Water flow between Ohau Channel and Lake Rotoiti following implementation of the diversion wall Part B

CBER Contract Report 116

Prepared for Bay of Plenty Regional Council
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Table of contents

Front cover – Photo of diversion wall taken by Wendy Paul

Figures

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Tables

No table of figures entries found.

Executive Summary

To help improve water quality in Lake Rotoiti, a diversion wall was completed in July 2008, to divert the water emanating from the Ohau Channel towards Okere Arm in Lake Rotoiti. The objective was that this water would be directly transported into the Kaituna River instead of entering the main basin of Lake Rotoiti. A report was produced in response to a request from the Rotorua Lakes Technical Advisory Group to determine water velocities in the region of the wall, to consider the effectiveness of the diversion. This subsequent report has been written to follow-up on the recommendation that vertically resolved measurements of water current and direction in Lake Rotoiti should be investigated. The timing of the data collection was April to May when an underflow is more likely to be present.

Three current meters were positioned on the lake bed to measure water speed and direction immediately above the lake bed. Two meters, Acoustic Doppler Velocimeters (ADV) measured water temperature, current and direction just above the lake bed, one within the new diversion channel and the other within Lake Rotoiti at the entrance to the main body of the lake. A third meter, Acoustic Doppler Profiler, (ADP) was situated on the Lake Rotoiti side of the wall but closer to the wall and nearer to its end and measured current and direction vertically through the water column and water temperature near the lake bed. Water temperature and current speed and direction data were recorded at each station at fifteen minute intervals from 17 April to 1 May, 2009. These data were supplemented with temperature, chlorophyll fluorescence, dissolved oxygen and conductivity data collected with a Bio-Fish along a transect from the western end of Lake Rotorua, through the Ohau Channel and as far as the eastern end of Lake Rotoiti, on 12 April, 2008 and 14 April, 2009. Rainfall, temperature, wind speed and direction data from Rotorua Airport were also used for comparison with flow direction data from the current meters.

The direction of flow within the diversion channel was always towards the Kaituna River at a mean speed of 5.8 cm s^{-1}. At the other two sites in Lake Rotoiti the direction of flow

was towards the Lake Rotoiti, between 37 and 51% of the time at mean speeds of 3.1-3 cm s^{-1}.

Bio-Fish transects through Lake Rotorua, Ohau Channel and Lake Rotoiti have been used to compare 2008 and 2009 in April. Water temperature was warmer in 2008 than 2009. Lake Rotorua shows little vertical variation of temperature through the water column whereas Lake Rotoiti was thermally stratified in both years. Water temperature in the surface mixed layer and aligned with the bed of Lake Rotoiti at the western end of the lake is slightly cooler (~0.5^{o}C) for both years. Dissolved oxygen (DO) concentrations in April 2008 correspond with the temperature profile in both lakes, with the exception of no variation in the dissolved oxygen concentrations horizontally in the surface mixed layer of Lake Rotoiti. Chlorophyll fluorescence was higher in Lake Rotorua than in Lake Rotoiti in April 2008. In 2008, there were elevated levels of fluorescence at the eastern end of Lake Rotorua, and in the western basin of Lake Rotoiti adjacent to the lake bed in the surface mixed layer. In 2009, chlorophyll fluorescence was lower in Lake Rotorua than Lake Rotoiti. In the western basin of Lake Rotoiti, adjacent to the lake bed in the surface mixed layer, fluorescence levels were very slightly lower than those in the rest of the surface mixed layer. Conductivity is for the most part was higher in Lake Rotoiti than in Lake Rotorua and also at the western side of both lakes. In 2009, there are elevated levels in the bottom waters of Lake Rotoiti. The higher conductivity levels at the western end of Lake Rotoiti are concentrated around the region of the diversion wall.

Flows in Ohau Channel increased on 20 and 21 April, peaking at 12.5m^3s^{-1} then steadily increased from 25 April with peak flow on 29 April at 15m^3s^{-1}. Flows in Kaituna River were stepped due to the flood gate control but the overall trend was similar to that in the Ohau Channel. Stage height at the Ohau monitoring site increased by about 0.04m peaking at 3.37m on 21 April, then steadily increased from 24 to 29 April when it reached 3.45m. The difference between the lowest and highest stage height was 12.6 cm. As with the flows, a similar trend occurred with the Kaituna River stage heights. Both periods of increased flow and stage height coincided with increased rainfall over the same time periods.

Also coinciding with the periods of increased rainfall were two periods of faster flow into Lake Rotoiti measured at LAKE 1 but this only coincided with the first period at LAKE 2. The variable that was present on both occasions was high rainfall which coincides with measurements at LAKE 1 but a temperature differential was present during the first period but not the second which coincides with the findings at LAKE 2. As water flow at LAKE 1 was predominantly to the SE to SW throughout the study but faster during the high rainfall periods, the question is whether this station was so close to the end of the wall that it is always affected by backflow at this time of the year? The temperature differential seems to have a clear effect as the position and speed of flow evident at LAKE 1 and LAKE 2 during the first period is consistent with what would be expected of an underflow. The fact that faster flow in the direction of the lake was not evident at LAKE 2 during the second period when the temperature differential was absent somewhat affirms this.

Introduction

Following a recent report on data gathered in August and September, 2008, this report was prepared in response to a request from the Rotorua Lakes Technical Advisory Group for the Centre for Biodiversity and Ecology Research at the University of Waikato to provide further information on water flow in the vicinity of the Ohau Channel diversion wall. The specific focus of the investigation was to examine more closely the fate of the water diverted from Lake Rotorua once it reached the end of the Ohau Channel Diversion Wall. To better understand the processes involved in current flow within the diversion channel and near the exit of the Western basin region of Lake Rotoiti currents were measured near the lake or channel bed by two current meters and across a vertical profile by a third current meter. Measurements were made during April and May, at a time of year when an underflow is more likely to exist.

Background

Before the diversion, due to density differences between the two waterbodies, namely Lake Rotorua and Lake Rotoiti, an underflowing plume of cooler, denser water from Ohau Channel has flowed into Lake Rotoiti predominantly during winter (Gibbs et al., 2003; Hamilton et al., 2005). Typically, underflows allow gravity to take the cool, dense water on a path ‘downhill’ along the deepest channel (Pickrill & Irwin, 1982). Wind has also been found to have an effect on direction of surface and return flows in Lake Rotoiti (Stephens, 2004). In the previous report on the diversion of Lake Rotorua water, results showed that there was a possible underflow but this could not be corroborated by other variables measured. Correspondence between wind direction and current direction was also found (Hamilton et al., 2009). Hence, it was decided to explore the whole water column during April to gain further insight.

Methods

Study Site

Figure 1.

The focus of this study was the region at the end of the Ohau Diversion Wall and the Okere Arm of Lake Rotoiti (Figures 1 and 2). Bio-Fish data was collected along a transect from Ngongotaha in Lake Rotorua, through the Ohau Channel and into the eastern end of Lake Rotoiti (Figure 3). The speed of flow, flow direction, and temperature data used in this report were collected with current meters (Sontek ADV Triton and Sontek ADP Argonaut-XR) installed at three sites from 17 April to 1 May 2009 (Figure 2). The Acoustic Doppler Profiler (Sontek ADP Argonaut-XR) was located at site 1 (LAKE 1) at a water depth of 6.8 m deep on the Lake Rotoiti side of the diversion wall. Current and direction data was collected from 38 cm above the sediment surface in ten 50 cm intervals or cells through the water column. Temperature data were collected from near the lake bed by the same instrument. Speed of flow, flow direction, and temperature data were measured by two meters (Sontek ADV Triton) positioned just above the lake or channel bed at OHAU 1 at a water depth of 5 m within the diversion channel and LAKE 2 at a water depth of 9.5 m on the Lake Rotoiti side of the diversion wall but further from the wall than LAKE 1 (Figure 2). Data were recorded at intervals of 15 minutes.

Meteorological data (hourly wind speed and direction, rainfall and air temperature) were obtained from Rotorua Aerodrome Automated Weather Station (38° 7' 0'' S and 176° 19' 0'' E) at elevation 285 m AMS.

