The Hamurana Stream in Lake Rotorua: some potential effects of its diversion on the trout fishery and on summer nutrient dynamics

NIWA Client Report: HAM2005-025
June 2005

NIWA Project: BOP05233

The Hamurana Stream in Lake Rotorua: some potential effects of its diversion on the trout fishery and on summer nutrient dynamics

Dave Rowe
Max Gibbs
Eddie Bowman
Stan Lodge

Prepared for

Environment Bay of Plenty

NIWA Client Report: HAM2005-025
June 2005

NIWA Project: BOP05233

National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

Contents

Reviewed by:

Dr G. McBride

Approved for release by:

Dr D. Roper

Formatting checked

Executive Summary

With the need to provide a short term (i.e., within 50 years) solution to the problem of deteriorating water quality in Lake Rotorua, it has been suggested that the Hamurana Stream be diverted directly to the Ohau Channel outlet from the lake. This would reduce the nutrient inputs to the lake by 54.6 t y^{-1} (12.3%) of the total nitrogen and 6.4 t y^{-1} (18.5%) of the total phosphorus. Although this diversion would result in a major reduction in nutrients, it could also have potentially serious consequences for the trout fishery because trout use the Hamurana Stream as a refuge habitat from the warm lake water during summer. At present, detailed plans for the method of diversion are being developed by Environment Bay of Plenty. To accompany such plans, a 'proof-of-concept' study is required to identify all the environmental consequences, both positive and negative, of a complete diversion.

Environment Bay of Plenty commissioned NIWA to (1) determine the size and structure of the cold-water plume at the mouth of the Hamurana Stream, and assess the size of the trout refuge habitat provided by it in summer months, and (2) to determine the role of the potentially oxygen and nutrient-rich stream waters on the lake's biogeochemistry, particularly the supply and transport of nutrients from sediments to the lake water column during the summer months. As timing prevented a tagging study of trout movement to refuge habitats in Lake Rotorua during the 2004/05 summer, an evaluation of historical data on the trout was carried out to provide information on whether trout condition and size could be reduced in 'hot' versus 'cold' summers and hence whether the cold-water refuge habitat plays an important role in trout growth dynamics. Condition factor was also compared for trout in Lake Rotorua (refuge habitats present) and Lake Rotoehu (refuge habitats absent).

Effects on trout and the trout fishery

The trout refuge habitat in the Hamurana Stream plume was confined to the shallow (< 1m deep) shelf around the stream mouth and did not extend into the deeper waters of the lake. On 4 March 2005, it was estimated to be 8700 m^2 in size, which is about 4-5 times larger than the refuge habitat at the mouth of the next largest cold water inflow, the Awahou Stream. Overall, it is likely to contribute 40-50% of the total summer refuge habitat in the lake. The changes in trout condition over summer months indicated that the cold-water refuge habitats in Lake Rotorua (including that provided by the Hamurana Stream) are not vital to trout growth dynamics (and hence survival) and that any benefit that they may provide is easily obscured by other factors that affect trout growth. This does not mean that a benefit is absent, only that other factors (e.g., food supply, trout density) can be expected to have a much greater influence on trout growth over summer months than the summer increase in water temperature and the presence of cold-water refuge habitat. A comparison of changes in condition for trout between Lake Rotorua (refuge habitats present) and Lake Rotoehu (refuge habitats absent) indicated that the presence of refuge habitats may provide some overall benefit to trout in Lake Rotorua, irrespective of variations in summer water temperatures. Unfortunately, the data were too few to substantiate this, and it could easily represent a difference in food supply or trout density

between these lakes, as much as a lack of refuge habitat. Changes in growth and condition aside, the main effect of the diversion will be its effects on angling. The localised, summer fishery at the mouth of the Hamurana stream will clearly be lost. In addition, loss of the cold water entering the lake may result in a lake-wide change in trout distribution. The data on fishing methods and effort indicated that catch rates declined in hot summers and that there was an increase in shore-based fly-fishing around stream mouths in late summer as trolling declined elsewhere in the lake. This change in fishing effort suggests that, during summer months, many trout could move from surface waters in the middle of the lake to the lake shores, especially the shores around the north western edge of the lake where cold-water refuge habitats occur. Loss of the Hamurana Stream could well change this shift in distribution with implications for the fishery.

Summer nutrient dynamics

At the time of the survey, the data showed that the cold inflow had warmed to within 2ºC of open lake water before leaving the shallow shelf and thus there would be no pooling of the inflow in the deeper waters of the lake. Consequently, the inflow is unlikely to have a substantial effect on the biogeochemistry associated with nutrient release from those sediments. However, because a density current was found to form a thin (< 5 cm) layer on the lake-bed, it is highly likely that, during summer, nutrient uptake by benthic microphytes (i.e., low-growing algal and plant mats on the lake bed) could remove much of the dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) from the inflow before it disperses into the lake. While this nutrient removal from the inflow would not remove the nutrients from the lake, it would result in a biological lag before the nutrients become available for the growth of planktonic algae. Thus, there could be a substantial reduction in the DIN and DRP in the inflow water that is available to support summer algal growth in the lake. This has implications for the way nutrient inputs are treated in lake models.

Complete diversion of the Hamurana Stream would clearly affect the localised summer fishery that is known to occur around the mouth of this stream. But effects on the wider, lake-wide fishery are uncertain at present. The area of cold-water, refuge habitat that would be lost by complete diversion of the Hamurana Stream is relatively large compared with the other cold-water refuge habitats, and any uncertainty as to its importance for the Rotorua fishery requires a degree of caution before committing to the diversion. For example, the effects of long-term climate change may exacerbate the loss of cold water refuge habitats in future summers should this cause water temperatures in Lake Rotorua to rise above their present summer maxima. This stance assumes that diversion would need to occur over all months of the year, including summer months. Data on the Hamurana plume structure plus new knowledge of seasonal nutrient dynamics in the inshore region of similar lakes indicate that this may not be so. We suspect that large amounts of nutrients in the plume are removed by the low-growing plants on the lake- bed around the mouth of the Hamurana Stream, mainly during summer months. If so, operation of the diversion for a 9-month period from April to December, inclusive, with natural discharge occurring during the 3 hottest months of summer, could provide the cold-water refuge that currently exists, without adding to the plant growth nutrients that are immediately available in the lake water column to support or stimulate phytoplankton growth over the summer months. A strategy of seasonal diversion may therefore be possible, which retains the trout fishery around the Hamurana Stream mouth in summer and removes a high proportion of nutrients from the lake during the rest of the year. The following recommendations are made to address uncertainties over the role of the Hamurana Stream refuge for the trout fishery and to assess the effects of a seasonal management strategy on lake water quality:

- That the trout tagging study proposed in 2005, proceed in 2005/2006 to determine the movements of trout in the lake and to provide some data on their relative usage of the various cold-water springs over summer months.
- That the size of the refuge habitat at the mouth of the Hamurana Stream be measured concurrently with the trout tagging study on at least 3 occasions to determine whether its size changes substantially over the summer period.
- That the DYRESM-CAEDYM model of Lake Rotorua be run to assess the effect of the seasonal management strategy on lake water quality, but using the parameters as defined by this study, and that the nutrient uptake rate of the benthic microphytes across the shallow shelf be investigated.

1. Background

The increase in supply of plant nutrients nitrogen (N) and phosphorus (P) to Lake Rotorua over the past century has produced an unacceptable deterioration in its water quality (e.g., Rutherford 2003). Each year, these nutrients are accumulated in lake sediments and are recycled into the water column, especially during summer months when they stimulate a greater density of planktonic algae. Restoration of the lake to improve water quality (and to reduce flow-on effects to Lake Rotoiti) requires a reduction in the external inputs of N and P from streams and groundwater as well as a reduction in the internal supply from the sediments. As most groundwaters are relatively old with 8 out of 12 having mean residence times over 60 years, there may be a lag of up to 170 years in the appearance of N and P in the spring inflows following changes in the catchment (Morgenstern et al. 2004). Consequently, a reduction in N and P loads in the catchments today (e.g., from reduced fertiliser use) may not produce the desired reduction in the spring-fed stream nutrient loads for many years and It is predicted that nutrient loads in some of the springs (e.g., Hamurana) are likely to double in the next 50 years (Morgenstern et al. 2004). Therefore, changes in land-use alone will only help restore the lake in the long term (i.e., > 50 years). Other remedial actions are required to reduce nutrient inputs from the spring-fed inlet streams in the short term (i.e., < 50 years).

One option that has been proposed by Environment Bay of Plenty is to divert the Hamurana Stream inflow directly to the lake outlet (the Ohau Channel) thereby removing one of the largest inputs of nutrients into Lake Rotorua and one that is predicted to increase substantially over the next 50 years. This diversion is expected to provide a benefit to Lake Rotorua in the short term and, along with other management strategies, will enable the lake to better cope with the expected increase in nutrient loads from the remainder of the catchment.

The proposed diversion is feasible from both a nutrient-budgeting and engineering perspective and could be implemented with the installation of a single confining wall along the north-eastern shore of Lake Rotorua to the Ohau Channel. However, the Hamurana Stream inflow is the largest cold-water spring inflow to Lake Rotorua and, as trout congregate in and around its cool waters during the hotter summer months (i.e., January-March), it provides an important fishery for anglers at this time and is thought to be an important cold-water refuge for the trout. Diversion of this stream therefore has the potential to adversely affect the trout population and fishery in Lake Rotorua. Furthermore, the cool, oxygen-rich water entering the lake may also play a role in its biogeochemistry, affecting the supply and transport of nutrients from sediments to the water column during summer months. This could occur if the stream water is not mixed with lake water soon after it enters the lake and if it underflows lake water to pool within the deeper regions of the lake.

The scope and extent of such potential impacts on trout and nutrient dynamics needs to be identified as part of the decision-making process to determine whether diversion of the Hamurana Stream inflow would provide an overall benefit to the recovery of Lake Rotorua. Consequently, Environment Bay of Plenty commissioned NIWA to undertake a "proof-of-concept" study. In this report, we present the results of a survey to measure the size and location of the cold-water plume from the Hamurana Stream within Lake Rotorua. This survey was carried out on a typical mid-summer (March 2005) day when the difference between lake water temperature (>20ºC) and stream water temperature (approximately 13ºC) was maximal and when the plume could be expected to underflow the warmer lake water. We also present the results of an examination of historical data on the trout fishery to determine whether trout in the lake are stressed by warm summer water temperatures to the point where their growth could be affected, and whether a reduction in the amount of cold-water refuge habitat would amplify this. Additional data are provided on trout catch rates and methods to determine whether diversion of the stream may have an effect on the fishery independently of effects on trout growth.

2. Size and location of the cold-water plume

2.1 Introduction

Stream water entering a lake rarely disperses rapidly at the point of entry. Rather it tends to move out into the lake as a coherent flow which entrains ambient lake water into the flow and thus forms a plume which may be many times larger than the initial volume of the inflow. Entrainment (drawing in) of the ambient water into the flow is part of the mixing process, which eventually allows the stream water to disperse throughout the lake. The size of the definable plume extending from the stream mouth out into the lake is dependent on a number of factors including the velocity and cross-sectional area of the inflow, the temperature-induced density difference between the inflow and the lake water, the shape and slope of the lake bed at the point of entry, and the degree of in-lake mixing that occurs due to wind-waves and lake currents close to shore.

There are three physical principles that govern the physical mixing of an inflow in a large body of water:

1. **Conservation of mass** (mass flux = mass/time). The mass flux is defined as the mass of fluid passing the inflow cross-section per unit time. The conservation of mass is critically important for determining concentrations of constituents within the inflow. In the Hamurana Stream inflow, while nutrient concentrations are important relative to the nutrient budget of the lake, the constituent which defines the trout refuge habitat is temperature.

2. **Conservation of momentum** (momentum flux = (mass × velocity)/time). Momentum is the product of an object's mass and velocity. In mixing processes, momentum flux is defined as the amount of stream-wise momentum passing the inflow cross-section per unit time. It is helpful to think of it as the units indicated above ; (mass × velocity)/time with the key component being velocity. The kinetic energy (the energy associate with motion) generated by the velocity of the inflow is conserved.

3. **Conservation of energy** (buoyancy flux = (mass × acceleration)/time). Buoyancy (negative or positive) arises from the density difference between two fluids. Buoyancy flux is defined as the submerged weight of the fluid passing through a cross-section per unit time. Buoyancy force is a function of the acceleration due to gravitational forces. Hence the critical component of conservation of energy is gravitational acceleration. This energy is potential or stored energy. Energy that is created by the density difference between the lake water and the Hamurana Stream inflow must be conserved.

