christchurch, NIWA, 91 p. Prepared for New Zealand Ministry for the Environment (MfE), published by MfE February 2005, reference number ME 589. http://www.mfe.govt.nz/publications/ser/spatial-patterns-environmental-quality-feb05/index.html

Snelder, T.H.; Woods, R.; Biggs, B.J.F. (2005). Improved eco-hydrological classification of rivers. *River Research and Applications 21*(6):609-628. Also see: http://www.niwascience.co.nz/ncwr/rec/

Spigel, R.H.; Farrant, B. (1984). Selective withdrawal through a point sink and pycnocline formation in a linearly stratified flow. *Journal of Hydraulic Research (IAHR), 22*(1): 35-51.

Spigel, R.H.; Ogilvie, D.J. (1985). Importance of selective withdrawal in reservoirs with short residence times: a case study. Proceedings of the 21st Congress of the International Association for Hydraulic Research, Melbourne, 19-23 August 1985, Volume 2, pp. 275-279, The Institution of Engineers, Australia, National Conference Publication No. 85/13.

Spigel, R.; Howard-Williams, C.; Hawes, I.; James, M. (2003). Predictions of water quality changes in Lake taupo under different nitrogen loadings: Further refinement of a coupled hydrodynamic-ecosystem model. NIWA Client Report CHC2002-042, prepared for Ministry for the Environment and Environment Waikato, NIWA Project EVW02503, Christhurch, National Institute of Water and Atmospherioc Research. 58 p.

TCB (Taranaki Catchment Board) (1988). Lake Rotorangi, Monitoring a new hydro lake. Stratford, Taranaki Catchment Board and Regional Water Board. 169 p.

TRC (Taranaki Regional Council) (2004). S.I.T.E. Newsletter to Schools No. 29. Stratford, Taranaki Regional Council, 4 p. www.trc.govt.nz/PDFS/SITE/site29.pdf

TRC (Taranaki Regional Council) (2006). Taranaki Generation Ltd. – Lake Rotorangi monitoring programme, Water quality and biological programmes, Annual report 2004-2005, Technical report 2005-76. Stratford, Taranaki Regional Council. 95 p.

Vant, W.N. (1987). Hypolimnetic dissolved oxygen: survey and interpretation. Chapter 6 (pp. 59-65) in: Vant, W.N. (Ed.), *Lake Managers Handbook*, Water and Soil Miscellaneous Publication No. 103, Wellington, National Water and Soil Conservation Authority, Ministry of Works and Development. 230 p.

Walter, K. (2000). Index to hydrological recording sites in New Zealand. NIWA Technical Report 73. Christchurch, National Institute of Water and Atmospheric Sciences. 216 p.

Ward, R.C.; Loftis, J.C.; McBride, G.B. (1990). *Design of water quality monitoring systems*. New York, Van Nostrand Reinhold. 231 p.

Wetzel, R.G. (1975). *Limnology*. Philadelphia, Saunders. 743 p.

Wetzel, R.G. (2001). *Limnology* (3rd Edition). San Diego, Academic Press. 1006 p.

White, E. (1983). Lake eutrophication in New Zealand – a comparison with other countries of the Organisation for Economic Co-operation and Development. *New Zealand Journal of Marine and Freshwater Research 17*: 437-444.

Young, D.; Foster, B. (1986). *Faces of the River*. Wellington, The Listener and the New Zealand Hydrological Society. 224 p.

APPENDIX A:

Time series for NRWQN data from the Mohaka River at Raupunga and Glenfalls.

Plots of flow at Raupunga are included in all graphs so that visual assessment can be made of possible correlations of water quality parameters with discharge. Parameters include:

Figure A1-

(A) Flow
(B) Flow (expanded scale)
(C) Temperature
(D) Specific conductance (conductivity at 25°C)

Figure A2-

(A) Clarity (200 mm black disk horizontal viewing distance)
(B) Turbidity
(C) Absorption coefficient of filtered water at 340 nm, g_{340}
(D) Absorption coefficient of filtered water at 440 nm, g_{440}

Figure A3-

(A) Ammonium (NH_4)
(B) Nitrate (NO_3)
(C) Total nitrogen (TN)

Figure A4-

(A) Dissolved reactive phosphorus (DRP)
(B) Total phosphorus (TP)
(C) Ratio of total nitrogen to total phosphorus (TN/TP)
(D) Ratio of dissolved inorganic nitrogen (DIN, assumed equal to $NO_3 + NH_4$) to dissolved reactive phosphorus (DIN/DRP)