Water temperature, conductivity, dissolved oxygen, chlorophyll fluorescence and conductivity data used in this report were obtained from monthly surveys using a Bio-

Fish (ASD Sensortechnik GmbH, Germany). These data were collected at 4 Hz whilst the instrument was towed behind a boat, undulating in a vertical path. A transect was completed on 12 April 2008 and 14 April 2009 across Lake Rotorua from Ngongotaha, through surface waters in the Ohau Channel and the diversion channel, then into the Western Basin of Lake Rotoiti and proceeding to the eastern end of the lake (Figure 3). Precise location of the Bio-Fish was obtained through the combination of GPS on the boat and a pressure transducer on the instrument. Each survey started at 10.00 hr and was concluded by 14.00 hr. Data from the Bio-Fish surveys were graphed with Ocean Data View (Version 4.1, 2009). On 12 April 2008, the diversion wall was in construction and not complete, whereas on 14 April 2009, the wall was complete.

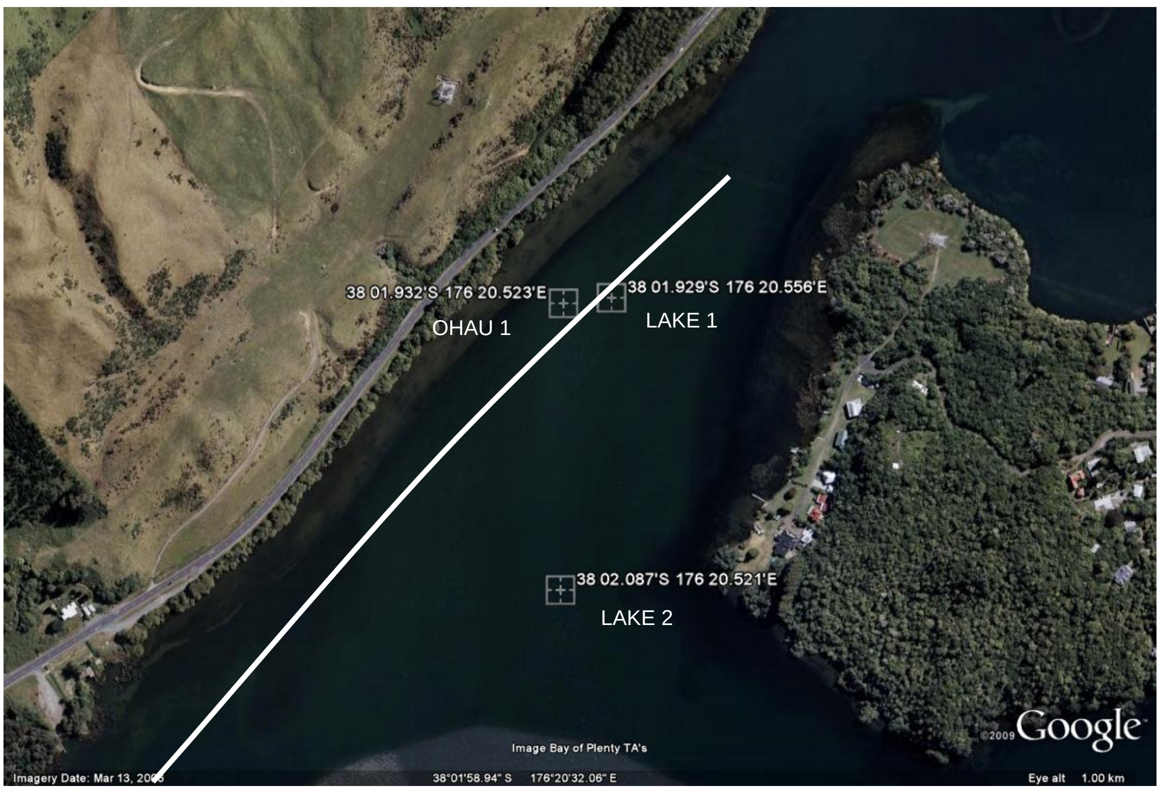


Figure 2. Satellite image courtesy of Google (2009), showing the placement of the three current meters, OHAU 1 (ADV), LAKE 1 (ADP) and LAKE 2 (ADV), 17 April to 1 May 2009. N.B. *Placement of the wall is an approximation*.

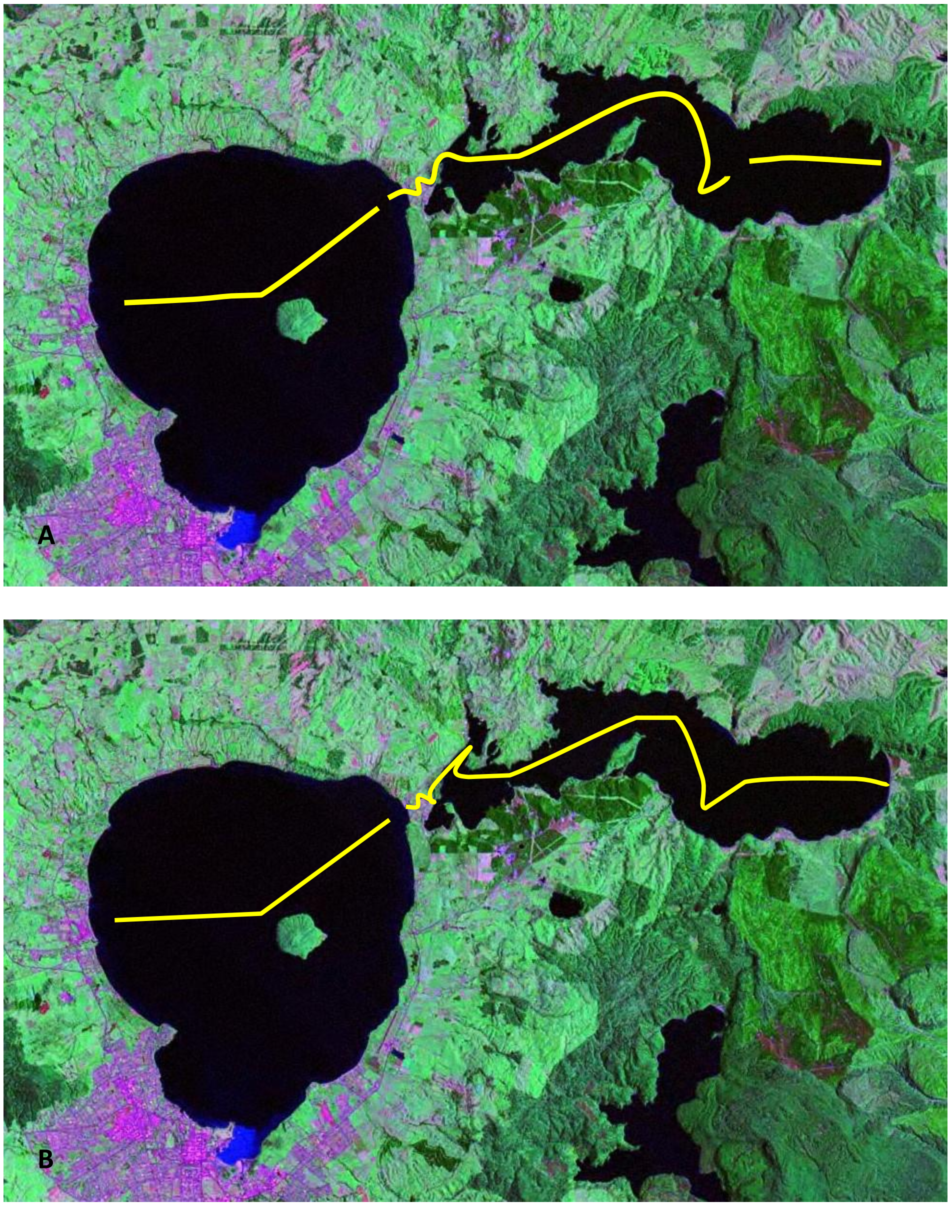


Figure 3. Transect of the Bio-Fish from Ngongotaha at the western end of Lake Rotorua, through Ohau Channel to the eastern end of Lake Rotoiti, (A) 12 April, 2008 and (B) 14 April, 2009.