At the point of entry to the lake, there is a degree of initial mixing (entrance mixing), which increases the volume of the inflow as lake water is entrained into the plume from the stream. Because the momentum of the inflow must be conserved, as the mass of water moving in the plume increases the velocity of the plume reduces. If the inflow is at a different temperature to the lake, the water temperature in the plume will become intermediate between these two temperatures and may cause the plume to sink or float. The inflow has an initial buoyancy associated with its velocity (i.e., it may enter as a jet). As it mixes, the resultant plume velocity reduces to a point where its buoyancy can be overcome by gravity. The temperature-induced density difference between the plume in the entrance mixing zone and the lake determines where the inflowing water will mix in the lake. Without a density difference, the momentum of the inflow would quickly dissipate due to the inertia of the lake water. However, if the inflow is warmer (less dense) or colder (more dense) than the lake water, the density boundary to the inflow will allow it to flow either across the lake surface or along the lake bed, respectively, as a density current. This density current will continue until the amount of entrained lake water negates the density difference by cooling or warming. The momentum of the plume continues until other mixing processes cause it to disperse (i.e., it is overcome by lake currents, etc.).

The Hamurana Stream inflow is much colder than Lake Rotorua water in summer (12ºC versus 20ºC) and hence the inflow is expected to form a density current which will move across the lake bed out into the lake. Under light northerly winds or calm conditions, there is often a well defined plume extending out towards the deep waters of the lake about 400-500 m offshore from the stream mouth. In summer, anglers fish the visible surface turbulence associated with the plume (Photo 2.1) because trout congregate within this area and high catch rates can occur. It is under these conditions that the cold water plume is likely to be important to the fishery in Lake Rotorua.

Photo 2.1. Picket fence of anglers fishing the apparent plume from the Hamurana Stream on misty Sunday morning in summer [6 Feb. 2005].

Conversely, under conditions of strong onshore winds from the south east to south west, wave action destroys the coherent cold-water plume, pushing it along the shoreline (littoral zone) where it rapidly warms to lake temperature and is not available as a cold water refuge habitat for trout.

These two mixing regimes also affect the dispersion of nutrients in the Hamurana Stream water into Lake Rotorua. Under calm conditions the formation of a density current on the bottom of the shallow shelf may isolate the nutrients in the inflow from the overlying lake water so that they would not be immediately available for primary production in the water column. At the same time these nutrients would be in close contact with the low-growing, benthic algae (microphytes) on the lake bed. These benthic microphytes may strip nutrients from the plume in this density current zone, further reducing their immediate availability to phytoplankton in the lake water column.

Under onshore wind conditions, the nutrients in the inflow water are likely to be prevented from moving out into the lake where they can be used for primary production and thus also confining their uptake in the littoral zone.

2.2 Methods

The ‘proof-of-concept’ study required the dimensions of the plume from the Hamurana Stream mouth to be defined and a quantitative assessment made of the size of the zone of usable trout refuge habitat, under hot, calm conditions in summer. With anglers fishing the plume, it was inappropriate to use a dye tracer and thus the plume was tracked by the temperature and conductivity differences between the Hamurana Stream water and lake water.

Photo 2.2: **Upper:** morning strong surface feature associated with the plume. **Lower**: afternoon showing apparent movement of plume further west as indicated by surface slicks. [4 March 2005].

The size and location of the cold-water plume from the Hamurana Stream was measured on 4 March 2005 under flat calm conditions following a strong south-westerly blow on the 3 March. The visible surface disturbance associated with the plume was angled slightly to the west of the stream mouth (Photo 2.2). Later in the day, the apparent surface features were well to the west of the stream mouth and the sampling grid used to locate the plume was expanded in that direction to make sure the survey data covered any cold water movement in that direction.

Historical gauging data (NIWA unpub. data) shows that the flow from the Hamurana Stream is typically about 2.7 $m^3\ s^{-1}$ but can range from 2.4 to 3.2 $m^3\ s^{-1}$. Stream velocity at the mouth is dependent on lake level but is in the range 0.24 to 0.29 $m\ s^{-1}$.

Water temperature and conductivity data were collected relative to water depth using a Richard Brancker Research XR420f freshwater profiler from a small boat. This instrument was lowered slowly through the water column and allowed to lie on its side on the lake bed for at least 5 seconds at each profiling station to ensure data collection from the near–bottom water (i.e., $\leq$5 cm above the lake bed). Cold water from the Hamurana Stream will preferentially flow along the lake bed as a density current.

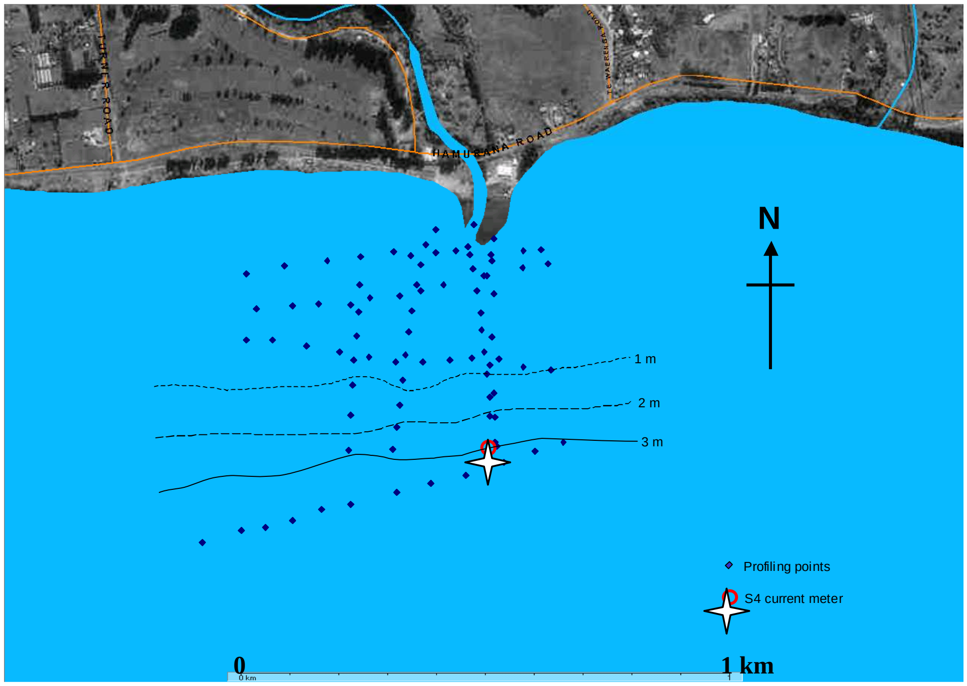

Figure 2.1: Sampling grid and approximate water depths adjacent to the Hamurana Stream mouth on 4 March 2005. [Base map from TUMONZ]

A sampling pattern consisting of a series of transects parallel to, and at right-angles to the shore, produced a grid of data across the shallow shelf adjacent to the Hamurana Stream mouth (Fig. 2.1) to a distance of about 600 m offshore and a depth of more than 3 m. The pattern of the grid was determined by visible evidence of the plume on the surface and examination of the temperature data after each transect run.

Location of each profiling station was made by laser-based survey using a geodometer set up on shore at the stream mouth. Positional accuracy of the reflector target mounted on the boat was to within ± 5 mm.

An S4 current meter was also located exactly 500 m from the mouth of the Hamurana Stream, in line with the stream channel. The current meter was mounted 0.5 m above the lake bed in water 3.0 m deep, on a stainless steel rod bolted through the centre of a 0.4 x 0.4 m square concrete paving stone, which had been lowered onto the lake bed by rope. Current data were collected in 2-minute bursts at 0.5Hz [240 readings] every 10 minutes.

Data obtained from the survey profiles were converted to contour plots of temperature and depth using the software package Surfer32 (Golden Software). Depth contour plots were drawn using data from the greatest depth recorded from each profile drop. Temperature contours were drawn for the near-surface water (i.e., the closest value recorded to the lake surface) and the bottom temperature contours were drawn from temperatures recorded at the greatest depth from each profile. Data used to construct the intermediate "trout refuge habitat" layer were the temperatures recorded at between 10 and 20 cm above the lake bed on each profiling drop. Linear krigging was used to extrapolate between points on the contour plots. Note that the contour lines drawn are an indication of likely positions of isotherms rather than an exact position. This limitation is due to the number of profiling points, the distance between profiling points, and the unequal spacing between individual profiles.

2.3 Results

2.3.1 Physical measurements

A local bathymetric map of the lake bed adjacent to the Hamurana Stream mouth (Fig. 2.2) was drawn from the maximum depth data obtained at each profiling station. This map shows a broad shallow shelf less than 1 m deep extending about 400 m offshore where a sudden drop off into deeper water occurs (see close depth contour lines). The depth structure indicates several possible deeper channels (see dashed arrows on figure 2.2). These slightly deeper channels may indicate preferred flow paths of the stream water under calm conditions.

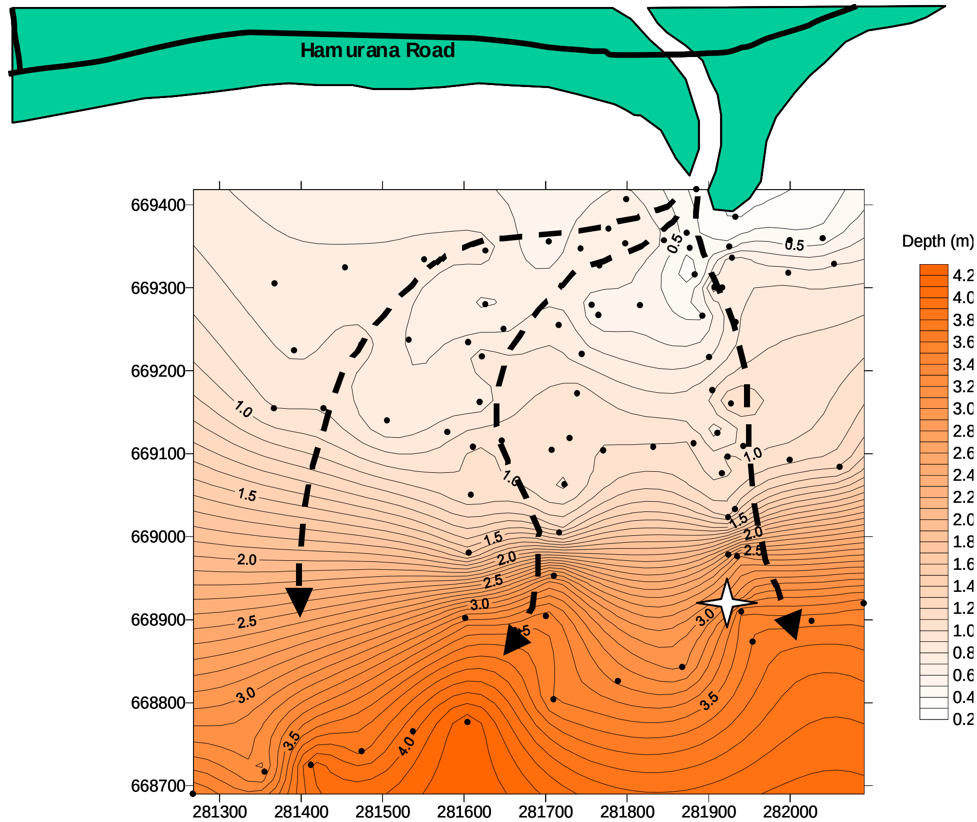

Figure 2.2: Depth contours of the lake bed adjacent to the Hamurana Stream mouth in relation to the lake edge (in green) showing the extent of the shallow shelf and drop off into deeper water. Dashed arrows may indicate preferred flow paths in deeper channels during calm weather. Distance between tick marks on the grid scale is 100 m and the star indicates the position of the current meter.

Current speed and direction data (Fig. 2.3) show there was a slow clockwise movement of lake water averaging about 3 cm s^{-1} across the face of the shelf for the whole period of the survey. There was a small shift in direction of the flow from 125 degrees (south east) to 75 degrees (north east) during the period of the survey, with an average direction of about 96 degrees true (i.e., close to due east).

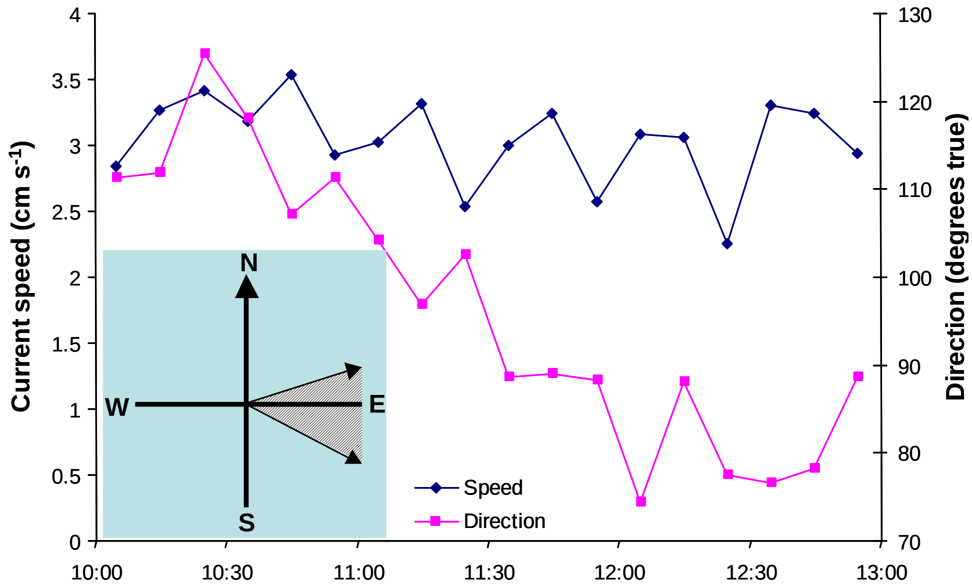

Figure 2.3: Current speed and direction 0.5 m above the lake bed in 3 m water depth on the drop off 500 m off the mouth of the Hamurana Stream during the survey. Inset shows current direction by compass rose.