Figure A5-

(A) Light absorbance of filtered water at 340 nm
(B) Light absorbance of filtered water at 440 nm
(C) Light absorbance of filtered water at 740 nm

Figure A6-

(A) BOD_5
(B) PH

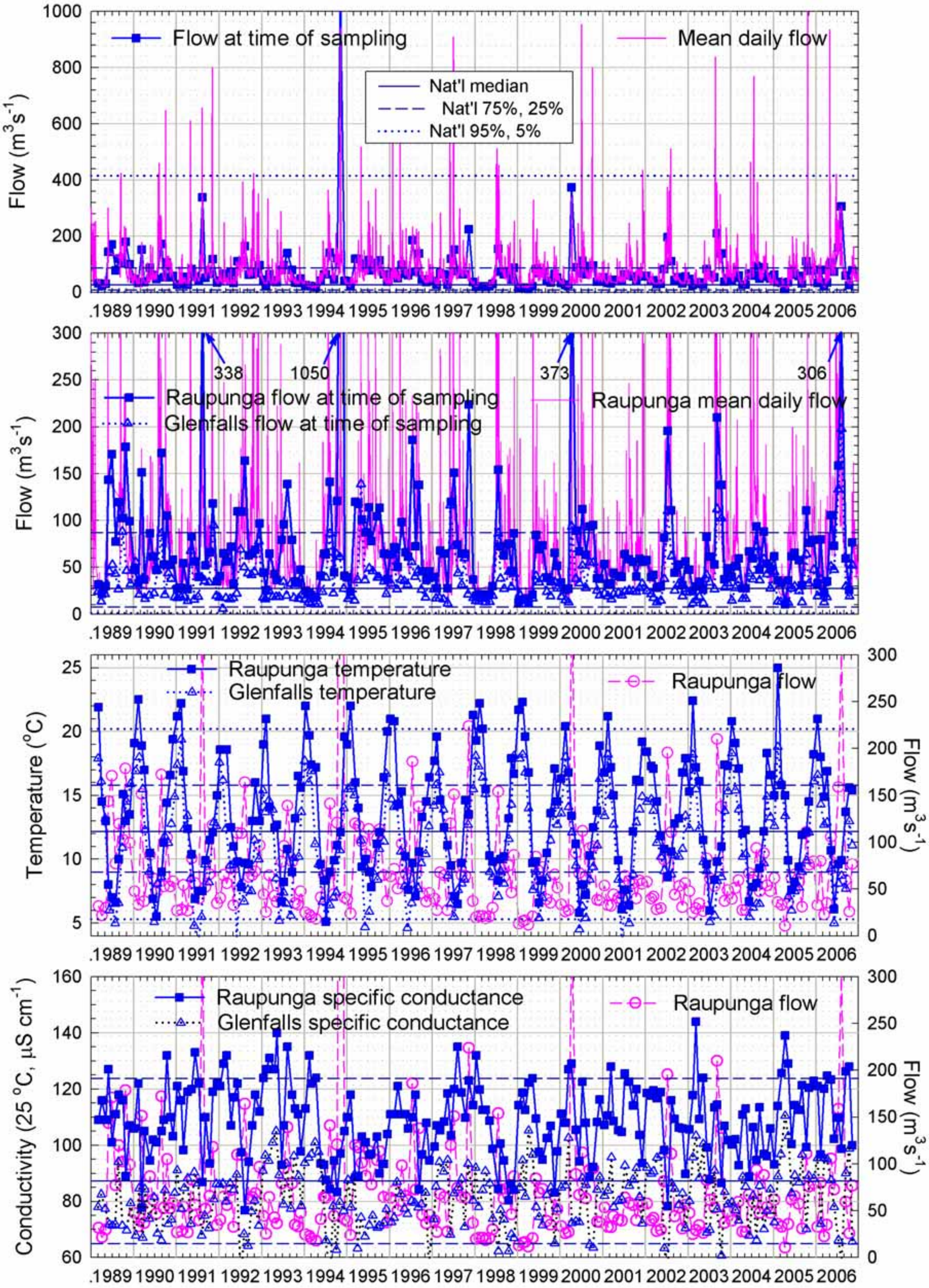

Figure A1: (A) Flow; (B) flow (expanded scale); (C) temperature; (D) specific conductance (conductivity at 25°C)