Flow and stage height recordings in Ohau Channel and Kaituna River were obtained from NIWA. The recording site for Ohau Channel is at Mission Bay U15: 016 455 where the flow in the channel is a product of lake height used to produce a rating. There is a weir at the Rotorua end of channel to control the water level in Lake Rotorua. Measurements for Kaituna River flow and stage height were taken at U15:035 499, downstream of the flood control gates at Okere Falls.

Results

Water temperature

The mean water temperatures for LAKE 1, OHAU 1 and LAKE 2 were 16.2, 15.4 and 16.0°C, respectively as in Figure 4. On average, the water in the diversion channel was between 0.6 and 0.8 degrees cooler than the lake water. The fluctuations seen in water temperature typically followed those in air temperature with water in the channel fluctuating most strongly. The range of temperatures were greatest at OHAU 1 with a range of 12.8-17.5°C, whereas LAKE 1 was 15.6-17.0°C and LAKE 2 was 14.4–16.9°C. OHAU 1 varied strongly with both LAKE 1 and LAKE 2, with the greatest temperature difference of 3.4 °C recorded on 21 April 2009 between the Ohau Channel site (OHAU 1) and the Lake Rotoiti site (LAKE 1). Water temperatures were ≥0.5°C cooler at OHAU 1 (Ohau Channel) than LAKE 1 and LAKE 2 for 63% and 56%, respectively, of all measurements.

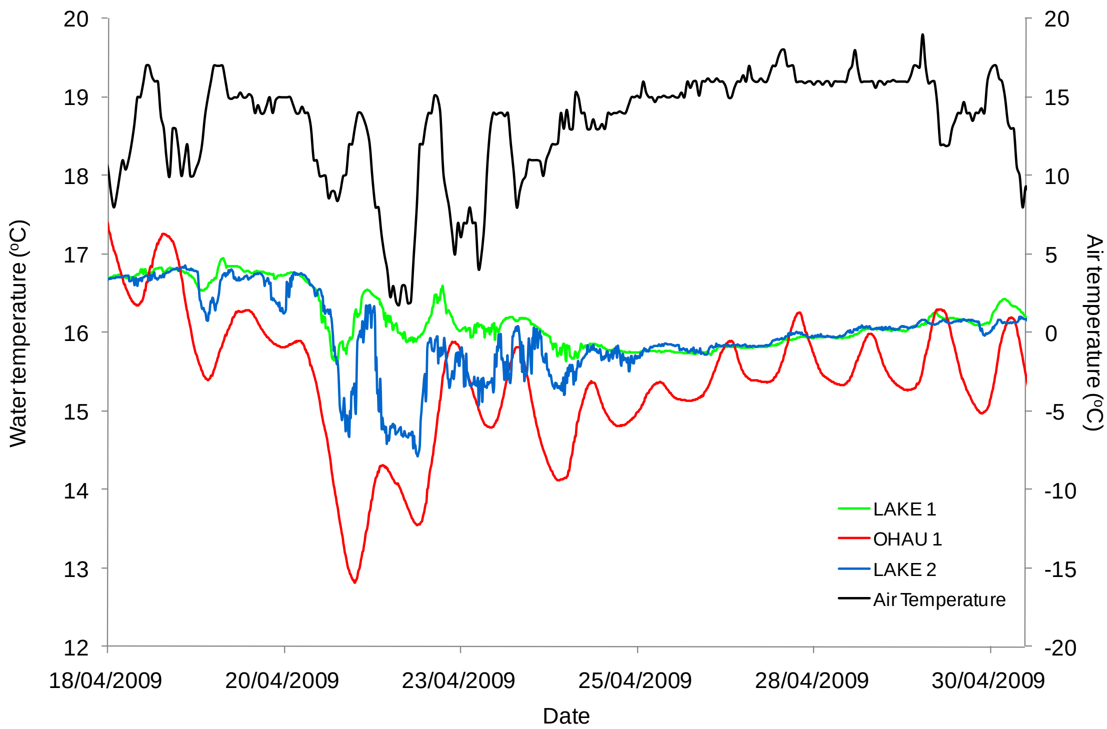


Figure 4. Temperature measured by current meter at sites Lake 1, Ohau 1 and Lake 2 and air temperature measured at Rotorua Airport, 17 April to 1 May, 2009.

Wind and current speeds and directions

Current speeds and directions at the three sites are shown in Figures 5, 6 and 7. The direction of flow at OHAU 1 was always towards the NE quadrant, aligned with the diversion wall and towards the Kaituna River (Figure 5). At LAKE 1 in Lake Rotoiti, water flowed in a S to SWW direction, towards the Lake Rotoiti, for 37% of the time while at the deeper site (LAKE 2) flow was towards the direction of Lake Rotoiti for 51% of the time (Figures 5 and 6). Water flow speeds at LAKE 1 were faster nearer the lake bed than they were nearer to the surface (Figure 6) and fastest when the water was flowing in the SSE direction (Figures 6 & 7). There are two time periods when the water was flowing faster than at other times (Figure 7) at LAKE 1. During the first faster period (20 and 21 April) the water nearer the surface is flowing towards the SW and nearer the bottom towards the SSW. The wind at that time is coming from the SSE (Figure 12). Hence, the entire water column was flowing towards the lake during that period whilst the wind was coming from the opposite direction. The second fast-flowing period at LAKE 1 covered a longer time period (25-29 April) when the water was flowing towards the south near the surface and towards the SSW near the bottom (Figure 6). Concurrently, the wind was coming from the NNE direction, thus going in the same direction as the water was flowing. At LAKE 2, water was mainly flowing towards the lake (SSW) from 17 to 24 April, then changed to flow towards the diversion wall in a NW direction for the next 5 days, then returned to the SSW direction for the remainder of the sampling period (Figure 8). Water flow speeds at LAKE 2 were fastest when flowing in the SSW direction, especially on 21 and 22 April (Figure 9) when the greatest temperature differential between channel and lake water existed (Figure 4). Fastest current speeds at LAKE 3 (Figure 9) coincided with fastest wind speeds from 20-23 April (Figure 11) when water was flowing in the SSW direction (Figure 8) towards the lake and wind was coming from the SSE direction (Figure 12) from the lake towards the wall. To reiterate, when wind and current speeds were fastest at LAKE 2, the current was flowing was almost into the wind.

Current speeds at OHAU 1 (within the diversion channel) were ≥ 5 cm s^{-1} for 54% of all measurements whereas current speeds ≥ 5 cm s^{-1} at LAKE 1 and LAKE 2 (within the lake) were measured for 17 and 16% of the time, respectively (Figure 5). The mean speed during the sampling period was 5.8 cm s^{-1} at OHAU 1 and 3.3 and 3.1 cm s^{-1} at LAKE 1 and LAKE 2, respectively. The range of current speeds was 0-13.8 cm s^{-1} at LAKE 1, 0.2-13.2 cm s^{-1} at OHAU 1 and 0.04-10.8 cm s^{-1} at LAKE 2. The greatest percentage of flow was at current speeds of 2-4 cm s^{-1} at LAKE 1, $\geq$ 5 cm s^{-1} at OHAU 1 and 1-3 cm s^{-1} at LAKE 2 (Figures 5, 7 & 9).