2.3.2 Temperature measurements

Temperature measurements showed that the Hamurana Stream was 12.4ºC and that the open lake water was a maximum of 21.4ºC. Temperature contour plots show the location and size of the Hamurana Stream plume at the surface (Fig. 2.4A) and at the lake bed (Fig 2.4B) across the shallows adjacent to the stream mouth. Although visual cues on the lake surface (Photo 2.2, lower) indicated that the plume extended well to the west of the stream mouth, the reality was a pooling of the inflow water on the shallow shelf in line with the angle of the stream mouth as mixing occurred. Of interest is the apparent up-welling of colder water to the surface, centred about 150 m off shore (Fig. 2.4A). As the water column across the shelf is <1 m deep, this effect is most likely caused by warmer lake water being entrained into the top of the plume from either side near the shore as the stream enters the lake as a jet. Turbulence within the plume as it slows and pools, mixes colder water closer to the surface (Fig 2.5).

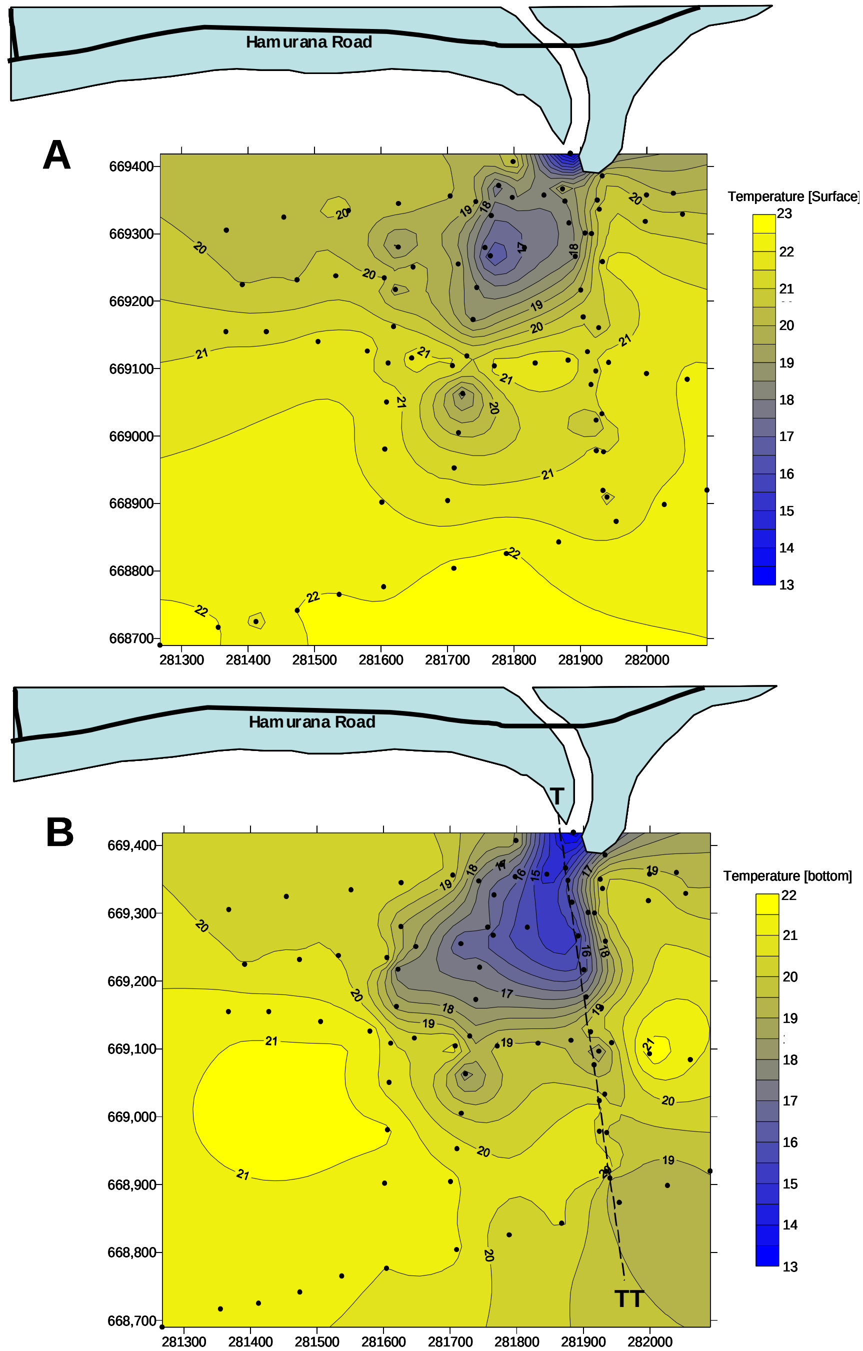

Figure 2.4: Contour plots of **A**) surface and **B**) bottom temperatures relative to the stream mouth, showing the position and size of the surface and bottom plumes under calm conditions on the study day. The cold water appears to pool on the shallow shelf rather than maintaining a well defined flow path across the shelf. Distance between tick marks on the grid scale is 100 m. Broken line T--TT show transect line data points used in Figure 2.5.

Because the stream inflow was much colder than the ambient lake water, it was heavier (more dense) and, consequently, it plunged at the outer edge of the entrance mixing zone to form a density current close to the lake bed (Fig. 2.5). Because the inflow initially occupies the full depth of the water column, the sideways expansion of the plume is due to the entrainment of lake water into the plume from the sides as the inflow mixes with the lake water. From the leading edge of the entrance mixing zone (Fig. 2.4B) the density current moved in a south to south-easterly direction to the edge of the shallow shelf and then flowed down the slope of the lake bed into deeper water. The temperature of this part of the plume at 18-19ºC was still colder than the ambient lake water at about 22ºC and this temperature difference was sufficient to maintain the density current as a discrete flow along the lake bed.

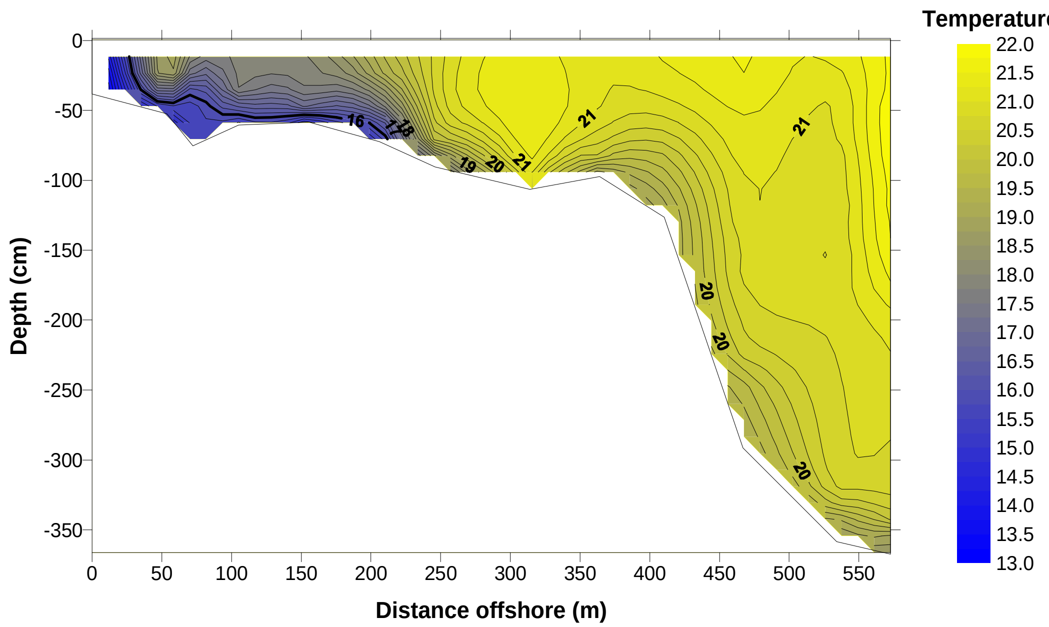

Figure 2.5: Contour plot of temperature along the axis of the plume (Figure 2.4B, transect line T--TT) from the Hamurana Stream mouth (top left)to the deep lake water(bottom right) showing the formation of the temperature-induced density current along the lake bed. The 16ºC isotherm is enhanced to show the relative position of preferred trout refuge habitat (i.e., <16ºC) (see text and section 3).

The apparent patchiness of the density current flow path (Fig. 2.4B) is a reflection of the thinness of the density current layer on the lake bed and the difficulty of detecting this water even with the profiler lying on its side on the lake bed (i.e., temperature sensor within 5 cm of the lake bed).

The contoured data from a transect of depth profiles along the axis of the plume shows that the cold inflow began to plunge about 50 m from the Hamurana Stream mouth and was mixing with lake water from above as well as the sides to a distance of about 250 m offshore. The degree of mixing in this zone raised the temperature of the plume to about 18-19ºC as it moved beyond the entrance mixing zone. The position of the downstream plume (density current) is indicated by the cooler water just above the lake bed across the shelf to the drop off and down the slope into deeper water.

A consequence of the cold inflow mixing with warm lake water was an increase in the temperature of the plume from the sides and top. The bottom of the plume, being protected from mixing by the lake bed combined with the tendency for cold water to sink, remained the coldest part of the plume. The significance of the warming is that it reduces the area of the plume regarded as trout refuge habitat in hot calm conditions.

Adult rainbow trout have an intolerance to very warm water (>20ºC) and do best when water temperatures are in the range 13-15ºC (see section 3). In the Rotorua lakes, where summer water temperatures can exceed 20ºC, they will seek refuge from warm lake temperatures in the cooler waters around cold spring-fed inflows. In general, waters less than 16ºC will provide such refuge habitat. Adult rainbow trout are not benthic and in lakes they swim at least 10 cm above the lake bed but generally much higher in the water column. Given that an adult rainbow trout is about 10 cm deep (dorsal fin to belly), to maintain a minimum distance of 10 cm above the lake bed, they need cold water at least another 10 cm higher in the water column (i.e., their minimum refuge habitat will be a cold-water layer 10-20 cm above the lake bed). They will also use any cold water more than 20 cm above the lake bed, but a thin cold-water that is less than 10 cm above the lake bed will provide very little if any usable refuge habitat. These two factors (temperature and minimum depth above the lake bed) therefore combine to provide a definition of trout refuge habitat:

Trout refuge habitat is that part of the plume of a cold stream inflow that is about 16ºC or less at a height of at least 20 cm above the bed of the lake.

Applying these criteria to the transect data (Fig. 2.5), it is apparent that the 16ºC isotherm extends up to 20 cm or more above the lake bed for a distance of about 100 m offshore, but is less than 10 cm in depth beyond this. Redrawing the spatial temperature contours for a layer 10-20 cm above the lake bed (Fig. 2.6) provides an estimate of size of the trout refuge habitat which may be compared with the size of similar habitats associated with other cold inflows to Lake Rotorua (e.g., Awahou Stream, Table 2.1). Note that the area of the “bottom” 16ºC isotherm in Fig. 2.4B includes the thin layer of cold water within 5 cm of the lake bed, and so represents the total extent of the cold water plume from the Hamurana Stream. These data and associated stream flow data can be compared with similar data collected from the Awahou Stream (4 km west of the Hamurana) on 8 April 2005 at maximum stream flow (i.e., no water supply abstraction from the Taniwha Spring) and on 7 April with a "normal" water supply abstraction rate of 55 L s^{-1} (Table 2.1).