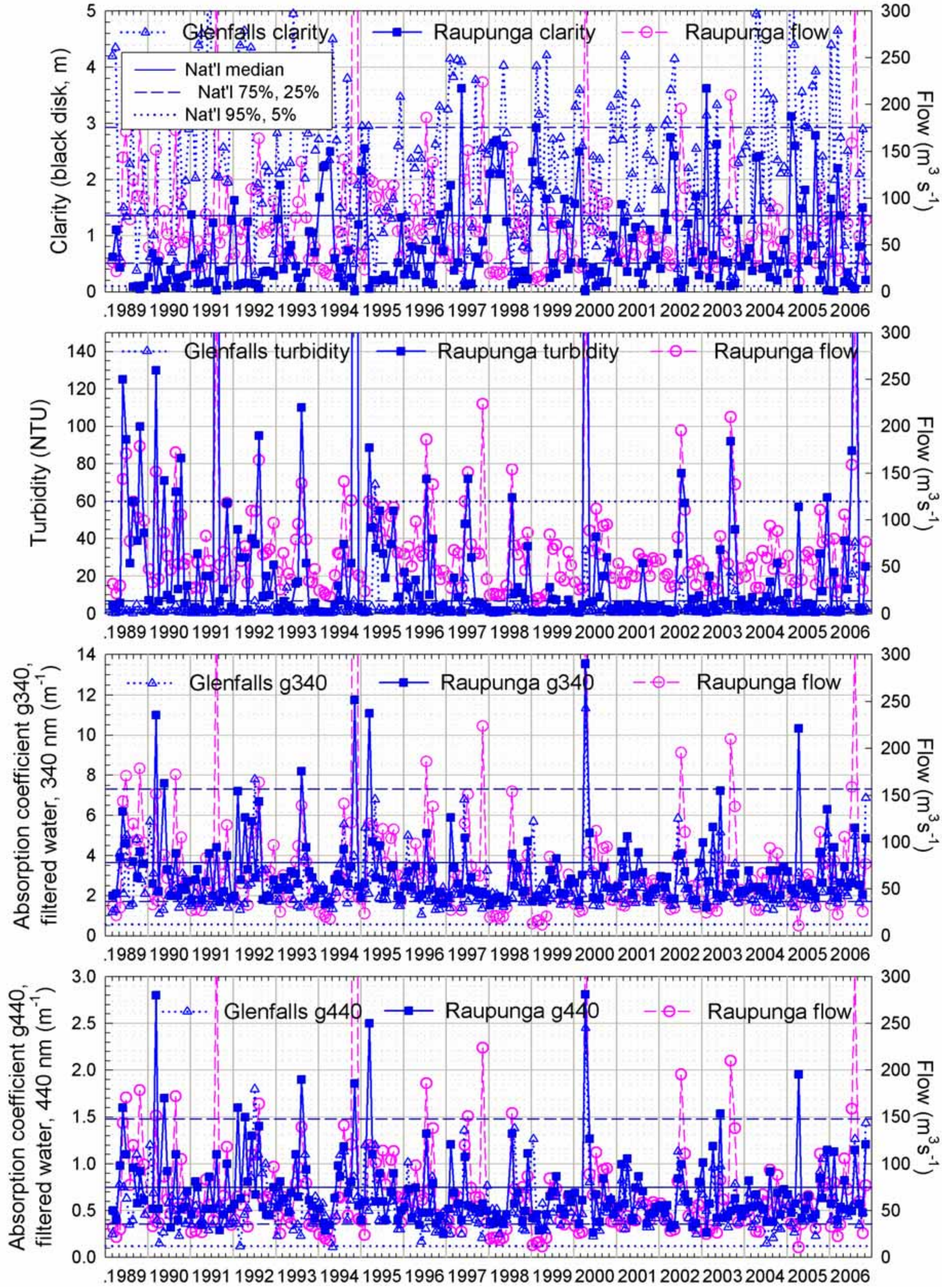

Figure A2: (A) Clarity (200 mm black disk horizontal viewing distance); (B) turbidity; (C) absorption coefficient of filtered water at 340 nm, g_{340}; (D) absorption coefficient of filtered water at 440 nm, g_{440}

