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Manatū Ahu Matua

A study and manipulation of Lake Tutira

October 1973 – April 1977

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Acknowledgements

Steve Pullan's involvement and dedication throughout the Lake Tutira study far exceeded what could have reasonably been expected. A boat that leaked, challenging diving conditions, gear that regularly failed and night time sampling highlighted Steve's skills and ability to deal with a variety of unusual conditions. So too did chemical analysis in primitive conditions, sorting weed samples and processing trout far into the night irrespective of how long the day had been. Steve made an outstanding contribution, I couldn't have asked for a better co-worker or friend.

Andy Carruthers, an angler from the Hawkes Bay Acclimatisation Society, was committed to the Lake Tutira study from the beginning, investing an enormous amount of time voluntarily to the study. Andy's practical skills were invaluable – especially during the construction, installation and maintenance of the aerohydraulic guns and associated equipment. Problems were there to be resolved and nothing was too much trouble. Andy performed a key liaison role with those in the local community who became involved in various aspects of the study. To Steve and myself he was generous to a fault. Sadly, Andy has since passed away and this report is a belated tribute to him.

Thanks are due to colleagues and friends from the Ministry of Agriculture and Fisheries who assisted with many aspects of the construction and installation of the aerohydraulic guns. I don't think anyone will forget the aerohydraulic gun installation celebration at the Tutira Outdoor Education Centre!

Without Rob McColl's involvement, support and advice a crucial component of the study could not have been undertaken. His agency, the Department of Industrial and Scientific Research (DSIR) carried out chemical analyses of water samples collected during the study (other than the analysis carried out at the lake). Rob compiled a draft of water quality results in anticipation of a final report and since that time has continued to "encourage" me to document the study. Despite this we have remained good friends!

In compiling this report the first task was to create an electronic data base from data recorded in pencil. From that point my husband, Colin Townsend kindly provided support with data analysis and then compiled tables and figures presented in the report. He also provided editorial input for which I am most grateful. In his role as Professor of Zoology he stresses the importance of writing up studies in a timely manner to his students. Needless to say, he is far from impressed with the 35 year time lag considering that it makes something of a mockery of today's scientific publishing culture!

I have to thank Ian Gear for his encouragement, support and comments on the script all of which have been motivating. And finally, I am indebted to Victoria Lamb, MAFBNZ for appreciating the value of documenting this historic study and providing support throughout the process.

Purpose of this report

The purpose of this report is to document a study and experimental manipulation of Lake Tutira conducted from 1973 – 1977 by the Ministry of Agriculture and Fisheries in an attempt to alleviate eutrophic conditions because of concern for the rainbow trout fishery. Currently the Ministry of Agriculture and Forestry Biosecurity New Zealand (MAFBNZ) is conducting a *Hydrilla verticillata* eradication programme in four Hawke's Bay water bodies, including Lake Tutira, the largest of the four, and adjoining Lake Waikopiro. Given the lack of recent studies on the condition of Lake Tutira, the importance of data from the 1970s study was recognized. Since then data analyses have been completed and a comprehensive picture developed about the state of Lake Tutira in the 1970s.

Despite the lake manipulation project taking place more than 30 years ago, measures of lake ecology made then are still relevant to the current *Hydrilla* eradication programme. Recent applications of endothall and the use of grass carp are already having an impact on the *Hydrilla* beds and other aquatic plants. These changes may in turn cause modifications to aspects of the wider lake environment, such as water quality, phytoplankton and the trout stocks. Having detailed historical data available allows comparisons to be made between most aspects of the two initiatives, something that is expected to facilitate interpretation of results from the *Hydrilla* eradication programme.

Reason for the lake study and manipulation

Despite the rainbow trout fishery being the primary motivation behind the 1970s study a range of variables needed to be monitored to develop an understanding of the lake as an integrated whole. Furthermore, the baseline study was critical for evaluating whether, and in what ways the lake manipulation might have impacted on the wider lake ecology.

Another fundamental aspect of such baseline studies is the chronology of events and activities that have taken place within the catchment and the lake prior to the study. Indeed the current condition of Lake Tutira reflects the cumulative impact of these past activities.

Development of the Lake Tutira catchment for farming from the 1800s saw extensive bush clearance that resulted in erosion and siltation of the inlet streams. Trout were first released into the lake in the early 1900s and ever since the fishery has been highly valued as the only sizable lake fishery in Hawkes Bay. Sandy Creek, the main inlet stream, provided suitable conditions for trout spawning but the smothering of gravels by sediment made stocking the lake necessary to maintain the fishery. In the 1920s *Elodea* was discovered in the lake and this was followed in the early 1960s by *Hydrilla*, a serious pest plant. Aerial topdressing of fertilizer began in the 1950s and was soon followed by increased aquatic plant growth and a decline in water quality. By the late 1960s increasing concern was being expressed about worsening conditions in the lake and the impact eutrophication was having on the rainbow trout fishery. For instance, rather than having suitable habitat throughout the entire water column during summer, trout were being confined to the warm surface waters by a lack of oxygen from the thermocline (8 to 10 metres deep) to the lake bed. This was only one symptom of a serious situation that saw the Ministry of Agriculture and Fisheries initiate the project to facilitate mixing of the water during summer in an effort to relieve the eutrophic conditions that were impacting the rainbow trout fishery.

Study design

A before/after design was adopted for the Lake Tutira manipulation.

For the first two years relevant aspects of the lake environment were sampled to provide a baseline for comparison with the following two years when lake manipulation took place.

Physicochemical measures included water temperature, dissolved oxygen concentration, nutrients and other indicators of water quality and trout habitat. Phytoplankton growth responds to several environmental factors that are therefore important to monitor given the possibility of changes during lake manipulation. For instance, the possibility of prolific phytoplankton growth shading aquatic plant beds could have consequences for trout food such as common bullies and insects that live in the weed beds and feature prominently in trout diet. As well as sampling habitat features that might affect trout directly or indirectly, trout were sampled regularly throughout the study to monitor growth, diet and distribution.

After gathering two years of baseline data six aerohydraulic guns that had been installed in the lake began operating. An account of the aerohydraulic gun design, construction, installation and operation is provided in Appendix 1. For six months (November to April) in each of the summers of 1975/76 and 1976/77, lake water was artificially circulated by the guns. All aspects of the baseline monitoring were continued throughout the 18 month lake manipulation period.

Data were also gathered from Lake Waikopiro, a small lake located adjacent to Lake Tutira. Given the planned manipulation of Lake Tutira, we considered Lake Waikopiro could provide a partial control being in the same location and subject to the same climatic and catchment influences as Lake Tutira but lacking any manipulation.

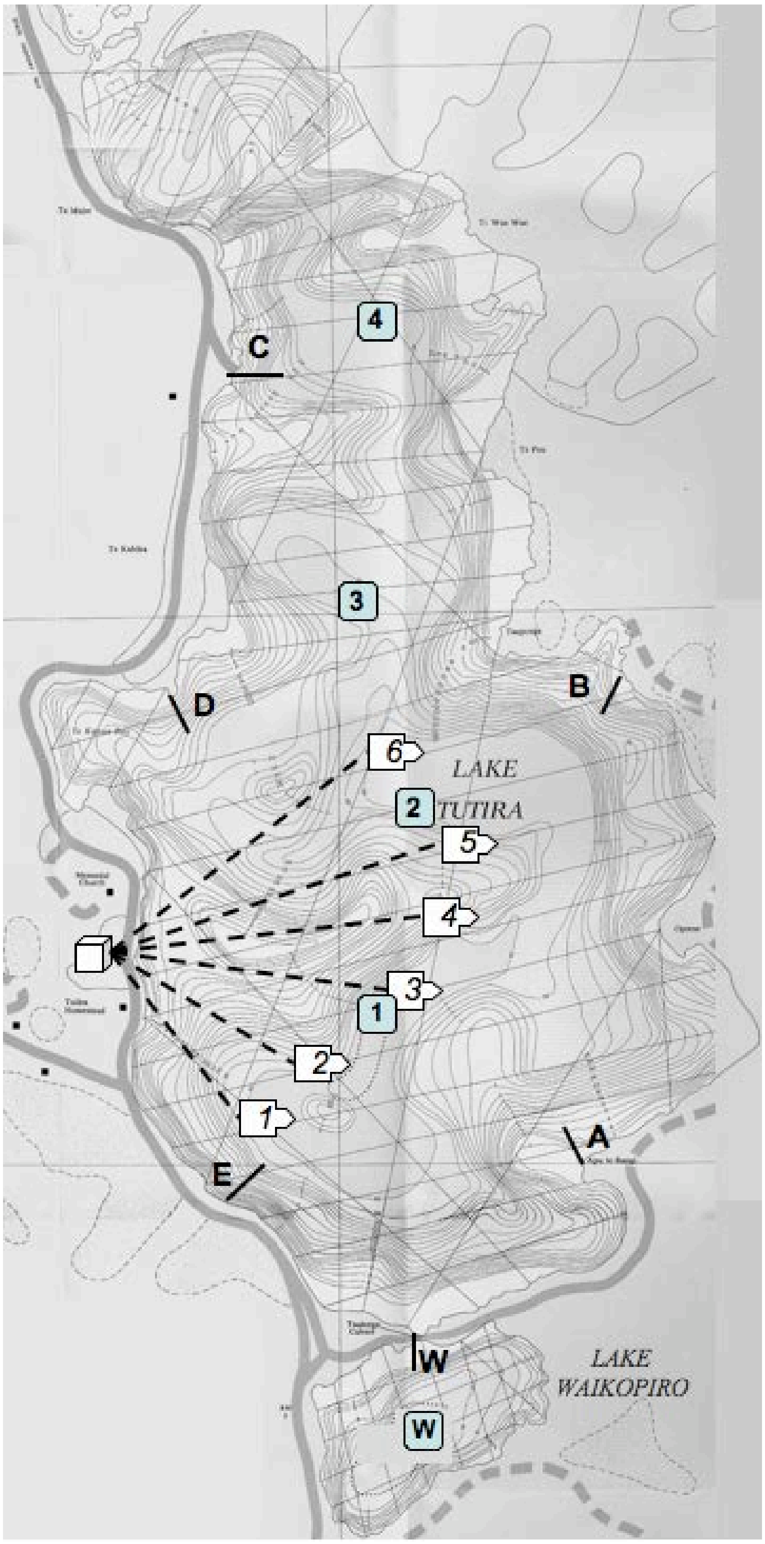
Description of Lake Tutira

Lake Tutira is located 50 km north of Napier on State Highway 2. Lake bathymetry documented by Irwin in 1974 (Plate 1) was used to determine the morphological features of the lake.

Morphological features of Lake Tutira

Area (ha)	174
Volume (m^3)	$36.1x10^6$
Shoreline (km)	7.99
Mean depth (m)	20.8
Maximum depth (m)	42
Maximum length (km)	2.4
Maximum width (km)	1.2

Plate 1. Lakes Tutira and Waikopiro, showing position of sampling stations (numbers in shaded boxes), aquatic plant transects (lines and letters), compressor shed, tubes (dotted lines) and aerohydraulic guns (white symbols with numbers).



Sampling programme

Four sampling stations were established from the deepest southern basin to the shallower northern part of Lake Tutira (Plate 1). Features such as temperature, light penetration and oxygen concentration were measured monthly or bimonthly at one metre intervals from the surface to the lake bed throughout the study. Other parametres monitored on a monthly or bimonthly basis at these stations included pH and the nutrients reactive phosphorus, total phosphorus, nitrate-nitrogen and ammonium-nitrogen. Rather than being measured at metre intervals these parametres were measured from water samples collected at 0, 1, 5, 10, 15, 25, and 35 m depths. Phytoplankton measures including the composition and number of phytoplankton, total pigment, chlorophyll *a*, and Pmax (a measure of maximum phytoplankton productivity) were also collected from these depths.

The extent and height of aquatic plant beds were monitored bimonthly from five transects located around the edge of the lake (Plate 1). Similarly trout were sampled on a bimonthly basis throughout the study using nets with three different mesh sizes at a variety of locations around the lake. Apart from trout monitoring, the sampling regime established in Lake Waikopiro was the same as that in Lake Tutira. Appendix 2 provides a detailed summary of the sampling schedule.

Variations in this schedule were tailored to the logistics of the lake manipulation. For instance, monthly sampling of physical and chemical parametres during the first year was reduced to every other month in the second. That year Lake Waikopiro sampling was suspended. Monthly sampling in both Lakes Tutira and Waikopiro resumed when the aerohydraulic guns started operating in October 1975 and continued for nine months until June 1976. Whereas monthly sampling of physicochemical attributes continued in Lake Tutira, sampling biological attributes took place bimonthly over the summer until April 1977. Similarly, Lake Waikopiro sampling took place bimonthly in the final year of regular sampling. From April 1977 until March 1980, when the aerohydraulic guns ceased operating, water temperature and dissolved oxygen readings were taken at Station 1 at strategic times only.

Documenting study results

For clarity, Lake Tutira study results have been documented according to three components.

- Physicochemical and phytoplankton features – required to assess the level of eutrophication in Lake Tutira and identify seasonal patterns associated with enrichment.
- Aquatic plants – to identify undesirable introduced plant species and assess distribution and extent of plant beds.
- Rainbow trout stocks – to assess the state of rainbow trout stocks including growth, feeding and distribution.

These components cannot be considered independently however, as complex interactions between and among them create the distinctive lake ecology of Lakes Tutira and Waikopiro. Where interactions were of special interest they have been recorded. Of course the major component of the study was the evaluation of the effect of the aerohydraulic guns on aspects of lake ecology. This has been addressed under each of the three components and drawn together in a summary at the conclusion of the report.

Component 1
Physicochemical and phytoplankton features of Lakes Tutira and Waikopiro

Data gathering

Water temperature (°C) was measured at metre intervals from the surface to the lake bed at Stations 1-4 in Lake Tutira and in Lake Waikopiro using a temperature meter. Sampling took place monthly or bimonthly from October 1973 to April 1977 and during selected months after that until March 1980.

Climatic data including sunshine hours, rainfall and temperature (mean monthly maximum, mean monthly minimum and mean monthly) were accessed from the NIWA climate database from three weather stations, respectively Napier Nelson Park, Tutira Station and Mohaka Forest, located closest to Lake Tutira

Oxygen concentration (g/m^3) was measured at metre intervals from the surface to 15 m using an oxygen meter and then for 25 m and 35 m using a Winkler titration method. Oxygen readings were collected from Stations 1-4 in Lake Tutira and from Lake Waikopiro. From February 1976 oxygen concentration was measured at all depths using the oxygen meter.

Light penetration was recorded at metre intervals using a solar radiation light meter. The euphotic extinction co-efficient was calculated from the slope of irradiance against depth as the depth where 1% of the irradiance remains.

Secchi disc readings were also taken at four Lake Tutira stations and in Lake Waikopiro.

pH measurements were taken using a pH meter from six or seven depths either monthly or bimonthly at four Lake Tutira stations and at Waikopiro over the course of the study.

Nutrients: total P, soluble reactive P, nitrate-N and ammonium-N (mg/m^3) were monitored monthly or bimonthly at six or seven depths from Stations 1-4, Lake Tutira and five depths from Lake Waikopiro. Total P and nitrate-N were measured by the methods of Strickland and Parsons (1968). Acid-molybdate reactive P was measured by an automated method which eliminates arsenic interference. Ammonium-N was measured by an automated method adapted from Crooke and Simpson (1971).

Phytoplankton was sampled from six depths at four Lake Tutira stations. Water was collected using a Van Dorn bottle and 50 ml samples were extracted and preserved with Lugol's solution. Counts of 1 ml phytoplankton samples were made using a microscope. Dr Vivienne Cassie, DSIR, identified the phytoplankton taxa. This data set is incomplete due to mislaid samples and results.

Chlorophyll a and phaeophytin (mg/m³) samples were collected from four stations and six or seven depths in Lake Tutira and at five depths in Waikopiro. Water was collected using the Van Dorn and 1 litre of that was filtered. Total pigment and chlorophyll *a* concentrations were determined at the DSIR Taupo laboratory.

Pmax (mgC/m³/hr), a measure of potential phytoplankton productivity, was determined on 19 occasions between December 1973 and April 1977. Water samples were collected at 2, 5, 10, 15, 25 and 35m from Station 1 and treated with ^{14}C in the laboratory. During two hour incubations, samples from each depth were exposed to six different light intensities, corresponding to different depths, to establish a value of Pmax corresponding to intensities that consistently produced the average of the two highest productivity readings.

Findings

Water temperature

Water temperature is a major driver of lake processes. Temperature data collected for Lakes Tutira and Waikopiro exhibited a strong seasonal pattern. During July, August and September water temperature from the surface to the lake bed was constant at approximately 10°C. Surface temperatures began to increase from October onwards until warm surface water was completely partitioned off from the cold deep water by the metalimnion[1], the phenomenon of stratification. Within the metalimnion, large temperature changes took place over a short distance creating a density barrier between the upper epilimnion and lower hypolimnion. The lack of total mixing between these layers for up to seven months (November to May) has serious consequences for lakes as enriched as Lakes Tutira and Waikopiro. As air temperature dropped from March onwards, surface water temperatures declined causing the thermocline[2] to deepen and completely break down by about June. When water temperatures throughout the lake were similar, water circulated again, allowing oxygen and nutrients to be redistributed.

[1] The metalimnion is the region of rapid temperature change – gradient comprising a defined depth range.

[2] The thermocline is the specific depth of maximum temperature change with depth.

To describe the seasonal water temperature patterns during the study in greater detail, surface water temperatures will be considered first followed by temperature profiles and stratification.

Surface temperatures

During the study, surface temperatures (mean of 0, 1 and 2 m depths) in Lake Tutira ranged from a February 1974 high of 23.9° C to an August 1975 low of 9.6° C (Table 1). A comparison of temperatures between Stations 1, 2, 3 and 4 showed a high level of agreement so further analyses were confined to Stations 1 and 4. These stations were the farthest apart with Station 1 located in the deep southern basin and Station 4 in the shallower northern part of the lake (Plate 1). The similarity in surface temperatures between Stations 1 and 4 is shown for seven months from October to April each year in Table 1, and for the whole year in Figure 1.

Seasonal patterns in surface water temperatures from Stations 1 and 4 are shown from 1973-1977 (Figure 1). A comparison of monthly surface temperatures between the first two summer periods (October to April) showed the years to be very similar. But surface temperatures in the following two summers (1976/77, 1976/77) declined by up to 6°C (Table 1). Initially the 1975/76 temperature drop was thought to be caused by the aerohydraulic guns that had become operational in November 1975. The delivery of cold water from the hypolimnion to the lake surface was consistent with such a decline in temperatures.

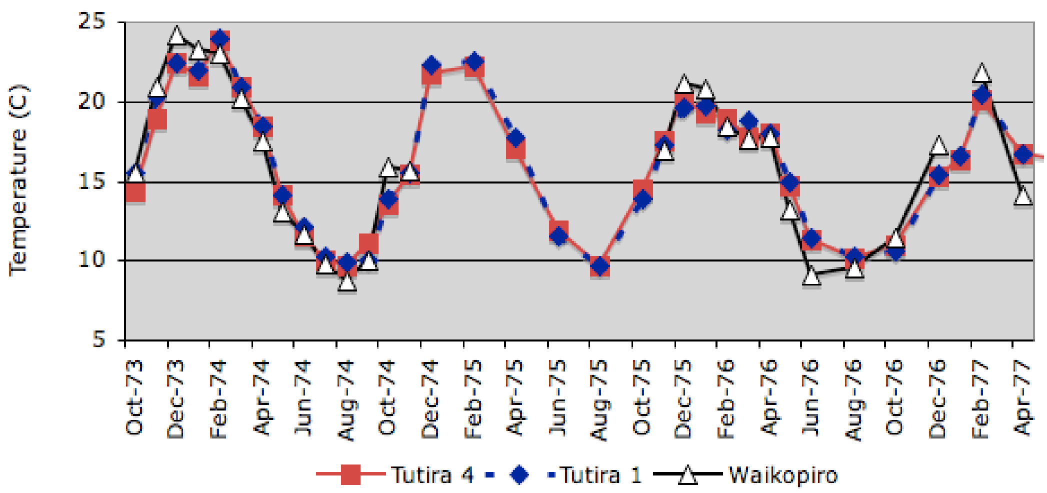
To test this hypothesis, Lake Waikopiro results were considered. The mean surface temperature maximum and minimum of 24.2°C and 8.6ºC in Lake Waikopiro were slightly warmer and cooler than in Lake Tutira. A small lake does not have the buffering capacity of a larger lake and is therefore likely to respond more directly to climatic influences such as air temperature highs and lows. Despite this, Waikopiro surface temperature patterns were very similar to those of Lake Tutira (Figure 1).

Table 1. Mean surface temperatures (0, 1 and 2 m) (°C) at Stations 1 and 4 in Lake Tutira and in Lake Waikopiro, 1973 - 1977.

Year	Station	Oct-73	Nov-73	Dec-73	Jan-74	Feb-74	Mar 74	Apr-74
1973/74	*Stn 1*	15.5	20.3	22.4	22	23.9	20.9	18.5
	Stn 4	14.3	18.9	22.4	21.6	23.8	21	18.5
	Waik	15.6	20.9	24.2	23.2	23	20.2	17.5
1974/75	*Stn 1*	13.8	15.5	22.5	x	22.6	x	17.8
	Stn 4	13.6	15.4	21.7	x	22.2	x	17
	Waik	x	x	x	x	x	x	x
1975/76	*Stn 1*	13.9	17.3	19.6	19.8	18.2	18.6	18
	Stn 4	14.5	17.5	20	19.3	18.9	17.8	18
	Waik	x	17	21.2	20.7	18.5	17.6	17.8
1976/77	*Stn 1*	10.6	x	15.4	16.5	20.4	x	16.7
	Stn 4	11	x	15.3	16.3	20	x	16.7
	Waik	11.4	x	17.3	x	21.9	x	14.1

Note: x = no data

Figure 1. Surface temperature at Stations 1 and 4 LakeTutira, and Lake Waikopiro



If the guns were responsible for cooler surface water in Lake Tutira, Lake Waikopiro surface temperatures should not show a corresponding similarity. But Waikopiro surface temperatures had also declined (Table 1). In fact, the Waikopiro pattern from 1973 to 1977 was identical to that of Lake Tutira, providing little support for the hypothesis that the guns were responsible for the change (Figure 1).

Climatic variability was an alternative explanation for surface temperature changes during the study. Accordingly, climatic records for sunshine hours, mean monthly maximum temperature, mean monthly minimum temperature, mean monthly temperature and rainfall data were accessed from NIWA and tabulated for October, November and December from 1973 – 1976 (Table 2).

The 1973 and 1974 springs were warmer, sunnier and drier than the same periods in 1975 and 1976.

Table 2. Climatic data for Lakes Tutira & Waikopiro (total rainfall, sunshine & average monthly temperatures) from October to December.

Year	Rainfall (mm)	Sunshine hours	Ave max temp	Ave Min Temp	Ave mean temp
1973	203.3	644.4	20.2	9.9	15.1
1974	270.8	699.1	19.3	9.7	14.5
1975	492.6	624.8	18.7	8.7	13.4
1976	390.3	564.7	17.9	8.7	13.3

Note: Data used from climate stations closest to the lakes

Temperature profiles and thermocline behaviour

To follow the formation and breakdown of stratification between 1973 and 1977 bimonthly temperature profiles were constructed for October, December, February, April and August for Station 1 in Lake Tutira and Lake Waikopiro (Figure 2).

For the first two years the thermocline in Lake Tutira exhibited the same pattern. A drop in temperature took place from more than 20°C at the surface to 10°C at 10 m. From the well developed thermocline to the lake bed the temperature remained consistent at approximately 10°C. The thermocline also remained stable at a depth of about 10 m for seven months (October-April) each year. The behaviour of the metalimnion itself during that period is expressed by depth and thickness (Table 3). In both years stratification broke down completely in June, allowing mixing of surface and deeper water during July, August and September.

Figure 2. Temperature profiles (degrees Celsius) at Station 1, Lake Tutira and Lake Waikopiro in October, December, February, April and August in different years. Colour coding follows through from October/December in year 1 (e.g. 1973) to February/August in year 2 (e.g. 1974).