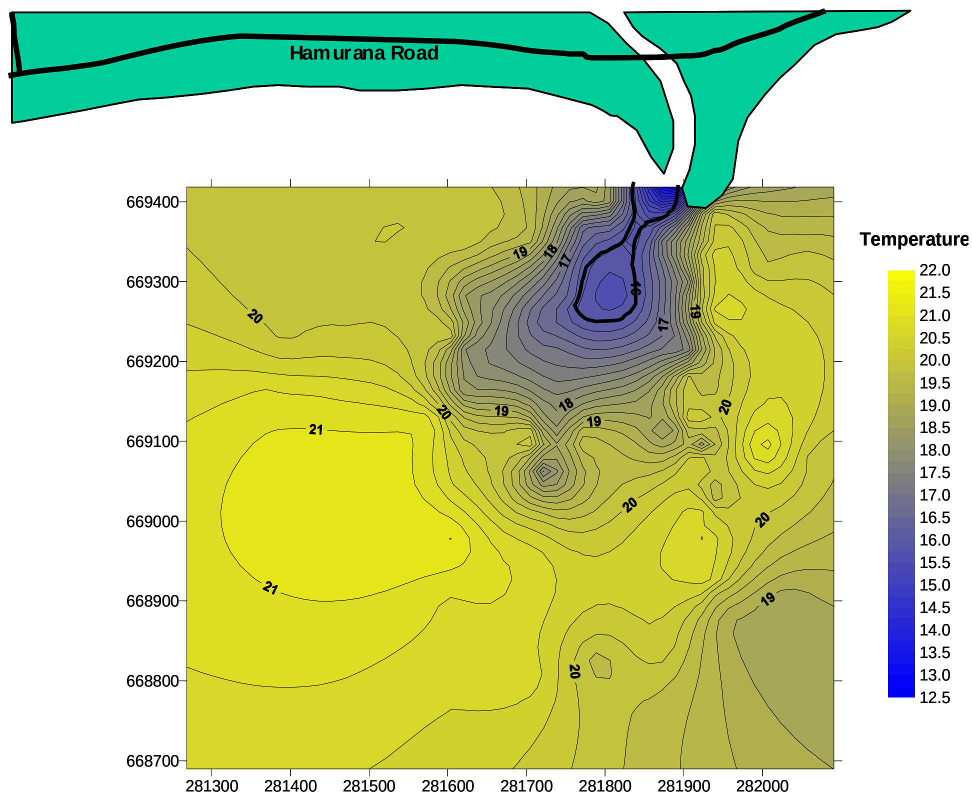

Figure 2.6: Contour plot of water temperatures for the layer 10-20 cm above the lake bed. The 16ºC isotherm has been enhanced to outline the area of the plume that meets the criteria of the trout refuge habitat. Distance between tick marks on the grid scale is 100 m.

While the two streams have similar water velocities at the mouth (Table 2.1), there is a much larger flow (approx. 40% greater) in the Hamurana Stream than in the Awahou Stream. However, whereas the area of the bottom layer from the Hamurana Stream is about double that from the Awahou Stream, the area of the trout refuge habitat provided by the Hamurana plume is about 4 times larger than that found at the Awahou Stream when there is no abstraction.

This lack of proportionality between the flows and areas of trout refuge habitat for the two streams is likely to reflect a difference in the shape of the lake bed adjacent to the mouth of each stream. The plume from the Hamurana Stream flows across a broad flat shelf and both the bottom layer area and trout refuge habitat layer area occur on this shallow shelf zone well away from the deeper water drop-off. In contrast, the Awahou Stream plume flows across a delta feature with steeper sides as well as a sudden drop-off at the lakewards end, and the bottom layer extends beyond the drop-off. The delta feature is likely to enhance dispersion of the plume into deeper water and thus increase the bottom layer area but reduce the trout refuge habitat area in the vicinity of the Awahou Stream.

Note that both sets of measurements (Hamurana and Awahou) were made under similar warm calm weather conditions and lake level. Changes in lake level are likely to induce large changes in the size of the trout refuge habitats at both these stream mouths. This is because, with constant inflow volumes from the springs, the inflow velocities, which influence the mixing process, will change as the cross-sectional area of the stream mouths change with the rising or falling water level in the lake.

Table 2.1: Comparison of bottom layer and refuge habitat layer areas relative to stream hydrology for the Hamurana Stream and the Awahou Stream with "normal" (nominally 55 L s^{-1}) and no abstraction for water supply. (* historic data for February, stream not gauged at the time of sampling).

Stream	Hamurana	Awahou (no abstraction)	Awahou (55 L s^{-1} abstraction)
Date collected	4 March 2005	8 April 2005	7 April 2005
Flow (m^3 s^{-1})	2.69*	1.645	1.590
Velocity (m s^{-1})	0.26*	0.254	0.245
Area of bottom layer (m^2)	24100	12200	8700
Area of refuge layer (m^2)	8700	2100	1800

2.3.3 Mixing proportions

There was a near-linear relationship between temperature and conductivity in the plume water (Fig. 2.7) confirming that there was no local geothermal influence on temperature. This allowed the use of a 2 end-member linear mixing model to assess the proportion of Hamurana spring water versus ambient lake water in the plume from the Hamurana Stream mouth (Fig. 2.8). The mixing model used was:

$$\% \text{ spring water} = \frac{(t_{sample} - t_{lake})}{(t_{spring} - t_{lake})} \times 100$$

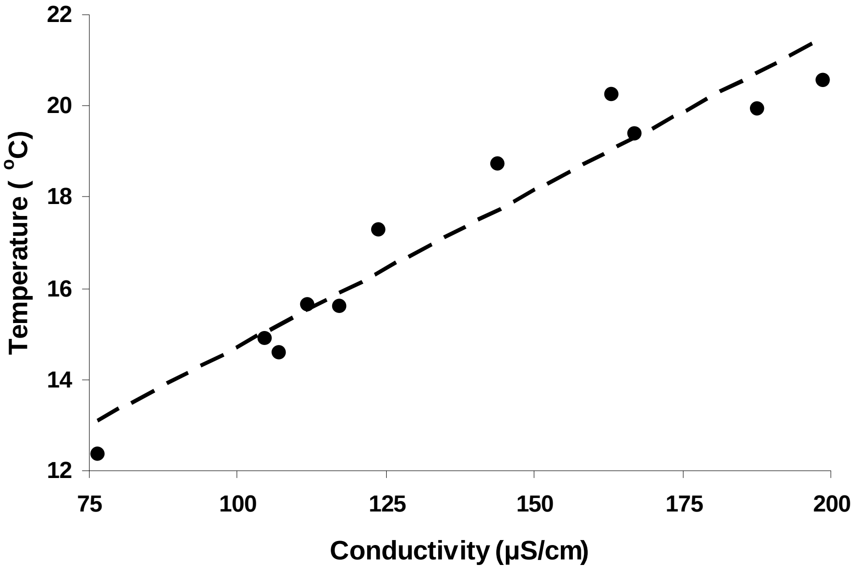

Figure 2.7: Relationship between temperature and conductivity in the plume water across the shallows. The near-linear relationship confirms that there is no local geothermal influence on the temperatures.

The contour plots (Fig. 2.8) show the degree of natural mixing that occurs due to entrainment of warm lake water into the cold inflow. They show that the plume contained about 30-35% spring water as it left the entrance mixing zone, indicating that the Hamurana Stream entrains about 3 times its own volume of lake water. There was little additional mixing in the plume downstream of the entrance mixing zone or as the density current flowed over the edge of the drop-off into deep water.

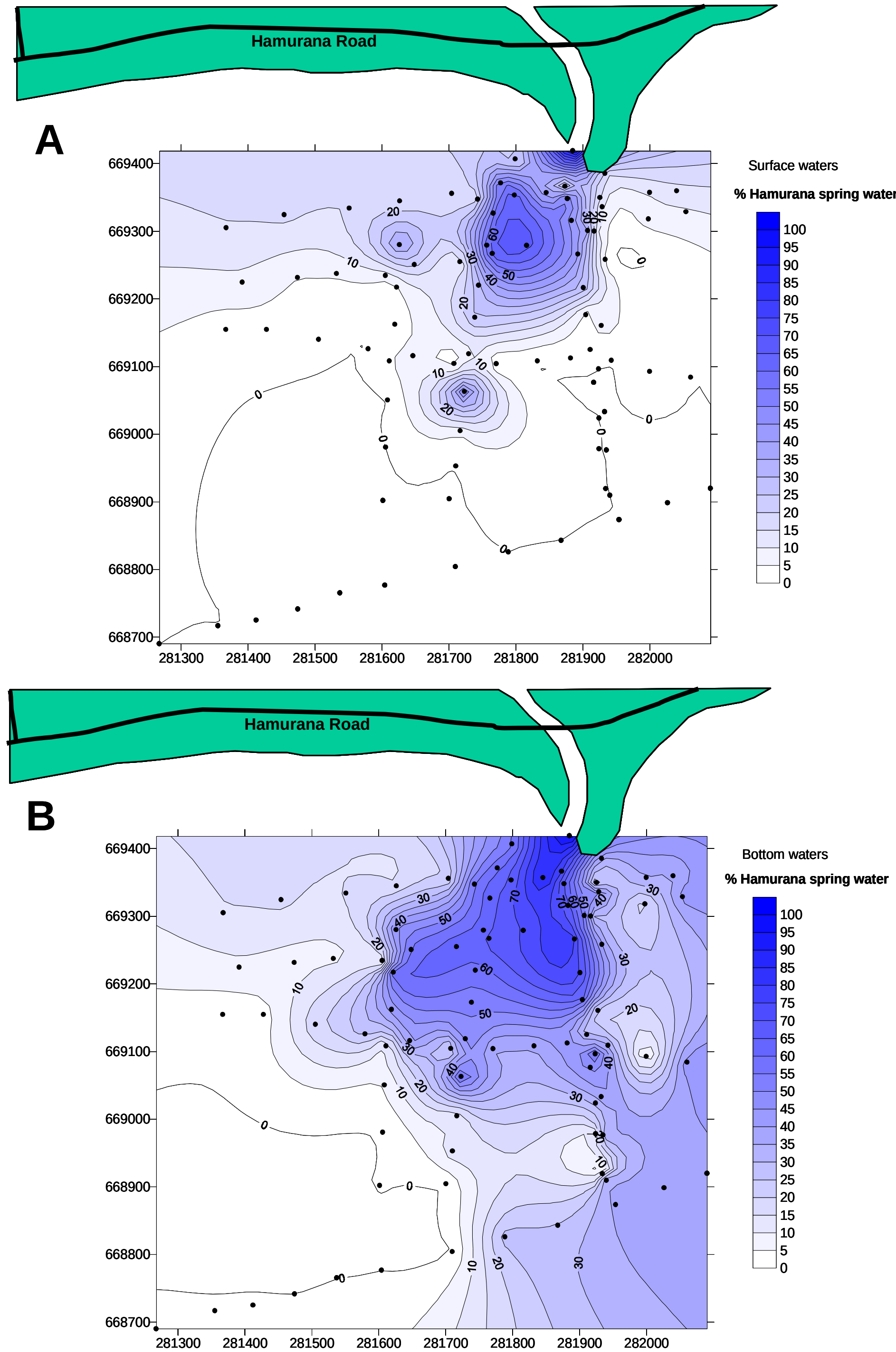

Figure 2.8: Proportion of Hamurana spring water versus ambient lake water **A**) at the surface and **B**) at the bottom in the plume from the Hamurana Stream mouth. There is some residual cold water along the shore from the strong onshore wind the previous day. Distance between tick marks on the grid scale is 100 m.

2.3.4 Implications for nutrient inputs

The tendency for the cold inflow water to pool on the shallow shelf and beyond this to sink to the lake bed as a thin-layer density current has the potential to bring nutrients in the spring water into close proximity with benthic algae (microphytes) which can use them for growth. The lake bed across the shallow shelf was observed to have an extensive covering of benthic microphytes despite the strong onshore winds which appeared to suspend detritus and sediment from the shelf zone the previous day.

Benthic microphytes have been found to remove almost all the nutrients from water in contact with them (Gibbs et al. 2005). As the Hamurana Stream plume moves out across the shallow shelf, it becomes a thin-layer density current similar to those found in Lake Taupo (e.g., Photo 2.3), which greatly increases the contact area with benthic microphytes on the shallow shelf as well as those present down the slope of the drop-off and in deeper water. This increases the potential for the benthic microphytes to utilise all of the nutrients from the inflow.

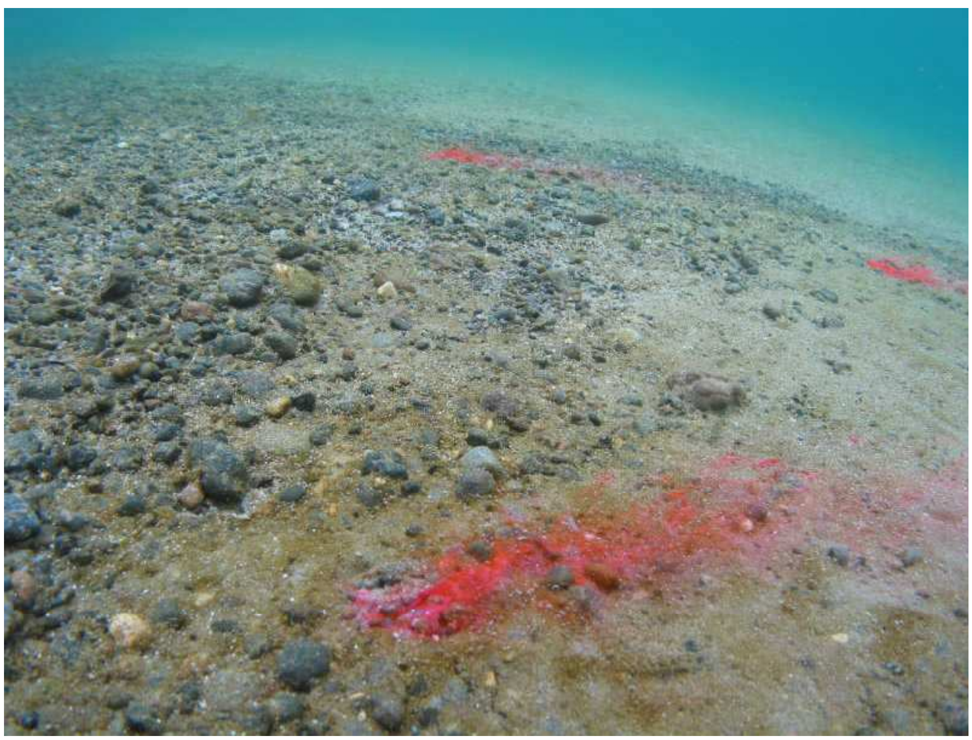

Photo 2.3: Dye tracer in a groundwater density current shows that it is just a few mm thick as it flows down the slope of the lake bed in Lake Taupo. The temperature difference was about 3ºC and the nutrients in the flow were being removed by a layer of benthic microphytes on the sediment surface (e.g., foreground). [Photo by Rohan Wells].