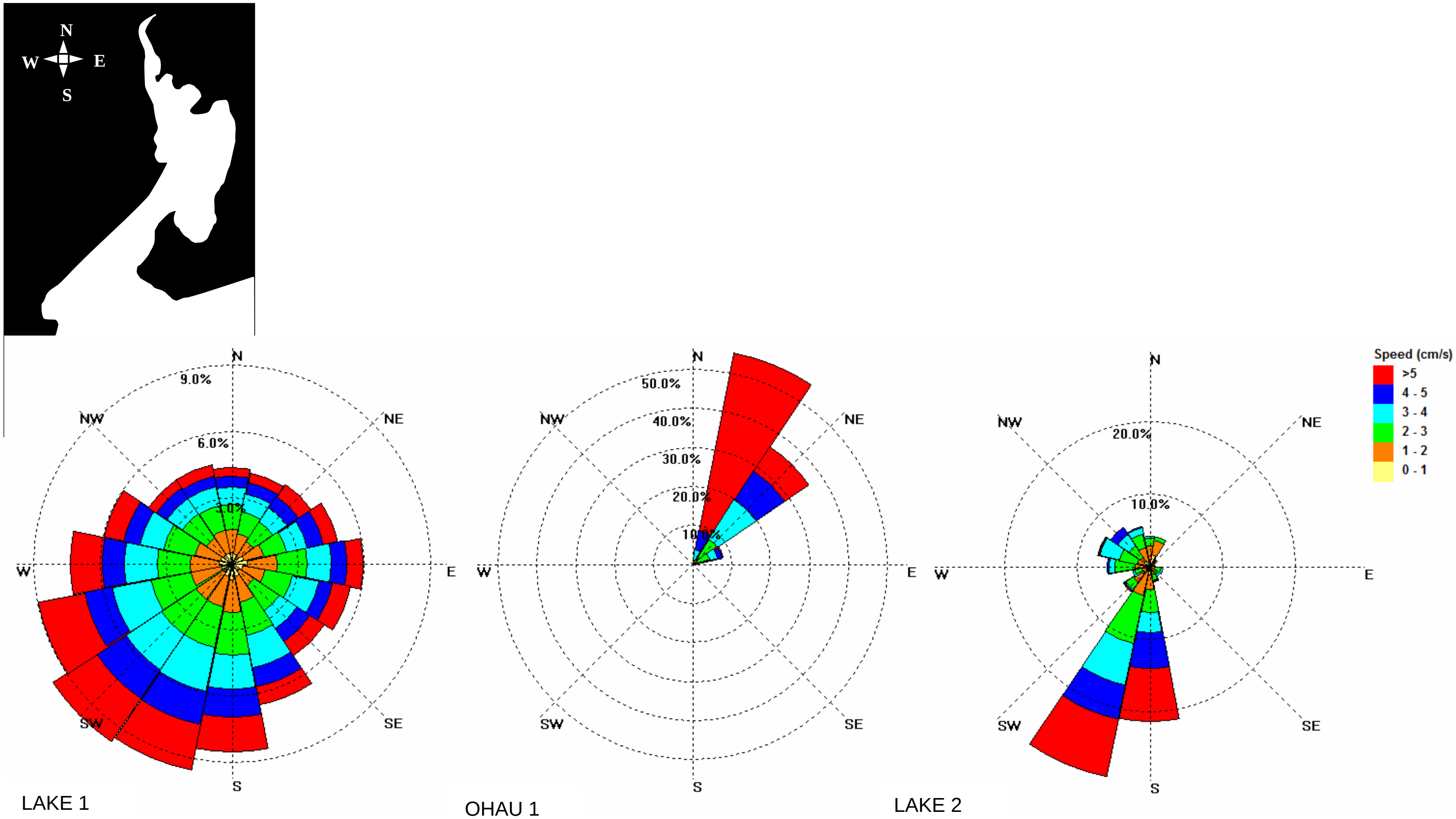


Figure 5. Water current speeds and directions through the water column at LAKE 1 and immediately above the lake bed at sites OHAU 1 and LAKE 2, 17 April to 1 May 2009. Inset is a schematic map of the Okere Arm.

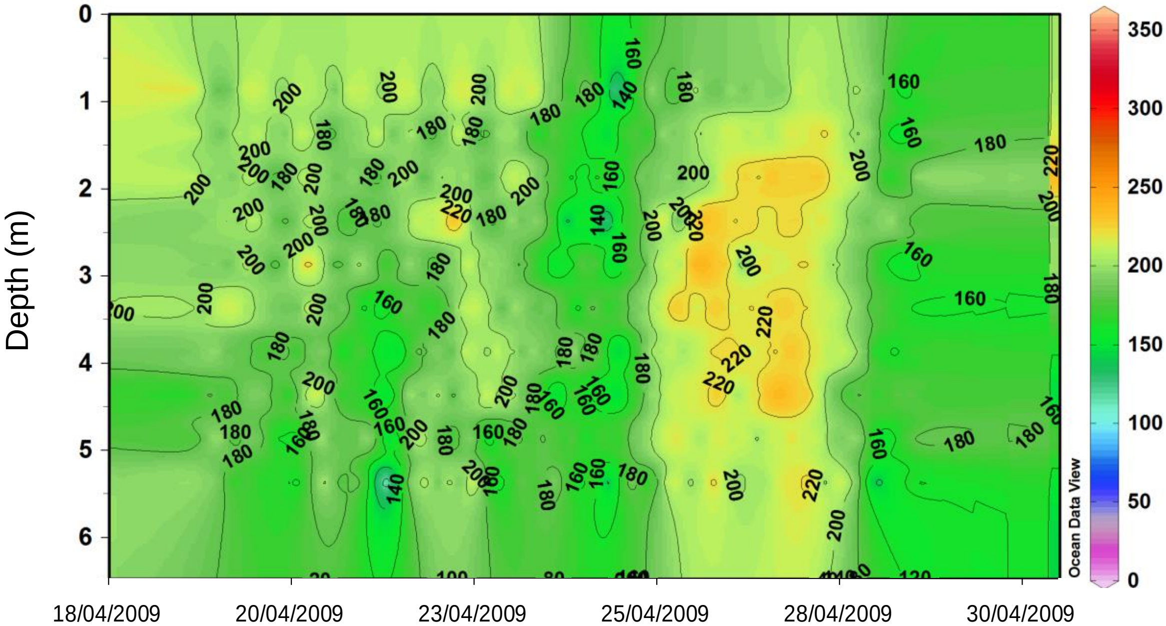


Figure 6. Direction of water currents through the water column at LAKE 1 from 17 April to 1 May, 2009.

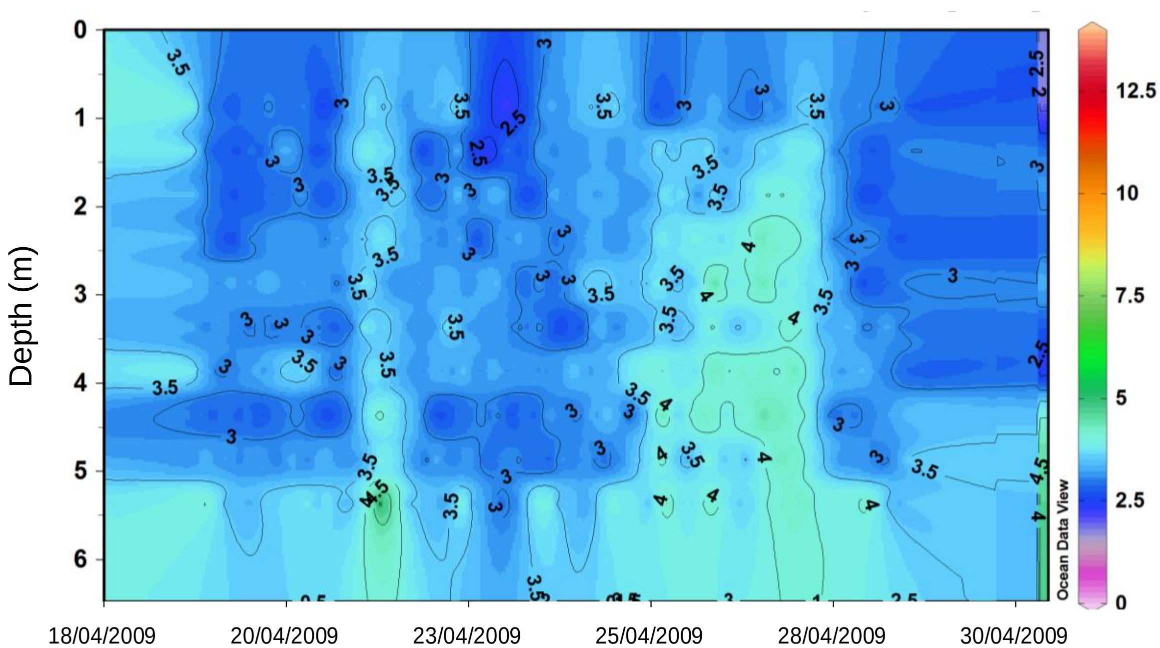


Figure 7. Velocity (cm s^{-1}) of water currents through the water column at LAKE 1 from 17 April to 1 May, 2009.