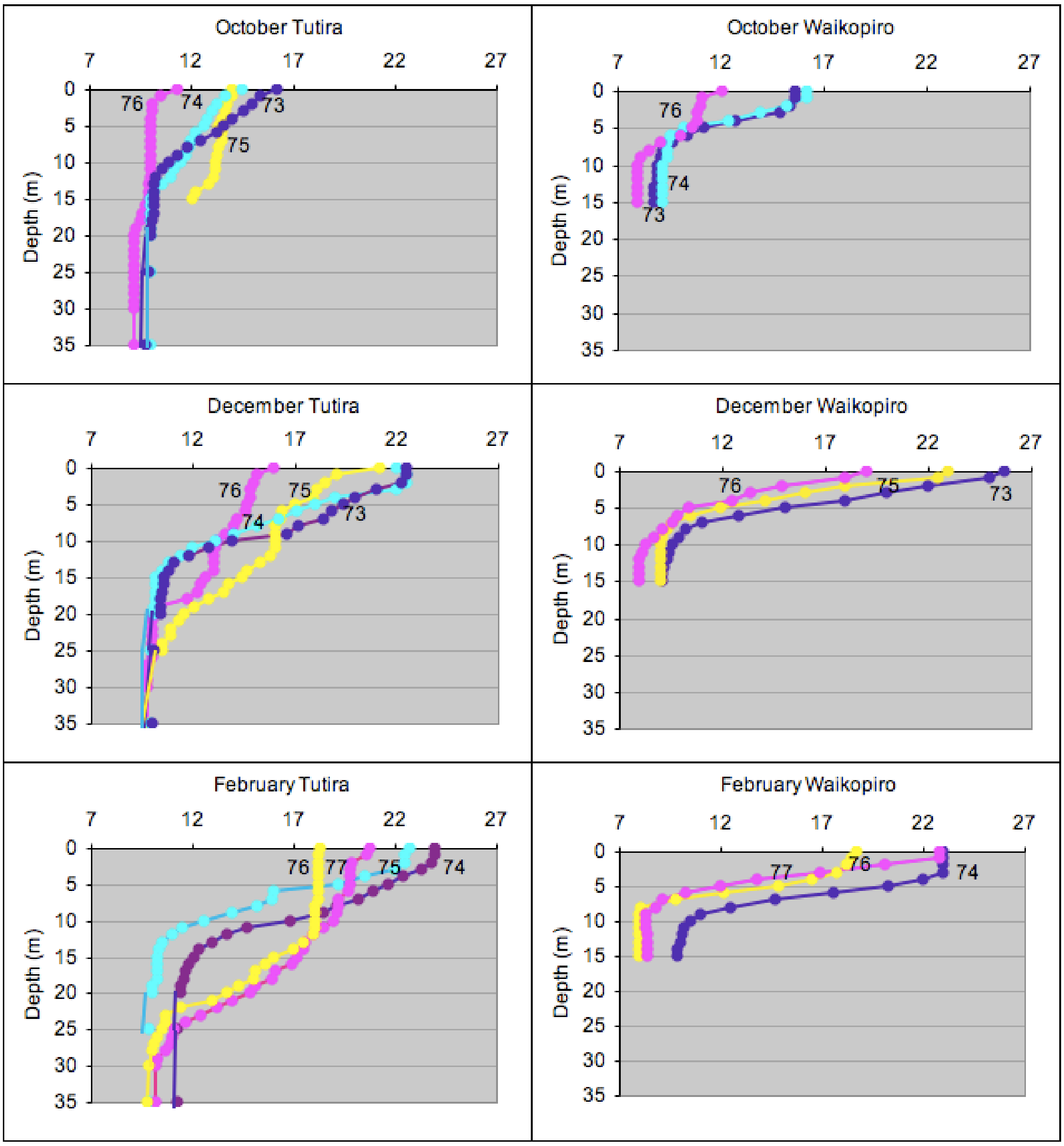
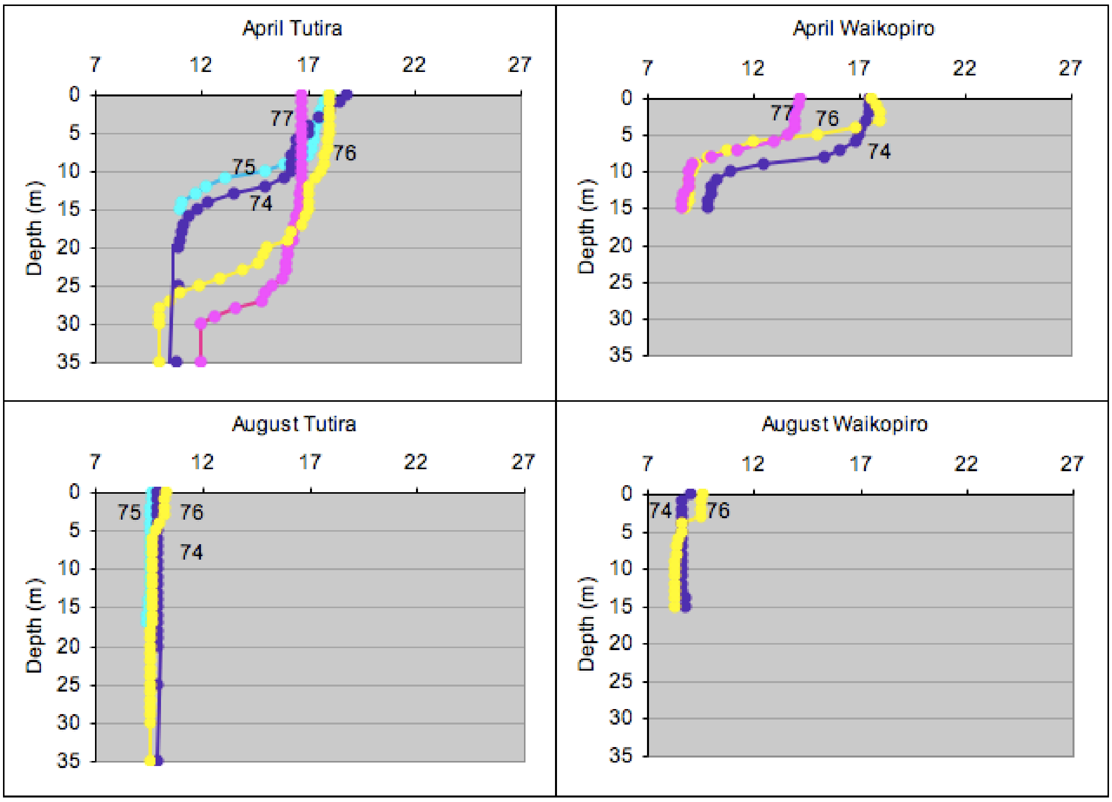


Figure 2 continued.



In contrast, the following two years presented a different stratification pattern. Surface temperatures were lower, temperature changes with depth were not as rapid and the metalimnion was both deeper and extended over a greater distance (Figure 2). The thermoclines also migrated downwards during the summer reaching 20-23 m in 1976 and 27-29 m in 1977 (Table 3). This enabled water circulation to take place down to these depths moderating the effects of eutrophication to some extent.

As with the first two years, the behaviour of the metalimnia in 1975/76 and 1976/77 were expressed according to depth and thickness (Table 3). This clearly showed how deep the metalimnia were and their downward progression over summer. Temperature data collected on specific occasions from 1977-1980 showed the pattern of cooler water and a deeper metalimnion persisted until 1980 when the available data indicated that the metalimnion was beginning to behave more like those of the first two years. Indeed the operation of the guns was discontinued in 1980.

Table 3. Upper and lower limits (m) of the metalimnion (numbers in bold) and depth of deoxygenated layer (< 1g/m^3) (in brackets) at Stations 1 and 4, Lake Tutira, 1973-1980.

Year	Station	Nov	Dec	Jan	Feb	Mar	Apr	May
1973/74	*Stn 1*	**3-4** (10)	**7-11** (9)	**7-11** (8)	**7-12** (8)	**7-12** (8)	**12-14** (12)	**15-16** (25)
	Stn 4	**5-6** (10)	**7-11** (9)	**8-12** (7)	**8-12** (9)	**8-12** (9)	**11-14** (11)	**16-18** (25)
1974/75	*Stn 1*	**9-10** (no)	**4-11** (no)	x	**4-10** (8)	x	**9-11** (11)	x
	Stn 4	**9-11** (14)	**8-9** (no)	x	**5-7** (7)	x	**10-14** (11)	x
1975/76	*Stn 1*	**11-12** (no)	**No T** (no)	**18-19** (25)	**15-16** (21)	**23-25** (21)	**23-25** (20)	**23-25** (24)
	Stn 4	**16-17** (no)	**15-16** (no)	**18-19** (25)	**16-17** (20)	**20-23** (20)	**21-23** (19)	**23-24** (23)
1976/77	*Stn 1*	x	**18-19** (no)	**No T** (35)	**20-23** (22)	x	**27-29** (29)	x
	Stn 4	x	**18-19** (no)	**20-22** (23)	**No T** (21)	x	x	x
1977/78	*Stn 1*	**No T** (no)	x	**15-20** (no)	**15-17** (22)	**18-20** (19)	**22-25** (23)	x
	Stn 4	**No T** (no)	x	x	**19-20** (22)	x	**22-25** (20)	x
1978/79	*Stn 1*	**11-13** (no)	x	**15-19** (16)	x	**19-20** (20)	x	x
	Stn 4	x	x	**15-17** (14)	x	**18-20** (20)	x	x
1980	*Stn 1*	x	x	**10-11** (12)	x	**12-14** (14)	x	x
	Stn 4	x	x	**9-12** (13)	x	**12-15** (13)	x	x

Note: No T = no well defined thermocline
(no) = dissolved oxygen concentrations did not fall below 1g/m^3
x = no data available

Whereas cooler spring weather may have been an important contributing factor for lower surface water temperatures in 1975/76 and 1976/77, it was unlikely to explain the significant changes that took place through the rest of the water column. What was consistent with a deeper metalimnion that migrated downwards during the summer was the operation of the guns – but with only partial success.

By comparison Lake Waikopiro did not display wide differences in thermocline behaviour between 1973/74 and 1975/76. Temperature drops were rapid right from the surface, resulting in a shallow and strongly developed thermocline (Figure 2). Surface water was completely separated from deeper water from October to April, or seven months each year.

Together, the climatic data, coincidence of surface temperatures in Lake Tutira and Waikopiro, temperature profiles and behaviour of both metalimnia and thermoclines indicated that the variability in thermal characteristics of these lakes was most probably due to two major influences:

- Surface water in both Lakes Tutira and Waikopiro reached higher temperatures during extended warm weather during spring.

- The difference in temperature profiles in Lake Tutira before and after operation of the guns commenced is consistent with a partially successful lake manipulation. Whereas total circulation was the desired outcome, the guns appear to have increased mixing by lowering both metalimnion and thermocline thereby increasing the volume of the epilimnion and reducing the volume of the hypolimnion

Dissolved oxygen

Sufficient dissolved oxygen is critical for lake dwelling fauna. Insufficient oxygen concentrations result in the exclusion of fauna from their usual lake habitats and a downgrading of the lake environment. In oligotrophic lakes that stratify, oxygen concentration is not an issue as the deeper hypolimnetic water remains oxygenated over summer. In contrast, eutrophic lakes that stratify, such as Lakes Tutira and Waikopiro, can suffer from oxygen depletion below the thermocline during summer. To appreciate the way oxygen concentration behaves three factors must be considered:

- Seasonal changes in water temperature which create the epilimnion, metalimnion and hypolimnion.

- Excessive phytoplankton growth in the epilimnion adding oxygen to surface waters but depleting oxygen in the deeper waters during decomposition.

- The release of nutrients (phosphate and ammonium) from bottom sediments when deeper water becomes anoxic.

Water temperature patterns together with nutrient fuelled phytoplankton growth create dissolved oxygen concentrations that are characteristic of enriched lakes.

Seasonal patterns

Lakes Tutira and Waikopiro exhibited strong seasonal patterns of dissolved oxygen concentration (Figure 3). In Lake Tutira when water was circulating during July, August and September, oxygen concentration was approximately 10 g/m^3 throughout the entire water column. By October, when surface water began to warm, phytoplankton activity increased dramatically causing water to become supersaturated with dissolved oxygen. Table 4 shows the depth to which supersaturated conditions extended and the mean of the % saturation values from the surface to that depth. For example, in October 1973, supersaturated water was present from the surface to a depth of 5 m. The mean of the five % saturation values was 161.6% and the highest value (186%) was recorded at a depth of 1 m. Super-saturation levels remained high until December, but from January to April levels were lower or supersaturated water was no longer present.

At the same time that phytoplankton activity was creating supersaturated conditions in spring, the thermocline was also strengthening and preventing the mixing of surface and deeper waters. Phytoplankton sinking down from the epilimnion were likely to be slowed by rapid density changes within the metalimnion allowing decomposition to take place from there down to the lake bed. As a consequence, oxygen in the thermocline was depleted before that of the deeper water (December 1973, Figure 3). In 1973, deoxygenation took place within the metalimnion before water at the lake bed was completely deoxygenated.

Decomposition at both depths deoxygenated the entire hypolimnion (representing 70% of the lake volume) within three weeks. At that time, water sampled from the thermocline appeared pink and emitted a strong odour of hydrogen sulphide, indicating that anaerobic bacterial decomposition was taking place. This phenomenon was not encountered again during the study but the same general relationship between the thermocline and deoygenation took place each year.

Data were tabulated to compare the depth of the thermocline directly with the point where oxygen concentration fell below 1 mg/m^3 for Stations 1 and 4 in Lake Tutira (Table 3 temperature section). Not only did the depth of the thermocline coincide between the two stations for different years but so also did the depth of oxygen depletion. For instance, during the first two years, from December onwards the thermocline was at a depth of about 10 m and the point where oxygen concentration fell to < 1 mg/m^3 was located within the thermocline.

Annual variations

Despite the seasonal consistency of both supersaturation and oxygen depletion, marked annual variations were identified. In 1975/76 and 1976/77, the third and fourth years of the study, the depth of oxygen supersaturated water increased. For instance in December and January 1977 supersaturated water extended to depths of 12 and 13 m. Furthermore, in October and April water did not become supersaturated as it had earlier in the study (Table 4). The differences between years appear to reflect water temperature profiles and the location and behaviour of the thermocline.

Table 4. Depth (m) of oxygen supersaturation from the surface and mean % oxygen supersaturation at Station 1 in Lake Tutira and in Lake Waikopiro,1973-1977.

Station 1, Lake Tutira

	Oct		Nov		Dec		Jan		Feb		Mar		Apr	
	Depth m	% Satn	Depth m	% Satn	Depth m	% Satn	Depth m	% Satn	Depth m	% Satn	Depth m	% Satn	Depth m	% Satn
1973/74	5	161.6	4	147.2	5	122.9	6	112.8	6	121.1	none	NA	3	108.6
1974/75	9	113.6	4	103	4	143.6	x	x	3	108.8	x	x	3	107.1
1975/76	8	111.9	9	113.5	5	123.5	6	113.6	none	none	4	115.1	none	none
1976/77	none	none	x	x	13	102.7	12	111.5	6	111.2	x	x	none	none

Lake Waikopiro

	Oct		Nov		Dec		Jan		Feb		Mar		Apr	
	Depth m	% Satn	Depth m	% Satn	Depth m	% Satn	Depth m	% Satn	Depth m	% Satn	Depth m	% Satn	Depth m	% Satn
1973/74	2	115.5	5	127.2	3	122	5	133.9	7	126.8	7	116.5	2	107.4
1974/75	3	119.8	1	113.3	x	x	x	x	x	x	x	x	x	x
1975/76	x	x	2	116.3	6	121.3	3	113.8	none	none	2	108.3	none	none
1976/77	3	106.2	x	x	2	118.4	x	x	1	111.8	x	x	none	none

Note: none = no supersaturated water
x = no data

Figure 3. Oxygen profiles (g/m³) at Station 1, Lake Tutira and Lake Waikopiro in October, December, February, April and August of different years. Colour coding follows through from October/December in year 1 (e.g. 1973) to February/August in year 2 (e.g. 1974).

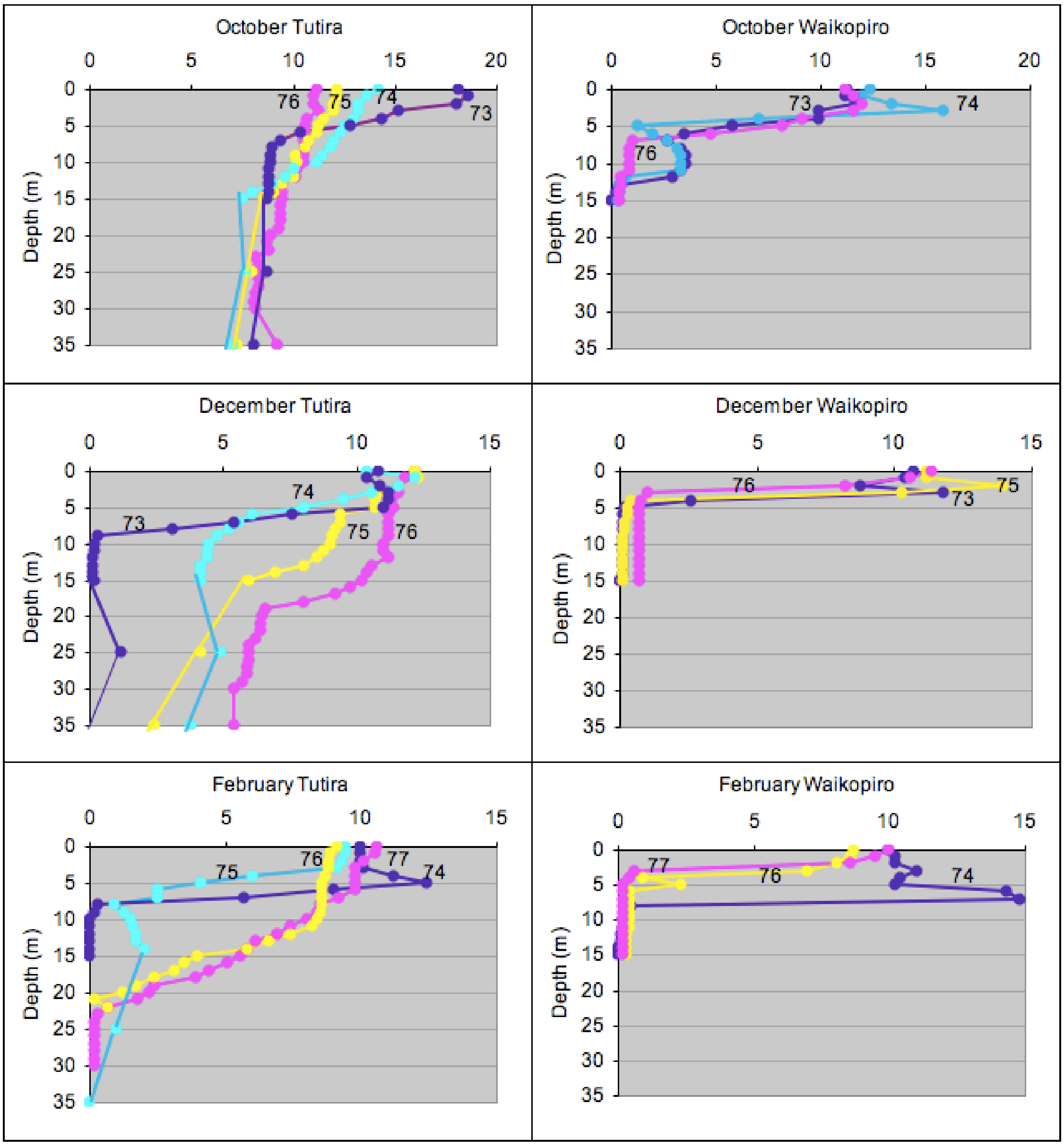
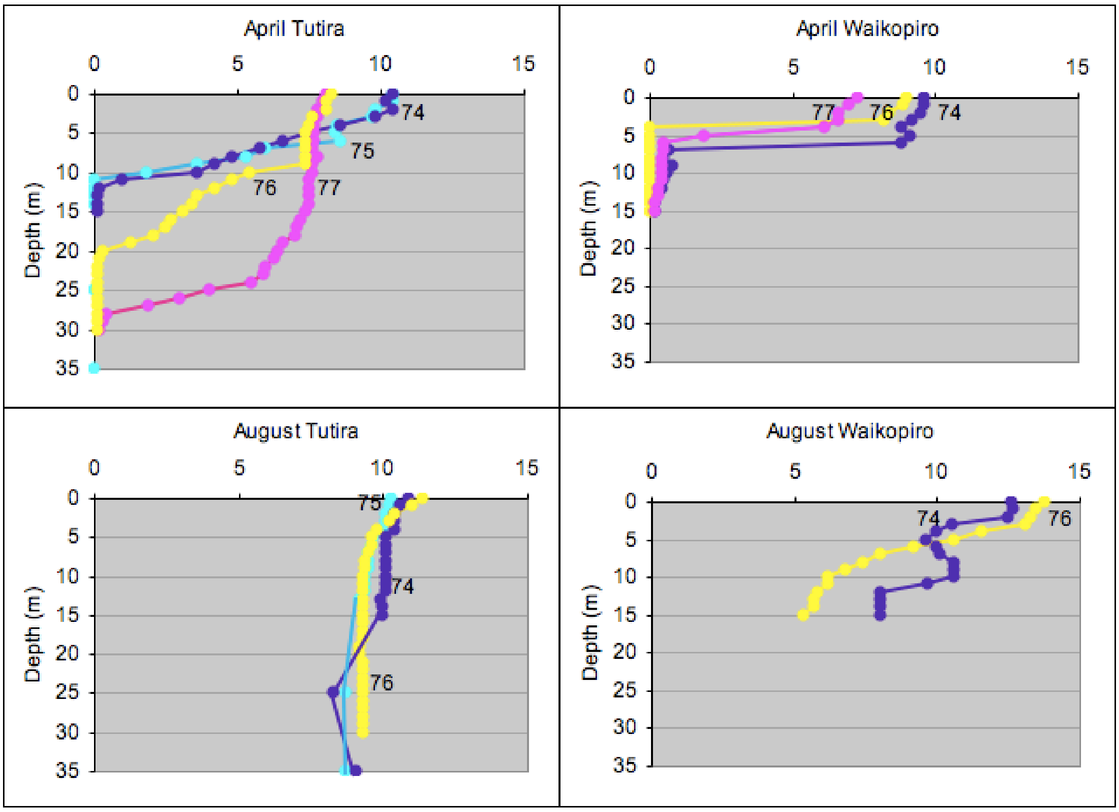


Figure 3 continued.



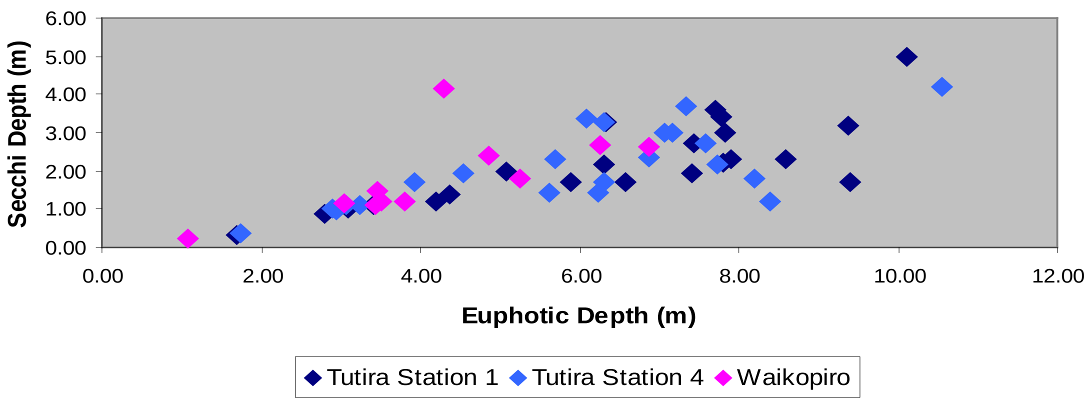
The point of deoxygenation also continued to remain closely associated with the thermocline from 1975 onwards but both features were considerably deeper. Indeed deoxygenation was not recorded in either November or December again. From March, thermoclines were generally deeper than 20 m and deoxygenation was at times only measured close to the lake bed. These results indicated that phytoplankton photosynthesis and decomposition respectively took place from the surface to the thermocline and from the thermocline to the lake bed irrespective of where the thermocline was located (Table 3).

In contrast to Lake Tutira, Lake Waikopiro is only 15 m deep and the thermocline formed at close to 5 m. Oxygen supersaturation and depletion took place over just a few metres from the surface of Lake Waikopiro during October 1973 and 1974 (Figure 3, Table 4). An extreme situation occurred in March and April 1974 when oxygen concentration fell from supersaturated to anoxic within 1 m. As with Lake Tutira, deoxygenation took place within the thermocline earlier than in deeper waters but in Lake Waikopiro this took place two months earlier than in Lake Tutira (Figure 3). Despite lower temperatures from 1975 on, Lake Waikopiro’s pattern of oxygen concentration varied little from 1973 to 1977, exhibiting a more extreme pattern of oxygen depletion than Lake Tutira.

Light penetration

Overall, both euphotic extinction and Secchi disc measures were relatively low, reflecting the eutrophic condition of Lakes Tutira and Waikopiro. The euphotic depth determined as 1% remaining irradiation is recognized as a more sensitive measure of light penetration than the Secchi disc but the two methods produced results that were positively correlated (Figure 4).

Figure 4. Relationship between Secchi and euphotic depths



In Lake Tutira, euphotic extinction values ranged from a low of 1.69 m in April 1977 to a high of 10.54 m in August 1974. Lowest and highest Secchi disc values were recorded in these same months, with values of 0.32 m and 5 m respectively (Table 5). Euphotic extinction values in Lake Tutira Stations 1 and 4 were also positively correlated (Figure 5), but Station 4 values were somewhat lower in 20 of the 29 paired readings. It is possible that sediment from the main inlet stream, together with the position of Station 4 in the shallower northern part of the lake, may have contributed to lower light penetration. Being less sensitive, Secchi disc readings from from Stations 1 and 4 were in close agreement (Table 5).

Table 5. Euphotic and Secchi depths(m) measured at Stations 1 and 4, Lake Tutira and Lake Waikopiro (October 1973 to April 1977).

	Oct-73	Nov-73	Dec-73	Jan-74	Feb-74	Mar-74	Apr-74	May-74	Jun-74	Jul-74	Aug-74	Sep-74	Oct-74	Nov-74	Dec-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Nov-75	Dec-75	Jan-76	Feb-76	Mar-76	Apr-76	May-76	Jun-76	Aug-76	Oct-76	Dec-76	Feb-77	Apr-77
Euphotic Depth (m)																																	
Tutira Station 1					6.33	9.37	9.39	6.32	7.84	8.69	10.10	7.41	4.37	7.90	8.59	4.28	2.80	8.27	7.43	7.07	5.89	6.57	3.09	4.19	3.41	5.07	7.79	7.69	7.50	2.96	6.32	7.80	1.69
Tutira Station 4					6.31	6.09	8.21	5.69	7.07	8.32	10.54	3.94	6.24	6.87	8.39	4.41	2.90	6.12	7.58	6.49	6.31	5.61	2.94	3.24	3.06	4.55	7.17	7.34	7.60	2.61	6.37	7.72	1.75
Waikopiro					4.29			6.73	6.25	6.18	4.86	5.26	6.87									5.30	3.47	3.43	3.56	3.81	3.05	3.46	3.76	2.17	3.09	3.51	1.09
Secchi Depth (m)																																	
Tutira Station 1		1.28	2.35	2.30	3.30	3.20	1.73	2.15	3.00		5.00	1.95	1.40	2.30	2.30		0.90		2.70		1.70	1.70	1.00	1.20	1.10	2.00	3.40	3.60				2.20	0.32
Tutira Station 4	1.17	1.38	2.40	2.25	3.30	3.35	1.78	2.33	3.00		4.20	1.70	1.45	2.34	1.20		1.00		2.70		1.71	1.43	0.98	1.09	1.10	1.92	3.00	3.69				2.17	0.38
Waikopiro	4.00	3.37	1.50	3.35	4.17	4.22	5.30		2.66		2.42	1.78	2.65	2.34	2.25						0.90		1.46	1.10		1.20	1.15					1.22	0.23

Note: euphotic depth is calculated from the slope of irradiance against depth as the depth where 1% of irradiance remains.

Whilst euphotic extinction and Secchi disc measures did not demonstrate clearly defined patterns throughout the study, seasonal patterns were evident. Light penetration values were generally lower in spring and in late summer and higher in winter during lake mixing. For instance, low light levels were recorded in October 1973, September and October 1974 and October 1976. This September/October decline from relatively high winter light penetration is likely to be associated with higher phytoplankton biomass. Low light levels were also recorded in April 1974 (for Secchi disc), 1975 and 1977. Rather than a low in April 1976, both Secchi and euphotic measures showed low light penetration earlier in January, February and March that year (Table 5).

Measures of euphotic extinction in Lake Waikopiro ranged from 1.09 m in April 1977 to 6.87 m in October 1974. Secchi depths ranged from 0.23 m in April 1977 to 5.3 m in April 1974. Comparing available light penetration measures from Lakes Waikopiro with those from Lake Tutira showed Waikopiro values were generally higher than those in Lake Tutira during the 1973/74 summer, similar in 1974/75 and lower in 1975/76 and 1977 (Table 5). When greater light penetration was recorded in Lake Waikopiro the water tended to appear brown rather than green as in Lake Tutira. Factors other than phytoplankton may need to be considered for Lake Waikopiro. For instance, oxygen depletion occurred at or above a depth of only 5 m indicating the whole process of phytoplankton growth and decomposition was compressed compared to Lake Tutira. To understand light penetration results for Lake Waikopiro further investigation is required.

pH

pH provides a measure of the alkalinity - acidity continuum for which changes partly reflect the uptake of carbon dioxide during photosynthesis (alkalinity) and the production of carbon dioxide during respiration (acidity). A pH of 7 is neutral.

pH results for Stations 1 and 4 in Lake Tutira were so similar that the following discussion applies to both stations (Table 6). From May to September when Lake Tutira waters were mixing, pH was neutral from the surface to the lake bed. When phytoplankton growth accelerated in spring, pH in the top five metres (above the thermocline) increased to around 9. A maximum pH of 9.45 was recorded in the surface waters during November 1973. High alkalinity predominated for seven months from October to April in the summers of both 1973/74 and 1974/75.