This nutrient removal process will be greatest in summer when light levels are maximal and water temperatures are warmest and the density current holds the inflow water against the lake bed, even in light winds. Strong onshore winds would disrupt this flow pattern for the duration of the blow but the flow pattern would quickly re-establish as the lake calms. As these density currents are driven by the temperature difference between the inflow and lake waters, it will be a seasonal phenomenon beginning in spring and ending in autumn when the lake temperatures are colder than the Hamurana spring (see section 3, Fig. 3.1A). Based on the projected temperature differences (see Fig. 3.1A), the spring water is likely to become a buoyant surface plume during most of winter and thus the nutrients in the inflow would be immediately available for primary production in the lake water column.

The plant growth nutrients, dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) that can be removed from the inflow water by the benthic microphytes comprise about 50% of the total nutrients in the spring water. The Hamurana Stream contributes 54.6 t y^{-1} or 12.3% of the total nitrogen (TN) and 6.4 t y^{-1} or 18.5% of the total phosphorus (TP) load to Lake Rotorua (Beyá et al. 2005). Of that load, about 25.8 t y^{-1} is as DIN and 3.1 t y^{-1} is as DRP.

Notwithstanding the potential removal of the DIN and DRP from the inflow water by benthic microphytes, these nutrients are not removed from the lake. Uptake has simply introduced a biological lag which may delay the release of those nutrients from the sediments, via nutrient cycling processes, back into the water column to support primary production in the lake by a few months or more. The biological lag is likely to alter the timing of the input of those nutrients so that they are not present in the lake water column to support summer algal blooms. The consequence of the biological lag is that the nutrient load from the Hamurana Stream in summer is incorporated into the sediments and becomes part of the internal load released as a continuous low level flux throughout the year.

As the plume from the Hamurana Stream is diluted with lake water by a factor of about 3 in the entrance mixing zone and then warms substantially before flowing out into the lake as a very thin layer across the lake bed, it is unlikely to have a higher dissolved oxygen content than the ambient lake water and hence it is unlikely to greatly affect the nutrient release processes from the sediments. Also, as the DIN and DRP are likely to have been removed from the inflow, it is unlikely to influence the apparent nutrient release rates from the sediments during stratification, by pooling in the deeper parts of the lake.

3. Importance of the cold-water habitat for trout

3.1 Introduction

Rainbow trout are well known as a 'cold-water' fish species, and the optimal temperature range for adults is 13-15ºC (Spigarelli & Thommes 1979; Stauffer et al. 1984). Adult trout grow best and thrive when water temperatures are in this range (Cho & Kaushik 1990). The long seasonal duration and wide depth range for such cold waters in the Rotorua and Taupo lakes are major factors contributing to the high quality of rainbow trout fisheries in these waters. Trout in lakes that are located in warmer or colder regions of New Zealand are not so fast growing.

Physiological adaptation to high water temperatures can occur in rainbow trout when they are confronted with temperatures beyond their optimal level. Their preferred temperature rises as they become acclimated to increased water temperature and studies on trout distribution and movement in the deeper Rotorua lakes (i.e., Rotoiti and Rotoma) confirm that as summer progresses and surface water temperatures increase, their depth distribution changes from deeper waters where temperatures are around 13ºC to shallower waters with a temperature of around 16ºC (Rowe & Chisnall 1995). However, such physiological adaptation is limited and adult rainbow trout can become more stressed as temperatures approach 20ºC. They are generally absent from waters where the temperature exceeds 21ºC (Rowe 1984; Rowe & Chisnall 1995) but may make temporary forays into such 'hot' waters to feed. In lakes where trout cannot move into deeper, colder waters (e.g., because the lake is too shallow, or the deeper waters lack oxygen), then feeding can be reduced and weight loss can lead to a decline in condition factor (Rowe 1984).

In deep lakes, surface waters heat up during summer months and form a surface layer (or epilimnion) over the deeper, colder-water (hypolimnion) resulting in temperature stratification. When the temperature of the epilimnion exceeds 21ºC, trout are mainly present in the colder, deeper hypolimnetic waters. However, in shallow lakes, wind-induced water mixing often prevents temperature stratification and so there is often no deep, cold-water layer or hypolimnion for trout to move to. Under these conditions, many trout congregate in cold-water streams, which may provide the only refuge habitat in shallow lakes. However, if these streams are absent, then trout must feed more to counter the higher physiological cost of coping with the warmer water. If they cannot increase their food consumption rate, then they lose weight and condition and can eventually die (Rowe 1984).

In Lake Rotorua, mean summer surface water temperatures exceed 21ºC between January and March each year (Fig. 3.1A). During this 3 month period, water temperatures exceeded 21ºC for about 45% of the time (i.e., about 41 days)(Fig. 3.1B). There were only 7 out of the 35 summers examined when surface water temperatures were generally below 21ºC (i.e., colder years). Therefore, adult trout face a thermal stress between January and March in Lake Rotorua for about 50% of the time in most (80%) years. Climate change may cause future summer water temperatures to rise even higher.

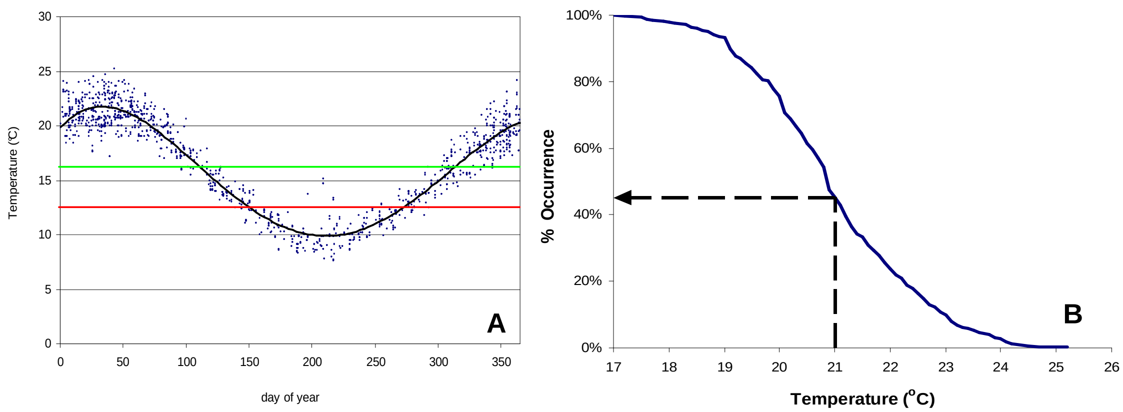

Figure 3.1: Daytime surface water temperatures in L. Rotorua over the period 1967-2002 (data from Environment Bay of Plenty); (**A**) seasonal changes (black line is 4th order polynomial fit) Red line represents the temperature of the Hamurana Stream water inflow. Green line is 16ºC, the trout refuge habitat temperature in summer. (**B**) cumulative % occurrence of temperatures from 1 January to 31 March. Broken arrow indicates the percent of time temperatures exceeded 21ºC.

E

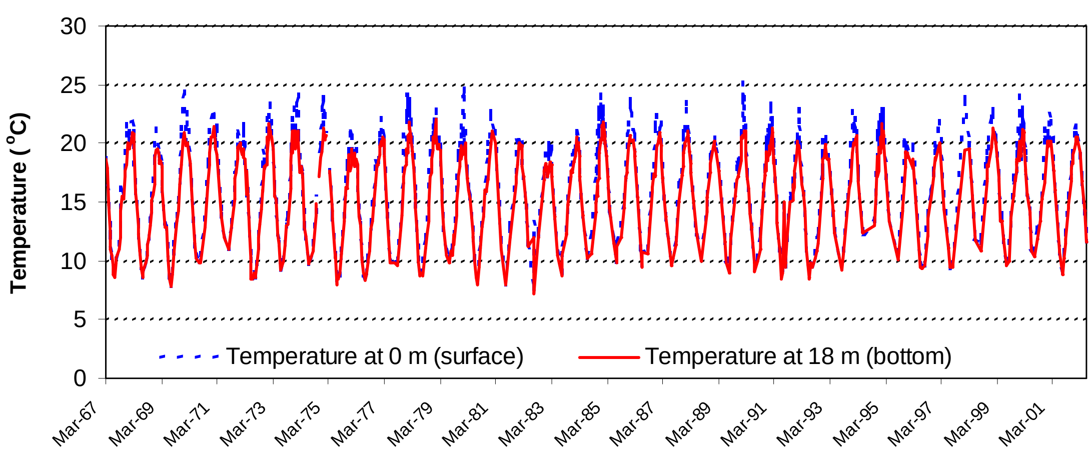

Figure 3.2: Differences in water temperature between the surface and bottom waters of Lake Rotorua (data supplied by Environment Bay of Plenty from monitoring site BCT18 up to 1992, and sites 2,5,7 thereafter).

Lake Rotorua is a relatively shallow lake (mean depth 11 m), and even in the deeper waters (max. depth 25 m) of the Rangiwhakapiri Basin to the west of Mokoia Island, the water is generally well mixed. Episodic stratification occurs during long, calm periods in summer months. However, for the period January to March between 1967 and 2002, the temperature of bottom waters (i.e., at 18 m) was generally within 1.2ºC of that at the surface (Fig. 3.2). Therefore, during the months of January, February and part of March, almost the entire volume of water in Lake Rotorua was often over 21ºC and the deeper waters of this lake provided little or no cold-water refuge habitat for trout.

When water temperatures in Lake Rotorua exceed 21ºC for periods of several days or more, trout can be expected to start concentrating in the refuge habitats provided by the cold, spring-fed inlet streams, especially if their main foods (e.g., smelt) are scarce, or if oxygen levels fall below acceptable levels in the deeper parts of the lake.

The water temperatures and mean flows for the main streams entering Lake Rotorua are shown in Table 3.1 below.

Table 3.1: Size of the main inflowing streams to L. Rotorua and their water temperatures during the period Jan-Feb (from Fish 1975 & Mosely 1982).

Source	Mean flow-1968 ($x10^3$ m^3/d)	% of total inflow	Temperature (Jan-Feb ^oC) (* most preferred by trout)
Rainfall	340.6	22.7	--
Hamurana Springs	256.2	17.1	12 *
Ngongotaha Stream	197.4	13.1	16
Utuhina Stream	191.4	12.7	16
Puarenga Stream	165.8	11.0	22
Awahou Stream	155.2	10.3	13 *
Waiteti Stream	129.6	8.6	15 *
Waiohewa Stream	42.2	2.8	18
Waingaehu Stream	25.6	1.7	18

Most of the streams entering Lake Rotorua are colder than the lake water during January and February. An exception is the Puarenga Stream, which is hotter than the lake because it receives geothermally heated water. The Hamurana, Awahou and Waiteti Streams are colder than the other streams (Table 3.1) and are all within the preferred temperature range for trout. Trout are therefore expected to prefer the Hamurana, Awahou and Waiteti Streams as refuge habitat and concentrations of adult trout are known to occur around these particular stream mouths during summer months (Eastern Fish & Game records). However, trout may also use the other streams as thermal refuge habitat because although they are warmer, they are still much colder than the lake water between January and March.

The relative size of the various stream refuge habitats in Lake Rotorua can be estimated in terms of stream flow, but this needs to be weighted by water temperature to reflect the preference of trout for the colder streams. To weight the contribution of each stream, its percentage of the total flow was increased by a factor of 0-4, where 4 is for optimal temperatures (13ºC), 3 is for temperatures in the range 14-15ºC, 2 is for temperatures of 16-17ºC, 1 for temperatures of 18-19ºC, and 0 is for temperatures over 20ºC (i.e., no thermal refuge). On this basis (Fig. 3.3), the Hamurana Stream potentially contributes the largest amount of cold-water refuge habitat (36% of the total refuge habitat) for trout in Lake Rotorua. However, local factors such as the inshore topography of the lake bed and the lake level, will greatly influence the actual size of refuge habitat for trout. For example, in April 2005, the Hamurana contained four times as much habitat as the Awahou (Table 2.1).

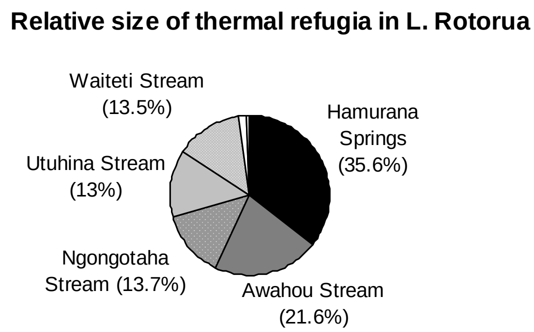

Figure 3.3: Relative size of the thermal refuge habitats provided by streams entering L. Rotorua estimated from stream flow weighted by temperature.