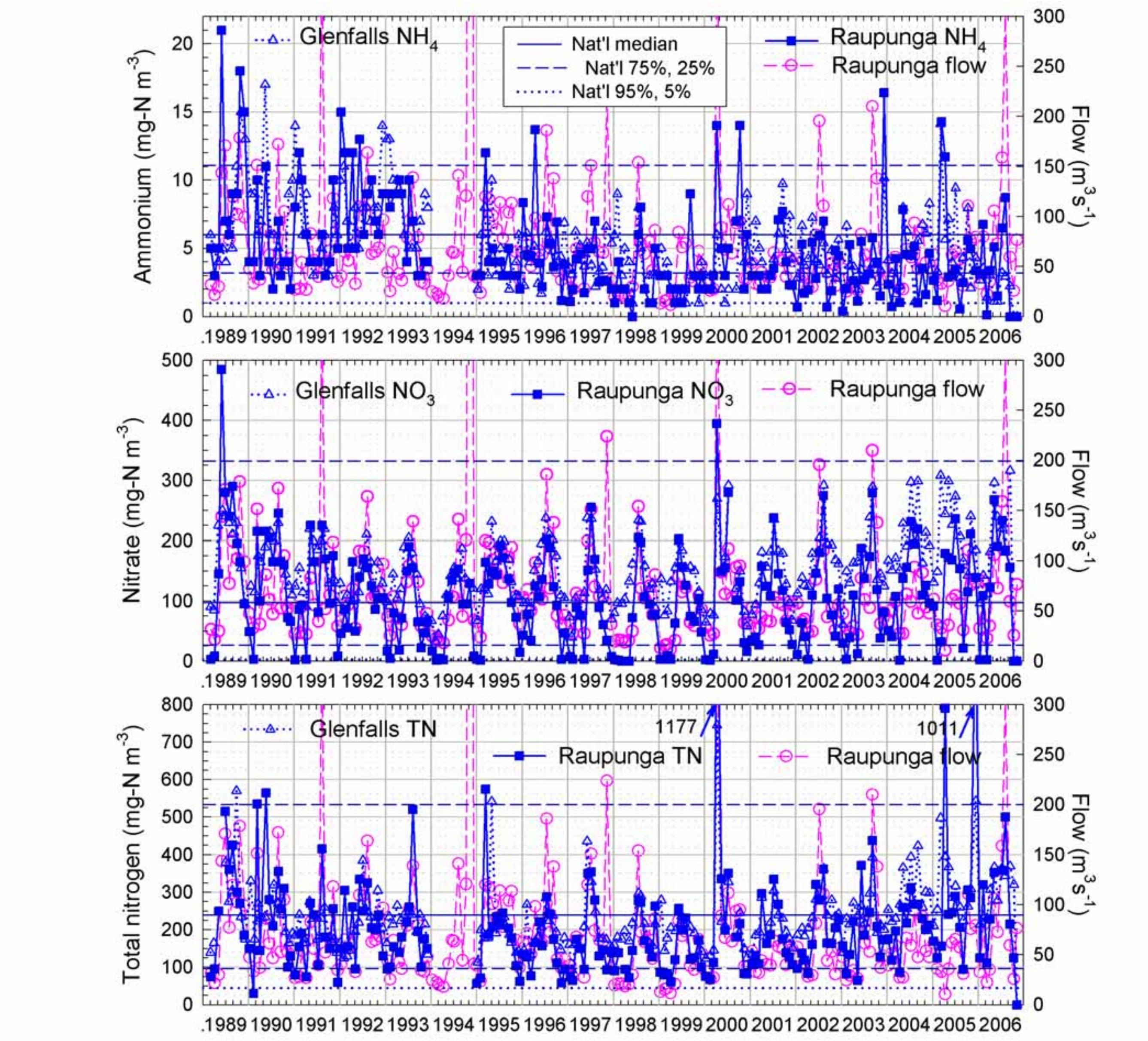

Figure A3: (A) Ammonium; (B) nitrate; (C) total nitrogen

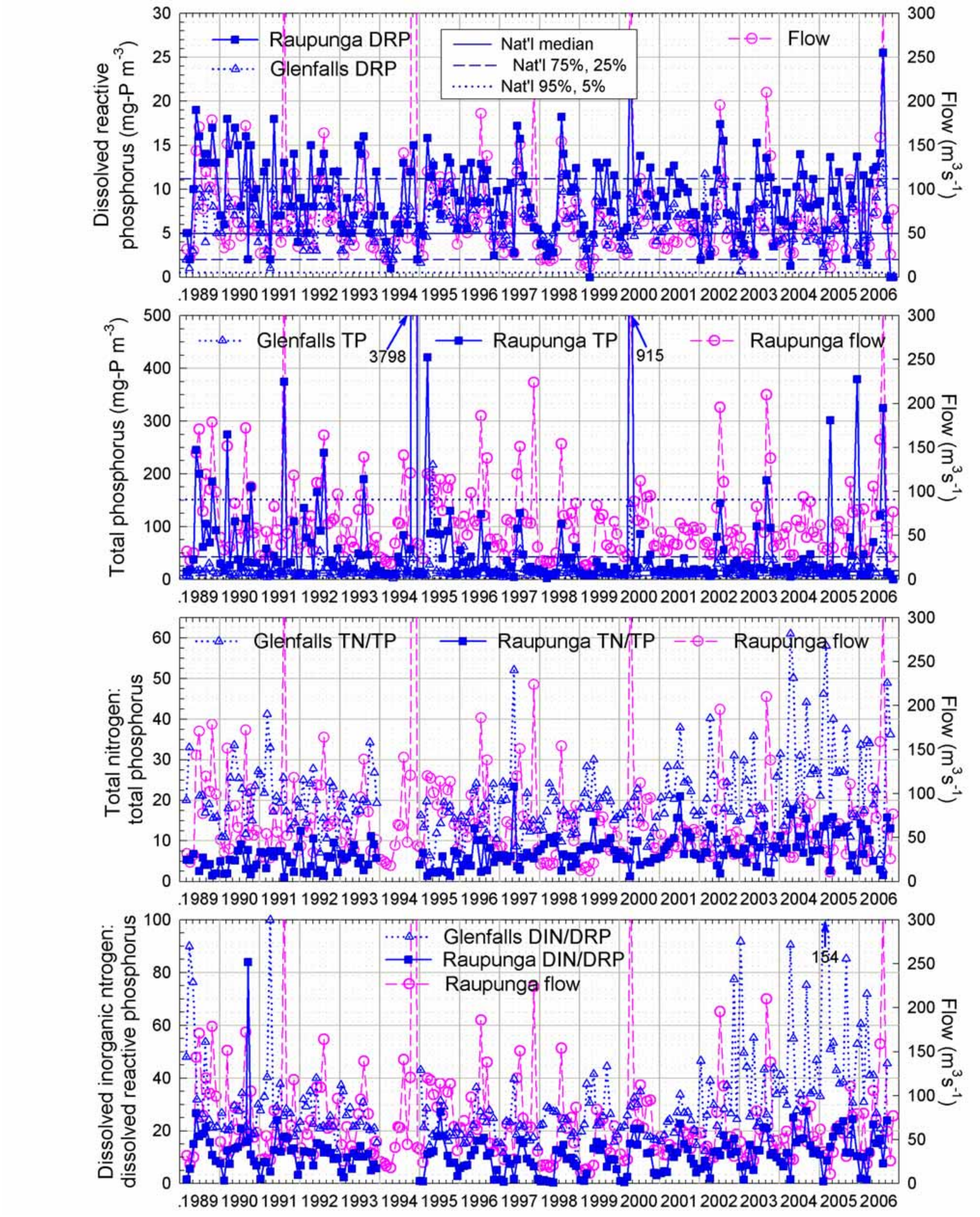

Figure A4: (A) Dissolved reactive phosphorus; (B) total phosphorus; (C) ratio of total nitrogen to total phosphorus; (D) ratio of dissolved inorganic nitrogen (as NH_4 + NO_3) to dissolved reactive phosphorus