During the following two summers, 1975/76 and 1976/77, alkaline conditions extended to a depth of 10–15 m, reflecting a deeper thermocline and associated volume of water that could support phytoplankton growth. Furthermore, the high pH recorded above the thermocline during the start of spring (October) and end of summer (April) in earlier years was not evident. This is consistent with cooler years, shorter summers and the operation of the guns.

Table 6. pH depth profiles at Stations 1 and 4 in Lake Tutira and in Lake Waikopiro.

Tutira Station 1

Depth (m)	Oct-73	Nov-73	Dec-73	Jan-74	Feb-74	Mar-74	Apr-74	Ma 74	Jun-74	Jul-74	Aug-74	Sep-74	Oct-74	Nov-74	Dec-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Nov-75	Dec-75	Jan-76	Feb-76	Mar-76	Apr-76	May-76	Jun-76	Aug-76	Oct-76	Dec' 76	Feb-77	Apr-77
0	9.2	9.5	9.1	9.6	9.6	9	9	7.9	7.6	7.4	7.7	8	9.3	8.5	9.2	9.3	8.9	7.6	7.9	8.5	9	9.1	9.1	8.8	9	8.1	7.8	7.9	8.3	8	8.5	9	7.9
1	9.3	9.4	9.1	9.5	9.6	8.9	8.9	7.9	7.6	7.5	7.6	8	9.3	8.4	9.2	9.2	8.9	7.4	7.6	8.6	9.1	9.1	9.1	8.8	9	8.2	7.9	7.9	8.2	8.1	8.5	9	8
5	9	9.2	9	9.5	9.2	8.9	8.5	7.9	7.6	7.5	7.7	7.8	9.3	8.4	8.5	8.1	8.6	7.2	7.5	8.4	8.9	8.9	8.9	8.7	8.7	8.1	7.8	7.9	8.1	8	8.3	8.9	8
10	7.8	7.4	7.2	7.3	7.9	7.5	7.8	7.8	7.6	7.5	7.7	7.7	8.4	7.6	7.4	7.4	7.2	7.1	7.2	8	8.6	8.4	8.2	8.3	8.4	8	7.8	7.9	8	7.9	8.2	8.8	8
15	7.6	7.4	7	7.2	7.4	7.1	7.2	7.7	7.6	7.4	7.7	7.8	7.7	7.2	7.4	7.4	7	7.1	7.1	7.6	8	7.8	7.9	7.8	7.9	7.5	7.8	7.8	8	7.9	8	8.5	8.2
25	7.5	7.3	7	7.2	7.2	7	7.1	7.5	7	7.5	7.5	7.8	7.6	7.4	7.2	7.2	6.7	7.3	7.4	7.7	7.6	7.5	7.2	7.3	7.4	7.3	7.3	7.8	7.9	7.7	7.6	7.4	6.8
35	7.5	7.3		7.1	7.1	7	7.1	7.4	6.9	7.5	7.5	7.8	7.5	7.2	7.2	7.1	6.7	7.1	7.2	7.4	7.6	7.3	7.2	7.2	7.3	7.2	7.2	7.3	7.9	7.7	7.4	7.3	6.7

Tutira Station 4

Depth (m)	Oct-73	Nov-73	Dec-73	Jan-74	Feb-74	Mar-74	Apr-74	Ma 74	Jun-74	Jul-74	Aug-74	Sep-74	Oct-74	Nov-74	Dec-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Nov-75	Dec-75	Jan-76	Feb-76	Mar-76	Apr-76	May-76	Jun-76	Aug-76	Oct-76	Dec' 76	Feb-77	Apr-77
0	9.2	9.4	9.1	9.5	9.5	9.1	8.9	7.9	7.6	7.4	7.7	8.2	9.3	8.3	9.2	9.3	8.8	7.5	7.8	8.6	9	9.1	9	8.8	9	8.1	7.7	7.9	8	8.1	8.5	9.3	8.1
1	9.2	9.4	9	9.4	9.5	9.1	8.9	7.9	7.6	7.5	7.7	8.3	9.3	8.2	9.1	9.4	8.8	7.4	7.7	8.7	9	9.1	9	8.8	9	8.1	7.8	7.9	8.2	7.7	8.5	9.3	8.1
5	9	8.9	9	9.1	9.5	8.9	8.6	7.9	7.6	7.5	7.7	8.1	8.7	8.2	8.3	9.2	8.5	7.6	7.4	8.4	8.8	9	8.8	8.7	8.6	8.2	7.8	7.9	8.1	8.1	8.4	9.1	8.2
10	8.1	7.4	7.2	7.3	7.9	7.5	7.6	7.8	7.7	7.5	7.8	8	7.8	7.7	7.4	7.2	7.2	7.3	7.5	7.8	8.6	8.3	8.2	8.2	8.3	7.8	7.8	7.9	8	8	8.2	8.9	8.3
15	7.7	7.2	7	7.2	7.4	7.1	7.2	7.8	7.6	7.5	7.8	7.9	7.6	7.2	7.2	7.1	7	7	7.5	7.5	7.8	7.7	7.9	7.8	7.9	7.5	7.8	7.8	7.9	7.9	8	8.3	8.3
25	7.4	7.2		8.2	7.3	6.8	7.1	7.3	7	7.5	7.7	7.9	7.5	7.1	7.2	7.1	6.9	7.2	7.4	7.4	7.5	7.2	7.3	7.3	7.3	7.2	7.3	7.8	7.9	7.7	7.4	7.5	8.2

Waikopiro

Depth (m)	Oct-73	Nov-73	Dec-73	Jan-74	Feb-74	Mar-74	Apr-74	Ma 74	Jun-74	Jul-74	Aug-74	Sep-74	Oct-74	Nov-74	Dec-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Nov-75	Dec-75	Jan-76	Feb-76	Mar-76	Apr-76	May-76	Jun-76	Aug-76	Oct-76	Dec' 76	Feb-77	Apr-77
0	8.2	8.8	9.3	9.3	9.4	8.2	8.4	7.5	7.8	7.4	8.1	8.4	9	8.8	8.8						9.3	9.2	8.8	8.1	8.6	8.3	8	7.5	8.5	9.3	9.2	8.7	8
1	8.2	8.7	9.3	9,.3	9.3	8.8	8.4	7.5	7.7	7.5	8.1	8.5	9	8.9	9						9.3	9.2	8.9	8.1	8.6	8.4	8.1	7.5	8.6	9.4	9.2	8.7	8
5	7.5	8.7	7.1	9.2	9.1	8.5	8.2	7.6	7.6	7.5	8.1	7.5	7.7	7.8	7.8						7.5	7.3	7.5	7.5	7.4	7.2	8	7.5	8.5	9.1	7.7	7.5	6.8
10	7.3	7.2	6.8	9.1	7.1	7.1	7	7.6	7.4	7.5	7.8	7.1	7.5	7.5	7.5						7.3	7.2	7.2	7.2	7.2	7.1	7.2	7.5	7.2	7.3	7.4	7.3	6.6
15	7.2	7	6.8	9.1	6.9	6.7	6.9	7	6.9	7.5	7.4	7.1	7.3	7.5	7.5						7.1	7	7	7	7	7	7	7	7.4	7.3	7.3	7.2	6.4

Despite the difference between years, decomposition was likely to be the dominant process influencing pH below the thermocline as a pH of around 7.0 predominated (Table 6). The lowest pH recorded was 6.7 from 25 m to the lake bed at Station 1 during April 1975.

Lake Waikopiro exhibited a very similar pH pattern to Lake Tutira. Differences included a slightly lower pH overall and a shallower depth of transition from alkaline to neutral/acid water. Whereas alkaline conditions reached 5 m at times during the first summer, a high pH was only recorded to a depth of 1 m in later years. This was consistent with a thermocline location of 5-7 m. There was one anomaly in the Waikopiro pH data. A pH of more than 9.0 was recorded from the surface to the lake bed in January 1974. At the same time a pH of 8.15 was also recorded at 25 m at Station 4 in Lake Tutira. A possible explanation is provided in the following section where nitrate-N results are discussed.

Nutrients

Total P and reactive P

Total P measures the total phosphorus content in the water, including phosphorus bound up in particulate matter and reactive P that is available for plant uptake.

Lake Tutira

Total P concentrations in Lake Tutira ranged from a low of 8 mg/m³ in the surface waters during May 1974, to a high of 293 mg/m³ near the lake bed in January 1974. Reactive P ranged from a low of 2.5 mg/m³ in surface waters during November 1975 to a maximum of 510 gm/m³ in deep waters during May 1976 (Table 7). A distinct seasonal phosphorus pattern was consistent at both Stations 1 and 4 and persisted throughout the study (Figure 6). Variations only related to concentration and depth distribution of phosphorus.

Total P

From total lake mixing in June until complete stratification by December in all but the first year, total P concentrations remained similar throughout the water column at about 30 – 50 mg/m³. This was followed by a substantial build up of total P in the hypolimnion that lasted until the lake destratified the following June (Figure 6). The first year, a maximum concentration of 120 mg/m³ total P occurred in the surface waters during October. In November the depth at which maximum total P occurred sank to 10 m and then from January to July into even deeper waters where concentrations at 25 and 35 m averaged 160 mg/m³ (Table 7). The high level of total P in surface waters during October and deep waters from January to June in 1973/74 was not repeated in later years. A variety of measures indicate that spring and summer of 1973/74 was particularly productive, with a level of phytoplankton biomass that could account for excessive total P concentrations sinking from the surface into deeper water.

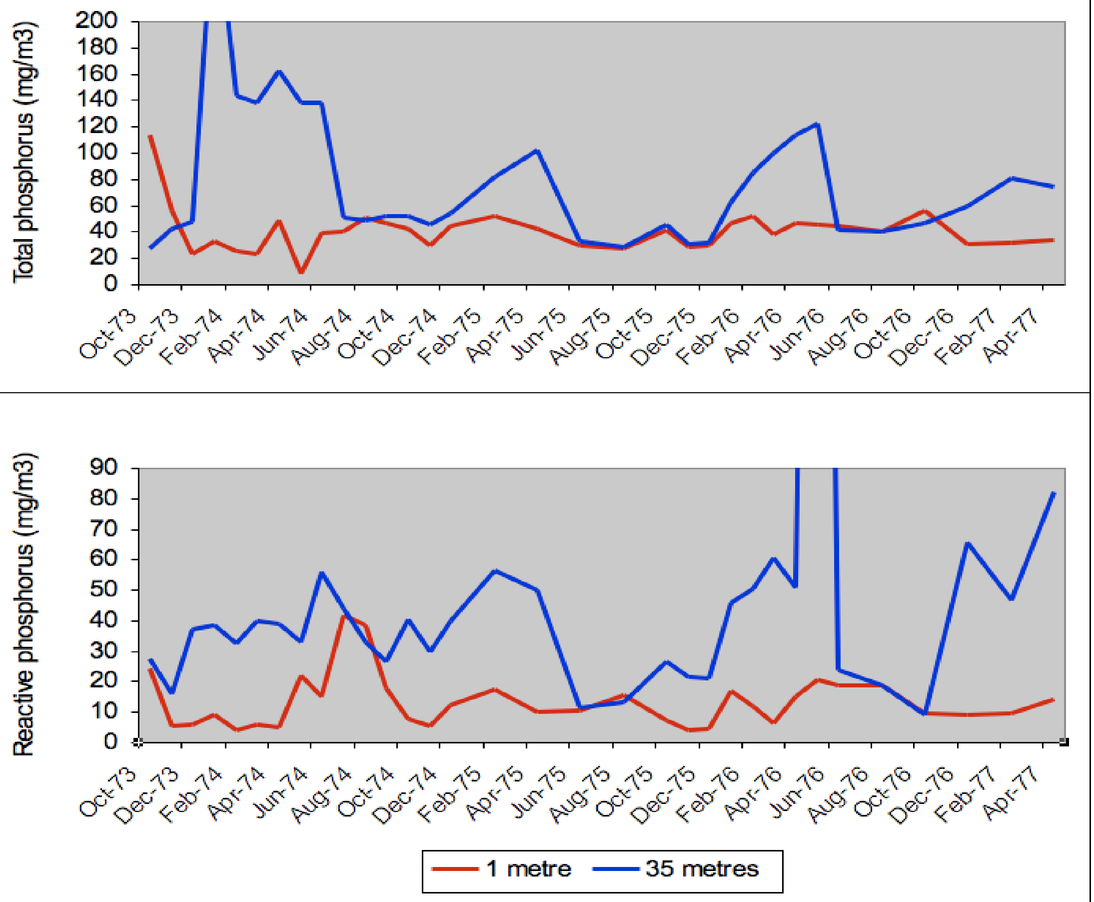
To appreciate the trend in total P, results for the reactive P component also need to be considered. Note that on five occasions total P concentrations from the deepest depths sampled were actually lower than reactive P. In Lake Tutira this was recorded in May 76, December 76 and April 77 and in Lake Waikopiro, June 74, May 76 and Feb 77. Differences were relatively small indicating that analysis may have generated the anomaly (Table 7).

Table 7. Phosphorus profiles at Stations 1 and 4 in Lake Tutira and in Lake Waikopiro.

Total P (mg/m^3) Tutira 1 Depth (m)	Oct-73	Nov-73	Dec-73	Jan-74	Feb-74	Mar-74	Apr-74	May-74	Jun-74	Jul-74	Aug-74	Sep-74	Oct-74	Nov-74	Dec-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Nov-75	Dec-75	Jan-76	Feb-76	Mar-76	Apr-76	May-76	Jun-76	Aug-76	Oct-76	Dec-76	Feb-77	Apr-77
0	120	46.2	22.5	32.4	19	22.5	50.5	47	38.7	49.2	48.5	44.3	37.2	24.1	39	48.8	33.9	28.2	33.8	53.9	23.3	31.5	42	46.6	50.5	40.6	21.9	45.1	30	49.4	20.5	24.4	29.5
1	114	56	23.5	32.5	25.5	23.7	48.5	8	39.8	40.2	51.3	46.3	42.6	29.6	45.2	52.4	42.4	29.4	27.9	41	28.9	30.2	46.8	51.6	38.6	46.9	45.8	44.6	40	56.4	30.4	32.2	34.4
5	32.7	56	35	32.5	33	27.8	41.8	58	47.1	52.2	50	49.8	41.9	31.5	39.5	58.8	49.6	28.7	29.9	47.7	28	31.5	45.3	50.6	47.1	47.2	43.6	44.1	45	44.4	23.6	32.4	28.2
10	32.7	78.5	50	70	27	44.1	43.2	64.6	38.7	30.3	50.3	54.3	40.7	28.2	20.5	30.5	40.4	25.3	31.4	41.5	28.2	22	41.7	49.9	38.6	51.5	38.6	41.2	40	44.2	27.7	35.6	35.7
15	23.3	44.5	40	95.5	89	111	12.5	60.7	40.3	51.7	49.8	50	53	20.5	26	29.5	46.8	24.3	27.7	32.3	29.2	14.4	29.1	36.7	37.4	42	38.9	46.4	40	41.2	21.2	32.2	30.5
25	44.8	46.4	35	74	76	108	25.2	56.2	133	46.1	44.5	55.3	45.9	36.8	23.6	39	59	34.3	28.9	33.3	24.3	24.1	48.7	66.8	57.7	87	60.8	46.4	38	32	36.4	58.9	50.8
35	27.4	42.3	48	293	144	139	162	138	138		48.5	52.3	52.2	45.4	53.8	82.1	102	33.1	28.8	46.2	30.9	31.5	63	84.6	100	114	122	41.5	40	47.3	59.3	81.1	74.2
Tutira 4																																	
0	100	39.5	24.5	35	19.5	20.4	35	63.6	35.6	116	45.3	50.3	31.8	32	41.7	207	32.4	27	35.3	59	31.8	36.3	45.1	58	44.8	48.8		47	17	54	31.1	30.9	36.1
1	106	52.7	27.5	39	16.5	24.5	32	63.5	41.6	58.1	49.1	88.8	40.2	37.8	49.8	66.7	37.4	28.7		56.4	37.2	51	46.1	63	49	51.8	51.1	47.3	24	73.9	55.7	34.9	42.2
5	38.4	59.8	33	60	48.5	26.3	46	54.3	36.7	53.2	50.6	59.5	44.9	37.3	52.9	56.4	54.7	30.4	29.9	51.3	38.9	41.2	46.3	62	57.4	38.2	44.4	45	37	57.5	54.2	39.8	58.3
10	17.4	81	50	37.5	27.5	34.7	38.2	55.4	36.4	46.7	44	49.5	41.6	29.9	26.9	36.7	32.9	24.8	31.1	31.3	24.1	27.1	38.3	70	45.2	47.2	37.2	43.9	29	49.1	28.2	34.4	38.5
15	26.6	53.3	78	137	114	133	133	57.2	36.7	49.6	48.8		47.3	30	39.5	60.2	77.6	31.2	31.6	50	27.5	14.4	33.9	87.1	39.7	42	40	42	85	45.9	40.7	31.2	33.8
25	40.1	75.5	77.5	124	117	157	159	173.5	158	51	49.3	50.3	49.6	50.1	26.2	78.6	88	25.8	30.5	52.8	3.1	60.2	73.2	71.9	155	161	65	48	67	53.8	64.1	150	33.5
Waikopiro																																	
0	33.3	32.7	40	31.5	14		141	116.5	22.1	68.7	98.1		99.1	57.3							34	30.2	42.2	66.8	57.7	83.2	79.7	65.2	81	41.6	64.1	60	52.9
1	56.3	18.4	47.5	40.5	16.5		57.7	75	66	84.5	105	90.5	92	82.4							35	36.3	42.7	84.6	62.4	81.3	78.9	71.6	82	90.8	74.7	75.6	61.3
5	94.7	78	48	59	25		47	68.5	48.4	82.7	107	46.5	77.4	187							50.7	104	111	145	81.5	100	103	74.7	50	75.6	105	111	23.9
10	57.2	40.7	55.5	109	119		191	100	40.8	84.2	36.7	36	37.9	52.8							30.4	68	115	138	165	185	141	78	43	62.5	90.6	181	79.1
15	158	243	185	276	676		535	1000	106	76.3	29.7	81.3	72.7	244							81	256	379	217	458	177	250	206	36	74.4	139	37.8	68.4
Reactive P (mg/m^3)																																	
Tutira 1 Depth (m)																																	
0	37.6	6.5	5	10	4	5	6	20	16	36	38.5	14.5	7.5	4.5	12.5	18	10	11	18	8.5	3.5	4.5	14.9	19.5	10.5	11	19	12.5	16	4	5.3	9.8	13
1	24.5	5.5	6	9	4	6	5	22	15	42	38.5	18	8	5.5	12.5	17.5	10	10.5	15.5	7.5	4	4.5	17	12	6.5	15	20.5	19	19	9.5	9.1	9.7	14.3
5	11.3	10	7	8.5	5.5	6.5	6	22	17	37	34	21	9	7	9.5	25.5	9	10.5	15.5	10	3.5	6	15.3	17.5	13	12	18.5	12.5	19	6.5	6.3	9.7	10.2
10	11.1	23.5	31.5	30	5	9.5	10	18	18	31	34.5	27.5	28	8	5	12.5	12	12	16	22	5	3.5	13.3	15.5	12	15	18	17	16	4.5	7.4	7	8.4
15	16.2	10	29.5	51.5	48	42	47	22	18	33	31.5	27	32.5	7	7.5	12	28	11	14	7	8	8	12.9	15	18.5	24	20	17	17	9	6.4	12.2	10.1
25	21.8	12.5	26	45	41	47	52	48	65	33	34.5	29	35	18.5	5.5	24	37	11	16.5	13	13.5	9.5	33.5	36	46	39	75	21.5	13	9.5	9.4	34.4	41.3
35	27.6	16	37	38.5	32.5	40	39	33	56		33	26.5	40.5	30	40	56.5	50	11.5	13.5	26.5	21.5	21	46.1	50.5	60.5	51	510	24	19	9	65.5	46.8	82.2
Tutira 4																																	
0	32.7	9	5	8	3.5	6	4	18	19	35	31	18.5	5.5	6.5	12	182	9.5	9.5	24	18.5	2.5	4.5	16.6	15.5	12	12	21	15.5	15	7	7.4	6.3	19.6
1	37.3	6.5	6	8	4	5	5	20	19	35	32.6	20	7	8.5	15.5	32.5	11	9.5	17	14	5	8.5	16.3	18	16	11	20.5	14	21	7	9.7	5.7	18.2
5	13.6	13	10	10	9.5	6	7	20	19	35	33.5	27.5	8.9	9	14	21.5	9	11	16.5	12.5	4.5	6	16.5	15.5	20.5	10	20.5	19.5	35	6.5	8.7	7.1	31.1
10	11.1	20	28	9.5	5	10	9	19	19	32	32.5	30.5	11.5	9	8.5	15.5	10	11	19	9.5	2.5	5.5	13.3	18	11	10	19.5	14.5	20	6.1	6.1	5.6	15.2
15	17.3	21	52.5	62	43.5	51	37	55	19	34	33.5		29.5	18.5	25.5	33.5	36	11		19.5	6	8	12.1	19.5	20	24	19.5	15.5	25	5.5	6.3	12.3	15
25	23.8	26.5	60.5	57	42	50.5	53	22	43	31	31.5	30	33	22.5	9.5	33	41.5	12	17.5	26	13.5	38	47.1	49	70	64	34..5	18.5	18	6	40.1	58.5	15.9
Waikopiro																																	
0	11.6	5	11.5	4.5	1		110	65	11	36	17.5		6	8.5							9.5	6.5	12.2	19	22	18	18	13.5	15	4.5	17.8	15.2	28.4
1	16.7	3.5	11	12.5	2		12	18	24	41	9	7	6	13							9.5	7.5	14.5	18	21.5	18	19.5	13	23	17	18.6	14.1	36.4
5	32.4	12	16	29.5	4.5		10	19	15	38	9	5	111	35.5							33	16	28	45.5	29	25	22	14.5	16	14	37.8	39.4	5.9
10	29.8	13	26.5	27.5	12.5		30	27	14	84	4	8.5	7.5	25.5							21	23	35.7	34.5	17	27	92	27	9	17	40.3	59.2	32.1
15	82.7	64.5	100	72	29.5		79	58	143	40	6	28.5	18.5	78							32.5	38	55.1	29.5	59	54	267	89	10	38	62.8	65.9	60.4

Essentially, patterns of reactive P followed those of total P showing strong December to June peaks in the hypolimnion (Figure 6). Given that reactive P is a component of total P this pattern indicated that reactive P made a major contribution to the concentration of total P below the thermocline. Decomposition of moribund algae releases both particulate and reactive P, accounting partly for the elevated P concentrations in bottom waters. The other contributing factor would be the release of reactive P from the sediments into deep water, a situation that is enhanced by anoxic conditions. Just as reactive P is released from the sediments it is reabsorbed when oxygenated conditions return at the time of lake mixing.

Figure 6. Total and reactive phosphorus at 1 m and 35 m depths, Station 1, Lake Tutira.



Note: In January 1974 total P concentration at 35 m was 293mg/m^3

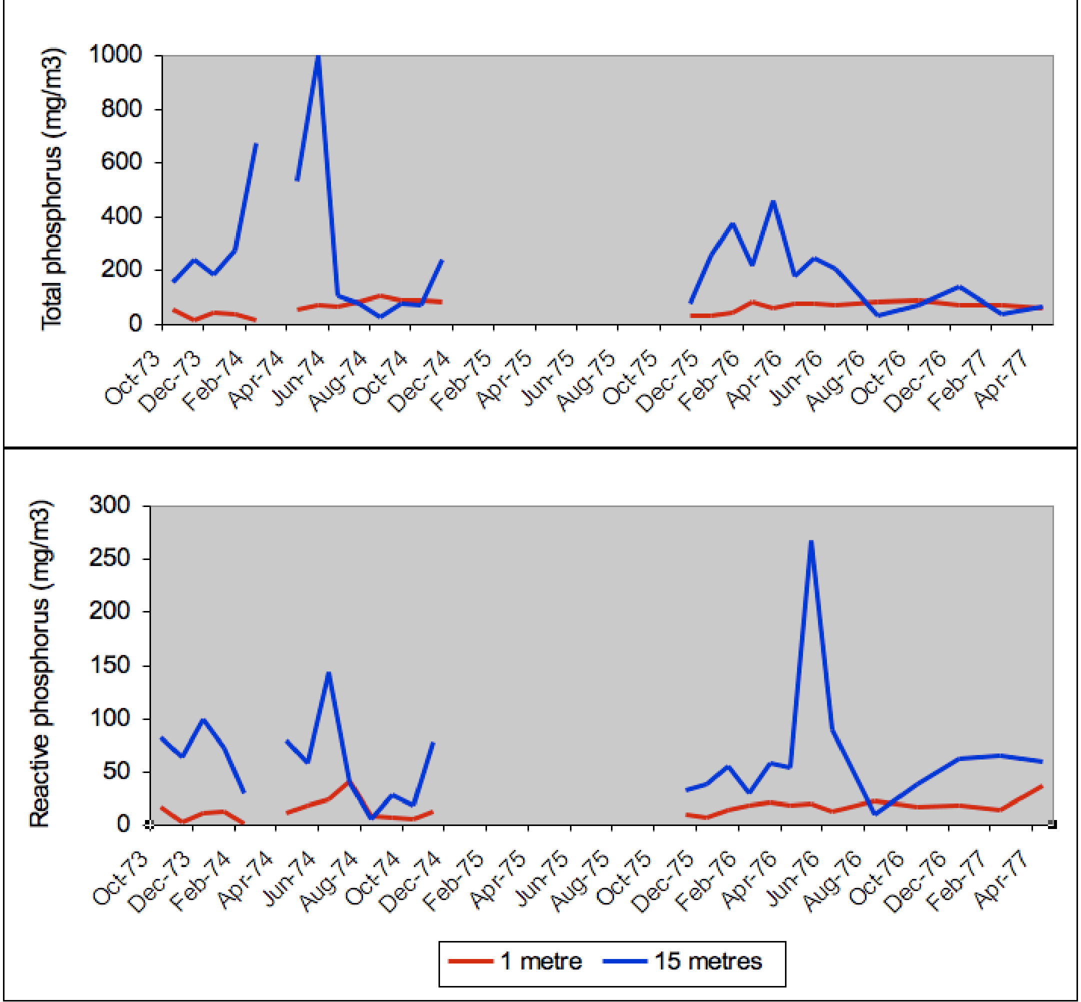
In May 1976 reactive P concentration at 35 m was 510mg/m^3

In surface waters, reactive P also reflected total P trends. Levels declined from October to December each year dropping to concentrations as low as 4 mg/m^3. Prolific algal growth in spring absorbs reactive P from surface waters, resulting in low reactive P concentrations that persisted through the summer.