At present, it is not known whether there is an active summer movement (e.g., a mass migration) of trout towards such cold-water springs when temperatures in the lake approach 21°C, or whether some trout simply encounter the cold-water plumes during their normal foraging activities and remain there until increasing appetite results in a return to the lake to feed. A mass migration would be expected to result in the movement of most trout (especially the more sensitive larger fish) towards the springs, resulting in very large concentrations around the stream mouths and a corresponding scarcity near the middle of the lake. However, fishing guides continue to catch trout in the vicinity of Mokoia Island (near the middle of the lake) over the January-March period, even when surface water temperatures in the lake exceed 21ºC and bottom waters would provide no refuge because they are only 1-2ºC colder (See Fig. 3.2). This suggests that the annual summer concentrations of trout that occur around the cold-water spring mouths are more the result of opportunistic encounters between trout and the cold-water plumes rather than an active migration of all trout towards such areas. Nevertheless, this hypothesis has not been tested and tagging studies are required to confirm or disprove it because a mass movement of trout towards the springs may have important effects on their distribution and hence on the fishery and its management.

The issue of trout distribution aside, Eastern Fish and Game are concerned that the cold-water refuge habitat in Lake Rotorua may provide an important summer habitat for the trout in this lake and that the removal of the largest of these (i.e., the Hamurana Stream) may adversely affect the trout population. This would occur if the cold-water refuge habitat was required by trout to maintain their growth and hence survival and if such habitat was a limiting factor during summer months.

If summer water temperatures do stress trout to the point where feeding and growth is affected over summer months, then it follows that trout in lakes lacking cold-water refuge habitat would be more affected during hot summers than in cold summers. In particular, reduced feeding because of thermal stress would be expected to result in a drop in weight for a given length leading to a reduction in condition factor. This effect would be expected to affect many more fish in lakes lacking thermal refuge habitat (e.g., Lake Rotoehu) than in shallow lakes where refuge habitats are present (e.g., Lake Rotorua). Consequently, a comparison of condition factors between hot and cold summers in lakes with and without thermal refuge habitat provides a way of testing the importance of such habitat for trout growth.

Analysis of historic creel census data for the length and weight of trout caught at various times provides a way of examining such changes in condition factor and these data have been collected by Fish & Game over the past 8 years. Consequently we analysed these data for lakes Rotorua and Rotoehu and compared the condition factor of trout between warm and hot years.

Because of the paucity of long term lake water temperature data over summer, the thermal regime for each summer was determined by analysis of annual air temperatures from the Rotorua airport meteorological station over the January-March period. The results of these analyses are reported below.

3.2 Methods

The meteorological records for the period 1995-2005 at the Rotorua Airport were examined and mean air temperatures extracted for each month as well as for the period

January-March for each year. The years in which mean temperatures over this 3 month period were relatively hot (>18ºC) versus cold (<16.5ºC) were identified. The years in which temperatures ranged between 16.5 and 18ºC were termed average years (i.e., neither especially hot nor cold).

Eastern Fish and Game routinely monitor angler's catches in the Rotorua lakes during the fishing season. Data on the sex, length and weight of individual trout are recorded along with information on capture date and method. Such data have been collected routinely since 1998 and therefore provide a basis for comparison of condition factor for the wild trout population between hot and cold summers. In addition, fin-clipped hatchery trout are routinely stocked into the lakes each year. The fin clip identifies when each batch of hatchery trout were liberated so their changes in length and weight can be measured over the following 3-4 years (again through monitoring of angler catches).

The number of wild trout sampled from angler's catches in Lake Rotorua over the main summer period (i.e., December-April) was 66 in 1998, 67 in 1999, 251 in 2001, 117 in 2002, 205 in 2003, and 172 in 2004. Thus, sample sizes were relatively small for 1998 and 1999. Linear regressions were used to detect trends (increases or decreases) in condition factor (and in length and weight) over the summer period for each year. The trends in condition factor were then compared between hot and cold summers. As a difference was found between male and female condition factor, changes in condition over summer were examined for each sex separately.

As a reduction in condition factor could be caused by an increase in length relative to weight, as well as by a drop in weight relative to length (as occurs when fish reduce feeding), we also calculated changes in mean length and weight of the sampled fish to determine the cause of changes in condition. We also examined potential sources of bias in these relationships that may arise because of the sampling method (i.e., creel census). In particular, we determined whether variation in the use of different fishing methods (e.g., fly fishing, shallow trolling, deep trolling) could result in selection of trout on the basis of either sex or size and thereby skew the results.

The creel census data on stocked hatchery fish was also used to compare changes in the condition factor of trout over summer months between lakes Rotoehu and Rotorua. These data provide a potentially more accurate assessment of changes in condition factor as they are specific to one year class of trout and so don't include variations related to the presence of multiple age groups. However, this means that sample sizes can be small and examination of the raw data indicated that useful comparisons were limited to the 1996 cohort through the 1998 summer, the 1997 cohort through the 1999 summer, and the 2002 cohort through the 2004 summer. Mean condition factors were calculated for these fish for both the pre-summer (i.e., October-December) period and the main summer period (i.e., January-March), and the change in these compared for hot and cold summers respectively.

We also examined data on the trout fishery in Lake Rotorua to determine temporal patterns in fishing methods (especially fly-fishing which generally occurs around cold spring streams).

3.3 Results

3.3.1 Hot versus cold summers

Relatively hot summers occurred in 1998 and 1999 whereas comparatively cold summers occurred in 1997, 2002 and 2004 (Table 3.2).

Table 3.2: Mean air temperatures at Rotorua Airport for each month (January-March) and for the period January-March inclusive. Years are classified into relatively hot versus cold years based on summer air temperatures exceeding 18.0ºC, or below 16.5ºC.

Year	Month	Mean monthly temperature	Mean summer temperature	Classification of years
1995	Jan	16.8		
	Feb	17.6	16.8	AVG
	Mar	16.1		
1996	Jan	17.9		
	Feb	17.9	16.8	AVG
	Mar	14.6		
1997	Jan	15.9		
	Feb	17.6	16.1	COLD
	Mar	15.0		
1998	Jan	17.4		
	Feb	19.5	18.1	HOT
	Mar	17.4		
1999	Jan	19.3		
	Feb	17.3	18.0	HOT
	Mar	17.3		
2000	Jan	16.8		
	Feb	17.8	16.7	AVG
	Mar	16.0		
2001	Jan	16.8		
	Feb	18.7	17.0	AVG
	Mar	15.4		
2002	Jan	17.1		
	Feb	16.3	16.5	COLD
	Mar	16.0		
2003	Jan	16.6		
	Feb	17.3	16.7	AVG
	Mar	16.1		
2004	Jan	18.5		
	Feb	16.4	16.3	COLD
	Mar	14.0		

Remaining years were generally average in terms of summer temperature. The availability of data on trout meant that comparisons between summers differing in temperature were limited to two hot summers (1998, 1999), two average summers (2001, 2003), and two cold summers (2002, 2004). Note, mean air temperatures used to classify the summer, include nights.

3.3.2 Summer changes in trout condition factor for Lake Rotorua

Changes in condition factor over summer months differed for male and female trout. Condition factor generally increased for males during summer months (Fig. 3.4). The one exception was in 2000/2001 (an average summer in terms of temperature) when it remained relatively constant. In contrast, and somewhat surprisingly, condition factor for females either remained relatively constant or declined over summer months, irrespective of the temperature.

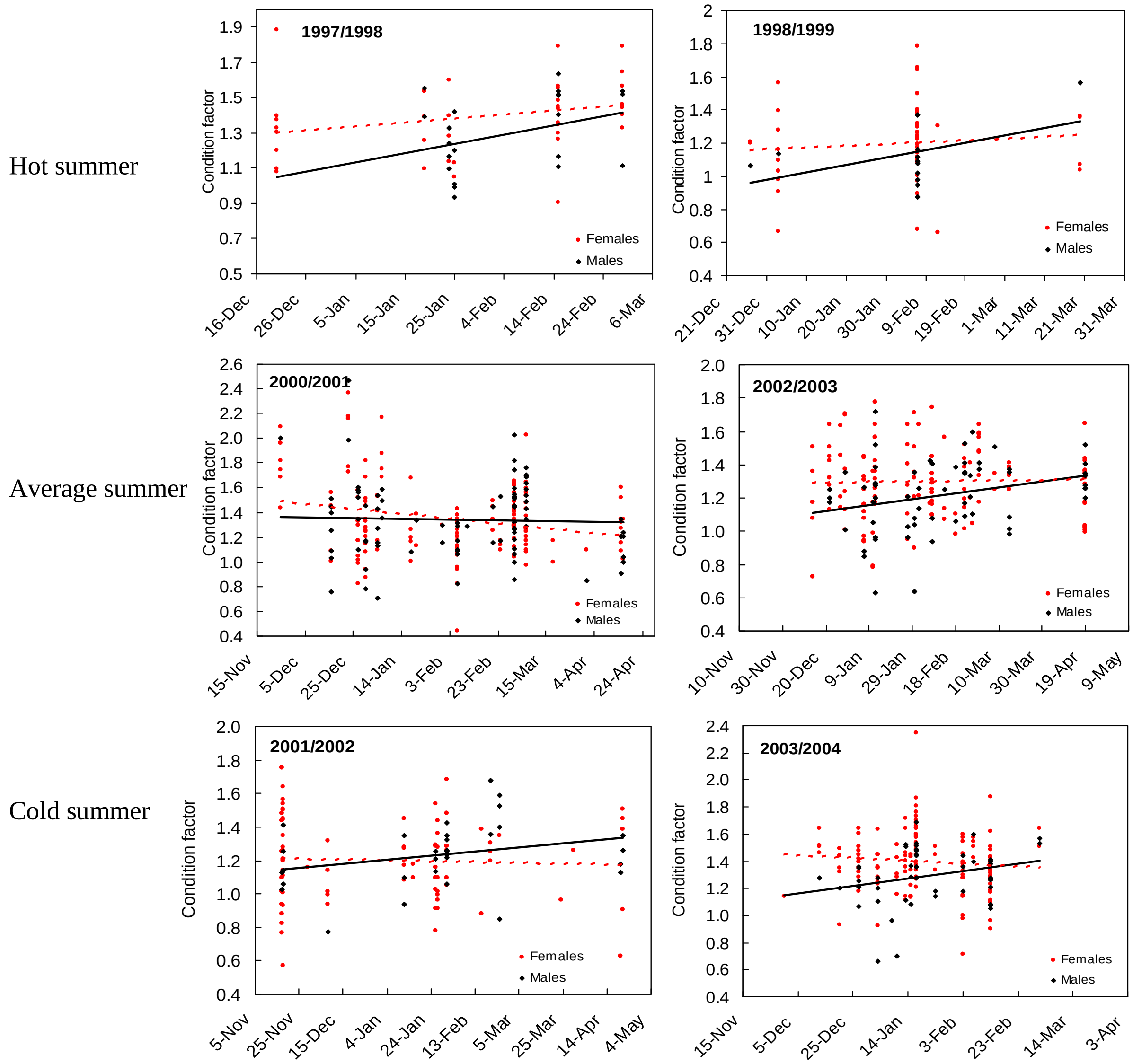

Figure 3.4: Changes in condition factor of rainbow trout in Lake Rotorua over summer months in ‘hot’, ‘average’, and ‘cold’ summers (lines are linear regressions- red for females, black for males).

The condition factor of both male and female trout tended to increase during hot summers and it declined for females in 2000/2001, 2001/2002 and 2003/2004 (i.e., average and cold summers). These data indicate that there is no general reduction in condition factor during hot summers, nor a greater reduction during hot compared with cold summers. A decline in condition for both sexes occurred in 2000/2001, which was an average summer in terms of water temperature.

Changes in trout size occurred over summer months and also differed between the sexes. The length of females caught by anglers increased in both 1997/1998 (hot summer) and 2000/2001 (average summer), and showed little change or decreased over all other summers (Fig. 3.5).