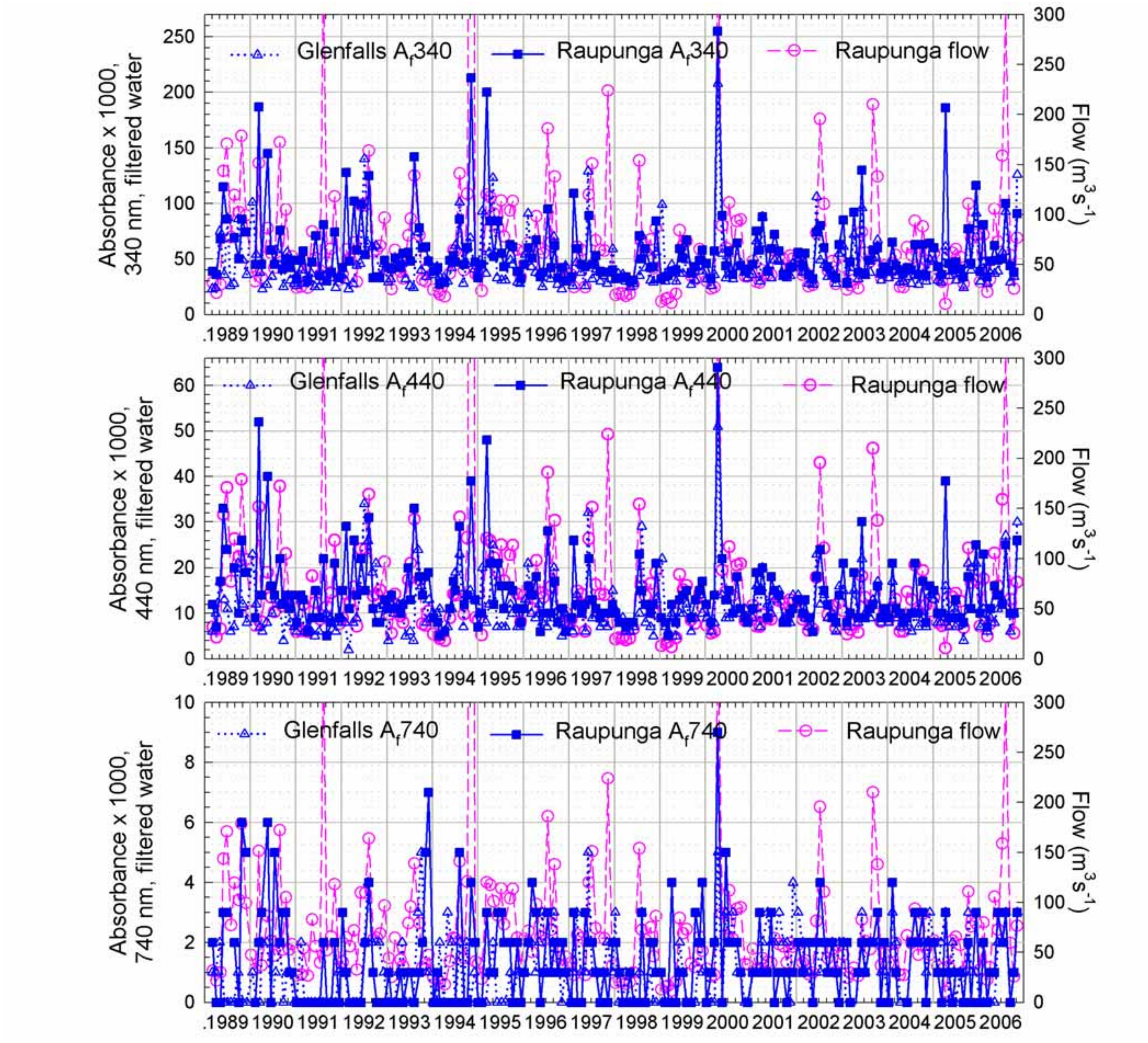

Figure A5: Light absorbance of filtered water at wavelengths of (A) 340 nm; (B) 440 nm; (C) 740 nm.