Lake Waikopiro

Concentrations of total and reactive P in Lake Waikopiro ranged respectively from 35 mg/m³ to 1000 mg/m³ and 2 mg/m³ to 267 mg/m³ (Table 7). Phosphorus patterns were generally similar to those in Lake Tutira. For instance, peak concentrations of total and reactive P built up in the hypolimnion prior to lake mixing in July. Furthermore, concentrations of reactive P dropped to low levels in surface waters from early spring to February. The difference between Lakes Waikopiro and Tutira was the significantly higher concentrations of both total and reactive P in Lake Waikopiro (Figure 7).

Figure 7. Total and reactive phosphorus at 1 m and 15 m depths, Lake Waikopiro.



High total P levels persisted in the bottom waters for nine months, from October to July. At these depths concentrations were more than three times those recorded for Lake Tutira. Unlike Lake Tutira, Lake Waikopiro only exhibited an even distribution of total P associated with mixing for one month - July. By August, concentrations above the thermocline were approximately twice that of the deeper water. An even distribution of reactive P was also limited to a single month - August. Higher concentrations were recorded in the hypolimnion for the rest of the year. In April, May and June, just prior to mixing, concentrations of reactive P were highest, reaching 143 and 267 gm/m³ respectively in 1974 and 1976.

Both patterns and concentrations of total and reactive P indicate that the smaller, shallower Lake Waikopiro was considerably more enriched than Lake Tutira.

Nitrate-nitrogen (NO3-N) and ammonium-nitrogen (NH4-N)

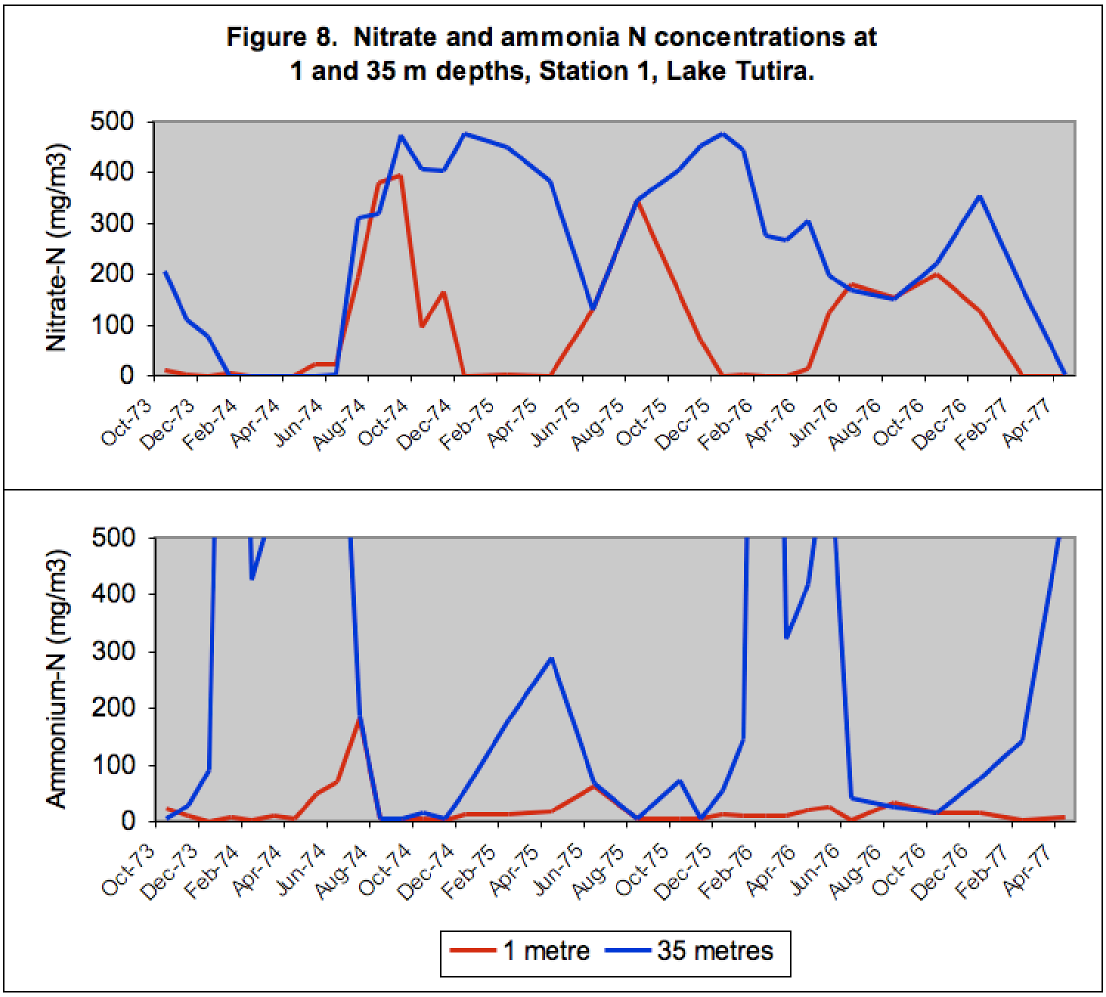
Both NO3-N and NH4-N are fundamental to phytoplankton growth. Nitrogen contained within phytoplankton cells is released on decomposition. In anaerobic conditions nitrogen is released as NH4-N but converted back to NO3-N in the presence of oxygen again.

Lake Tutira

Like phosphorus, nitrogen concentrations varied widely. Whereas NO3-N was undetectable in the surface waters in March 1974, a maximum concentration of 550 mg/m^3 was recorded during lake mixing in September 1974. Similarly, NH4-N was absent from surface waters during December 1973 but a maximum concentration of 2280 mg/m^3 was measured above the lake bed during February 1976 (Table 8).

Nitrate-nitrogen (NO3-N)

NO3-N exhibited a distinct seasonal pattern, increasing dramatically in surface waters following the June destratification and declining equally rapidly from an August/September peak to near zero by December. For the remaining six months of the year (December – May), concentrations remained near zero. This same pattern of NO3-N occurred in the hypolimnion during the first year of the study. But following years showed high NO3-N concentrations persisted in deep water for most of the year with decreases associated with lake mixing (Figure 8).



In June, turnover, circulation and oxygenation accounted for dramatic NO3-N increases in the epilimnion to match those of the hypolimnion. Similarly, formation of the thermocline during October/November together with accelerated spring phytoplankton growth most likely accounted for the extended absence of NO3-N in the epilimnion and the rise to a maximum of 477 mg/m³ in the hypolimnion. The absence of NO3-N fits with the redox sequence – lose dissolved oxygen, lose NO3-N, and likely right down to sulphate reduction that would account for the hydrogen sulphide odour that year and colour indicating sulphate reducers.

At a more detailed level, NO3-N concentrations were evenly distributed throughout the water column during winter mixing (June - September) but showed an increase during those months each year; from approximately 200 to 500 mg/m³, Stations 1 and 4, 1974; 130 to 350 mg/m³, 1975; and 180 to 200 mg/m³, 1976 (Table 8).

Table 8. Nitrate N and ammonia N profiles at Stations 1 and 4, Lake Tutira and Lake Waikopiro

Nitrate N (mg/m³) Tutira 1 Depth (m)	Oct-73	Nov-73	Dec-73	Jan-74	Feb-74	Mar-74	Apr-74	May-74	Jun-74	Jul-74	Aug-74	Sep-74	Oct-74	Nov-74	Dec-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Nov-75	Dec-75	Jan-76	Feb-76	Mar-76	Apr-76	May-76	Jun-76	Aug-76	Oct-76	Dec-76	Feb-77	Apr-77
0	18	1.6	19.4	4.1	0.1	0	0.7	18.5	18.3	197	370	388	84	170	0.5	2	0	134	346	158	65	0.3	4.2	0.3	0.3	14	126	182	154	201	127	0	0.5
1	12	1.9	1.2	4.5	0.1	0	0.5	24.7	22.3	195	380	396	96	165	0.3	3	0	131	346	160	69	0.3	2.6	0.3	0.3	14	126	181	154	201	129	0	0.6
5	31	1.1	1.2	5.7	0.4	0.3	0.5	17.6	24	201	374	424	177	171	3.5	1	0	130	349	176	92	3.5	1.1	0.3	0.3	14	126	181	157	209	131	7	0
10	23	9.3	1.9	0.3	0.1	0	0.8	30.8	22.8	167	399	484	268	271	283	246	64	134	346	396	112	55	30.6	0.3	0.3	15	125	181	155	207	144	6.8	0.4
15	133	35.9	104	0.1	0	0	0.4	24.4	25.9	202	395	474	421	491	447	465	404	130	346	358	326	193	69.6	0.31	52.5	172	128	179	155	231	172	61.6	0.3
25	181	52.1	133	57.5	0.1	0	0.2	1	3.8	200	382	470	464	492	259	516	477	130	346	343	446	448	13.1	271	239	238	155	178	150	237	328	192	63.2
35	207	111	78.9	0.9	0	0	0.6	0	4.1		320	473	406	405	477	452	383	130	347	408	454	476	445	276	266	306	197	170	152	221	356	172	1.5
Tutira 4																																	
0	19	0.9	0.3	5	0.5	10.7	0.3	42.5	22.1	207	351	523	88	157	0.5	0.5	0	135	343	169	74	0.3	0	0.3	0.3	0.3	132	190	170	219	123	0	1.4
1	23	0.6	0.6	15.3	0.6	15	0.2	39.6	17	219	357	550	96	179	1.5	0.5	2	136	337	168	78	0.3	0	0.3	0.3	0.3	131	188	169	212	123	0	0.2
5	25	1.1	0.6	7.8	2.1	10	0.8	42.2	19.7	184	371	527	171	175	1	0.5	0	135	348	185	96	0.3	0	0.3	0.3	0.3	131	187	170	205	129	0	0.3
10	21	7.2	1.2	8.4	0.3	2	1.9	33.8	20.8	231	372	520	328	267	287	232	74	136	347	289	108	52	56.6	0.3	0.3	8.5	132	186	172	194	141	0.9	0.2
15	141	68.5	52.1	1.7	0.1	0	0	105	27.1	207	380		472	409	448	453	316	134	352	363	268	161	90.6	2	34	193	138	187	171	226	172	19.3	0.3
25	193	83.4	103	1	0	0	0.3	0.8	3.8	311	409	506	494	498	273	495	391	136	350	391	453	371	369	195	134	106	137	183	171	231	356	0.1	0.3
Waikopiro																																	
0	3	1.5	4.9	0.2	0.8		5.7	3	2.9	84.5	61		1	0							4	1.5	0	0.3	0.3	0.3	0.3	114	386	0.3	0	0	1.9
1	4	1.4	4.3	0.5	1.3		0.5	4..1	3.3	63.6	67	7	0	0							4	1.5	0	0.3	0.3	0.3	0.3	117	378	0.3	0	0	0.6
5	143	0.2	34.8	0.3	0.6		0.4	2.1	2.8	78.5	72	86	0	0							3	2	3	36	0.3	0.3	0.3	116	385	0.3	0.2	0	1.3
10	202	115	24.7	12	0.1		0	2.8	2.5	65.5	88	94	0.5	22.5								2	0.2	3	3.5	3	2.5	112	316	0.3	1.8	0.3	1.9
15	29	0	0.3	4	0		0	0.2	2.5	77.9	125	70	0	0							6	3.5	3.5	4	6.5	6	7.5	0.3	304	0.3	0.8	2.3	4.4
Ammonia N																																	
Tutira 1																																	
0	9	8	0	7	2	8	12	38	60	184	7	3.5	43	1.5	7	10	14.5	59.5	22.5	4	3	11.5	8.3	8	14.5	13	18	4.5	22	7	12.5	3.2	5.7
1	24	11	0	8	2	9.5	5	49	70	182	6	4	6	3.5	12	13	17	62.5	4	6	5	13	10.5	11	11	22	25	2.5	35	16	15.5	2.4	7.1
5	7	16	5	13	4	12	4	54	66	177	11	3.5	10	6.5	19	16	12.5	61	6.5	7	5	12.5	10.3	10	17.5	16	21.5	0.3	28	13	13.1	9.9	16.3
10	4.5	180	175	25.5	35	36.5	9	51	73	187	6	3	24.5	10.5	24	14	10.5	61	6	43	8	43.5	23.6	8	21	18.5	26	0.3	28	8	14.7	16.4	6.3
15	4.5	42	93	304	266	306	352	69	77	177	9	3	13.5	3.5	11	20	62	59.5	6	41	5	15.5	36.9	11	47.5	21	27.5	0.3	28	13	14.7	52.2	7
25	4	13	20	110	195	297	361	470	400	182	10	4.5	8	4	29	15	79.5	61.5	7	49	2	7	79.5	129	243	311	529	0.3	31	18	22.3	91.7	278
35	5	28	90.5	1769	428	563	704	830	940		5.5	6.5	16.6	5	56	179	288	66.5	5	74	4	55.5	146	2280	324	419	679	41.5	27	15	75.1	144	562
Tutira 4																																	
0	8.5	1	<1	11	9	5.3	0	28	40	165		4	12.5	7	13	9	12	46	10	3	21	9	13.9	9	15	16	40	11	27	13	8.7	11.6	8.1
1	2	16	4	13	9	4.5	1	39	57	172		2.5	16.5	8	15	16	15	52.5	6	9	5	21	11.5	9	14.5	15	27	10.5	31	13	29.9	5.5	9.4
5	2	20	10	26	13	5	12	44	60	169	8	5.5	12	11.5	16	15	14	49	8	8	10	19	12.7	12	15.5	12	37	18	41	11	24.5	9.8	15.6
10	2	140	101	22.5	27	69	18	39	44	165	9	7.5	23	19	37	14	11	50.5	6	30	10	46.5	34.4	8	14.5	10.5	24	7	45	10	21.8	13.5	10.7
15	2	49	133	419	355	408	478	120+	38	165	11		15.5	6		24	158	59	8.5	70	14	33.5	40.1	8	30	22	24	9	52	16	17.7	56	11.2
25	11	50	121	355	377	566	545	696	790	160	7.5	9	24.5	9		51	203	65	9	96	9	239	156	307	522	589	72	16	37	22	55.9	337	12.5
Waikopiro																																	
0	6.5	3	16	5	4		0.8	29	7	241	23.5		8	8							6	13	11.7	8	15	0	9	341	176	7	6.5	12.4	12
1	12.5	27	18	6.5	9		23	52	18	248	25	0.3	7	12							9	23.5	12.8	9	16.5	9.5	10.5	365	128	13	15	15	14.8
5	18.5	26	57	8	4		18	73	14	238	29	2.5	12	56.5								955	22.7	16	22	385	10	351	254	15	456	308	322
10	190	112	224	565	421		610	55	12	243	35.5	2	8	121							1000	1615	1415	780	828	212	370	399	697	820	856	1510	980
15	635	860	1612	2050	1910		1950	2700	2710	250	50	2.5	35	703							2520	3821	2680	2850	4390	380	4990	5162	795	1370	2050	3145	1210

Ammonium-nitrogen (NH4-N)

The most striking feature of the NH4-N pattern was a rapid and substantial build up and decline in concentration in the hypolimnion between December and June each year. Highest concentrations were recorded during summer from January to May (203 – 830 mg/m³), with exceptional concentrations recorded in January 1974 (1769 mg/m³) and February 1976 (2280 mg/m³). From June to early spring between the annual peaks NH4-N concentrations remained low.

Concentrations of NH4-N in surface waters were low except during destratification when NH4-N from the hypolimnion caused levels to increase and then decline with the circulation of oxygenated water (Figure 8).

Another consistent pattern was the build up of NH4-N within the thermocline during spring most years. The highest concentration (180 mg/m³) occurred in November 1973, the warmest spring when phytoplankton sank into the thermocline and decomposed there.

Nitrate-nitrogen/ammonium-nitrogen relationships

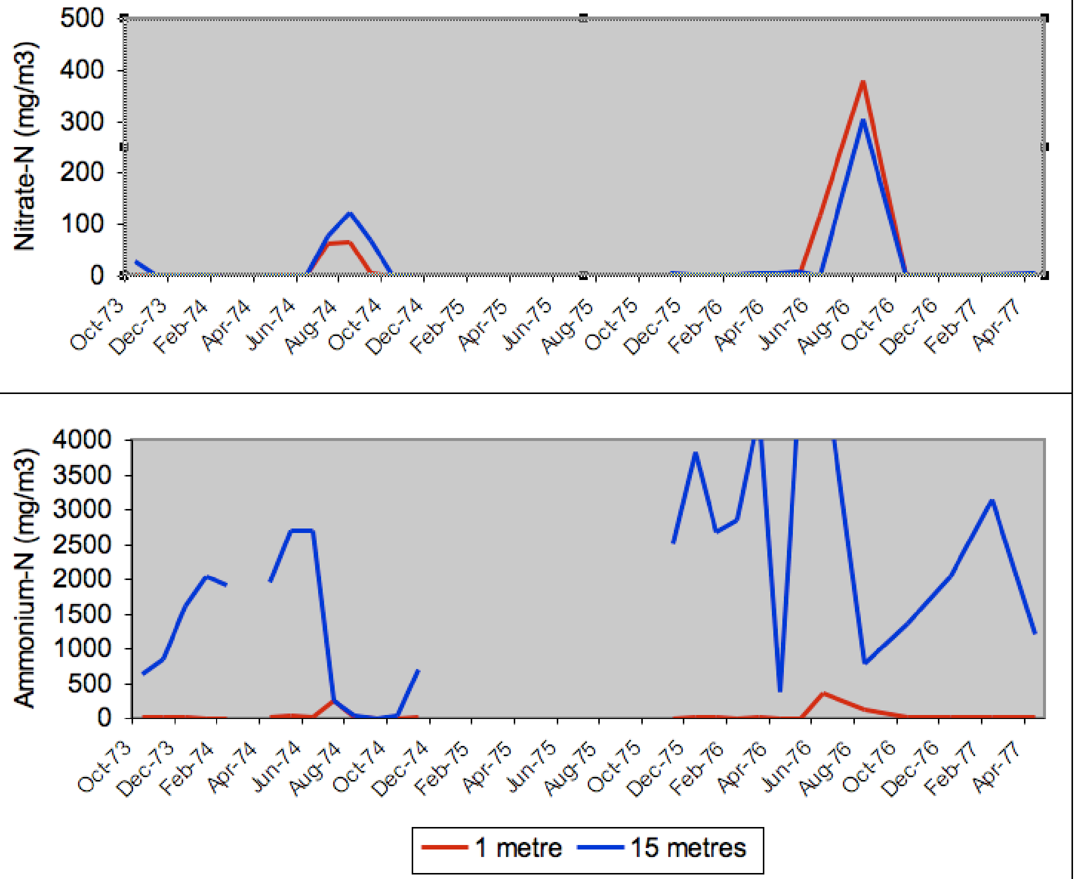
Patterns of NO3-N and NH4-N were clearly inter-related. At the time NO3-N concentrations were uniformly high (during mixing when dissolved oxygen levels were high), NH4-N concentrations were low. Spring phytoplankton growth was associated with rapid depletion of NO3-N to near zero levels from the surface down to the thermocline. Beneath the thermocline decomposing phytoplankton drifted down to the lake bed releasing NH4-N. But in the presence of oxygen NH4-N is converted back to NO3-N and this accounted for the increase in concentrations of NO3-N at depth. Whereas NH4-N concentrations were low during mixing an increase was first detected at 10 m during formation of the thermocline in November. Phytoplankton sinking to the lake bed were slowed in the metalimnion and decomposed there, causing deoxygenation and elevated NH4-N within that layer. By January/February when much of the hypolimnion had lost oxygen, concentrations of NH4-N rose, particularly in the deepest water. So both NH4-N and NO3-N (from the oxygen that remained) accumulated in the bottom waters over the summer months when stratification was strongest.

The behaviour of NO3-N during the first summer was an exception to other years as near zero concentrations were recorded right from the surface to the bottom of the lake in February, March and April (Table 8). The spring of 1974 was very warm and the process of stratification and deoxygenation took place particularly rapidly. By November, NO3-N had been depleted from the surface down to the thermocline. Below the thermocline NO3-N had been converted to NH4-N in the deoxygenated conditions. As the thermocline deepened in May and June, NO3-N reappeared from the surface down to 15 m. But levels of NO3-N remained near zero in the still deoxygenated deeper water. Over the same summer period, NH4-N concentrations remained very low in the epilimnion but rose to extreme levels within the metalimnion and particularly in the deeper waters. Whereas the NH4-N pattern occurred in later years, the 1974 NO3-N pattern did not. This most probably reflected an extreme year and one that was not repeated during the study.

Lake Waikopiro

Patterns and concentrations of NO3-N and NH4-N in Lake Waikopiro indicated a more enriched situation than Lake Tutira. Unlike Lake Tutira, NO3-N concentrations remained uniformly low throughout the entire water column for most of the year (Figure 9).

Figure 9. Nitrate and ammonia N concentrations at 1 and 15 depths, Lake Waikopiro.



Nitrate-nitrogen

NO3-N concentrations increased briefly during lake mixing (July 1974, August 1976). The rapidity of the process was demonstrated during mixing in August 1976. From uniform concentrations in the 300 – 400 mg/m³ range, NO3-N concentrations had fallen to 0.3 mg/m³ from the surface to the lake bed by October. During spring 1973, monthly sampling enabled the decline in NO3-N to be tracked. First, concentrations fell in the surface waters, then at the lake bed followed by the thermocline between 5 and 10 m (Table 8). Phytoplankton uptake in the surface water, conversion to NH4-N in deeper deoxygenated waters and the regeneration of NH4-N from the lake sediments were the processes responsible for this pattern.

Ammonium-nitrogen

NH4-N followed a simple pattern. Apart from the period of lake mixing, concentrations of ammonium N were relatively low from the surface to 5 m. From there down, NH4-N concentrations generally increased to hundreds of mg/m^3 at 10 m and thousands of mg/m^3 at 15 m (Figure 9). For instance, at 10 and 15 m in January 1974, concentrations were respectively 565 mg/m^3 and 2050 mg/m^3. A maximum concentration of 5162 mg/m^3 was recorded at 15 m in June 1976. Apart from lake circulation in September and October 1974, concentrations near the lake bed were consistently high throughout the study, frequently exceeding 2000 mg/m^3 (Table 8).

Results indicate that chemical destratification in Lake Waikopiro was brief. In July 1974, there was a short lived even distribution of NH4-N from the surface to the lake bed. The only other mixing period sampled was in June and August 1976. In June NH4-N concentrations showed that stratification was still in place but by August concentrations had already increased uniformly from the surface to the lake bed indicating that turnover had taken place between samplings.

Phytoplankton

Phytoplankton taxa sampled from Lake Tutira were identified by Dr Vivienne Cassie, formerly at the Botany Division of DSIR.

Phytoplankton taxa of Lake Tutira

Chlorophyceae (green algae)

- *Closterium aciculare*
- *Closterium acutum*
- *Staurastrum pingue*
- *Dictysphaerium pulchellum*
- *Ankistrodesmus*
- *Actinastrum*

Bacillariophyceae (diatoms)

- *Melosira granulate* (now known as *Aulacoseira granulate)*
- *Nitschia acicularis*
- *Synedra acus*

Dinophyceae

- *Ceratum hirundinella*

Cryptophyceae

Cryptomonas ovata

Myxophyceae (blue-green algae)

Oscillatoria sp

Anabaena aphaniozomenoides

Microcystis aeruginosa

Chroococcus limneticus

Phytoplankton counts

Each month from January to December 1974, phytoplankton samples were collected at 0, 1, 5, 10, 25 and 35 m depths. Taxa were recorded from 1 ml samples at each depth, then the results were combined and divided by six (the number of depths) to give a water column count that could be compared between months. For four months (January to April) a binocular microscope was all that was available for identifying and counting phytoplankton. Therefore it is likely that counts were compromised during that period. Furthermore, when Dr Cassie applied a relative abundance measure to the monthly phytoplankton samples, her assessment was that phytoplankton numbers were unexpectedly low. She suggested that the water samples may not have been concentrated as required. Whilst these limitations place constraints on interpretation of the phytoplankton results, the data that exist are presented here.

From accumulated monthly phytoplankton counts between January and December 1974 the abundance of various taxa is shown in decreasing order in Table 9.

The green algae *Staurastrum* and *Closterium* and the diatoms *Melosira* and *Synedra* were numerically dominant taxa in Lake Tutira. *Oscillatoria* and *Anabaena*, the blue-green algae, did not feature in high numbers but the period over which they were abundant was limited to late summer. Furthermore they may have been underestimated given the microscope that was available for the summer counts that year.

Table 9. Monthly phytoplankton counts combined for each taxa in 1974.

Phytoplankton taxa	Number
Staurastrum	6332
Melosira	2990
Closterium	1510
Synedra	915
Ankistrodesmus	560
Oscillatoria	474
Ceratum	325
Closterium acutum	236
Actinastrum	171
Anabaena	12

Seasonal trends - 1974

Subdividing the counts of phytoplankton taxa for the year into three groups, namely summer/stratified (January – April), winter/lake mixing (May – August) and spring/stratification developing (September – December), revealed seasonal trends (Table 10).

Table 10. Seasonal occurrence of the major phytoplankton taxa in Lake Tutira during 1974.

Phytoplankton taxa	Jan–April (summer) No. phyto	May-Aug (winter) No. phyto	Sept-Dec (spring) No. phyto
Staurastrum	792	3063	2989
Closterium	323	1097	-
Melosira	-	200	2620
Synedra	-	-	911
Ankistrodesmus	-	164	396
Ceratum	285	-	-
Oscillatoria	225	-	234
Total	1625	4524	7150

Overall, spring phytoplankton counts were highest followed by counts made during lake mixing. The lowest counts were recorded during summer but may have reflected the quality of the microscope rather than the actual situation.

What is clear is the dominance of the green alga *Staurastrum* both in abundance and seasonally. A total count of 6332 *Staurastrum* was more than twice as high as the next most abundant taxon, the diatom *Melosira,* with a count of 2990. Indeed, *Melosira* was most abundant during spring, but did not feature during summer. *Synedra* was also a spring phytoplankton and was not recorded during summer or winter. In contrast, *Closterium* was present during summer but multiplied to become one of the two dominant taxa (along with *Staurastrum*) during winter mixing. Also present during late summer was the blue-green alga *Oscillatoria*. Counts of *Oscillatoria* and *Anabaena* made in 1974 do not reflect the extent of the bloom and surface accumulations of blue-green algae that summer.

Counts of the various phytoplankton taxa varied consistently with depth. Whereas numbers were high at the surface, maximum densities were usually found at 1 and 5 m. At the thermocline, abundance began to decline with lowest counts recorded at 25 and 35 m. Given algal requirements for light and nutrients, and the low light penetration characteristics of Lake Tutira, the surface few metres of the lake would undoubtedly represent the best phytoplankton growing conditions.

Records of the dominant taxa for selected months over the course of the study indicated that assemblages were quite stable. Dominant taxa for April 1974, 1975, 1976 and 1977 are shown in Table 11.

Table 11. Dominant phytoplankton taxa for April 1974-1977

Dominant taxa	April 1974	April 1975	April 1976	April 1977
1	*Oscillatoria*	*Oscillatoria*	*Oscillatoria*	*Oscillatoria*
2	*Closterium* =	*Anabaena*	*Staurastrum*	*Staurastrum*
3	= *Melosira*	*Staurastrum*		*Anabaena*

The presence of blue-green algal taxa is a feature of late summer when nitrate concentrations in the epilimnion were consistently at or close to zero. Given that nitrate may be limiting, the ability of some blue-green algae (e.g. *Anabaena* spp) to fix nitrogen would have conferred an advantage over other taxa during the late summer period.