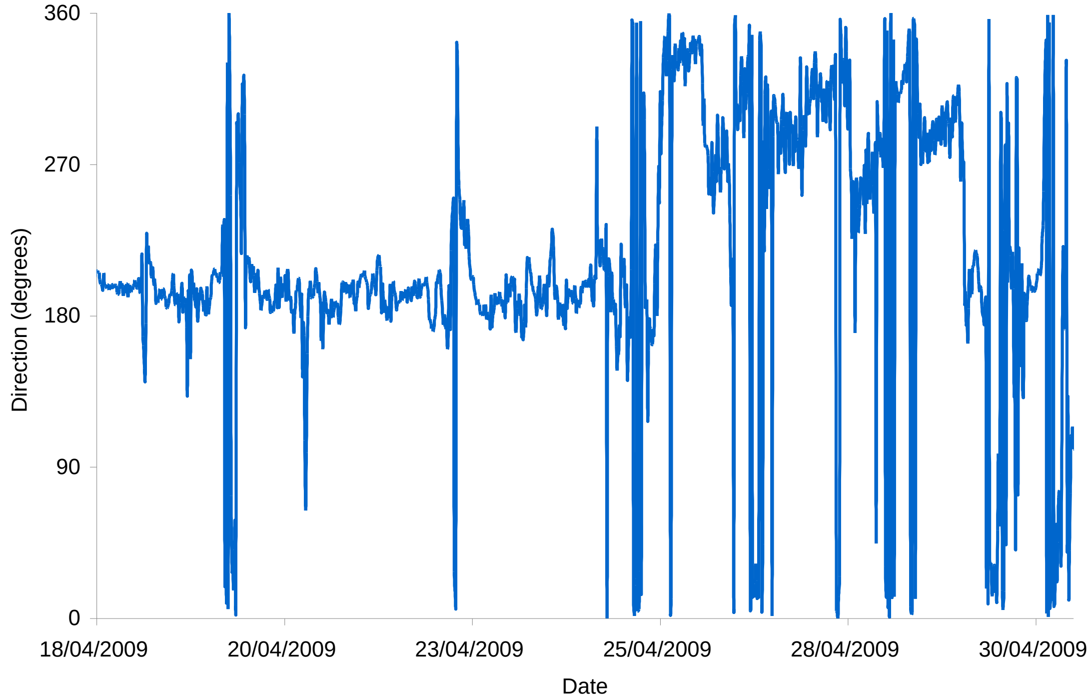


Figure 8. Direction of water currents near the lake bed at LAKE 2 from 17 April to 1 May, 2009.

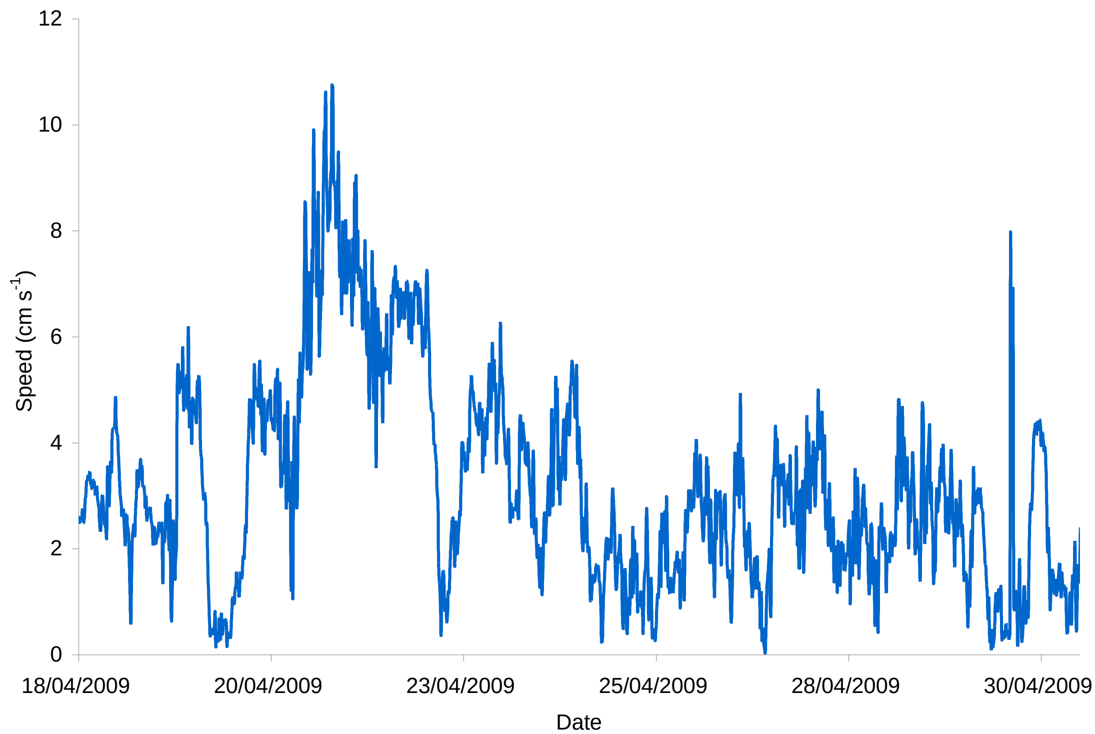


Figure 9. Velocity of water currents near the lake bed at LAKE 2 from 17 April to 1 May, 2009.

Wind came mainly from the north-easterly quarter on 19 April and 24-30 April 2009 and south to south-easterly directions (Figures 10 and 12). The fastest wind speeds recorded at Rotorua Airport during the period of current meter deployment were on 20 and 21 April 2009 (Figure 11).

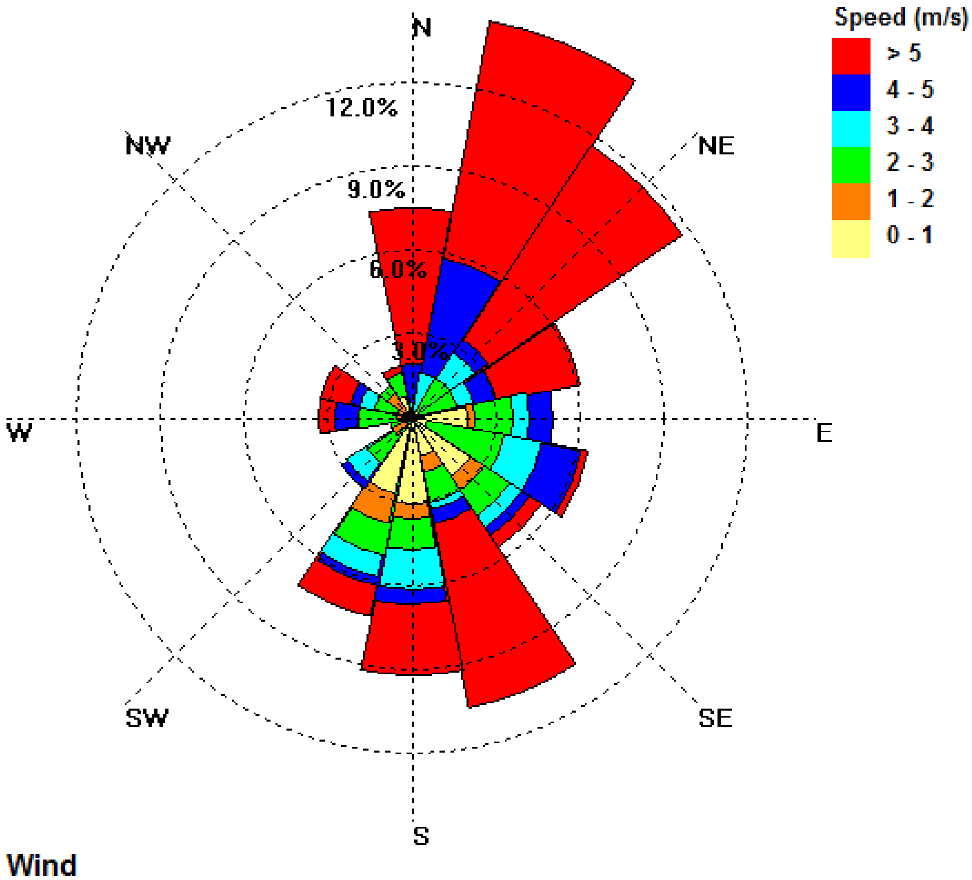


Figure 10. Wind speeds and directions measured at Rotorua Airport, 17 April to 1 May 2009. Inset is a schematic map of Okere Arm.