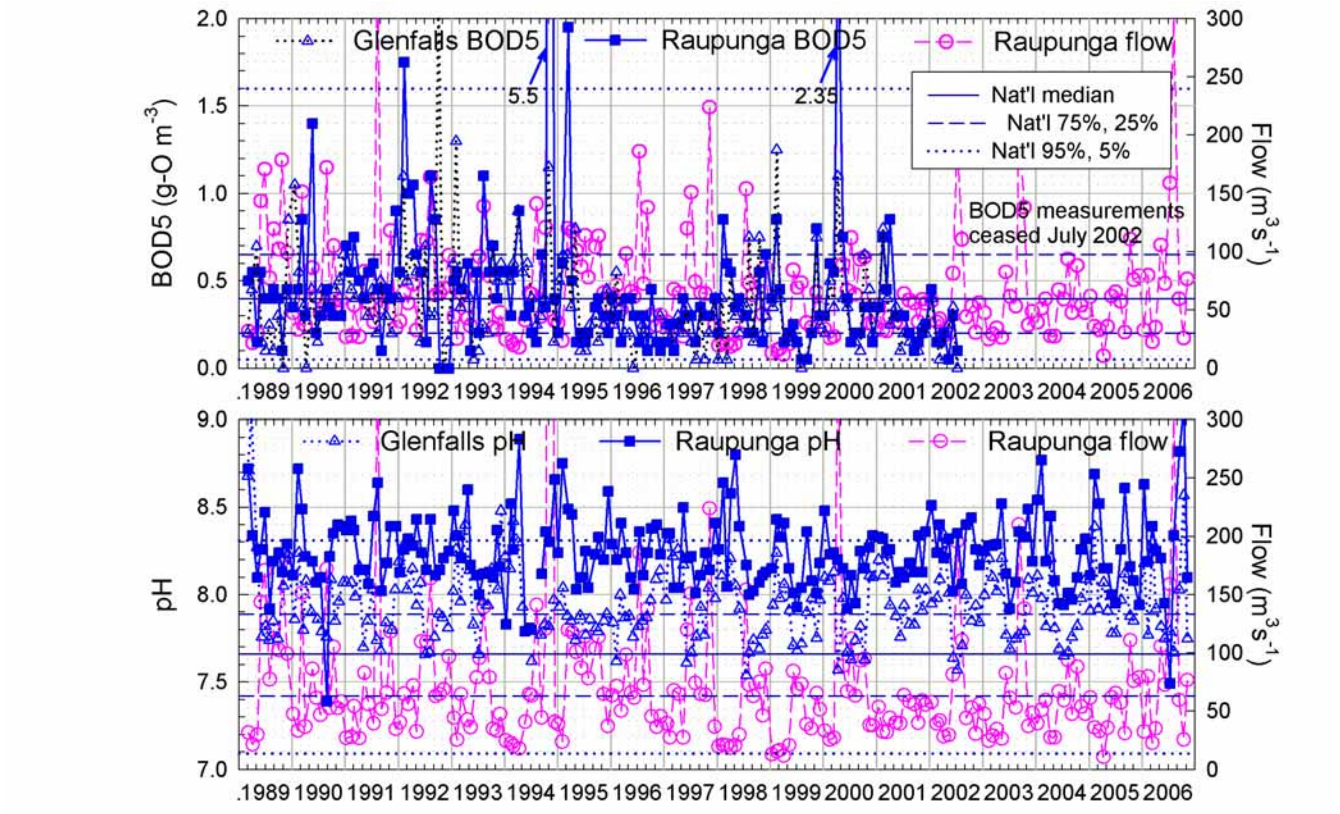

Figure A6: (A) Biochemical oxidation demand over 5 days; (B) pH.

APPENDIX B.

NRWQN statistics for the Mohaka River at Glenfalls*

Mohaka River at Glenfalls (HV6), National River Water Quality Network statistics

Glenfalls: 28 Feb 1989 - 9 Nov 2006. National statistics: 1989 - 2004.

	Flow m^3/sec	Temp deg C	Cond uS/cm @ 25 Deg C	DO % Sat	Clarity m	Turbidity NTU	Abs g340 /m	Abs g440 /m
Sample size	213	213	213	208	213	213	213	213
Nat'l sam size	*14894*	*14889*	*14886*	*14787*	*14828*	*14880*	*14836*	*14836*
Mean	34.14	11.1	81	102	2.33	2.6	2.41	0.54
Nat'l mean	*91.11*	*12.5*	*112*	*101*	*2.13*	*16.3*	*5.51*	*1.11*
Std dev	25.56	3.97	11.0	3.6	1.31	6.5	1.31	0.30
Maximum	197.7	19.4	111	123	7.65	69	11.3	2.45
95 percentile	86.13	17.9	97	107	4.40	8.3	5.13	1.13
Nat'l 95 perc	*415.00*	*20.2*	*238*	*111*	*6.89*	*60.0*	*17.0*	*3.38*
75 percentile	41.70	14.2	89	103	3.25	1.9	2.57	0.61
Nat'l 75 perc	*87.20*	*15.8*	*124*	*103*	*2.93*	*6.80*	*7.31*	*1.48*
Median	26.36	10.8	82	101	2.30	1.00	2.00	0.46
Nat'l median	*27.31*	*12.2*	*87.4*	*101*	*1.36*	*2.30*	*3.66*	*0.75*
25 percentile	17.70	8.1	72.6	100	1.35	0.64	1.68	0.35
Nat'l 25 perc	*7.53*	*9.0*	*64.9*	*98.2*	*0.51*	*0.98*	*1.72*	*0.36*
5 percentile	20.71	6.7	86.2	97.6	0.07	0.83	1.36	0.23
Nat'l 5 perc	*1.09*	*5.3*	*44.0*	*90.4*	*0.10*	*0.36*	*0.57*	*0.12*
Minimum	5.62	3.4	51.3	81.2	0.07	0.30	1.06	0.11

Mohaka River at Glenfalls (HV6), National River Water Quality Network statistics

(continued) Glenfalls: 28 Feb 1989 - 9 Nov 2006. National statistics: 1989 - 2004.