Chlorophyll a and Phaeophytin

The chlorophyll content of lake water provides a measure of phytoplankton biomass. Total chlorophyll is made up of chlorophyll *a*, the pigment involved in photosynthesis, and phaeophytin, the transformed pigment present in dead or dying phytoplankton cells.

Lake Tutira

In Lake Tutira, chlorophyll *a* concentrations ranged from undetectable in deep water at various times to a maximum of 61 mg/m^3 recorded at a depth of 5 m at Station 1 in February 1974. Phaeophytin also reached a concentration of 31.4 mg/m^3 at the same site, depth and month but peaked at 46.3 mg/m^3 in the equivalent situation at Station 4 (Table 12).

Chlorophyll *a*

To identify seasonal patterns in chlorophyll *a*, concentrations were plotted every two months from October to April and then August throughout the study (Figure 10). Results were variable. During the summer of 1973/74 peak concentrations were strongly focused at 5 m. By April it appeared that much phytoplankton biomass was in deeper water and another peak was recorded at the surface. Chlorophyll *a* did not reach the December - February levels again during the study, but phytoplankton concentrations greater than 10 mg/m^3 generally extended down to 10 m from October to March in the following two years, and down to 15 m in April as the thermocline deepened (Table 12, Figure 10). In the final summer, low chlorophyll *a* levels persisted until April when levels increased to more than 18 mg/m^3 in the epilimnion. During lake mixing, chlorophyll *a* levels were generally low and more evenly distributed than when the lake was stratified (Station 1, June 1974 and 1975 and Station 4, 1976).

Phaeophytin

Phaeophytin concentrations were generally lower than chlorophyll *a*, and varied with depth and season. At times when chlorophyll *a* (living phytoplankton biomass) was high in the epilimnion, phaeophytin or dead and dying phytoplankton was very low or absent in the hypolimnion (April 1974 and 1975). It is possible that phytoplankton cells were vigorous at these times and few individuals were sinking to the lake bed. In contrast, chlorophyll *a* was high in the epilimnion in April 1976 and phaeophytin concentrations were also relatively high in the hypolimnion, possibly indicating a less vigorous phytoplankton community and a greater proportion of moribund individuals sinking into deep water. During winter mixing, phaeophytin concentrations tended to be evenly distributed throughout the water column (June 1974, 1975).

Table 12. Chlorophyll a and phaeophytin profiles at Stations 1 and 4 in Lake Tutira and in Lake Waikopiro.

Chlorophyll a (mg/m³)

Depth (m)	Nov-73	Dec-73	Jan-74	Feb-74	Mar-74	Apr-74	May-74	Jun-74	Jul-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Nov-75	Dec-75	Jan-76	Feb-76	Mar-76	Apr-76	May-76	Jun-76	Aug-76	Oct-76	Dec-76	Feb-77	Apr-77
Tutira 1																											
0		6.3	11.5	1.9	1.4	16.5	1.9	4	6.4	1.5	33.7	1.5	2.2	17.5	7.3	11.7	10.4	16.9	10.4	8	12.2		4.6	2.2	2.4	5.8	18.7
1		7.6	11.1	1.7		15.3	6.4	4.2	13.7	10	34.3	3.9	3.7	14.1	9.5	11.2	12.3	17.8	13.6	10.2	11.5		5.8	7.04	3.9	6.1	20.9
5	8.1	52.1	14.1	61		1.2	9.4	3.8	11.7	11.2	23.3	5.4	1.7	14.3	10.7	11.2	10.4	15.9	13.3	8.7	4.7		7.7	4.9	2.4	7.3	18.2
10	2.3	2.2	7.5	3.8	4.5	2.2	1.3	4.7	12.1	15.6	7.1	4.4	1.5	9	13.6	2.92	7.45	17.8	10.4	12.2	4.4		9	6.07	5.8	6.1	20.4
15	1.1	1.1	0.5	0.2	6.8	3.4	8.2	7.7	11.6	2.9	4.5	6.6	1.9	5.8	11.2	1.53	2.43	2.81	5.4	11.9	1.3		10.9	4.61		1.7	17.3
25	0.4	0			0.2	7	1.9	2.1	0.1	0.7	3.9	6.8	1.7	6.8	7.2	0.65	0.5	2.19	2.7	1.5	0		12.1	2.01	3.2	0.7	1.7
35	1.5			0.9	0.9	4.9	1.4	4.2	1.7	2.4	1.7	6.8	2.9	11.7	1.7	0	0	1.94	3.2	0			17.5	3.88	1.4	0.2	0
Tutira 4																											
0		5.7	9.4		0.7	1.5	7.5		2.35	4.4	22.7	6.7	2.7	12.6	5.2	16	17.8	15.2	18.5	10.2	5.6	9.5	7.3		1.7	3.9	19.9
1		4.4	11.3			1.2	5.9		1.17	8.5	25.9	5.9	2.7	12.4	8.7	8.99	18.8	14.6	20.1	11	6.1	10.9	9.8	8.26	4.6	5.8	18
5		10.1	12.2	7.3	1	2.7	9.8		4.9	11.9	24.8	6.1	3.9	10	8.3	9.48	23	14.3	21	10.2	4.9	10.7	8	6.56	4.9	3.6	17.5
10		3.6	11.3	0.7	4	2.9	8.9		3.3	11.9	5.4	7.9		0.5	21.7	3.16	12	13.2	13.9	5.6	4.7	11.2	5.6	4.86	2.7	1.7	20.7
15		0.7	1.5	1.7	3.5	1.5	5.7		2.4	2.9	5.9	6.1		1.2	12.3	3.16	7.78	7.56	6.6	0.7	5.9	11.7	8.7	2.67	8.8	0	23.1
25			0			6.3	1.6		1.4	2.4	1.6	5.2	1.5	0.5	5	2.19	3.16	3.8	5.1	2.43	4.2		14.1	3.64	3.9	1.2	19.7
Waikopiro																											
0	3.3	1.4	1.6			7.04	0.9	3.3	0.2						34	14.6	3.69	17.9	9.4	0	22.4		21.1	13.6	21.6	4.9	23.9
1	4.3	1.1	2.8			19	0.5	66.9	0.5						29.8	14.9	5.51	12.3	6.8	15	19.7		19.2	65.9	9	3.6	22
5	17.5	60	11.8			4.86	0.7								3.2	18.9	14.6	3.43	9.5	1.9	17.3		10.5	30.1	7.8	0.7	9.2
10	0.8	14.2	1.4			2.43	22.4	25.4							0.5	3.07	1.3	8.22	10.7	23.3	3.4		13.9	16.8	9	0	16
15	0.6		1.9			1.7		0							0	3.56	0.32	6.39	6.8	1.9	2.2			12.6	18.5	5.6	9.1

Phaeophytin (mg/m³)

Depth (m)	Nov-73	Dec-73	Jan-74	Feb-74	Mar-74	Apr-74	May-74	Jun-74	Jul-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Nov-75	Dec-75	Jan-76	Feb-76	Mar-76	Apr-76	May-76	Jun-76	Aug-76	Oct-76	Dec-76	Feb-77	Apr-77
0		1.3	2.3	0.1	2.7	0	0.4	3.5	0.8	0.2	0	2.7	4.9	0	0.7	0.97	1.82	0	1.3	0	0		4.9	3.6	1	1.2	2.2
1		1.8	4.7	0.1		0	0.4	3	2.3	0	0	3.2	3.7	1.2	0.7	1.46	2.74	0	2.9	0.7	4.4		2.4	1.46	1.9	2.4	0
5	10.2	12	3.9	31.4		6.6	3	6.2	1.2	0	1.3	3.2	8.3	0	1.9	0.73	2	0	1	1	2.7		3.6	0.07	2.2	0	0.2
10	5.7	3.7	0.2	1.4	5.2	2.92	7.8	4.2	0.5	0	0	5.3	6.8	0	0.7	3.88	1.45	0	4.5	0	1		1.7	1.41	0	0.7	0.5
15	5	1.1	1.1	5.6	7.2	0	0.2	0.7	3.7	0	1.3	1.7	7	0	1.7	1.83	1.94	1.28	1.2	1.2	1.5		0	1		1.2	5.02
25	3.3	2.9			6.9	0	2.7	4.9	3.8	1.2	0	1.2	8	0	2.1	1.3	0.73	1.22	0	3.6	4.9		3.9	0	0	1.9	1.9
35	1.5			0.5	1	0	3	0.5	0.6	0	0	3.7	4.1	3.7	2.9	2.19	1.94	0.97	0	11.9			21.4	1.94	0.1	0.7	3.4
Tutira 4																											
0		3	3.2		1.5	2.92	1.2		0.86	0	0	0	3.9	5.8	3.4	0	2.19	0.32	0	0	1.3	6.8	0		2.6	7.5	0
1		2	2.4			0.24	0.7		0.13	1.2	0	0	5.1	5.8	5.6	2.19	0	0	0	0	4.3	6.3	0	4.13	0.7	5.3	3.4
5		2.5	2.6	46.3	2.3	0	0.3		2.3	0	0	0	2.9	2.7	6.3	7.77	0	0.97	0.7	0.5	3.8	6.5	0	14.8	1.9	6.8	0.2
10		2.3	1.6	7.2	3.1	4.37	1.2		0.92	0	0	0.7		12.9	0	2.92	0	0	1.3	1.5	2.9	9.5	4.1	2.45	3.8	7.1	1.5
15		0.6	1	3.4	1.8	0	2.4		0.96	4.6	0	1.3		2.4	0	0.73	0	0	1.2	1	2.7	8.9	0	2.26	0.8	7.8	1.2
25			1.1			6.32	2.3		0.8	0	2.4	1.7	4.6	2.7	0	0	0	1.27	0	1.2	1.7		0	0.27	1.7	6.3	2.4
Waikopiro																											
0	2.1	1.3	2			0	0.8	1.8	3.9							0	6.48	4.49	0.3	4.4	0.5		18.7	0.66	6.3	4.6	0
1	1.2	3.9	0.9			0	2.5	6.3	4.3						3.6	0	5.18	0.32	4.2	0	2.7		14.8	9.72	4.1	5.2	2.4
5	5.7	15.9	5.2			0	1.3								3.6	0	8.42	1.72	2.7	7.5	0		7.5	3.4	6	10.4	9.2
10	5	2.7	1.5			0	3.3	13.2							3.8	0	7.45	0	8.8	0.5	6.3		10.9	4.13	4.3	7.5	0
15	7.1		3.5			0		15.4							7.3	2.27	4.86	0.64	5.8	5.8	2.7			0	4.3	4.9	2.2

Figure 10. Chlorophyll a profiles (mg/m³) for Station 1, Lake Tutira and Lake Waikopiro during October, December, February, April and August from various years between 1973 - 1977. Note: Colour coding follows through from October/December in year 1 (e.g. 1973) to February/August in year 2 (e.g. 1974).

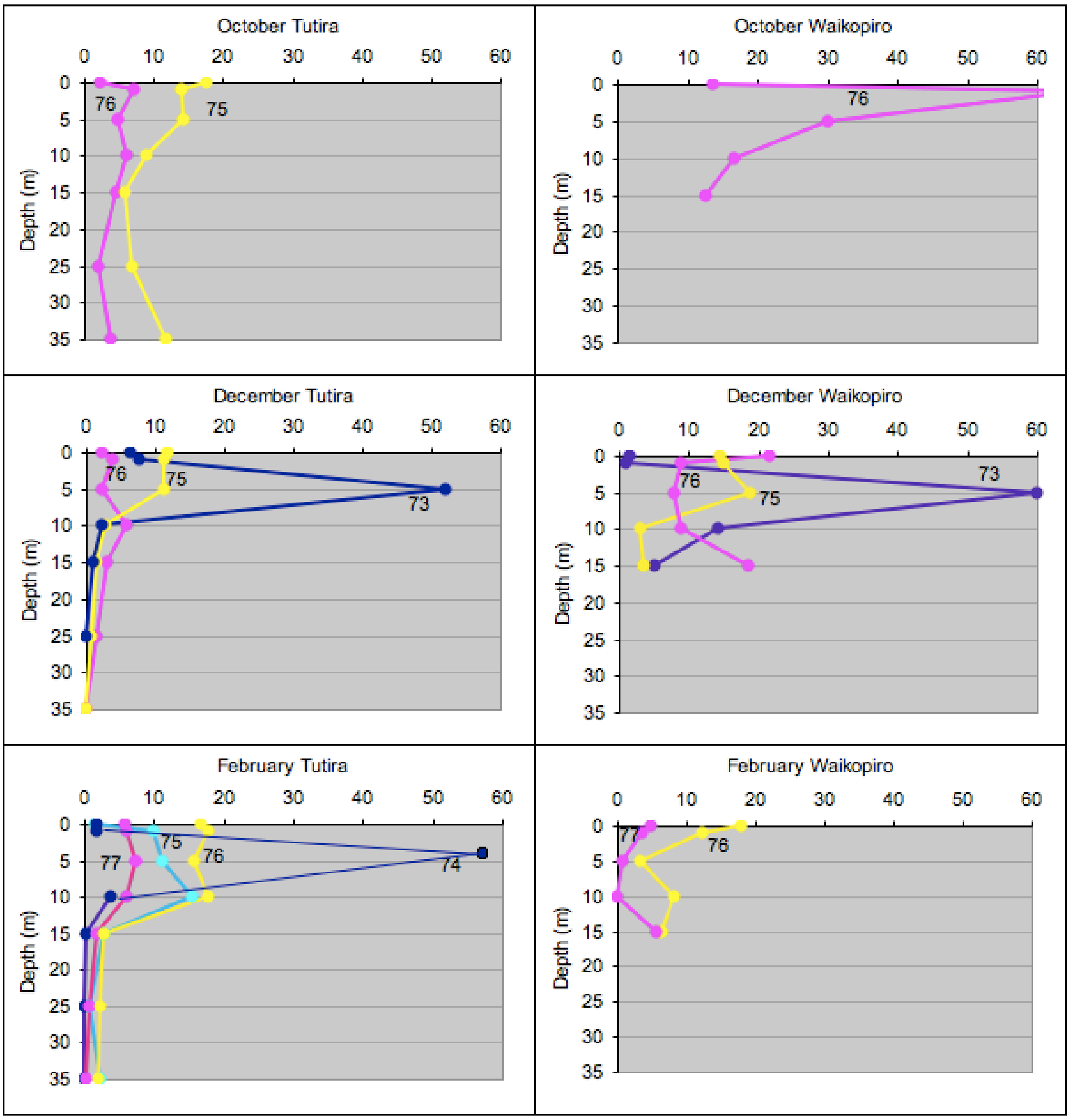
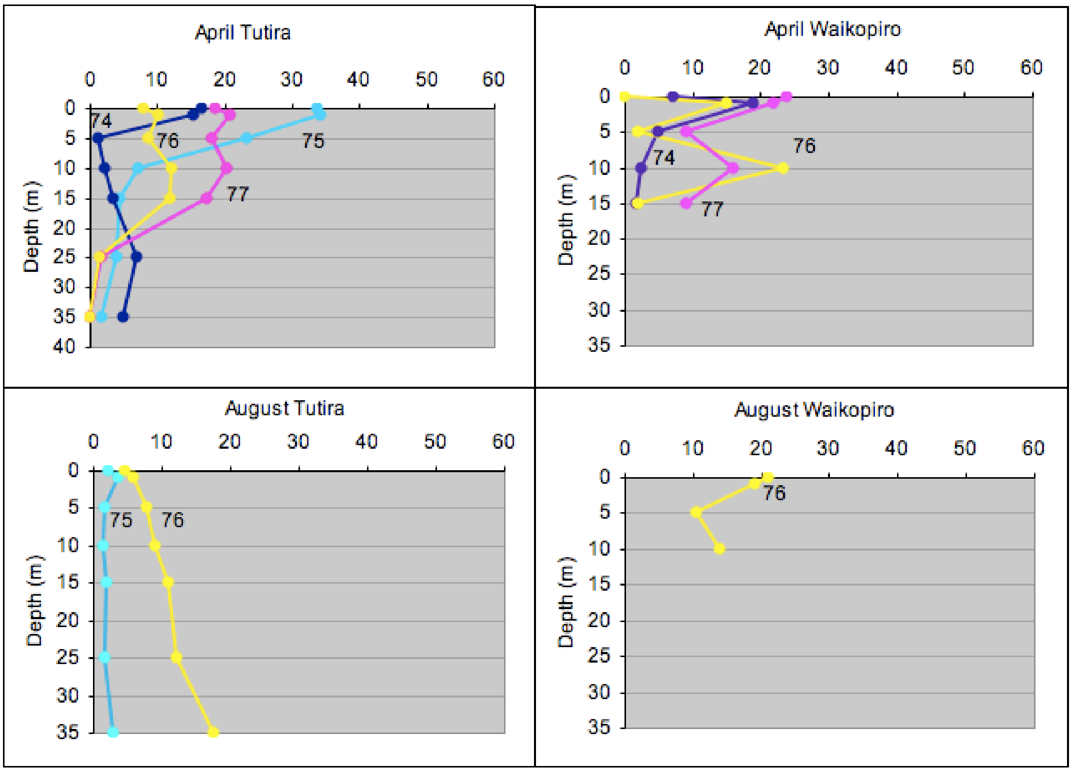


Figure 10 continued.



Chlorophyll *a*/phaeophytin relationship

Both chlorophyll *a* and phaeophytin results indicated the dynamic nature of phytoplankton communities. To shed further light on this, the chlorophyll *a*:phaeophytin ratio was calculated for the data (Table 13). Chlorophyll *a* accounted for almost 70% of total chlorophyll measures at Station 1 throughout the study, leaving phaeophytin accounting for the balance of just over 30%. During the first summer, when chlorophyll *a* peaked strongly at 5 m, most of the total chlorophyll was made up of living pigment. But from the thermocline down, phaeophytin, or dead and dying chlorophyll, tended to dominate the ratio. This pattern of chlorophyll *a* dominance in the epilimnion persisted in following summers. The end of summer ratios in April 1974 and 1975 and March 1976 were notable, however, because chlorophyll *a* dominated throughout the water column, indicating viable phytoplankton in the hypolimnion. During destratification, when deeper water was able to circulate and total chlorophyll levels were low, phaeophytin tended to make up a greater proportion of total chlorophyll. Indeed, in August 1975, phaeophytin dominated over chlorophyll *a* at all depths in both Stations 1 and 4. Two months later, in October 1975, spring phytoplankton growth was indicated in the ratio by a complete dominance of chlorophyll *a* (Table 13).

Table 13. Chlorophyll a as a proportion of total pigment (chlorophyll a plus phaeophytin) at Stations 1 and 4 in Lake Tutira and in Lake Waikopiro.

Tutira 1 Depth (m)	Nov-73	Dec-73	Jan-74	Feb-74	Mar-74	Apr-74	May-74	Jun-74	Jul-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Nov-75	Dec-75	Jan-76	Feb-76	Mar-76	Apr-76	May-76	Jun-76	Aug-76	Oct-76	Dec-76	Feb-77	Apr-77
0		0.83	0.83	0.95	0.34	1.00	0.83	0.53	0.89	0.88	1.00	0.36	0.31	1.00	0.91	0.92	0.85	1.00	0.89	1.00	1.00		0.48	0.38	0.71	0.83	0.89
1		0.81	0.70	0.94		1.00	0.94	0.58	0.86	1.00	1.00	0.55	0.50	0.92	0.93	0.88	0.82	1.00	0.82	0.94	0.72		0.71	0.83	0.67	0.72	1.00
5	0.44	0.81	0.78	0.66		0.15	0.76	0.38	0.91	1.00	0.95	0.63	0.17	1.00	0.85	0.94	0.84	1.00	0.93	0.90	0.64		0.68	0.99	0.52	1.00	0.99
10	0.29	0.37	0.97	0.73	0.46	0.43	0.14	0.53	0.96	1.00	1.00	0.45	0.18	1.00	0.95	0.43	0.84	1.00	0.70	1.00	0.81		0.84	0.81	1.00	0.90	0.98
15	0.18	0.50	0.31	0.03	0.49	1.00	0.98	0.92	0.76	1.00	0.78	0.80	0.21	1.00	0.87	0.46	0.56	0.69	0.82	0.91	0.46		1.00	0.82		0.59	0.78
25	0.11				0.03	1.00	0.41	0.30	0.03	0.37	1.00	0.85	0.18	1.00	0.77	0.33	0.41	0.64	1.00	0.29	0.00		0.76	1.00	1.00	0.27	0.47
35	0.50			0.64	0.47	1.00	0.32	0.89	0.74	1.00	1.00	0.65	0.41	0.76	0.37	0.00	0.00	0.67	1.00	0.00			0.45	0.67	0.93	0.22	0.00
Tutira 4																											
0		0.66	0.75		0.32	0.34	0.86		0.73	1.00	1.00	1.00	0.41	0.68	0.60	1.00	0.89	0.98	1.00	1.00	0.81	0.58	1.00		0.40	0.34	1.00
1		0.69	0.82			0.83	0.89		0.90	0.88	1.00	1.00	0.35	0.68	0.61	0.80	1.00	1.00	1.00	1.00	0.59	0.63	1.00	0.67	0.87	0.52	0.84
5		0.80	0.82	0.14	0.30	1.00	0.97		0.68	1.00	1.00	1.00	0.57	0.79	0.57	0.55	1.00	0.94	0.97	0.95	0.56	0.62	1.00	0.31	0.72	0.35	0.99
10		0.61	0.88	0.09	0.56	0.40	0.88		0.78	1.00	1.00	0.92		0.04	1.00	0.52	1.00	1.00	0.91	0.79	0.62	0.54	0.58	0.66	0.42	0.19	0.93
15		0.54	0.60	0.33	0.66	1.00	0.70		0.71	0.39	1.00	0.82		0.33	1.00	0.81	1.00	1.00	0.85	0.41	0.69	0.57	1.00	0.54	0.92	0.00	0.95
25			0.00			0.50	0.41		0.64	1.00	0.40	0.75	0.25	0.16	1.00	1.00	1.00	0.75	1.00	0.67	0.71		1.00	0.93	0.70	0.16	0.89
Waikopiro																											
0	0.61	0.52	0.44			1.00	0.53	0.65	0.05						1.00	1.00	0.36	0.80	0.97	0.00	0.98		0.53	0.95	0.77	0.52	1.00
1	0.78	0.22	0.76			1.00	0.17	0.91	0.10						0.89	1.00	0.52	0.97	0.62	1.00	0.88		0.56	0.87	0.69	0.41	0.90
5	0.75	0.79	0.69			1.00	0.35								0.47	1.00	0.63	0.67	0.78	0.20	1.00		0.58	0.90	0.57	0.06	0.50
10	0.14	0.84	0.48			1.00	0.87	0.66							0.12	1.00	0.15	1.00	0.55	0.98	0.35		0.56	0.80	0.68	0.00	1.00
15	0.08		0.35			1.00		0.00							0.00	0.61	0.06	0.91	0.54	0.25	0.45			1.00	0.81	0.53	0.81

Lake Waikopiro

As with other indicators of enrichment, chlorophyll *a* concentrations in Lake Waikopiro frequently exceeded those in Lake Tutira. For instance, chlorophyll *a* concentrations of 60 g/m^3 were recorded above the thermocline in December 1973, June 1974 and October 1976. Despite an incomplete record of chlorophyll *a* measures in Lake Waikopiro, some seasonal trends were evident. High chlorophyll *a* concentrations regularly occurred between the surface and 5 m during spring and early summer (October 1976, December 1973). By April/May, high concentrations had extended down to 10 m (April 1976, April 1977) (Figure 11). Despite April being at the end of summer, the chlorophyll *a*: phaeophytin ratios for April 1974 indicated that phytoplankton were active throughout the water column. This pattern was also noted that year at Stations 1 and 4 in Lake Tutira.

It was difficult to determine when destratification took place in Lake Waikopiro from chlorophyll results from only one June 1974 chlorophyll record and an incomplete July record. But the June chlorophyll *a* concentrations were very high near the surface, high at 10 m and absent at 15 m, indicating that mixing was not yet complete. Indeed, a phaeophytin concentration of 15.4 mg/m and 100% phaeophytin predominance at 15 m supported this observation (Tables 12 and 13). That destratification took place the following month was indicated by the even spread of NO3-N and NH4-N throughout the water column. Following destratification in July chlorophyll *a* concentrations began to increase rapidly in surface waters as spring phytoplankton growth proliferated again.

Pmax

Pmax provided a measure of potential phytoplankton productivity. Whereas phytoplankton in the surface waters of the lake generally have sufficient light and nutrients to maximize photosynthesis, the same is not so for phytoplankton at greater depths. During lake circulation however, it is possible that living phytoplankton are carried into deep water. Pmax values from samples collected in deep water showed that phytoplankton remained alive and capable of photosynthesis when carried up into suitable conditions near the surface once more. To investigate the condition of phytoplankton throughout the water column during the study, Pmax values were determined at Station 1.

From December to April throughout the study consistently high values were recorded from samples taken above the thermocline (2, 5 and 10 m depths). In contrast, low Pmax values from hypolimnetic samples suggested that phytoplankton below the thermocline were likely to be moribund or inactive during the summer period. But in

August, Pmax values were similar at all sampling depths, indicating that phytoplankton carried to the bottom of the lake remained capable of photosynthesis (Figure 11).

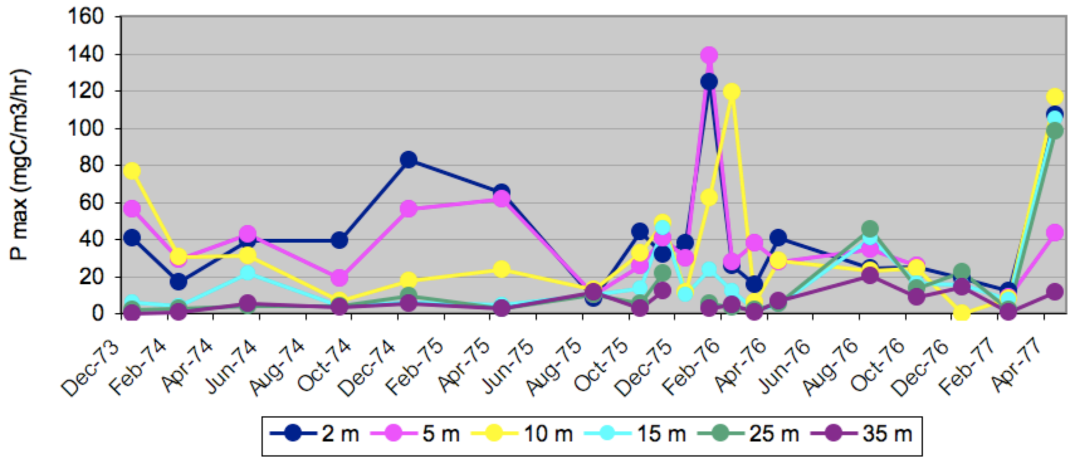


Figure 11. Pmax at six depths, Station 1, Lake Tutira December 1973 - April 1977

The basis of lake manipulation assumed that circulating Lake Tutira water during summer was one way of alleviating the effects of stratification and deoxygenation of deeper waters. Potentially productive phytoplankton had been identified in deep water during lake mixing using Pmax. By the same token Pmax could be used to detect lake mixing during summer and therefore was one way of evaluating the effectiveness of the aerohydraulic guns.