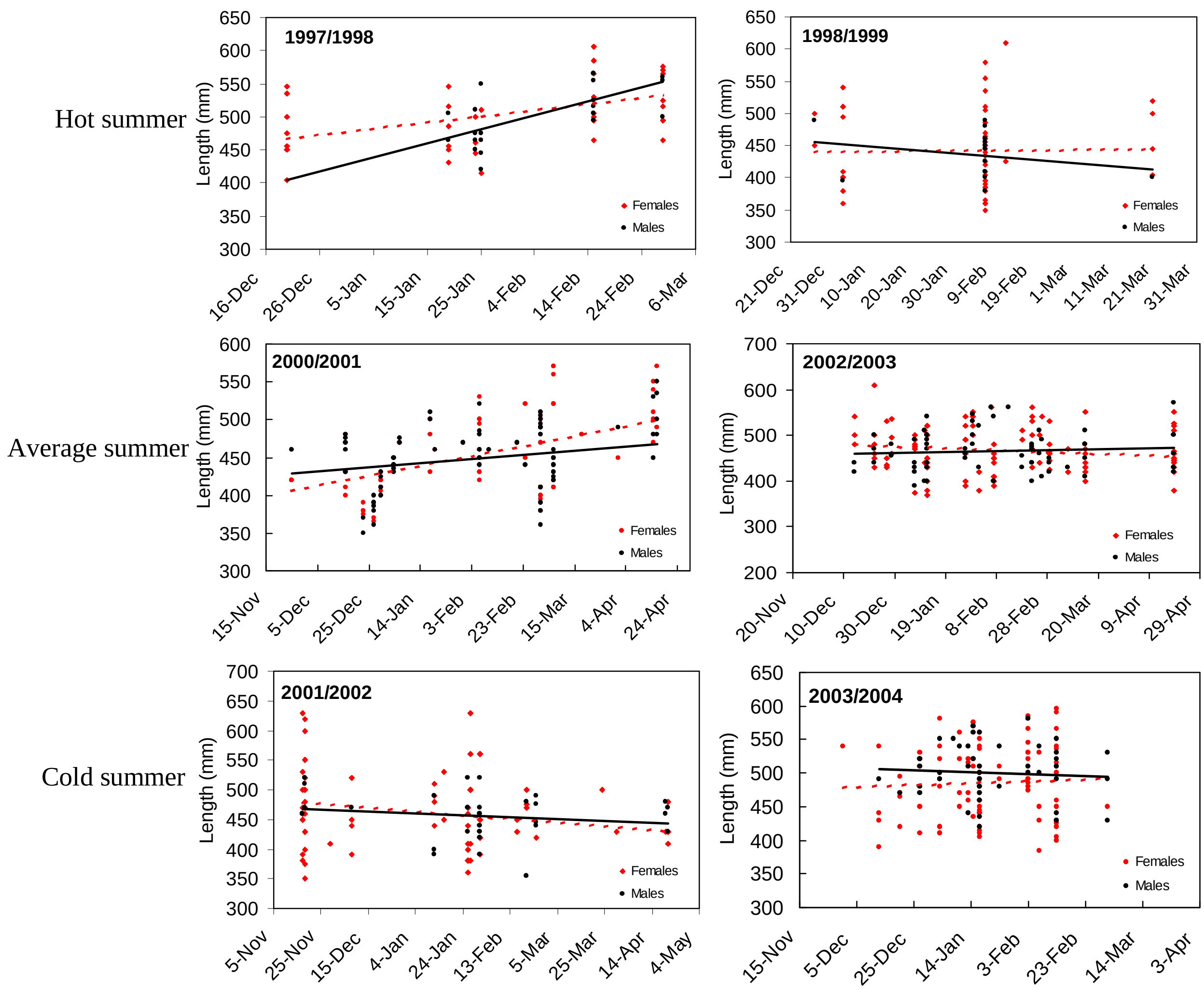

Figure 3.5: Changes in the length of angler-caught female trout over summer in Lake Rotorua. (Lines are linear regressions- red for females, black for males).

Similarly, the length of male trout increased in 1997/1998 but not in other summers (Fig 3.5). Thus, changes in length for males closely followed that for females.

Changes in the length of female trout over summer months were paralleled by changes in weight and a very similar trend occurred with males (Table 3.3). These data indicate that the marked decline in trout condition during the 2000/2001 summer (both male and female trout) was not caused by a reduction in weight but by an increase in length without a corresponding increase in weight. In 1997/1998 (a hot summer), both male and female trout increased in length as well as in weight, but during 2001/2002 (a cold summer) weight and length both decreased. Warm water temperatures are therefore associated with an increase in the size of trout caught by anglers in Lake Rotorua. This may indicate that warmer waters generally result in faster growth rates, but this can only be expected to occur so long as food (smelt) is plentiful and other key variables (e.g., oxygen levels) are not limiting. This also assumes that angler selection (i.e., the tendency for different angling methods to catch a certain group of fish based on differences in fish distribution and behaviour) does not result in a preponderance of larger fish when water temperatures are hotter. Data on growth rates during hot versus cold summers would be required to confirm this.

Table 3.3: Trends in weight and length (as indicated by the sign of regression slope coefficients) for angler-caught male and female trout during summer months in Lake Rotorua.

Summer Period	Temperature Regime	Slope coefficients from the regressions of size on date			
		Male		Female	
		Length	Weight	Length	Weight
1997/1998	Hot	2.121	0.027	0.956	0.013
1998/1999	Hot	-0.512	-0.001	0.049	0.002
2000/2001	Average	0.270	0.003	0.658	0.004
2001/2002	Cold	-0.157	-0.001	-0.314	-0.003
2002/2003	Average	0.098	0.003	-0.204	-0.001
2003/2004	Cold	-0.132	0.004	0.132	0.000

The changes in fish length and weight outlined above assume that the fish sampled are representative of the trout population as a whole. However, biases may arise from the sampling procedure (i.e., creel census) if different methods of angling select for larger or smaller fish, or for male versus female trout, and if the use of the selective angling methods varies over the summer period. It is therefore important to examine such assumptions as they may also help explain the results obtained.

There was no consistent pattern in the mean length and weight of male and female trout caught by anglers between 1997 and 2004 (Table 3.4). Males were shorter than females in 2000/2001 but longer in all other summers. Males were heavier in 2001/2003 and 2003/2004 but lighter in all other summers.

Table 3.4: Mean lengths and weights of angler caught fish from Lake Rotorua during summer months.

Summer period	Length (mm)		Weight (kg)	
	Males	Female	Males	Females
1997/1998	505.9	501.6	1.73	1.81
1998/1999	490.0	458.0	1.20	1.20
2000/2001	449.5	454.0	1.23	1.29
2001/2002	463.8	462.4	1.30	1.25
2002/2003	468.5	465.3	1.26	1.34
2003/2004	501.3	484.9	1.63	1.61

Fly-fishing generally caught the largest trout (Fig. 3.6) with the mean length of female fish caught by this method being greater than for all other methods in all summers. Fly-fishing also caught the largest males in 1997/1998, 1998/1999, 2002/2003 and 2003/2004, but not in 2001/2002 and 2000/2001. Changes in the extent of fly-fishing between seasons could therefore bias estimates of fish size.

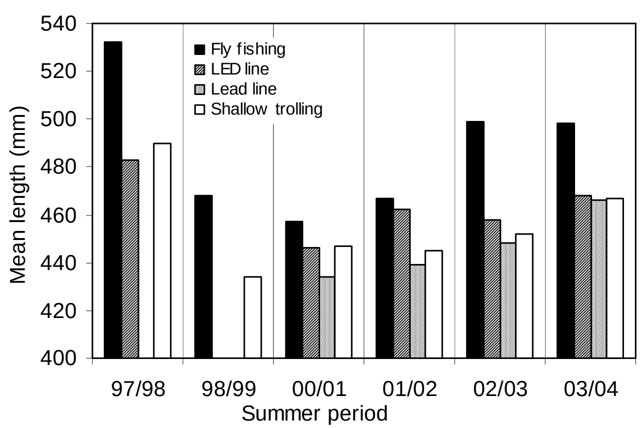

Figure 3.6: Mean lengths of trout caught by different fishing methods over summer in Lake Rotorua.

The proportion of the trout sampled by creel census that were caught by fly-fishing varied greatly among the summer periods (20% in 1997/1998, 18% in 1998/1999, 36% in 2000/2001, 25% in 20001/2002, 9% in 20002/2003 and 41% in 20003/2004). However, these variations could not explain the observed changes in trout size among years, and other factors are therefore responsible.

Sex ratios invariably favoured females and there was no consistent difference between methods (Table 3.5). Overall sex ratios (all angling methods combined) varied greatly between years. The percentage of female fish caught was relatively low for the two summers when average temperatures prevailed (i.e., 51% for 2000/2001 and 53% for 2002/2003), but was high for both the hot and cold summers (i.e., 59% for 1997/1998 and 79% for 1998/1999, and 68% for 2001/2002 and 69% for 2003/2004, respectively). Neither the changes in the proportions of male versus female fish, nor the differences in size between males and females, could explain the trends in trout size over the summer period noted previously.

Table 3.5: Proportions of female trout in anglers catches from Lake Rotorua by both method and summer period (the numbers in brackets indicate the number of trout sampled).

Summer period	Percentage (%) of female trout			
	Fly fishing	LED lining	Lead lining	Shallow trolling
1997/1998	69 (13)	44 (16)	--------	62 (37)
1998/1999	83 (12)	--------	--------	78 (55)
2000/2001	49 (91)	40 (68	56 (25)	73 (62)
2001/2002	62 (21)	64 (42)	70 (20)	78 (23)
2002/2003	32 (19)	56 (45)	46 (50)	56 (85)
2003/2004	71 (69)	61 (56)	78 (27)	71 (14)

3.3.3 Differences between lakes Rotorua and Rotoehu

Data on stocked hatchery trout (i.e., age cohorts) released into the lakes and later caught by anglers also provide a way of examining changes in the condition and growth dynamics of trout over the summer period. More importantly, they provide a way of comparing changes in the condition factor of trout over summer months in lakes with thermal refuge habitat (e.g., Lake Rotorua) and those without (e.g., Lake Rotoehu). Any increase in stress and consequent decline in condition induced by high water temperatures can be expected to be more marked in lakes lacking thermal refuge habitat than in lakes with such habitat.

The data for this comparison were more limited as fewer hatchery than wild trout were sampled. Examination of the raw data revealed that direct comparisons between these lakes were only possible for the 1996 cohort over the 1997/1998 summer, the 1997 cohort over the 1998/1999 summer, and the 2002 cohort over the 2003/2004 summer. Changes in condition factor over the 2001/2002 summer could be calculated for trout stocked into Lake Rotorua in 2000 (i.e., the 2000 cohort) but not for this cohort in Lake Rotoehu.

Condition factors were calculated for the cohorts of hatchery trout caught between October and December (i.e., before water temperatures become stressful) and the mean for these compared with that for the hatchery trout caught between January and March (i.e., the summer stress period). Differences were tested by analysis of variance. The results of these comparisons are shown in Table 3.6.

Table 3.6: Changes in trout condition factor over summer months in Lake Rotorua and Lake Rotoehu. (* indicates a significant difference at $P < 0.05$).

Summer period	Summer thermal regime	Rotoehu			Rotorua		
		Mean condition factor		Change	Mean condition factor		Change
		Oct-Dec	Jan-Mar		Oct-Dec	Jan-Mar	
1997/1998	Hot	1.26	1.00	-0.26*	1.32	1.16	-0.16*
1998/1999	Hot	1.20	1.17	-0.03	1.15	1.63	0.48
2001/2002	Cold	-	-	-	1.11	1.34	0.23
2003/2004	Cold	1.19	1.09	-0.10*	1.18	1.31	0.13

Condition factor for the hatchery-reared, stocked trout declined over summer in Lake Rotoehu in all three summers for which data were available (2 hot and 1 cold), with a large and statistically significant decline occurring in 1997/1998 (hot summer). The mean condition factor for hatchery trout also declined in Lake Rotorua over this summer period, but not as much as in Lake Rotoehu. In general, the loss in condition factor for trout in Lake Rotoehu over summer months was greater than for trout in Lake Rotorua, irrespective of the summer temperature regime. This provides some support for a beneficial effect of thermal refuge habitat on trout in Lake Rotorua. However, the differences in condition factor were small and/or non-significant in all years except 1997/1998. Furthermore, the differences could well be attributed to factors other than temperature (e.g., variations in trout food supply or in trout density between the lakes).

The growth rates for the hatchery trout (as approximated by log-linear fits to the size at age data) revealed large differences between cohorts within each lake (Fig. 3.7). However, these differences were not related to the thermal regime occurring over mid-summer (i.e., January-March). In general, the predicted mean length at 250 days poststocking declined for each of the 1996 to 1999 cohorts in both lakes and increased for the 2001 & 2002 cohorts. Such coordinated patterns among age cohorts in both lakes indicate that either the parentage of the hatchery-reared trout (i.e., genotype) has a greater effect on growth than environmental differences between lakes, or that broader-scale climate factors affecting both lakes (e.g., floods, duration of the growing season) are more important than the thermal regime occurring over summer months.

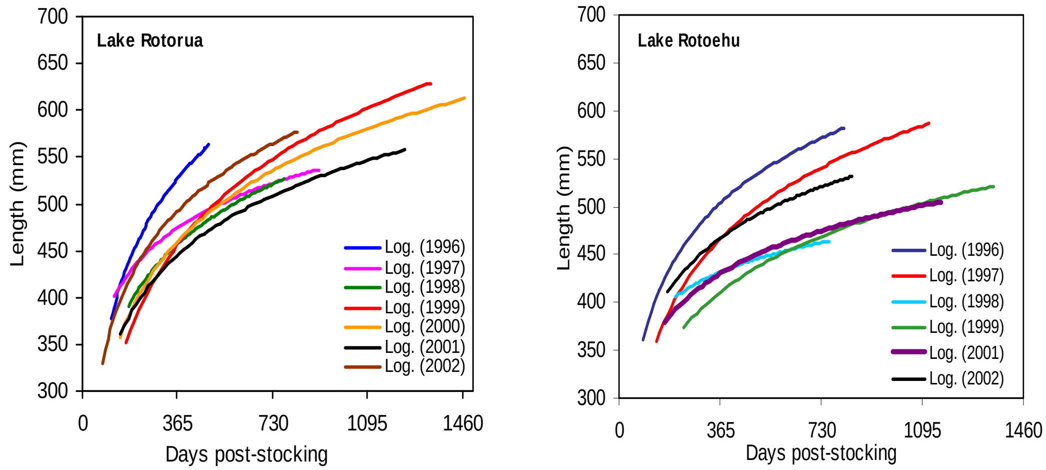

Figure 3.7: Growth rates for hatchery trout age cohorts stocked into Lake Rotorua and Lake Rotoehu as yearlings (year when stocked).