	NH4 ug/L N	NO3 ug/L N	TN ug/L N	DRP ug/L P	TP ug/L P	TN/TP	DIN/DRP	pH
Sample size	200	212	198	212	212	197	198	211
Nat'l sam size	*13894*	*14852*	*13832*	*14846*	*14818*			*14784*
Mean	5.2	153	234	6.0	15.8	20.5	31.0	7.94
Nat'l mean	*11.5*	*246*	*396*	*9.8*	*48.7*			*7.67*
Std dev	3.0	61	89	2.6	20.6	9.7	19.1	0.21
Maximum	17.0	316	745	13.1	217	61.1	153.6	9.02
95 percentile	10.2	259	386	10.6	39	38.3	72.4	8.29
Nat'l 95 perc	*45.0*	*971*	*1289*	*33.8*	*152*			*8.31*
75 percentile	6.8	191	268	8.0	16.0	24.4	34.3	8.07
Nat'l 75 perc	*11.1*	*333*	*533*	*11.2*	*43*			*7.89*
Median	4.4	148.9	220	6.0	11.0	19.0	25.9	7.92
Nat'l median	*6.0*	*97*	*240*	*5.0*	*17*			*7.66*
25 percentile	3.0	109.9	178	4.0	8.1	15.1	21.0	7.79
Nat'l 25 perc	*3.2*	*27*	*97*	*2.0*	*7*			*7.42*
5 percentile	1.1	69.0	135.9	2.0	5.8	6.8	15.3	7.66
Nat'l 5 perc	*1.0*	*3*	*45*	*0.5*	*3*			*7.09*
Minimum	0.0	0.0	0.0	0.0	0.0	2.5	9.1	7.54

* Note: rows containing medians and means are shaded, and rows containing national statistics have values underlined in blue italics

APPENDIX B, continued.

NRWQN statistics for the Mohaka River at Glenfalls*

Mohaka River at Glenfalls (HV6), National River Water Quality Network statistics								
(continued)	Glenfalls: 28 Feb 1989 - 9 Nov 2006. National statistics: 1989 - 2004.							
	Ca	**Mg**	**Na**	**K**	**Alk**	**Cl**	**SO4**	**BOD5**
	mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg-O/L**
					CaCO3		**SO4**	**(ceased**
	(------------------------------------ceased February 1990------------------------------------)							**July 02)**
Sample size	12	12	12	12	12	12	12	160
Nat'l sample size	*943*	*943*	*943*	*943*	*943*	*943*	*943*	*12716*
Mean	7.9	1.26	5.77	0.92	27.6	3.11	4.42	0.37
Nat'l mean	*9.8*	*2.00*	*8.71*	*1.31*	*32.1*	*8.13*	*7.45*	*0.54*
Std dev	0.93	0.13	0.58	0.11	2.53	0.40	0.74	0.29
Maximum	10.3	1.53	6.50	1.14	32.5	3.80	6.5	2.15
95 percentile	9.4	1.49	6.50	1.09	31.4	3.75	5.6	0.85
Nat'l 95 perc	*22.9*	*4.88*	*20.4*	*3.72*	*74.0*	*22.9*	*16.5*	*1.60*
75 percentile	8.0	1.30	6.18	0.99	30.0	3.33	4.55	0.50
Nat'l 75 perc	*10.6*	*2.38*	*9.40*	*1.60*	*35.0*	*9.90*	*7.50*	*0.65*
Median	7.8	1.24	5.80	0.92	26.3	3.05	4.25	0.30
Nat'l median	*7.70*	*1.62*	*5.90*	*0.82*	*26.5*	*5.10*	*4.50*	*0.40*
25 percentile	7.4	1.17	5.38	0.83	25.5	2.80	4.05	0.19
Nat'l 25 perc	*5.40*	*1.01*	*3.20*	*0.53*	*20.5*	*2.10*	*3.20*	*0.20*
5 percentile	6.8	1.13	4.98	0.78	25.3	2.67	3.77	0.05
Nat'l 5 perc	*3.30*	*0.60*	*1.30*	*0.35*	*12.5*	*0.50*	*1.90*	*0.05*
Minimum	6.70	1.12	4.70	0.76	25.0	2.50	3.60	0.00

* Note: rows containing medians and means are shaded, and rows containing national statistics have values underlined in blue italics