The aerohydraulic guns operated from November - April in both 1975/76 and 1976/77. Pmax values from December to February during the first year of operations exceeded all previous levels for 2, 5, 10 and 15 m samples, and similarly for 2, 10, 15 and 25 m samples in April the second year of operations (Figure 11). Despite these peaks, samples from 25 and 35 m did not show a corresponding increase in potential phytoplankton productivity in the first year of operations, indicating that mixing of deep hypolimnetic water was not taking place. Temperature profiles (Figure 2) place the thermoclines at greater depths in both 1975/76 and 1976/77 summers. This could account for the higher Pmax values at 15 m in 1975/76 and 15 m and 25 m in 1976/77, and lower Pmax values at 25 and 35 m in 1975/76 and 35 m in April 1977, depths that were below the deeper thermoclines of those two summers (Figure 11). Given Pmax was only measured at Station 1, temperature and oxygen profiles were important indicators of Pmax behaviour through the rest of the lake (Figure 3). Indeed, the agreement of temperature and oxygen profiles between Stations 1 and 4 indicated the effect was common to the entire lake (Tables 1 and 3).

Pmax results indicated that during the two summers the guns were operating the thermoclines were lowered. Furthermore, elevated values of Pmax in deeper water provided evidence for enhanced circulation of lake water during those summers.

Component 2
The aquatic plant beds of Lake Tutira

Data gathering

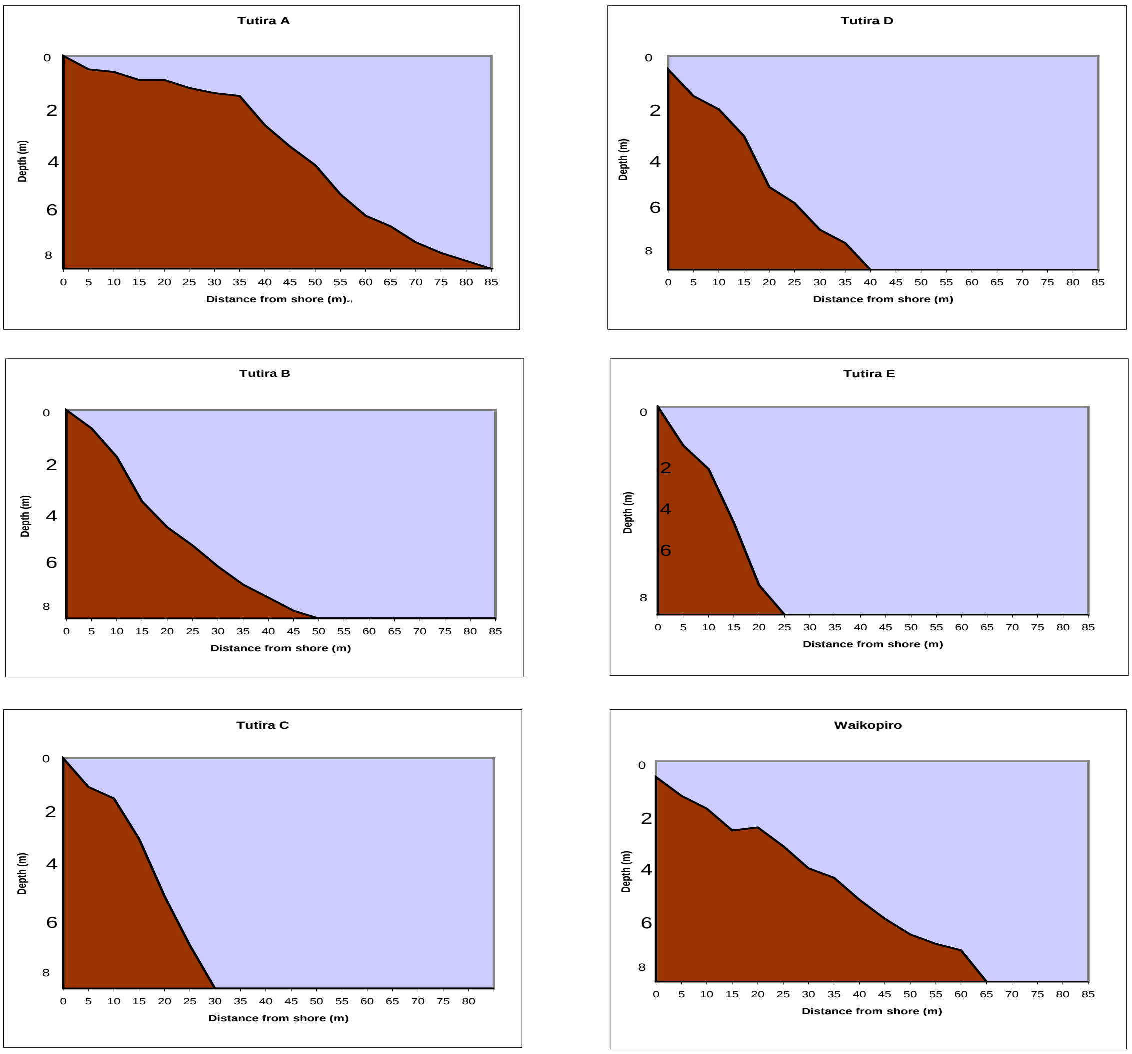
Aquatic plant transect locations were chosen around Lake Tutira to include a range of lake bed gradients, as determined from lake bathymetry. Five transects were established in Lake Tutira (A-E) and one in Lake Waikopiro (Map).

Transects in Lake Tutira ranged from gentle (Transect A), to steep (Transects C and E). Transects B and D had intermediate gradients. The gradient of the Lake Waikopiro transect was gentle, most closely resembling Tutira A (Figure 12).

Aquatic plant bed heights were measured along each of the six transects at approximately two monthly intervals from February 1974 to April 1977, spanning a period including four summers and three winters. For each transect, a rope marked at 5 m intervals was set perpendicular to the shore. Measurements of total lake depth and depth to the top of the aquatic plant beds were taken at each 5 m mark for the entire length of the bed. This was achieved by a boat person moving along each transect and recording while a diver measured the depths with a weighted rope. In this report 'aquatic plant bed height' is the distance from the top of the plant bed to the lake bed. In some transects the beds were almost completely dominated by *Hydrilla verticillata* while others had a mixture of *Hydrilla* and *Elodea canadensis*.

To provide an index of aquatic plant condition, samples were collected from Transects A, B and D at total depths of approximately 3 m and 6 m, respectively. From these samples, 100 plant strands, each 30 cm long, were dried for 30 hours at 100°C. The condition index, recorded both for 3 m and 6 m depths, was expressed as g/m dry weight. This analysis was performed for both *Hydrilla* and *Elodea* where these occurred. Note that no record is available of abundance or biomass of these species per unit area.

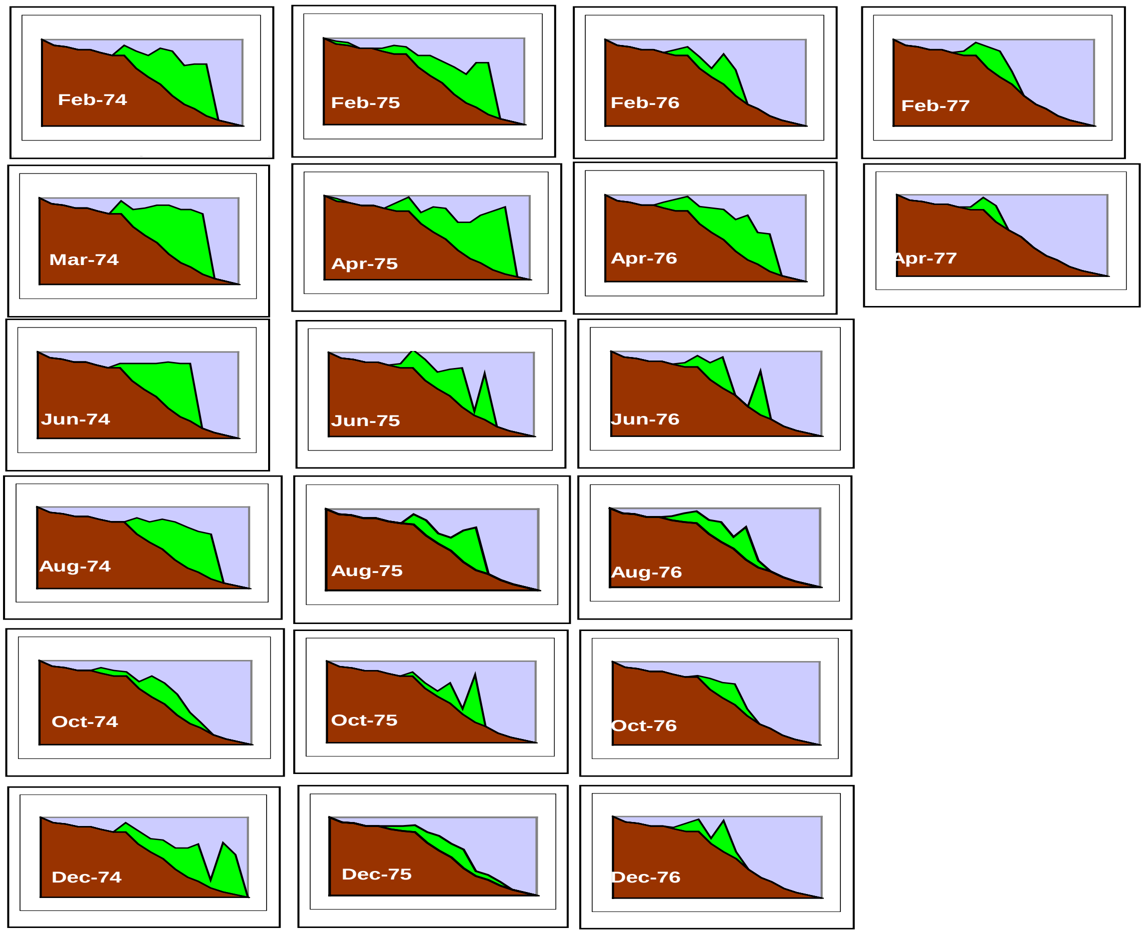
Figure 12. Lake bed profiles for the five Lake Tutira transects and the Lake Waikopiro transect.



Findings

Elodea was the principle plant species in Lakes Tutira and Waikopiro prior to 1963 when *Hydrilla* was first detected. Since then, *Hydrilla* has replaced *Elodea* as the dominant species. This was reflected in transects where samples were collected. Whereas Tutira Transect A and the Waikopiro transect were made up predominantly of *Hydrilla*, a mixture of *Hydrilla* and *Elodea* was a feature of Transects B and D. The plant bed profile for Lake Tutira Transect A is presented in Figure 13, showing a tendency for a decline in plant bed height and breadth from a summer/early autumn peak (February-April) to a winter/early spring low (August-October) and a marked general decline over the length of the study period.

Figure 13. Tutira A aquatic plant profiles throughout the study period. Note that maximum depth is 8 m and the transect extends for 85 m from the shore.



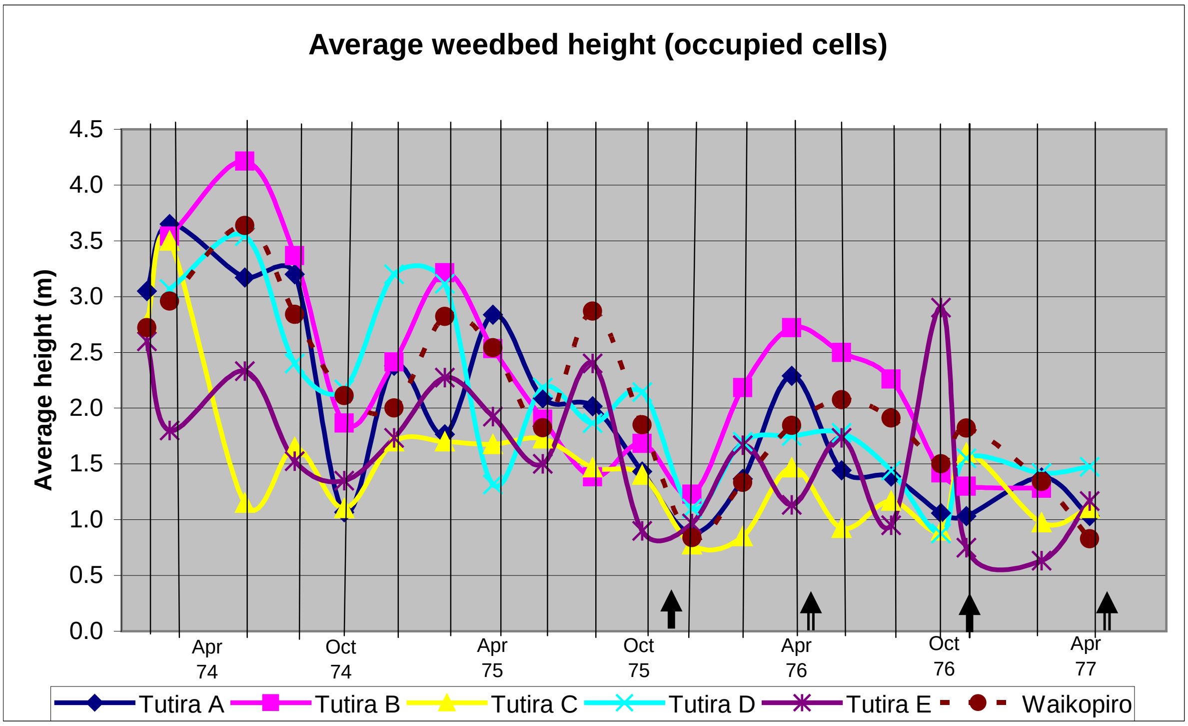
Data for all the plant profiles from 1974-77 are presented in the following table.

Table 14. Aquatic plant depth profiles (m) (top of plants to lake bed) for the five Lake Tutira profiles and the Lake Waikopiro profile.

	To shore (m)	Lake depth (m)	Feb-74	Mar-74	Jun-74	Aug-74	Oct-74	Dec-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Dec-75	Feb-76	Apr-76	Jun-76	Aug-76	Oct-76	Nov-76	Feb-77	Apr-77
Tutira A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0.5	0	0	0	0	0	0	0.3	0.3	0	0	0	0	0	0	0	0	0	0	0	0
	10	0.6	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	20	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	25	1.2	0	0	0	0	0.5	0	0.3	0	0	0	0	0.3	0	0.5	0	0.4	0	0.1	0	0
	30	1.4	0	0	0	0	0.5	0	0.8	0.7	0.4	0	0	0.5	0.5	1	0.3	0.9	0	0.8	0.3	0.2
	35	1.5	1	1.2	0.5	0	0.5	1	0.7	1.4	1.8	1	0.4	0.7	0.8	1.4	1.1	1.2	0.2	1.2	1.2	1.3
	40	2.6	1.5	1.6	1.6	1.5	0.6	1.2	1	1	1.9	1.5	0.5	1.1	1	1.5	1.6	1.4	1	0.5	1.9	1.6
	45	3.4	1.9	2.5	2.4	2	1.9	1.3	1.8	2.3	1.5	1	0.5	1.5	0.7	2.2	2.9	2	1.4	3	2.3	0
	50	4.1	3.3	3.5	3	2.9	2	1.8	2	2.9	2.5	1.3	2	1.4	2.8	2.7	0	1.2	2	0.6	1.2	0
	55	5.2	4.2	4.5	4.3	3.7	2	2.1	2.5	2.7	3.8	3.1	0.5	1.9	2.4	3	0	3.3	0.7	0	0	0
	60	6	3.6	5	5	4	1.1	2.9	2.7	3.5	0.4	4.2	4.7	0.5	0	4.2	4.2	0.7	0	0	0	0
	65	6.4	4.2	5.4	5.4	4	0.5	3.8	4.2	4.5	4.4	0	0	0.5	0	3	0	0	0	0	0	0
	70	7	4.7	5.5	0	4.3	0	0.8	4.7	5.5	0	0	0	0.4	0	3.4	0	0	0	0	0	0
	75	7.4	0	0	0	0	0	4.9	0	6.4	0	0	0	0	0	0	0	0	0	0	0	0
	80	7.7	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	85	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tutira B	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	5	0.7		0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0	1.1	0.9	
	10	1.8		0.7	1.9	1.4	0.2	1.2	0.8	1.9	1.9	1	1	1	0.8	1	1.5	1	0.3	2	1.5	
	15	3.5		0	3	1.8	1.1	1.4	2.5	1.2	1.2	2	1.8	1	1.8	2.7	2.3	1.7	1.5	0.8	1.4	
	20	4.5		2.6	4.1	3.6	1.7	2.8	3.9	3.2	2.5	2.1	2	1.9	2.6	1.6	3.6	1.4	1.3	0	1.3	
	25	5.2		3.9	4.1	5.6	3.6	3.2	5.2	4	2	1.5	1.6	1	3.2	3.7	2.6	3.2	1.8	0	1.3	
	30	6		4.9	5.2	4.7	3.1	4.2	5.1	0	0	1.7	2.1	2.3	3	4.6	0	4	2.2	0	0	
	35	6.7		5.3	5.5	0	1.5	3.7	4.5	4.4	0	0.7	1.6	1	1.7	0	0	0	0	0	0	
	40	7.2		6	5.7	3.1	0	0.4	0	0	0	0.7	0	0.4	0	0	0	0	0	0	0	
	45	7.7		1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	50	8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tutira C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
	5	1	0	0	0	0	0.5	0	0.5	0.7	0.5	0	0	0	0.2	0	0.2	0.5	0.2	0	0.1	0.1
	10	1.4	0.5	0	0	1	0.3	0.9	1	1	1	0.8	0.6	0.6	1.1	0.9	0.8	1.3	0.7	0.8	0.2	0.8
	15	2.8	1.5	1.5	0.8	2.3	2.5	1.4	2.4	1.7	2	1.1	1.5	0.9	1.4	2.5	2	1.7	2	2	2.4	2.4
	20	4.8	2.8	3.7	1.5	0	0	2	2.9	3.3	3.4	2.5	2.1	1.2	0.7	1	0.7	0	0.7	2	1.2	1.1
	25	6.5	4.2	5.3	0	0	0	2.5	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0
	30	8	4.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tutira D	0	0.5		0	0	0	0	0	0	0.5	0	0	0	0	0		0	0	0	0	0	0
	5	1.5		0.7	1.1	0.6	0.5	0	0.8	0.8	0.5	0.2	0.4	0.5	0		0	0	0	0	0.5	0
	10	2		1.1	1.5	1	1	0	1.4	1.5	1.2	1	0.7	0.5	1		1	0.2	0.5	0.7	0.8	0.3
	15	3		2.4	2	1.5	2.7	1.6	2.2	2.4	1.8	1.4	1.5	0.7	1.6		1.8	1.4	1	1.2	1.3	1.4
	20	4.9		3.9	3.8	3.4	3.1	2.8	3.3	1.7	1.4	2.6	1.7	0.3	1.9		2.4	2.6	0	2.2	2.5	2.5
	25	5.5		4.8	4.6	3.6	3.2	3.4	5	1	3.3	2.5	2.2	1.3	1.8		2.2	2	2	2.1	2	1.7
	30	6.5		5.5	5.9	4.3	2.5	4.7	6	0	4.9	3.5	3.9	3.3	2.2		1.5	1	0	0.2	0	0
	35	7		0	5.9	0	0	3.5	0	0	0	0	4.6	0	0		0	0	0	0	0	0
	40	8		0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
Tutira E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	1.3	0	0.9	0.5	0.3	0.5	0.4	1.4	0.7	0.5	0	0.2	0.1	0.4	0.5	0.3	0	0	0.5	0	0.3
	10	2.1	0.9	0.5	1.5	1	1.1	1.7	1.5	1.8	0.8	1	0.5	0.7	0.5	1.3	1	0.8	0.8	1	0.5	1.4
	15	3.9	4.3	4	5	3.7	2.8	3.1	3.2	0.9	3.2	3.8	2	2.1	4.1	1.6	3.9	1.1	1.9	0	0.9	1.8
	20	6	0	0	0	1.1	1	0	3	4.3	0	0	0	0	0	0	0	0	0	0	0.5	0
	25	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0
Waikopiro	0	0	0.5	0	0	0	0	0	0	0	0	0		0	0	0.2	0	0	0	0	0	0
	5	0.6	0.6	0.3	0	0	0	0	0	0.4	0	0		0	0.1	0.5	0	0	0	0	0.3	0.3
	10	1	1.5	0.5	1	0	0	0.5	0.7	0.9	0.3	0		0.1	0.1	0.6	0.5	0	0	0	0.4	0.4
	15	1.7	2.5	1	2	0.3	0.7	1	1.1	1.2	1	0.7		0.5	0.7	1.2	0.7	0.9	0.4	0.5	0.6	1
	20	1.6	2.9	1.6	2.4	1.5	0.6	1.1	1.6	1.7	1.6	1.2		1.1	1.3	2	1.1	1.4	0.8	1.4	1.6	1.3
	25	2.2	2.9	2.7	2.7	1.7	0.9	1.2	1.8	2.2	1.4	2.1		1.2	1.8	2.4	2	1.4	1.4	1.8	2	1.5
	30	2.9	4.1	2.9	2.7	2.7	1.9	1	3	2.7	1.5	2.6		1.3	2.1	2.7	2.4	1.7	2.4	2.1	2.3	0.5
	35	3.2	4.5	3.4	3.5	2.8	1.7	2.4	4	2.7	2.3	1.5		0	2.6	3.5	2.9	1.7	2.6	3.3	2.2	0.8
	40	3.9	5	3.9	4.4	3.1	2.8	3.4	4.4	4.5	2.5	3.6		0	0.5	3.5	3.4	2.7	2.5	0	0	0
	45	4.5	0	4.4	4.9	3.6	3.3	4.3	4	4.7	4	4.3		0	2.8	0	3.6	2.5	0.4	0	0	0
	50	5	0	4.5	5.4	4.1	3.7	4.3	4.8	4.4	0	4.2		0	0	0	0	3	0	0	0	0
	55	5.3	0	5	5.5	4.2	3.4	0.8	0	0	0	4.7		0	0	0	0	0	0	0	0	0
	60	5.5	0	5.3	5.5	4.4	0	0	0	0	0	3.8		0	0	0	0	0	0	0	0	0
	65	6.5	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0

Average plant bed heights were plotted for all six transects between 1974-77 allowing a comparison among Tutira bed transects of different gradients and between Lakes Tutira and Waikopiro (Figure 14).

Figure 14. Average weedbed heights for the transects in Lake Tutira and Waikopiro throughout the study period. Solid arrows show when the guns began operation and open arrows show when operation ceased.



A marked decline in both mean and maximum plant bed height took place over the course of the study. Plant beds were highest in March 1974 when maximum heights for all transects ranged from 4 to 6 m. By April 1977, plant bed profiles were very much reduced, with maximum heights ranging from only 1.5 to 2.5 m (Table 15).

Within this overall downward trend, a seasonal pattern was apparent, with the lowest plant bed heights consistently recorded in October and December (late winter/spring) over the three years. Plant bed height increased after late winter/spring to reach maxima between February and June (late summer to early winter), but with some variation among transects. In 1975, two peaks occurred in the growing period, one in February/April and a smaller peak in August/October separated by a trough in June.

Table 15. Mean and maximum aquatic plant bed heights (from top of plants to lake bed) in Transects A to E in Lake Tutira and in the Lake Waikopiro transect. Plant condition (g/m of plant strand) is given for both *Hydrilla* and *Elodea* at 3m and 6 m depths where these occur.

	Feb-74	Mar-74	Jun-74	Aug-74	Oct-74	Dec-74	Feb-75	Apr-75	Jun-75	Aug-75	Oct-75	Dec-75	Feb-76	Apr-76	Jun-76	Aug-76	Oct-76	Nov-76	Feb-77	Apr-77
Average aquatic plant bed height (occupied cells) (m)																				
Tutira A	3.1	3.7	3.2	3.2	1.1	2.4	1.8	2.8	2.1	2.0	1.4	0.9	1.4	2.3	1.4	1.4	1.1	1.0	1.4	1.0
Tutira B		3.5	4.2	3.4	1.9	2.4	3.2	2.5	1.9	1.4	1.7	1.2	2.2	2.7	2.5	2.3	1.4	1.3	1.3	
Tutira C	2.8	3.5	1.2	1.7	1.1	1.7	1.7	1.7	1.7	1.5	1.4	0.8	0.9	1.5	0.9	1.2	0.9	1.6	1.0	1.1
Tutira D		3.1	3.5	2.4	2.2	3.2	3.1	1.3	2.2	1.9	2.1	1.1	1.7		1.8	1.4	0.9	1.6	1.4	1.5
Tutira E	2.6	1.8	2.3	1.5	1.4	1.7	2.3	1.9	1.5	2.4	0.9	1.0	1.7	1.1	1.7	1.0	2.9	0.8	0.6	1.2
Waikopiro	2.7	3.0	3.6	2.8	2.1	2.0	2.8	2.5	1.8	2.9		0.8	1.3	1.8	2.1	1.9	1.5	1.8	1.3	0.8
Maximum aquatic plant bed height (m)																				
Tutira A	4.7	5.5	5.4	4.3	2	4.9	4.7	6.4	4.4	4.2	4.7	1.9	2.8	4.2	4.2	3.3	2	3	2.3	1.6
Tutira B		6	5.7	5.6	3.6	4.2	5.2	4.4	2.5	2.1	2.1	2.3	3.2	4.6	3.6	4	2.2	2	1.5	
Tutira C	4.8	5.3	1.5	2.3	2.5	2.5	2.9	3.3	3.4	2.5	2.1	1.2	1.4	2.5	2	1.7	2	2	2.4	2.4
Tutira D		5.5	5.9	4.3	3.2	4.7	6	2.4	4.9	3.5	4.6	3.3	2.2	0	2.4	2.6	2	2.2	2.5	2.5
Tutira E	4.3	4	5	3.7	2.8	3.1	3.2	4.3	3.2	3.8	2	2.1	4.1	1.6	3.9	1.1	1.9	1	0.9	1.8
Waikopiro	5	5.3	5.5	4.4	3.7	4.3	4.8	4.7	4	4.7		1.3	2.8	3.5	3.6	3	2.6	3.3	2.3	1.5
***Hydrilla* condition at 3 m (g/m)**																				
Tutira A	0.41	0.30	0.18	0.27	0.30	0.17	0.31	0.26	0.18	0.15	0.17	0.00	0.11	0.09	0.09	0.18	0.10	0.19	0.00	0.25
Tutira B					0.13					0.15		0.20		0.17	0.12	0.08	0.15	0.14	0.15	
Tutira D		0.36		0.26	0.15									0.13	0.10	0.07	0.07	0.08	0.11	0.12
Waikapiro		0.34	0.69	0.15	0.13	0.15	0.15	0.26	0.33	0.10	0.08									
***Hydrilla* condition at 6 m (g/m)**																				
Tutira A	1.89	1.37	0.93	1.36	0.77	0.80	1.72	1.73	0.83	0.51	1.14		0.55	0.70	0.44	0.99	0.71	1.14		1.02
Tutira B				0.18	0.14	0.10	0.13	0.15		0.11	0.10	0.14		0.15	0.15	0.10	0.13	0.14	0.12	
Tutira D		0.41	0.28	0.18	0.19	0.11	0.16				0.09	0.12		0.11			0.06	0.09	0.12	0.14
Waikapiro		0.59	0.59	0.10	0.17	0.16	0.11	0.21	0.33	0.17	0.09									
***Elodea* condition at 3 m (g/m)**																				
Tutira B		0.61	0.66	0.29	0.30	0.24	0.20	0.21	0.46		0.16			0.48	0.39					
Tutira D		0.43	0.44	0.31	0.38	0.25	0.19	0.23	0.24	0.14	0.42	0.24								
***Elodea* condition at 6 m (g/m)**																				
Tutira B		0.96	0.45						0.33											
Tutira D								0.26	0.20	0.18				0.55	0.40	0.21	0.20			0.71

In contrast to the peaks and troughs that characterised most transects, average plant bed height for the steep Transect C remained consistently below 1 m except for the first measurement. A notable feature of the plant bed profiles from October 1976 to April 1977 was increased patchiness (Table 15), and the appearance of dead and rotting weed at the end of some transects.