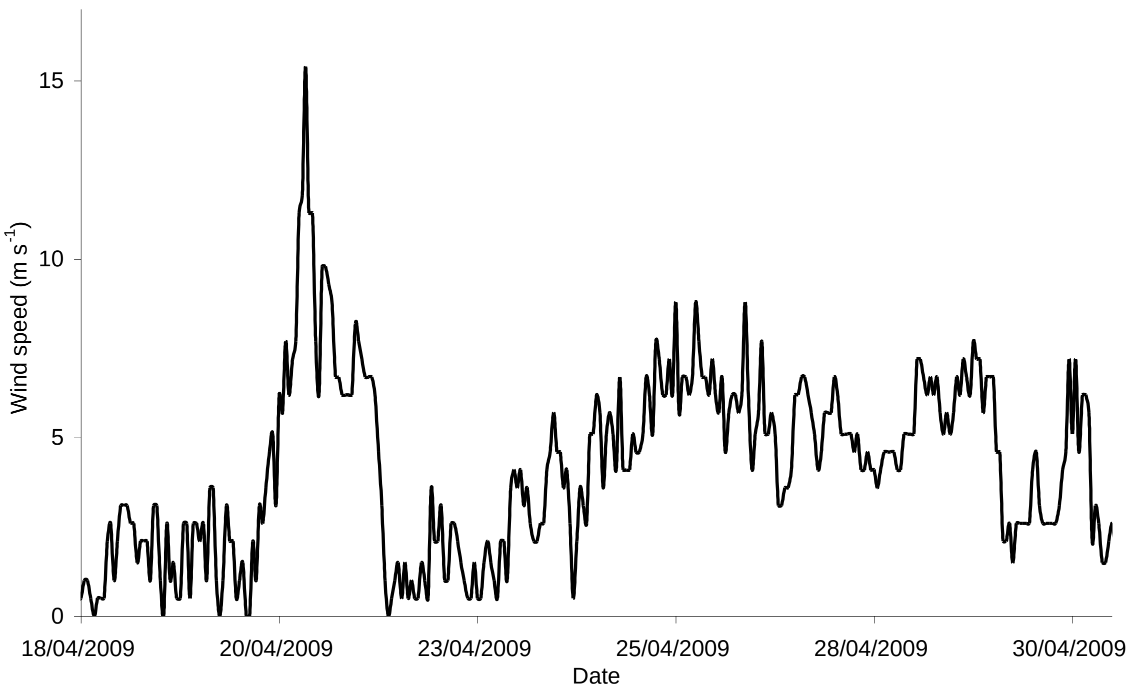


Figure 11. Wind speeds at Rotorua Airport from 17 April to 1 May, 2009.

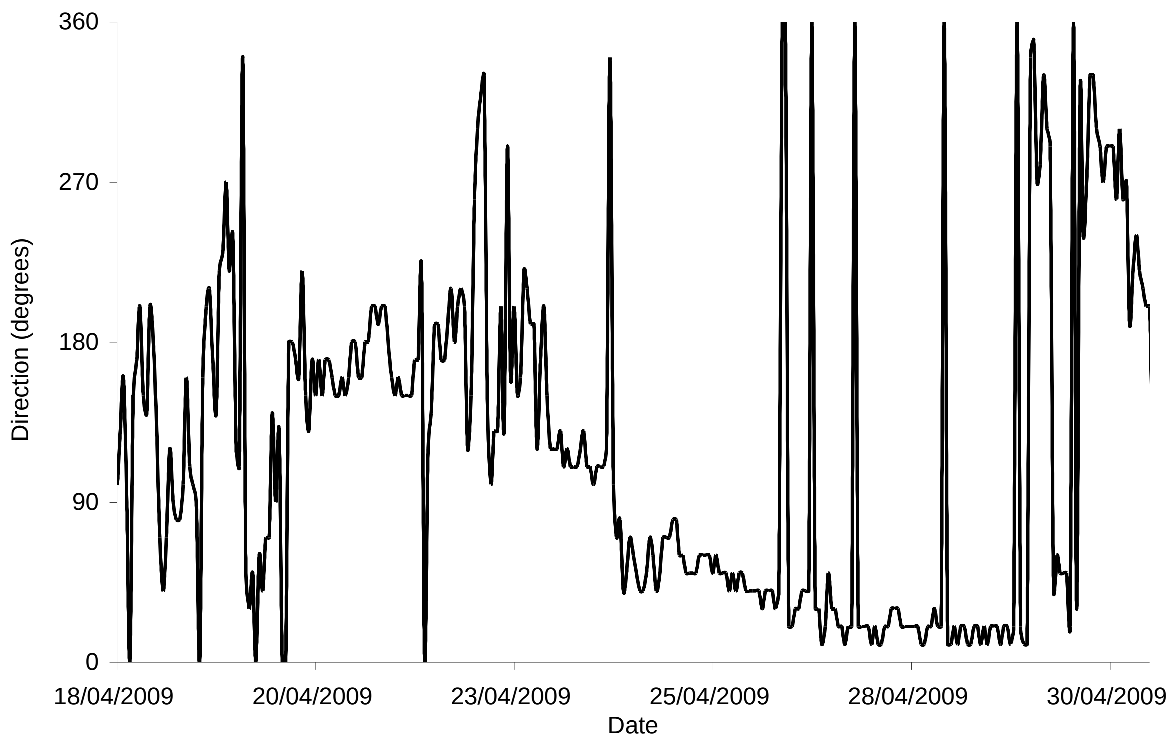


Figure 12. Direction that wind was originating from at Rotorua Airport from 17 April to 1 May, 2009.

Bio-Fish profiles

Figures produced from data arising from Bio-Fish transects through Lake Rotorua, Ohau Channel and Lake Rotoiti have been used to compare 2008 and 2009 in April. Temperature profiles in both are compared in Figure 13. The temperature is warmer in both lakes in April 2008. Lake Rotorua shows little vertical variation of temperature through the water column, with the exception of slightly increased surface temperature at the Ohau Channel end of the lake for both years. Lake Rotoiti is thermally stratified for April 2008 and 2009, with the thermocline presiding at approximately 20 m depth. Water temperature in the surface mixed layer and aligned with the bed of Lake Rotoiti at the western end of the lake is slightly cooler (~0.5^{o}C) for both years.

There is only a record of concentrations of dissolved oxygen (DO) in April 2008 which correspond with the temperature profiles (Figures 13 and 14). However, there is no variation in the dissolved oxygen concentrations horizontally in the surface mixed layer of Lake Rotoiti.

Chlorophyll fluorescence was higher in Lake Rotorua than in Lake Rotoiti in April 2008 and lower in Lake Rotorua than Lake Rotoiti in April 2009 (Figure 15). We attribute decreases in fluorescence in surface waters (0-3 m) in Lake Rotoiti in 2008 and 2009, to the effects of solar quenching; a remnant of bright light near the middle of the day quenching the emission of fluorescence by phytoplankton. In April 2008, there were elevated levels of fluorescence at the eastern side of Lake Rotorua, and on the western basin of Lake Rotoiti adjacent to the lake bed in the surface mixed layer. In 2009, there were elevated levels of fluorescence at the eastern side of Lake Rotorua. On the western basin of Lake Rotoiti adjacent to the lake bed in the surface mixed layer fluorescence levels were very slightly lower. Conductivity is for the most part higher in Lake Rotoiti than in Lake Rotorua and also at the western side of both lakes. In 2009 there are elevated levels in the bottom waters of Lake Rotoiti. The higher conductivity levels at the western end of Lake Rotoiti are concentrated around the region of the diversion wall.