3.3.4 Water temperature effects on the fisheries.

There was a seasonal change in angling methods over the summer period in Lake Rotorua. Both shallow trolling and deep trolling (using LED or lead lines) were the main methods used from late December (Christmas) until mid-January (Fig 3.8). Trolling (both deep and shallow, but primarily deep) continued to be used throughout the summer period, but in mid- to late-January, both types of trolling declined and fly-fishing increased in importance. Fly fishing was the main method used/censused in the lake until the end of March. Fly-fishing is generally confined to shore-based angling at stream mouths and the increase from mid-summer onwards occurred as trout become more concentrated around the mouths of the spring-fed streams. Although these differences may be due in part to the census procedure, they are also likely to reflect actual changes in fishing patterns in the lake as water temperatures increase and some trout respond by frequenting the stream mouths.

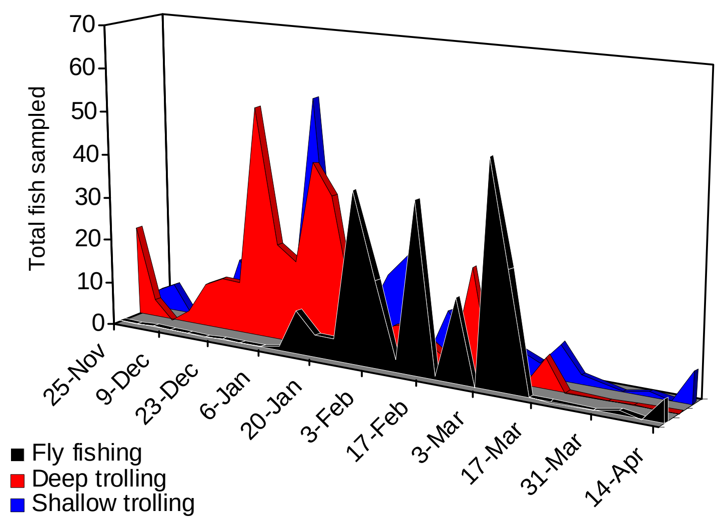

Figure 3.8: Changes in angling methods over summer months in Lake Rotorua (creel census data for 1998-2004 seasons combined).

The catch per unit effort (CPUE) data for Lake Rotorua were calculated for each fishing season (i.e., from October to June) and include spring, autumn and winter catches as well as summer catches. Nevertheless, as most fishing occurs in Lake Rotorua over the summer holiday period, the CPUE data can be expected to reflect trout catch rates at this time.

Annual mean catch rates (trout caught per rod per hour) were highest for the years in which summer temperatures were average (i.e., 0.43 for 2001 and 0.48 for 2003), intermediate in the years in which summer temperatures were coldest (i.e., 0.34 in 2002 and 0.36 in 2004), and lowest for the years in which summer temperatures were hottest (i.e., 0.29 in 1998 and 0.30 in 1999). These differences imply an association between summer temperatures and catch rates. Although the data are too few to substantiate such a relationship, a reduced catch rate for trout in hot summers could be related to a decline in trout catchability related to decreased feeding activity, or to a change in trout distribution and failure of most anglers to adapt to this. The latter seems more likely. However, such a pattern may also be related to a number of other factors and more long-term data would be required to confirm a relationship between summer temperatures and catch rates.

4 Discussion and recommendations

4.1 Effects of stream diversion on trout and on the trout fishery

Diversion of the Hamurana Stream will remove the main factor contributing to the localised summer fishery based on its mouth. Anglers who fish this stream will be forced to go elsewhere, and in this sense diversion will have a negative impact on the trout fishery. In the long term, recovery of the lake will benefit the trout population (by increasing water quality and reducing eutrophication) and a short term loss of a localised fishery for a long term gain in the trout population may be acceptable to managers. However, the issue addressed here was the wider-scale effects of diversion on the trout population and fishery.

The results presented indicate that hot summers (typical of those experienced over January to March in 1997 and 1998) do not significantly reduce the condition factor of wild trout in Lake Rotorua. Annual variations in condition were apparent, but were not related to summer water temperatures. Other factors, primarily annual differences in food availability (e.g., smelt), and possibly in trout density, are therefore likely to be of over-riding importance for trout growth dynamics. These conclusions may change if climate change causes future summer lake water temperatures to rise even higher than at present. Overall, the results of the present data review indicate that the cold-water refuge habitat in Lake Rotorua is not 'vital' to trout growth and that any benefit that it does provide is generally over-ridden by other factors affecting growth. This does not mean that a benefit is absent. The consistent difference in condition for trout over summer between Lake Rotorua and Lake Rotoehu suggests that the presence of thermal refuge habitat may well provide some benefit to trout in Lake Rotorua. Unfortunately, the data are too few to substantiate this difference, and factors other than the presence/absence of thermal refuge habitat (e.g., food supply, water quality, trout density) could also account for it.

While we cannot exclude the possibility of a small effect on the summer growth dynamics of the trout population in Lake Rotorua due to a reduction in cold-water refuge habitat, it will have a minimal affect on the size and mortality of trout. However, the distribution of trout in Lake Rotorua could change and the summer fishery for trout may still decline if the Hamurana Stream is diverted. Apart from the loss of fishable water, a change in the distribution of trout during the warmer summer months could result in a decline in trout catchability. This possibility is reflected in both the decline in catch rates for hot summers and in the changes in fishing methods used during summer months. It appears that the cold-water spring mouths provide some anglers with an opportunity to increase catch rates via fly-fishing as the effectiveness of shallow trolling in the lake declines. In this sense, diversion of the Hamurana Stream would remove the opportunity for fly-fishing at its mouth and so could deprive anglers of an opportunity to offset the general reduction in summer catch rates in the lake, especially during hot summers. The extent of this potential impact is unknown and a tagging study would be required to provide data on this issue.

Although the catch statistics above provide some evidence that trout congregate around the mouths of coldwater springs during summer months, there is no data to indicate the relative magnitude of such a shift in distribution (i.e., whether it affects a relatively small number of trout or most). Furthermore, there is little data to indicate the relative importance of the various stream mouths for the summer fly-fishing fishery (e.g., whether local conditions favour the Awahou over the Hamurana or Waiteti etc.). Data presented in this report indicate that the Hamurana Stream can be expected to provide the largest area of cold-water refuge habitat for trout to congregate in and that this could be 4-5 times larger than in the Awahou stream depending on the amount of water being abstracted from its springs. Overall, the Hamurana Stream can be expected to account for 40-50% of the total summer refuge habitat for trout in the lake. The loss of this amount of trout refuge habitat might be exacerbated should climate change raise the water temperature of the lake above present maxima in future summers.

Data on trout use of the Hamurana is therefore required to provide an indication of its importance for trout movements and distribution patterns in the lake. Such information is best determined by tagging a relatively large number of trout and determining their movements in the lake over spring and summer. We therefore recommend that the trout tagging study proposed in 2005, proceed in 2005/2006 to determine the movements of trout in the lake and to provide some data on their relative usage of the various cold-water springs over summer months.

4.2 Implications of stream diversion for summer nutrient dynamics

The impacts of the proposed diversion on trout outlined above assume that diversion will occur during the months January-March because it is required for nutrient removal at this time as well as during the rest of the year. However, the results obtained in this study, plus new data on the role of benthic microphytes in stripping nutrients from cold, nutrient-rich, spring waters entering lakes, now indicate that this assumption may be questionable.

Nutrient budgets for lakes traditionally assume that the nutrient loads in the stream inflows are ‘instantaneously’ mixed throughout the whole lake and thus they immediately contribute to the primary production in the lake water column. Our data indicate that this is not necessarily true for stream inflows where the stream water flows over a broad near-shore shallow shelf such as at the mouth of the Hamurana Stream. The hydrodynamics of the inflowing water and the shape of the lake bed adjacent to this stream mouth provide a mechanism whereby the readily available plant growth nutrients (DIN and DRP) in the inflow can be removed by benthic microphytes. Consequently, there would be a large biological lag between the time of nutrient input and when those nutrients become available to support primary production in the lake water column.

This situation is a consequence of the thermal dynamics created by the topography of the lake bed in front of the Hamurana Stream. This topography currently provides trout refuge habitat in summer but can also be expected to result in significant nutrient stripping over summer. If so, then water diversion during the potentially critical 3 month summer period for trout may not be as necessary as implied by the overall nutrient budget, and retention of the natural flow (i.e., status quo) during these 3 months may be desirable to offset any risk to the fishery. This management strategy would need to apply from January to March inclusive and, assuming no seasonal difference in nutrient content of the spring water, it would reduce the total N and P removed from Lake Rotorua, by the diversion of the Hamurana Stream to the Ohau Channel, by 25%. Most of these remaining nutrients can be expected to be sequestered by the benthic microphytes and will not contribute directly to summer phytoplankton growth in the lake.

We recommend that the DYRESM-CAEDYM model of Lake Rotorua be run to assess the effect of this option on the water quality of the lake. Because of the way thermal dynamics affect the position of inflows to the lake in summer, we also recommend the model parameters be adjusted so that all nutrients in the cold stream and groundwater inflows are directed into the sediment recycling pool in the model rather than the water column of the lake, except for the 3-month period from mid June to mid September, inclusive, when thermal dynamics could make these inflows positively buoyant and thus their nutrient content would enter the water column directly.

If the trout tagging study proceeds, we recommend that the size of the refuge habitat at the mouth of the Hamurana Stream be measured concurrently with that study on at least 3 occasions to determine whether the size changes substantially over the summer period. An investigation of the nutrient uptake rate of the benthic microphytes across the shallow shelf should also to be considered.

5. References

Beyá, J.; Hamilton, D.; Burger, D. (2005). Analysis of catchment hydrology and nutrient loads for Lakes Rotorua and Rotoiti. Report from Centre for Biodiversity and Ecology Research, University of Waikato, Hamilton, New Zealand. 73p.

Cho, C.Y.; Kaushik, S.J. (1990). Nutritional energetics in fish: energy and protein utilisation in rainbow trout (*Salmo gairdneri*). In Bourne, G.H. (ed.) *Aspects of food production, consumption and energy values*. Volume 61: 132-172. World Review of Nutritional Diet. Karger, Basel.

Fish, G.R. (1975). A nutrient budget for Lake Rotorua. In Jolly, V.H. & Brown, J.M.A (eds.). New Zealand Lakes. Auckland University Press.

Gibbs, M.; Clayton, J.; Wells, R. (2005). Further investigation of direct groundwater seepage to Lake Taupo. NIWA client report HAM2005-050 to Environment Waikato. Project NumberEVW05289. 27 p.

Morgenstern, U.; Reeves, R.;Daughney, C.; Cameron, S. (2004). Groundwater age, time trends in water chemistry, and future nutrient load in the Lakes Rotorua and Okareka area.. Institute of Geological and Nuclear Sciences Ltd. Client report 2004/17 to Environment Bay of Plenty. Project Number: 520W2008. 63 p.

Mosely, M.P. (1982). New Zealand river temperature regimes. Water & Soil Miscellaneous Publication No. 36. New Zealand National Water & Soil Conservation Organisation. Wellington.

Rowe, D.K. (1984). Factors affecting the foods and feeding patterns of lake-dwelling rainbow trout (*Salmo gairdnerii*) in the North Island of New Zealand. *New Zealand Journal of Marine and Freshwater Research 18*: 129-141.

Rowe, D.K.; Chisnall, B.L. (1995). Effects of oxygen, temperature and light gradients on the vertical distribution of rainbow trout, *Oncorhynchus mykiss*, in two North Island, New Zealand lakes differing in trophic status. *New Zealand Journal of Marine and Freshwater Research 29:* 421-434.

Rutherford, K. (2003). Lake Rotorua nutrient load targets. NIWA client report HAM2003-155 to Environment Bay of Plenty. Project number BOP04220. 59 p.

Spigarelli, S.A.; Thommes, M.M. (1979). Temperature selection and estimated thermal acclimation by rainbow trout (*Salmo gairdneri*) in a thermal plume. *Journal of the Fisheries Research Board of Canada 36*: 366-376.

Stauffer, J.R.; Meliskey, E.L.; Hocutt, C.H. (1984). Interrelationships among preferred, avoided and lethal temperatures of three fish species. *Archives of Hydrobiologia 100*: 159-169.

6. Acknowledgements

The positional data for the temperature profiling was provided by R Ovendon. Using his survey skills greatly simplified the fieldwork on that day. The Eastern Fish and Game Council provided the data on trout.