In addition to average and maximum plant bed height, Table 15 also includes the plant condition factor (g/m dry weight of weed strands) determined for 3 m and 6 m depths. Condition data are presented both for *Hydrilla* and *Elodea*. To investigate factors that might be important in determining plant bed height and condition, a correlation matrix is presented in Table 16 showing the relationships between the plant variables (*Hydrilla* only) and Secchi depth, euphotic depth (depth where light has declined to 1% of surface light), chlorophyll *a*, nitrate N, reactive P and temperature.

Table 16. Correlation matrix showing relationships among plant and physicochemical variables for Lake Tutira Transect A

	Average aquatic plant bed height	Maximum aquatic plant bed height	Mass per length shallow	Mass per length deep	Secchi depth	Euphotic depth	Chlorophyll a	Nitrate-N	Reactive-P	Temperature
Average aquatic plant bed height (m)	1									
Maximum aquatic plant bed height (m)	0.81	1								
Hydrilla condition at 3 m (g/m)	0.41	0.20	1							
Hydrilla condition at 6 m (g/m)	0.47	0.46	0.83	1						
Secchi depth (m)	0.58	0.42	0.11	0.14	1					
Euphotic depth (m)	0.46	0.36	0.00	-0.05	0.86	1				
Chlorophyll a (ug/L)	0.68	0.44	0.68	0.57	0.32	0.04	1			
Nitrate-N (mg/m3)	-0.05	-0.06	-0.24	-0.31	0.58	0.33	-0.45	1		
Reactive-P (mg/m3)	0.22	0.16	0.04	0.11	0.48	0.18	-0.26	0.41	1	
Temperature (C)	0.20	0.14	0.48	0.53	-0.32	-0.15	0.46	-0.82	-0.30	1

Plant bed heights and plant condition factors were strongly positively correlated with each other. It seems that these different measures of performance are responding in a similar way to changing conditions in the lakes. In other words when plant bed height is in decline dry weight of weed strands is also in decline and vice versa.

All the weed measures increased with an increase in lake temperature, probably reflecting the seasonal patterns already described. Positive trends were also detected between plant bed height measures and light availability, perhaps reflecting a limiting effect of light availability on growth.

Unusually, all the plant measures were highly correlated with chlorophyll *a*. As this is a measure of phytoplankton biomass it seems that plant beds and phytoplankton increased and declined at similar times, which is somewhat at odds with the general view that high density phytoplankton blooms tend to shade out plant beds, resulting in plant decline. The negative correlations between the plant measures and nitrate-N probably arises because the aquatic plants did best at the same time as phytoplankton and, when productivity of phytoplankton is high, nitrate-N concentration in lake water tends to be reduced.

Component 3
Lake Tutira rainbow trout stocks

Data gathering

Trout stocking data were compiled from 1959-1978. Each year, the Hawkes Bay Acclimatisation Society (now Hawkes Bay Fish & Game) released one year old fish into the lake during the winter months. In later years all fingerlings were fin clipped for identification of each year class and a percentage were tagged for growth information from angler-caught fish.

Set netting was carried out every two months over the study period. To determine the most appropriate mesh size, a trial was conducted using three different stretched mesh sizes – 1.5, 2.5 and 3.5 inches, or 3.8, 6.4, and 8.9 cm. Net selectivity was apparent so all three nets were used during each two monthly sampling. Twenty metre long nets were set overnight, generally from 5.00 pm to 9.00 am. Set netting was not confined to specific locations but took place around the lake. Trout were measured and weighed and the presence of a fin clip or tag was recorded. Stomach contents were removed, identified and counted. Condition Factor, a measure of trout health based on the length-weight relationship, was calculated.

Echo sounding enabled the depth of trout to be identified. To calibrate the echo-gram, trout of various sizes were hung beneath the beam so that trout could be recognized and recorded. Echo sounding runs were then made back and forth across the lake. Trout depth was recorded from the echo-grams once back on shore. Echo sounding took place from December 1973 – July 1974, including a summer/winter period. Set nets were also used to determine trout depth by setting them down the slope of the lake bed.

Fish trapping – The Acclimatisation Society operated a fish trap in Sandy Creek over the spawning period. Some trout were selected for stripping eggs and milt to be fertilized and reared at the Society's Green Meadows hatchery in Taradale. Trap records provided for 1974 and 1975 show fin clip, length, weight and sex of migrating trout and the date they were processed in the trap.

Findings

Trout stocking

Trout stocking in Lake Tutira began in response to the inability of Sandy Creek to provide adequate spawning habitat for the trout population in the lake. Both small stream size and siltation from erosion in the catchment over the years had compromised natural spawning. To maintain the fishery, hatchery reared fingerlings were released into the lake. Records of releases from 1959 – 1977 are shown in Table 14. Numbers varied quite considerably until 1973 when it became important to maintain the same stocking regime over the course of the study. Recognition of year classes was also important so fin clips were used for each year's release. Stocking took place each year on a single occasion during the winter months. Fingerlings, that generally measuring 12 – 14 cm came from the Green meadows (Taradale) Tongariro (Taupo) and Ngongataha (Rotorua) hatcheries.

Table 14. **History of stocking of fingerlings of rainbow trout in Lake Tutira from 1959 to 1978.** A number of fish were tagged in most years, to allow for angler recovery and reporting. From 1973 to 1977, all stocked fish were fin clipped (1973 right pelvic, 1974 left pelvic, 1975 no fin clip, 1976 adipose, 1977 left ventral).

Year	Number of fingerlings introduced	Number tagged	Year	Number of fingerlings introduced	Number tagged
1959	700		**1969**	10 700	0
1960	832	100	**1970**	22 038	2 038
1961	6 630	200	**1971**	17 752	780
1962	2 624	124	**1972**	17 280	0
1963	12 248	300	**1973**	10 100	300
1964	7 700	400	**1974**	10 000	300
1965	10 400	400	**1975**	10 000	300
1966	10 000	0	**1976**	10 000	No record
1967	19 250	400	**1977**	10 000	No record
1968	28 200	200	**1978**	10 617	No record

Trout growth and condition

The study of Lake Tutira's rainbow trout stocks is based on more than 680 trout that were captured by set netting between 1973 and 1978. Trout were grouped according to year class (date of release in the lake) and sampling date. The number caught, mean length and mean condition factor of the sampled trout are presented in Table 15.

Table 15. Numbers caught, mean length and mean condition factor for each stocked year class of rainbow trout from June 1973 to November 1978.

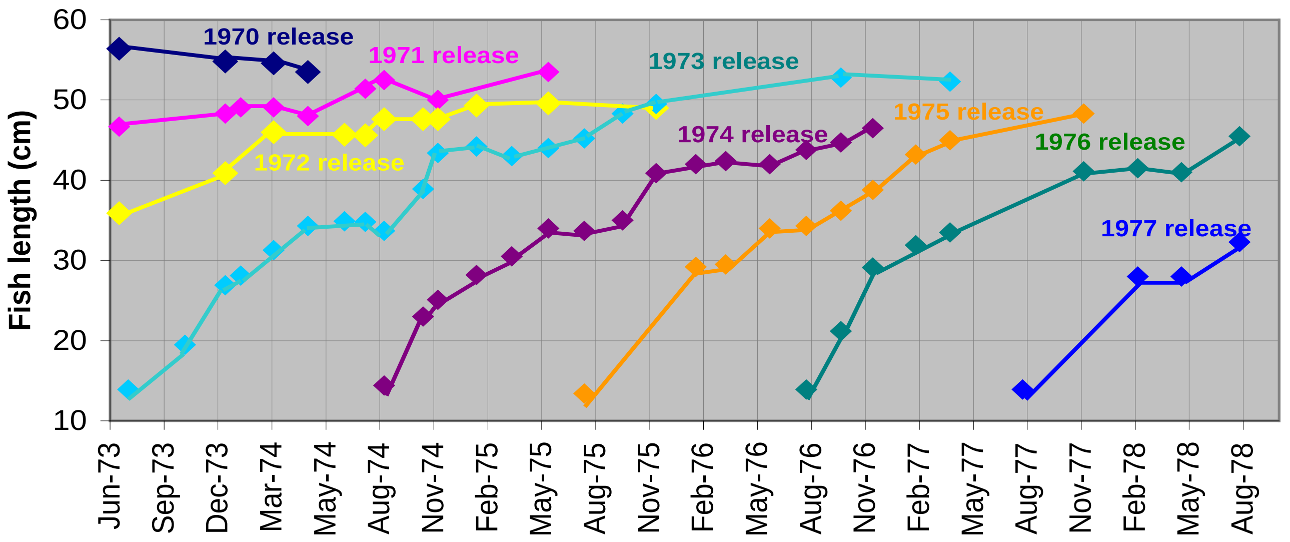
YEAR CLASS	20/06/73	08/10/73	09/11/73	14/12/73	09/01/74	05/03/74	01/05/74	01/07/74	05/08/74	05/09/74	09/11/74	04/12/74	06/02/75	06/04/75	06/06/75	05/08/75	08/10/75	03/12/75	07/02/76	28/03/76	09/06/76	09/08/76	06/10/76	28/11/76	08/02/77	06/04/77	15/11/77	13/02/78	27/04/78	02/08/78	28/11/78
Number																															
1970	4			5		1	1																								
1971	10			3	3	2	1		2	1		1			3	3															
1972	7			3		2		3	4	2		2	1		1	4		2													
1973	1	36		25	13	36	22	17	9	9	8	2	5	2	9	5	6	18					1			1					
1974										1	4	15	14	14	17	3	20	19	12	12	7	12	9	2							
1975																			12	16	11	12	48	7	5	2	3		1		
1976																							2	28	12	20	20	5	4	5	2
1977																												1	1	9	3
Mean length (cm)																															
1970	56.4			54.8		54.6	53.5																								
1971	46.7			48.3	49.1	49.1	48.0		51.4	52.5		50.0			53.5	52.0															
1972	35.9			40.9		46.0		45.7	45.6	47.6		47.6	49.3		49.6	49.0		49.0													
1973	14.0	19.5		26.9	28.1	31.3	34.3	34.9	34.8	33.7	38.9	43.4	44.2	43.0	44.0	45.2	48.3	49.5					52.8			52.3					
1974										14.4	23.0	25.1	28.2	30.5	34.0	33.7	35.0	40.9	42.0	42.4	42.0	43.8	44.7	46.5							
1975																			29.2	29.5	34.0	34.3	36.2	38.8	43.2	45.0	48.3		46.0		
1976																							21.2	29.1	31.9	33.5	41.1	41.5	41.0	44.0	40.0
1977																												28.0	28.0	33.0	33.0
Mean condition factor																															
1970	42.2			35.6																											
1971	47.5			44.1	47.0	41.2				39.3		42.2			36.1	38.7															
1972	48.8			58.5		44.6		43.2		39.1		41.5	36.5		39.9	38.2															
1973				56.2	55.8	45.3	42.7	43.7		42.6	40.9	49.7	45.0	52.6	42.7	45.5	38.6	34.1					42.7			37.0					
1974											50.3	49.2	46.5	49.6	45.4	50.3	44.9	45.9	43.4	39.6	40.2	43.6	42.7	45.3							
1975																		45.3	45.1	43.5	42.3	44.0	46.0	46.2	46.4	37.3	44.1		46.7		
1976																							55.7	44.4	44.5	43.1	41.8	44.7	42.4	35.2	41.7
1977																												44.9	42.3	41.7	46.9

Note: In some instances trout numbers used for length measurements and condition factor varied due to circumstances where weights were not recorded because of eel damage, releasing live trout etc.

Growth patterns

To identify growth patterns, the mean length of each year class has been plotted by sampling date (Figure 12). There was a consistent pattern of length increases across year classes. Trout growth was rapid from the time of release (one year olds) until winter the following year (two year olds) when growth slowed during July to October. Another surge of growth took place in spring but slowed to a halt from February to June. A slower increase in length resumed again the following spring (three year olds). Despite the flatter profile for the older year classes, 1970, 1971 and 1972 releases also exhibited little to no length increase during the February – June period.

Figure 12. Mean lengths of rainbow trout for 1970-1978 releases.

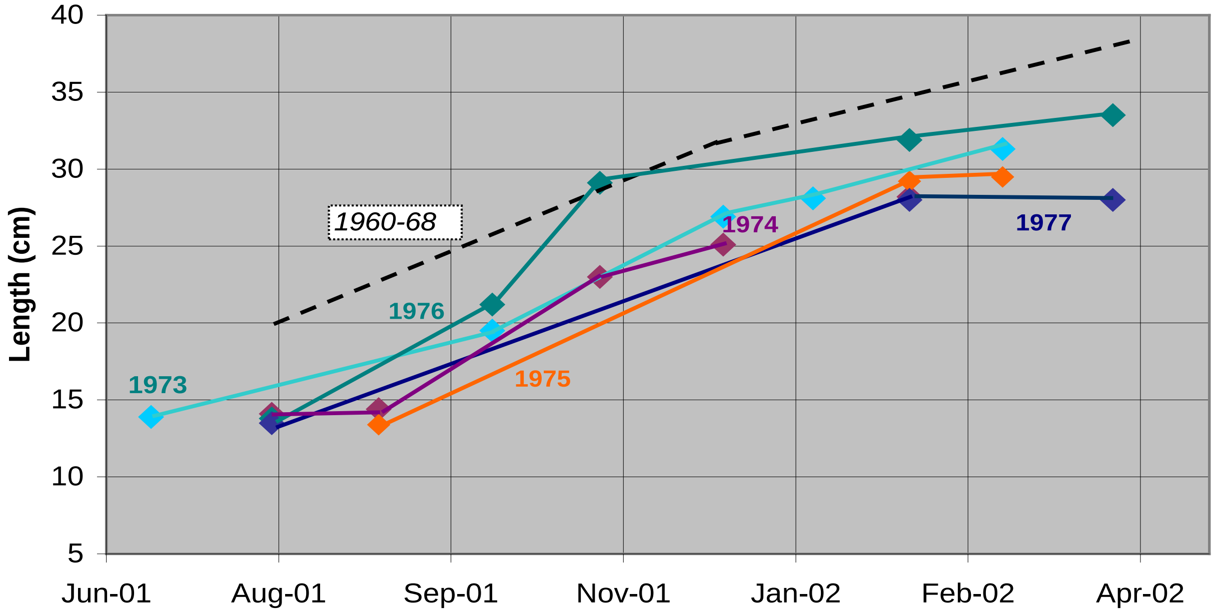


In summary, the length data have revealed two trends that are consistent between the trout year classes in Lake Tutira. The first is a slowing in length increases over the winter period July – September as shown clearly by the 1973, 1974 and 1975 year classes, respectively, one year after their release. The second is a flattening of the length profile each year from approximately February to June.

Growth before and during aerohydraulic gun operations

What is not evident from the length data is the impact lake mixing may have had on the rainbow trout stocks. For this to be demonstrated trout data must be compared before and during the period of aerohydraulic gun operation that began in November 1975. Accordingly, the growth curves of trout year classes during their first eight months in the lake are superimposed in Figure 13. Year classes 1973 and 1974 were in the lake prior to lake mixing, year class 1975 was released three months prior to mixing and year classes 1976 and 1977 were stocked during mixing. There is no discernable difference between the growth curves of trout stocked before or during lake mixing. Indeed the similarity in growth over the first eight months is striking.

Figure 13. Mean length of rainbow trout in year of release. The average growth curve is shown for fish in 1960-68 for comparison.



For comparison, the average growth curve for trout in Lake Tutira during the 1960s is also shown (Graynoth 1973) [3]. These records are from tag returns from angler-caught fish and suggest that a consistent difference of approximately 5-6 cm in length existed between 1960s and 1970s trout stocks. This difference, which persisted in two, and to a lesser extent, three year old trout in the 1960s can be explained by size at stocking. In the 1960s, 20 cm trout were released whereas in the 1970s fingerlings were only 12 – 14 cm. Whereas that difference was reflected in both the 1960s and 1970s growth curves the two annual periods of reduced growth revealed in our study (October and December to April) did not appear in the 1960s growth curve. Fitting the curve on the basis of tag returns rather than two monthly sampling would account for this difference. Therefore it is possible that the periods of slower growth could also have been taking place in the 1960s.

Longevity and maximum size

Graynoth noted that "rainbow trout have a comparatively short life span and seem to die off rapidly around 56 cm in length at an age of four plus years". The longevity and maximum length (cm) of year classes during this study is shown in Table 16. The 1970 – 1973 year classes netted during the current study likewise reached an age of four to five years (Table 16).

[3] E Graynoth. 1973. *The Hawke's Bay Trout Fishery*. Fisheries Technical Report No, 114, NZ Ministry of Agriculture and Fisheries. 45p.

Table 16. Age and mean length reached by rainbow trout age classes between 1970 – 1977.

Year class	Release date	Last capture	Time in lake + 1 yr for trout age	Maximum length achieved (cm)
1970	Aug 70	May 74	4 yr 9 mo	56.4
1971	Aug 71	Aug 75	5 yr	53.5
1972	Aug 72	Dec 75	4 yr 4 mo	49.6
1973	July 73	Apr 77	4 yr 9 mo	52.8
1974 *	Aug 74	Nov 76	3 yr 3 mo	46.5
1975 *	Sept 75	Apr 78	3 yr 7 mo	48.3
1976 *	Aug 76	Nov 78	3 yr 3 mo	44.0
1977 *	Aug 77	Nov 78	2 yr 3 mo	33.0

* Capture dates for trout in these year classes cannot be assumed to be final.

Trout in these year classes reached a maximum mean length of more than 50 cm during their time in the lake. The longevity of the younger year classes from 1974 onwards could not be confirmed before the conclusion of the study. Therefore it can be assumed that rainbow trout reached similar maximum ages and lengths throughout the 1960s and 1970s.

Trout health - condition factor

One measure of trout health is condition factor (CF), a length-weight relationship that varies with the weight of the fish. Thus a trout in poor condition will weigh less than a trout of the same length in good condition.

CFs were calculated using the formula $CF = \frac{W \times 3612.73}{L^3}$

where W is weight in grams and L is length in centimetres.

Interpreting CFs of older and spawning trout can be difficult because weight can be made up of gonad material or full stomachs rather than flesh. For this reason CFs are presented for each year class from the date of first capture until August the following year before maturation (Figure 14).

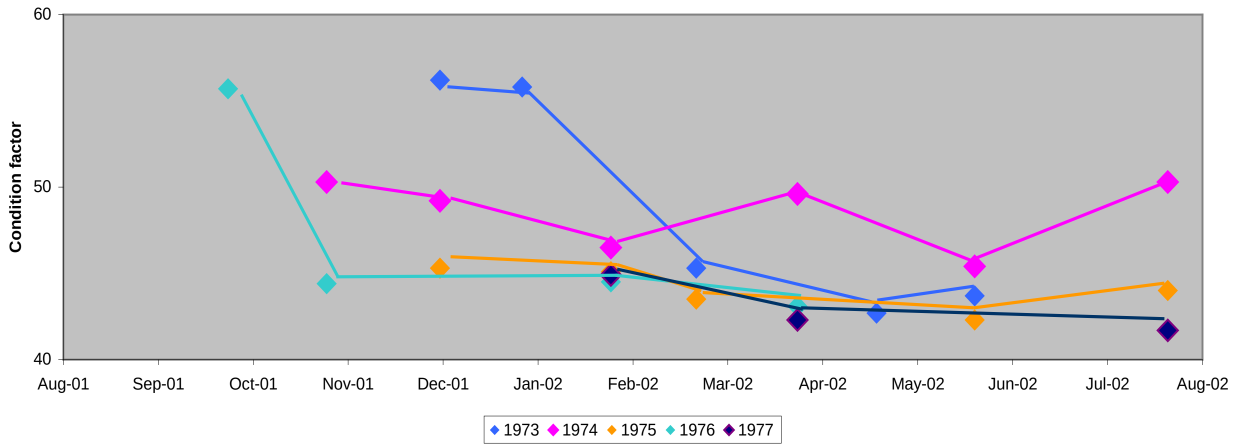


Figure 14. Mean condition factor for each year class during year of release.

Mean condition factor dropped over the summer period (December to April) for all year classes except 1974. By June, CFs had started to increase and the increase extended to August for all but the 1977 year class. This pattern of trout health mirrored the stalling of length increases after the lake stratified (Figure 12) and reinforces the view that Tutira trout are adversely impacted by eutrophic conditions during summer.

Trout diet

To investigate the diet of Lake Tutira rainbow trout, the stomach contents of 615 trout were sorted and assigned by sampling date to the categories listed in Table 17. The frequency of occurrence of each category of food item in trout stomachs was recorded (top part of table) as was the total number of individuals of that food item in all stomachs combined (bottom part of table). Percentage of empty stomachs was also recorded.

Table 17. Diet of rainbow trout from 1974 to 1978. (a) Frequency of occurrence of items in stomachs. (b) Total number of items in all stomachs combined.

(a) No. of stomachs containing	8/01/74	5/03/74	1/05/74	1/07/74	5/09/74	1/11/74	4/12/74	2/02/75	11/04/75	2/06/75	2/08/75	7/10/75	3/12/75	5/02/76	29/03/76	8/06/76	9/08/76	6/10/76	28/11/76	8/02/77	19/04/77	15/11/77	13/02/78	27/04/78	23/08/78	28/11/78
Number of stomachs	17	42	24	20	12	12	20	21	16	30	15	26	43	24	28	19	24	19	24	17	23	24	6	6	14	22
No. empty stomachs	7	19	2	2			3	10	5	8	4	5	8	3	9	4	6	3	4	5	1	1	1	1	4	3
Common bullies	3	15	13	10	11	7	13	10	3	3	3	13	15	9	13	6	6	12	15	6	14	9	4			2
Galaxiids													3													
Daphnia																	1		5							
Chironomids	2	2				2	2					2			6		7		3							1
Waterboatmen	5	5	12	7	2	1	1		7	11	4	4	6	6	4		2	1	1	4	2					1
Dragonfly larvae	2			2		3	5			4		8		10	1	1			2	2	1				3	
Damselfly larvae																			2							
Mayfly larvae	1					1	1					6		2			2									
Planorbis																		1	1							
Water mites			2			1															4					
Tubifex	2										5				1											
Potamopyrgus	1		14	10	3	5		2	2	15	7	5	4	5	4	7	5	5	5		7	2		4	4	2
Limnaea																	1	1	1	1	1					
Terrestrial arthropods	1	2	3	7		4		1	2	3	1	1	8	1	1		6	1	4	3	11	19	1	3	2	14
Feathers						1									1	1									1	
Terrestrial leaves							1									2								1	2	
Lake weed		1	3	5	4	3		1	5	12	4			1	3	6	7	1	5		8	1		1	5	5
Periphyton/algae														1		1	1									0
Slime														3					1	1						1

(b) No. of items all stomachs combined	8/01/74	5/03/74	1/05/74	1/07/74	5/09/74	1/11/74	4/12/74	2/02/75	11/04/75	2/06/75	2/08/75	7/10/75	3/12/75	5/02/76	29/03/76	8/06/76	9/08/76	6/10/76	28/11/76	8/02/77	19/04/77	15/11/77	13/02/78	27/04/78	23/08/78	28/11/08
Common bullies	9	683	55	41	70	100	432	99	51	101	4	91	282	57	238	54	9	373	137	103	84	36	39			6
Galaxiids													7													
Daphnia																	100		2700							
Chironomids	295	16				3						4			18	100	74		31							10
Waterboatmen	22	58	65	33	2	1			115	98	35	10	101	556	68	5	3	1	19	633	29					1
Dragonfly larvae	4			3		14	20			5		82		18	1	1			2	2	1					
Damselfly larvae																			2							
Mayfly larvae	1					1	1					11		2			2				9					
Planorbis																		1	4							
Water mites			31			20									12						1512					
Tubifex	3																									
Potamopyrgus	4	2	182	18	6	10		2	3	505	184	22	10	82	49	48	13	149	5		46	32		112	69	25
Limnaea																	16	1	26	1	1					
Terrestrial arthropods	2	5	4	8	9	5		1	2	3	3	1	69	1	1		6	1	95	353	112	1040	4	5	2	122
Feathers						1									6	3									1	
Terrestrial leaves							1									2								1	2	
Lake weed		1	3		5	3		1	5	91	23		1	3	3	6	7	1	5		8	1		1	5	5
Periphyton/algae														1		1	1									
Slime														3					2	1						1

A wide variety of aquatic food items appeared in trout diets. Fish prey included common bullies and galaxiids. Chironomids, waterboatmen, dragonfly, damselfly and mayfly larvae made up the aquatic insect component while the snails were represented by *Potamopyrgus, Limnaea* and *Planorbis. Daphnia* and *Tubifex* (blood worm), respectively, live in the water column and in the lake sediments. Water mites appeared periodically in the diet.

Terrrestrial insects were a source of trout food, falling prey when hovering above or landing on the surface of the lake. Manuka beetles, grasshoppers, crickets, cicadas, blowflies, bees, spiders and yellow wasp-like insects were all components of the diet.

Finally, several items found in trout stomachs could not be classed as food, including feathers, terrestrial leaves, weed fragments, periphyton/algae and slime.

Major food items

The *common bully* was consistently the most important food for trout both in terms of percentage frequency and total number of individuals. Bullies are also relatively large, providing a greater biomass than the smaller items.

Potamopyrgus, a small snail associated with the aquatic plant beds, followed common bullies in both percentage occurrence and numbers recorded throughout the study. Despite high numbers being ingested during winter, *Potapopyrgus* have thick shells that would be difficult to digest.

W*aterboatmen* are small prey that regularly appeared in the diet, sometimes in large numbers.

Terrestrial arthropods also regularly occurred in small numbers in trout stomachs, but on a number of occasions predominated in the diet. Apart from bullies, terrestrial prey tended to be larger than aquatic food items.

One-off high density occurrences

Exceptional numbers of three food items were recorded on one sampling occasion each. In November 1976, 2700 *Daphnia* were recorded from five trout stomachs. As *Daphnia* are part of the zooplankton, trout must have been feeding in the water column. Similarly, 1512 mites were recorded from four trout stomachs in April 1977. Apart from these single instances, *Daphnia* and water mites rarely appeared in trout stomachs. In contrast, manuka beetles were found in small numbers in the diet each spring but completely dominated the stomach contents of 17 of the 19 trout in November 1977.