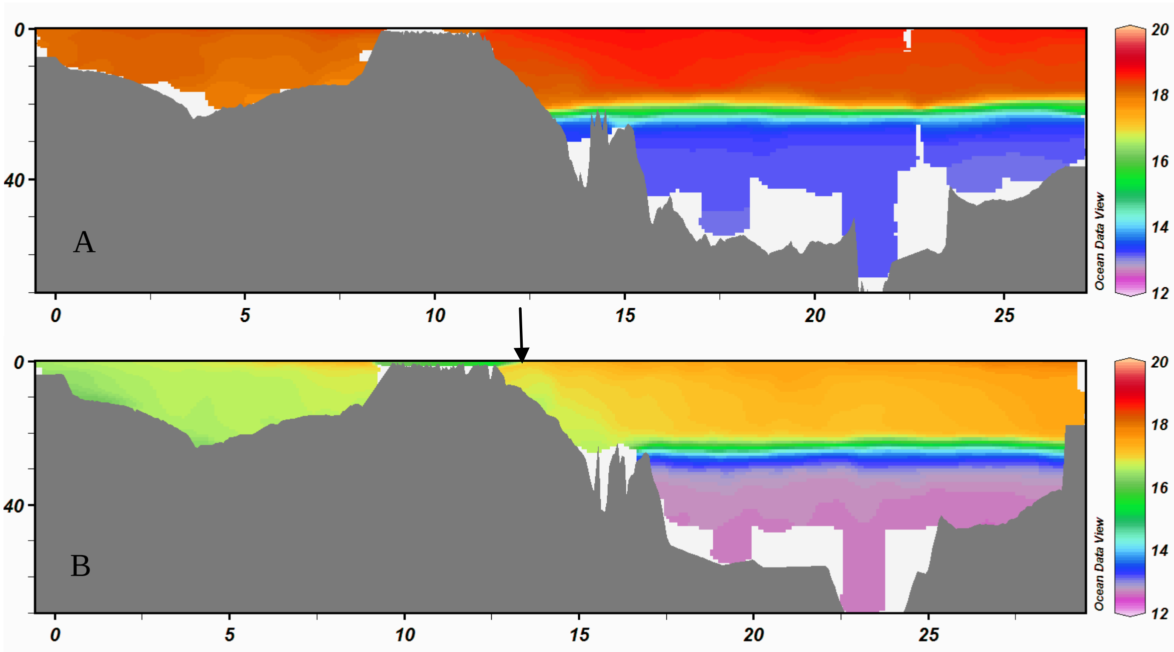


Figure 13. Water temperature (°C) for (A) 12 April, 2008 from a Bio-Fish transect across Lake Rotorua from Ngongotaha to the Ohau Channel (0-8 km), through the Ohau Channel (8-12 km), to the eastern end of Lake Rotoiti (12-27.5 km) and (B) 14 April, 2009 from a Bio-Fish transect across Lake Rotorua from Ngongotaha to the Ohau Channel (0-9.5 km), through the Ohau Channel (9.5-13 km), the diversion channel (13-14.3 km) to the eastern end of Lake Rotoiti (14.3-30 km). The arrow denotes the end of the diversion wall.

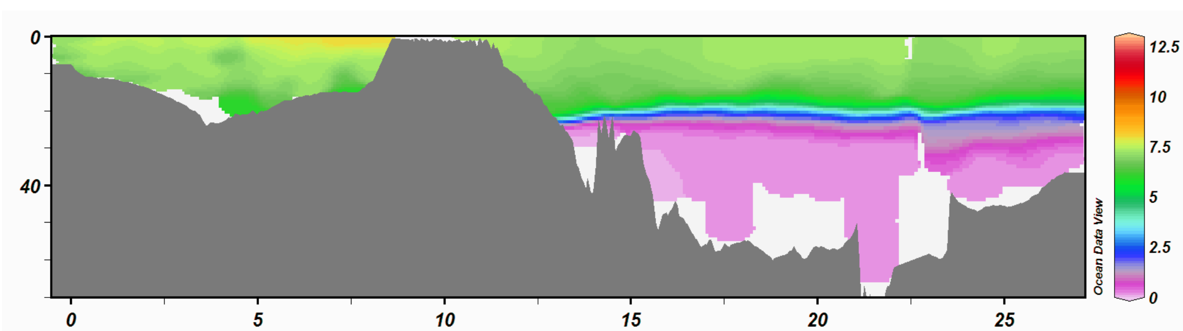


Figure 14. Dissolved oxygen (mg L^{-1}) for 12 April, 2008 from a Bio-Fish transect across Lake Rotorua from Ngongotaha to the Ohau Channel (0-8 km), through the Ohau Channel (8-12 km), to the eastern end of Lake Rotoiti (12-27.5 km)

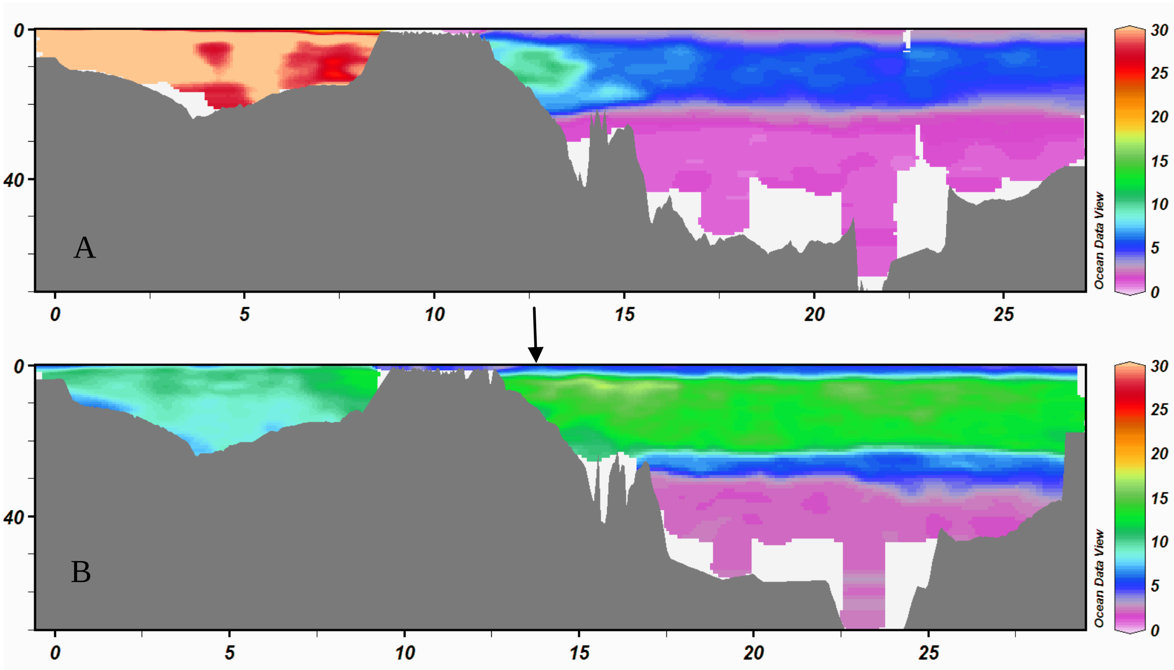


Figure 15. Fluorescence (ug L^{-1}) for (A) 12 April, 2008 from a Bio-Fish transect across Lake Rotorua from Ngongotaha to the Ohau Channel (0-8 km), through the Ohau Channel (8-12 km), to the eastern end of Lake Rotoiti (12-27.5 km) and (B) 14 April, 2009 from a Bio-Fish transect across Lake Rotorua from Ngongotaha to the Ohau Channel (0-9.5 km), through the Ohau Channel (9.5-13 km), the diversion channel (13-14.3 km) to the eastern end of Lake Rotoiti (14.3-30 km). The arrow denotes the end of the diversion wall.