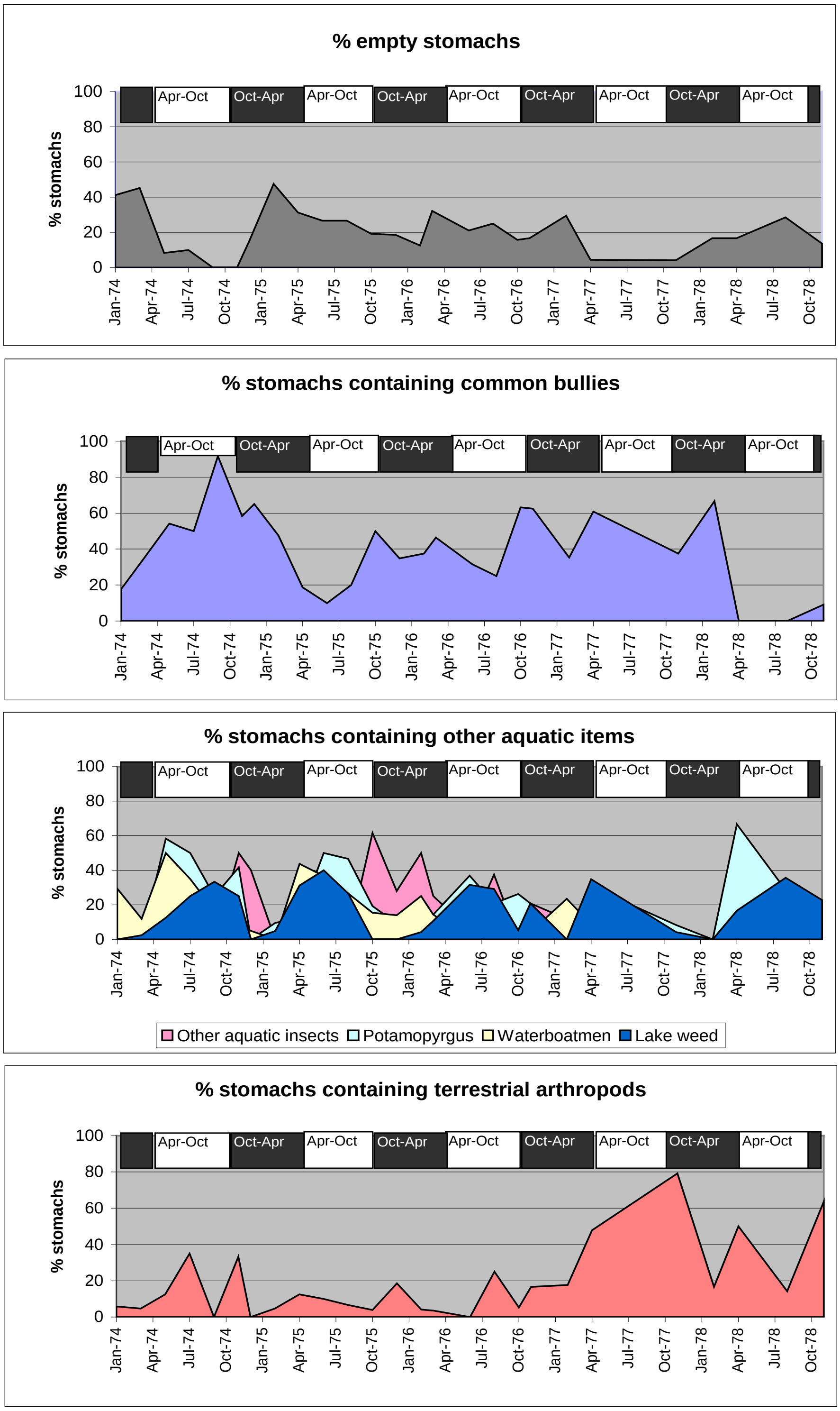
Seasonal patterns

To investigate seasonal patterns in trout diet the percentage of trout stomachs containing each type of food item was plotted by sampling date as was percentage of empty stomachs (Figure 15). Percentage of empty stomachs reached peaks in April 1974, 1975, 1976 and 1977. This coincides with poor water quality conditions where trout were confined to the layer of water between the warm surface water which was well above the optimum temperature for trout (16-18°C), and deoxygenated water within the metalimnion and below the thermocline. These conditions dominated the lake from November, when the lake stratified, to April each year and appeared to have adversely impacted trout feeding. The annual flattening in the trout growth curves during that period is also likely to reflect these conditions (Figure 12).

During winter each year the percentage of trout stomachs that contained plant fragments peaked (mainly in July). Given that aquatic plants provide habitat for *Potamopyrgus* which also peaked in trout stomachs at this time, it is likely that plant material was being accidentally ingested when *Potamopyrgus* were being picked off the plants. *Potyamopyrgus* is seemingly not an optimum food item but was an important food source for trout during winter when other food items were not as available. In October each year trout growth slowed (Figure 12), perhaps reflecting the absence of good quality food items over winter. It is also possible that the development of spawning condition, when food is channeled into ripening gonads rather than growth, may be a contributing factor. Furthermore, the lack of spawning habitat in the tributaries of Lake Tutira and the associated inability of trout to spawn is likely to have affected trout condition in the post spawning period.

Trout growth in spring tended to be supported by bullies, waterboatmen and other aquatic insects. These food items remained in the diet over summer and, in the case of waterboatmen, peaked in late summer.

Figure 15. Percentage of rainbow trout stomachs that were empty or contained specified food items.



Longer term trends

Bullies dominated trout diet throughout much of the study, although in April 1977 the incidence of terrestrial arthropods in trout stomachs increased to rival bullies. Then in March 1978 bullies all but disappeared from the diet for the rest of the year. Chironomids and other aquatic insects exhibited an overall decline as food items in 1977 and 1978. Aquatic plant beds also declined over this period but whether there is a causal link is unknown. These patterns, together with an April peak of *Potamopyrgus*, indicate that trout diet might have been changing towards the end of the study.

Trout maturity

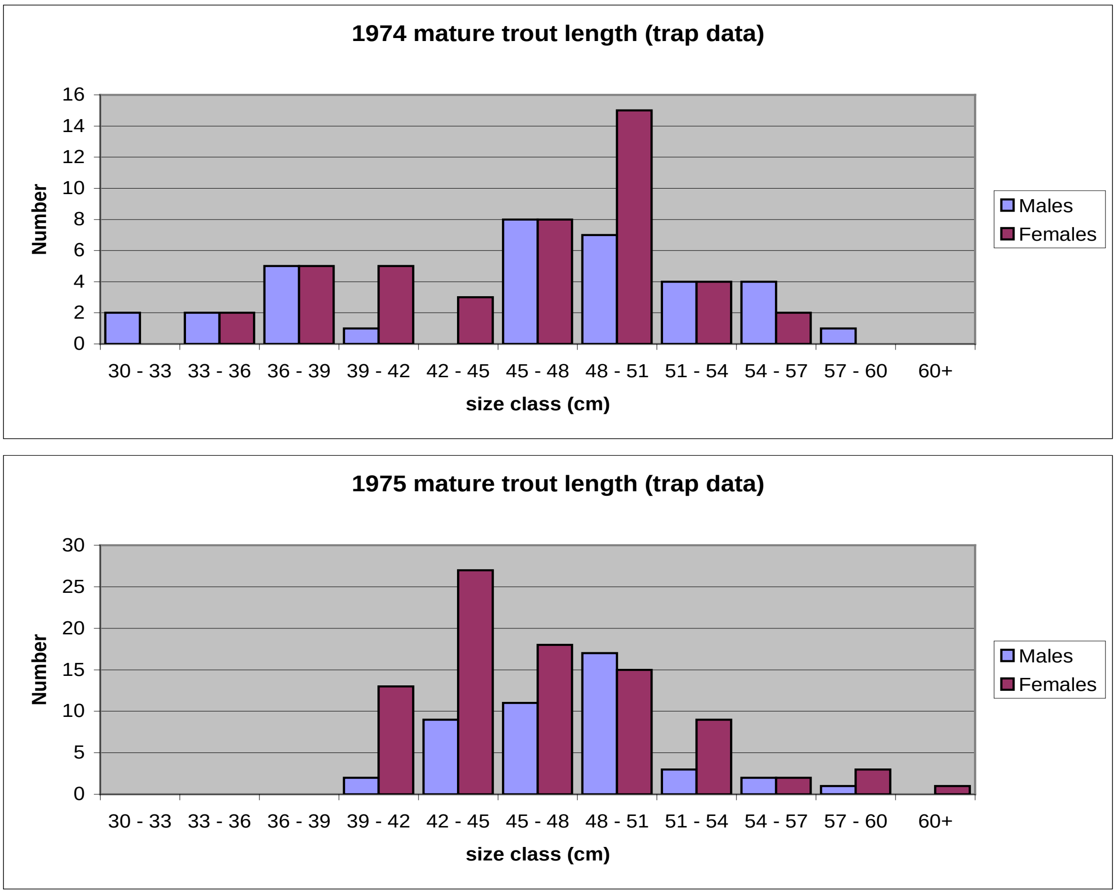
The age of rainbow trout at maturity was determined from set net results in July 1974, and July and October 1975 (Table 18). Gonads of both male and female fish were inspected for degree of ripeness. Mature trout had generally been in the lake for only one year (two year olds) and were on average 34.5 cm long. Of the total catch, ripe trout represented 52.9%, 58.8% and 80% respectively for the months of June, July and October.

Table 18. Age, mean length and percentage of ripe trout (1973 and 1974 year classes) taken in set nets.

Year class	Number of trout	Date netted	Age	Mean length (cm)	% ripe
1973	17	Jul 1974	2 yr	34.2	58.8
1974	17	Jun 1975	1 yr 10 mo	34.8	52.9
1974	20	Oct 1975	2 yr 2 mo	34.6	80.0

To discover if these young ripe trout made spawning migrations into Sandy Creek that had been the main spawning stream before becoming heavily silted, data from the Sandy Creek trap were assessed for 1974 and 1975 (Figure 16).

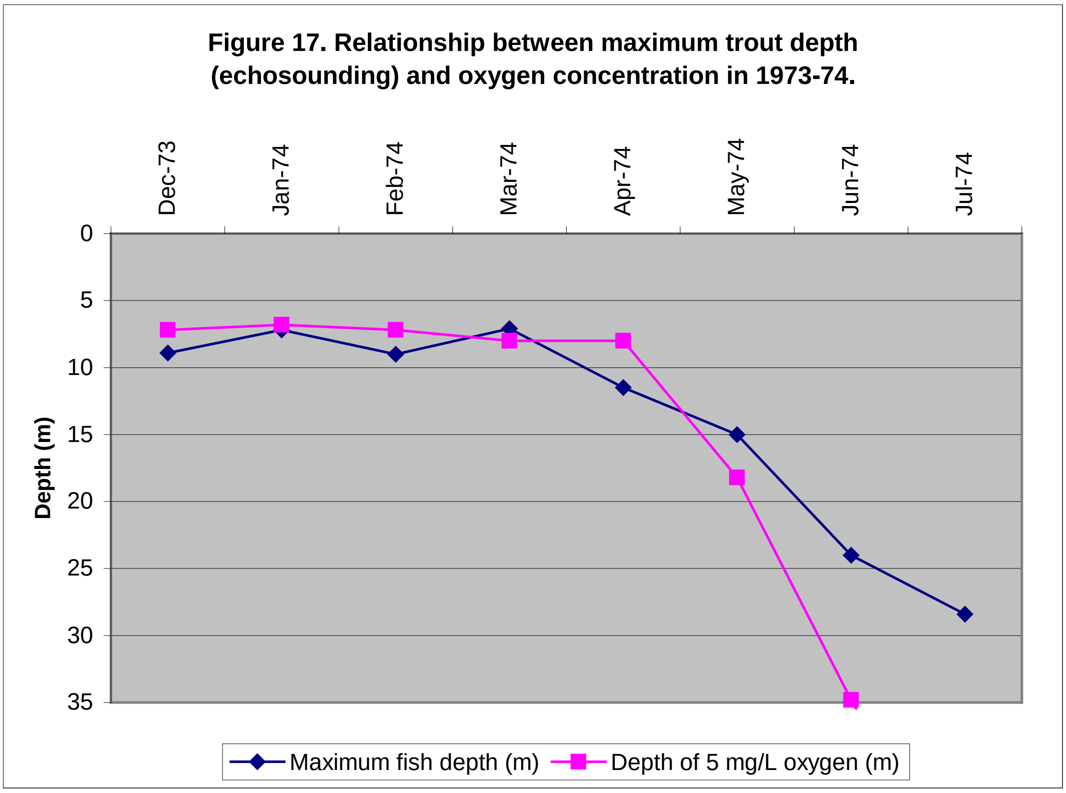
Figure 16. Size frequency distributions in 1974 and 1975 of male and female rainbow trout trapped as they migrated up the main spawning tributary stream (Sandy Creek).



In 1974, 34.5 cm trout were recorded and represent the smallest and youngest (2 year olds) of the 76 trout moving up into the trap. The largest measured more than 57 cm. Females numbered 44 and males 32. In 1975, 132 trout arrived at the trap, 88 females and 44 males. Most females measured between 42 and 51 cm. Some trout were selected for their eggs and milt to rear next year's fingerlings at the Green meadows hatchery. When this practice ended fingerlings for Lake Tutira were sourced from the Ngongataha and Tongariro hatcheries.

Depth distribution of rainbow trout

We appreciated that adverse conditions faced trout during stratification, relating both to trout tolerances for temperature and oxygen concentration, but gauging how trout actually reacted was important. The depth distribution of trout was monitored in two ways. Trout depths were recorded using an echo sounder mounted on a boat that made multiple runs across the lake. Trout positions were measured and recorded. The maximum fish depth for each month was plotted between December 1973 and July 1974 (Figure 17).



From December 1973 until March 1974, maximum trout depth was less than 10 metres. As the thermocline broke down in April and May, maximum trout depth increased to reach 28 metres in July. The profile of maximum trout depth was mirrored by the 5 mg/l oxygen profile, indicating that low oxygen levels in the thermocline and hypolimnion dictated the depth trout can inhabit.

To check the echo sounding results, trout depth was also measured using set nets on one occasion in December 1973. Weighted nets were set down the lakebed profile and the position of trout caught in the nets marked and measured. All 36 netted trout were located at depths between 1-8 metres in the nets. Oxygen concentration corresponding to eight metres depth, measured 5.4 mg/l, reinforcing the echo sounding results.

Responses of rainbow trout to the pressures of living in Lake Tutira

Our studies of rainbow trout stocks in Lake Tutira provided an insight into the pressures rainbow trout experienced living in the lake and their responses.

Fingerlings released into the lake about August increased rapidly in length until January (Figure 13). From then, during the period of lake stratification, water quality conditions constrained trout habitat and condition factor declined (Figure 14).

With the resumption of lake circulation in May, the percentage of stomachs containing weed fragments and *Potamopyrgus* increased, peaking about July (Figure 15). A heavier reliance on *Potamopyrgus* suggested that other more nutritious prey items were not as available over winter.

At a length of approximately 34 cm, just one year after release, some trout were found with ripe gonads (Table 18) and a number of that year class migrated into Sandy Creek entering the fish trap (Figure 16). Ripe trout with no spawning habitat can re-absorb eggs but this has the effect of depressing growth and condition from August to October (Figure 12).

Trout growth increased again during spring as the variety of available trout food expanded, but ceased when the lake stratified once more. Flattened growth curves persisted for up to six months for two and a half year old trout (Figure 12). The narrow band of habitable water between warm surface water and a deoxygenated metalimnion and thermocline confined fish during this period (Figure 17). That trout growth ceased for six months is an indicator of the degree of stress imposed by this set of conditions.

Trout experienced both stratification and an inadequate spawning situation (Figure 16) each year until mortality at a maximum length of 50–56 cm and an age of four to five years (Table 16).

The experimental manipulation of Lake Tutira: an interpretation of results

The collection of a comprehensive data base comprising physicochemical, phytoplankton, aquatic plant and rainbow trout components was fundamental to the Lake Tutira study and experimental manipulation. To assess the effectiveness of the aerohydraulic guns data collected "before" and "during" their operation were compared.

The "before" data revealed an integrated process taking place in the lake comprising physicochemical and phytoplankton features that could be used as indicators of change associated with the operation of the aerohydraulic guns. For instance, water temperature patterns such as summer surface water temperature and the formation and depth of the mtalimnion and thermocline played a key role in other lake processes. So too did nutrient availability, having a major influence on phytoplankton biomass. In turn, the biomass of phytoplankton that sank out of the epilimnion and then more slowly through the colder, denser waters of the metalimnion likely resulted in a pattern of deoxygenation that peaked in the thermocline at discrete periods of time. Deoxygenated conditions not only caused changes to nutrients but also other important aspects of lake ecology such as rainbow trout distribution.

Comparing the features monitored "before" (1973-75) with those same features monitored "during" the aerohydraulic gun operations (1975-77) revealed the following:

- Annual temperature profiles and thermocline behaviour were different.
- Dissolved oxygen behaviour, both supersaturation and deoxygenation, were different.
- pH, specifically alkalinity associated with phytoplankton growth in the epilimnion, was different.
- There were annual differences in nutrient behaviour.
- There were also annual differences in phytoplankton biomass (chlorophyll *a*) patterns.
- Potential phytoplankton productivity (Pmax) values from the lake surface to more than 15 m depth were higher "during" than "before" gun operations.
- Monitoring aquatic plant transects revealed a downward trend in the extent and height of the plant beds throughout the study. This trend was consistent and already taking place before the guns began operating, indicating that influences, other than the guns were affecting the plant beds.
- The depth of oxygenated water suitable for rainbow trout habitation was extended during the operation of the guns.

Both Lake Tutira summer surface water temperatures and the formation and depth of the thermocline showed distinct differences “before” and “during” aerohydaulic gun operations. The fact that Lake Waikopiro showed the same surface water temperature pattern as Lake Tutira over the four summers indicated that climatic factors rather than gun operation may have been the most important contributing factor for surface temperatures. In contrast, the formation and depth of the thermocline in Lakes Tutira and Waikopiro were distinctly different during aerohydraulic gun operation. Whereas the metalimnion and thermocline in Lake Tutura was much deeper and migrated downwards during summer, the thermocline in Lake Waikopiro formed strongly at 5-7 m as it had the first two summers. These results indicated that deep water in Lake Tutira was being circulated causing a deeper thermocline to form and move down during the gun operations. It was clear though that complete circulation was not achieved. Further evidence that the deeper thermocline was induced by artificial circulation occurred in 1980 when the aerohydraulic guns were switched off and the thermal profile began to resume the form of those in the first two years.

Dissolved oxygen patterns mirrored water temperature patterns reflecting the influence of the aerohydraulic guns and the control water temperature and the thermocline exerted on phytoplankton biomass, decomposition and deoxygenation.

pH differences were recorded but again these were more likely to reflect the extent of phytoplankton biomass during warmer summer water temperatures that occurred in the first two years of the study.

Pmax peaks from the surface to more than 15 m were much higher when the guns were operating than before. But from 25 m to the lake bed Pmax values remained relatively low. Although this indicated that mixing did not take place throughout the entire water column, the aerohydraulic guns were responsible for altering the thermal and other characteristics of the lake from the surface to more than 15 m.

Rainbow trout had been confined to a depth of 5 m or less during summer anoxic conditions over the first two summers. But when the aerohydraulic guns began operating, the depth of suitable trout habitat (a minimum of 5 g/m^3 dissolved oxygen) increased to 15 m at the height of summer and up to 25 m in early and late summer.

Significant changes were recorded for some important features monitored during the Lake Tutira study despite the manipulation being only partially successful. Whether the compressor was under capacity, an insufficient amount of air was delivered to the lake or the design of the aerohydraulic guns was not optimum, the equipment needed to operate more effectively to prevent the lake from stratifying and maintain complete circulation over the summer period.

Despite this outcome a comprehensive data base from the 1970s will be advantageous for identifying and understanding longer term changes in the condition of Lakes Tutira ad Waikopiro. Furthermore the historic data base used together with current monitoring is likely to contribute to an evaluation of the *Hydrilla* eradication programme being conducted in Lakes Tutira and Waikopiro by MAFBNZ.

Appendix 1. Equipment used in the manipulation of Lake Tutira

The objective of experimentally manipulating Lake Tutira was to prevent or disrupt the formation of the thermocline thereby preventing deoxygenation of the hypolimnion. Moving deep, cool water to the surface prior to summer was expected to facilitate the absorption of oxygen and create cooler surface water, both of which would be advantageous to rainbow trout and lake dwelling communities. The design, installation and operation of the aerohydraulic guns are documented here.

Techniques for increasing oxygen concentrations in hypolimnetic waters in Canada, the USA and the UK had involved mechanical stirring, injection of oxygen or air, or a combination in which air bubbles were used to lift water from the depths of the lake to the surface. The latter technique was adopted for Lake Tutira, following a design for aerohydraulic guns described in a thesis of J.E. Abbot, 1970 entitled *Thermal stratification and aeration of reservoirs*. Masters of Engineering (Civil), Auckland University.

Abbot had estimated that an average of 0.001216 kWh/m^3 was needed to achieve destratification in a variety of lakes, reservoirs and ponds. Given that the volume of Lake Tutira is 35,772,200 m^3, and using a 37.3 kW compressor, it was estimated that 1166 hours (48.6 days) of operation would be needed to circulate the lake water once. Thus, the intended six months of operation would cause 3.6 circulations.

A 50 kW compressor and an after cooler were installed on a concrete pad in a shed with a 3 phase power supply. The shed was approximately 40 m from the lake shore. On leaving the after cooler, compressed air was passed through a manifold where it was diverted into six equal flows by adjustable gate valves and flow metres. The iron pipes that delivered air to the lake were buried in a trench (and passed in a purpose-built tunnel under the main road). From the shore, air was delivered to the basal chambers of the six aerohydraulic guns via 4000 m of polythene tubing, anchored to the lake bed at 10 m intervals by nylon rope to 4.9 tonnes of concrete blocks (Figure 18)

The aerohydraulic guns consisted of 0.06 m chambers bolted by angle aluminium to 13 m long, 0.5m diametre fibreglass tubes. They were installed in a 30–40 m deep trough in the deep southern basin (Map). Iron bars were used to anchor the guns 5 m above the substrate and large air filled plastic drums were used to buoy the guns below the position of the thermocline at approximately 10 m. Locating the guns in the southern basin of the lake and at that position within the water column was to maximise their operation.

Air was delivered to the basal chambers at a pressure of 70.31 gm/cm^2 resulting in a regular release of bubbles up the tubes every 8-9 seconds. Simultaneously hypolimnetic water was sucked through portholes in the base of the chamber refilling it ready for the next bubble to be released up the tube. The bubbles pushed water in front of them and sucked deeper water behind creating a one way movement of deeper lake water through the thermocline and up to the surface. The movement of deep water across the surface surrounding the guns could be clearly seen. The aerohydraulic guns were successfully operated from November to April, for each of five years, commencing in the summer of 1975/6 and concluding after the summer of 1979/80.

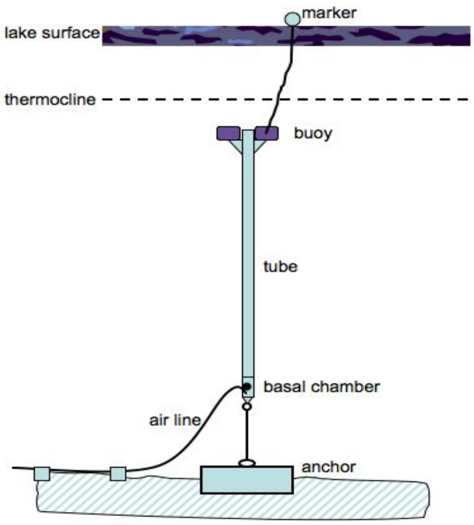


Figure 18. Design and placement of an aerohydraulic gun in Lake Tutira.

Appendix 2

Sampling schedule for physicochemical and phytoplankton parameters - Lakes Tutira and Waikopiro 1973 - 1980

Note: The sampling schedule for Station 1 represents the schedule for all four stations.

Lake Tutira Station 1: Temperature, oxygen and light measurements (0-35 m every m)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1973/74	x	x	x	x	x	x	x	x	x	x	x	x
1974/75	x	x	x	x	x		x		x		x	
1975/76	x	x	x	x	x	x	x		x		x	
1976/77	x	x	x	x	x	x	x		x		x	
1977/78	x		x	x	x		x					
1978/79		x		x		x				x		x
1980				x		x						

Lake Waikopiro: Temperature, oxygen and light measurements (0-15 m every m)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1973/74	x	x	x	x	x	x	x	x	x	x	x	x
1974	x	x										
1975/76		x	x	x	x	x	x	x	x		x	
1976/77	x		x		x		x					

Note: x Sampling carried out
(shaded) Sampling not carried out

Lake Tutira Station 1: Total P, reactive P, nitrate N, ammonia N and pH (0, 1, 5, 10, 15, 25, 35 m depths)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1973/74	x	x	x	x	x	x	x	x	x	x	x	x
1974/75	x	x	x	x	x		x		x		x	
1975/76	x	x	x	x	x	x	x		x		x	
1976/77	x	x	x	x	x	x	x		x		x	

Lake Waikopiro: Total P, reactive P, nitrate N, ammonia N, pH (0, 1, 5, 10, 15 m depths)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1973/74	x	x	x	x	x		x	x	x	x	x	x
1974/75	x	x										
1975/76		x	x	x	x	x	x	x	x		x	
1976/77	x		x		x		x					

Note: Chemical features sampled but not included in the analysis: calcium, magnesium, sodium, potassium, chloride, sulphate, silica, conductivity, alkalinity and turbidity

Lake Tutira Station 1: Chlorophyll a, phaeophytin and Pmax (0, 1, 5, 10, 15, 25, 35 m)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1973/74		x	xo	x	xo	xo	x	x	x	x		o
1974/75			o		x		xo		x		xo	
1975/76	xo	xo	xo	xo	xo	xo	xo	x	x		xo	
1976/77	xo		xo		xo		xo					

Lake Waikopiro: Chlorophyll a and phaeophytin (0, 1, 5, 10, 15 m depths)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1973/74		x	x	x			x	x	x	x		
1974/75												
1975/76		x	x	x	x	x	x	x			x	
1976/77	x		x		x		x					

Note: Water samples for deriving Pmax were only collected at Station 1.
o = the months Pmax samples were collected.

Lake Tutira: Aquatic plant profiles and samples (transects A - E)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1973/74					x	x			x		x	
1974/75	x		x		x		x		x		x	
1975/76	x		x		x		x		x		x	
1976/77	x	x			x		x					

Lake Waikopiro: Aquatic plant profile and samples

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1973/74					x	x			x		x	
1974/75	x		x		x		x		x		x	
1975/76			x		x		x		x		x	
1976/77	x	x			x		x					

Lake Tutira: Rainbow trout sampling

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
1973/74	x	x	x	x	x	x			x		x	
1974/75	x		x		x		x		x		x	
1975/76	x		x		x		x		x		x	
1976/77	x	x			x		x					