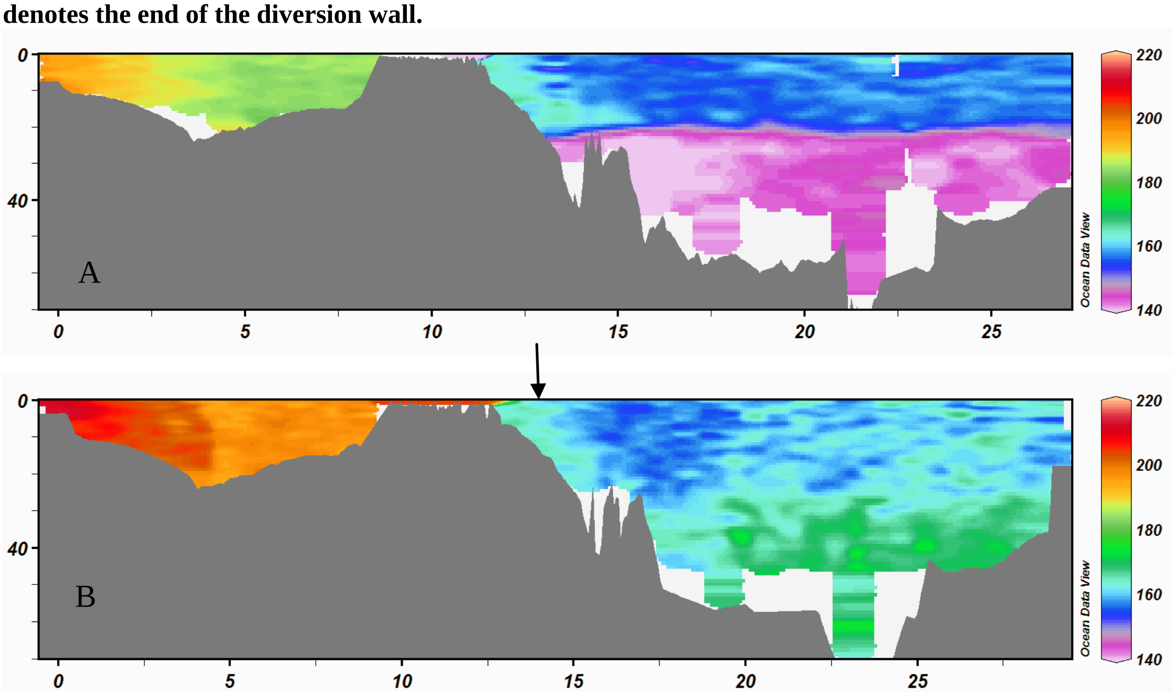


Figure 16. Conductivity (µS cm^{-1}) for (A) 12 April, 2008 from a Bio-Fish transect across Lake Rotorua from Ngongotaha to the Ohau Channel (0-8 km), through the Ohau Channel (8-12 km), to the eastern end of Lake Rotoiti (12-27.5 km) and (B) 14 April, 2009 from a Bio-Fish transect across Lake Rotorua from Ngongotaha to the Ohau Channel (0-9.5 km), through the Ohau Channel (9.5-13 km), the diversion channel (13-14.3 km) to the eastern end of Lake Rotoiti (14.3-30 km). The arrow denotes the end of the diversion wall.

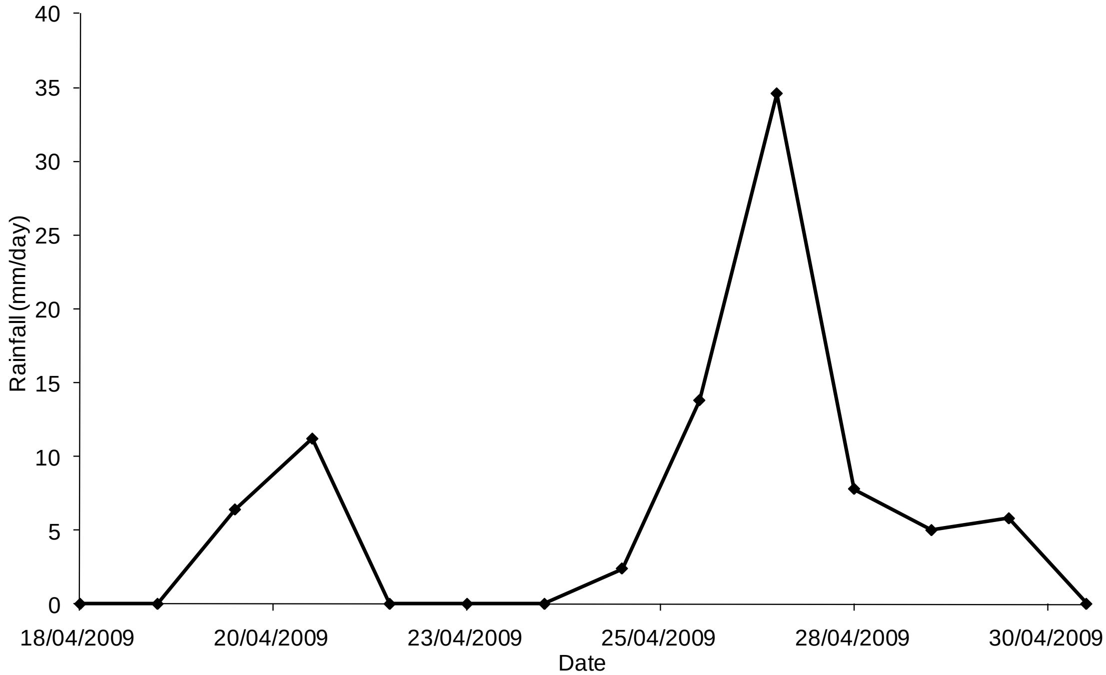
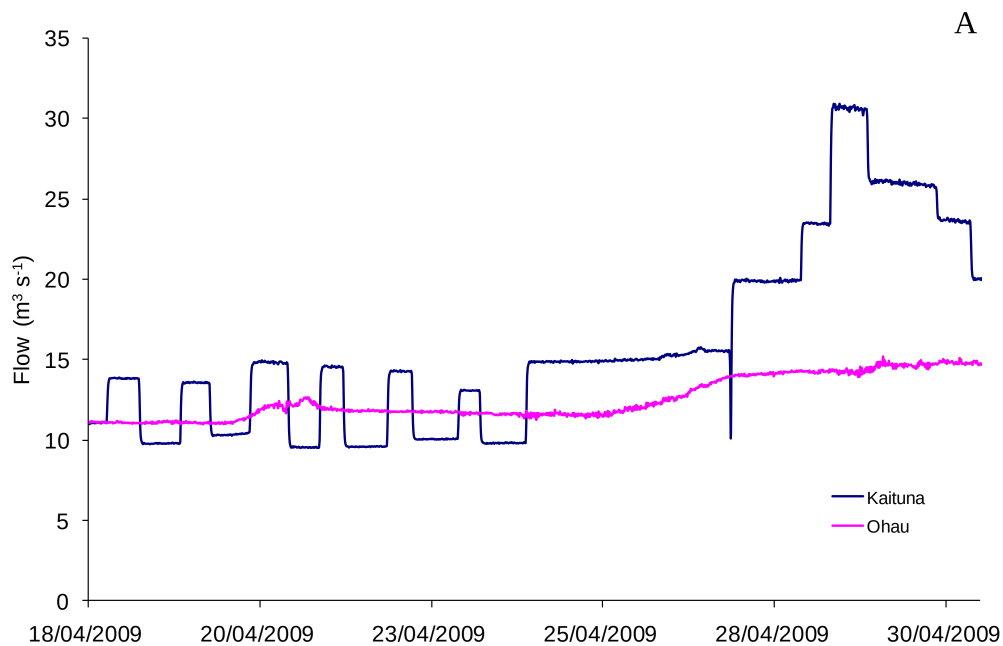


Figure 17. Daily rainfall measured at Rotorua Airport, 17 April to 1 May, 2009.

There was rainfall on eight of the sixteen days during the study period. Rain fell during two defined periods, on 20 and 21 April then for a more prolonged period from 25 to 29 April with the greatest rainfall of 35mm falling on 27 April, 2009.



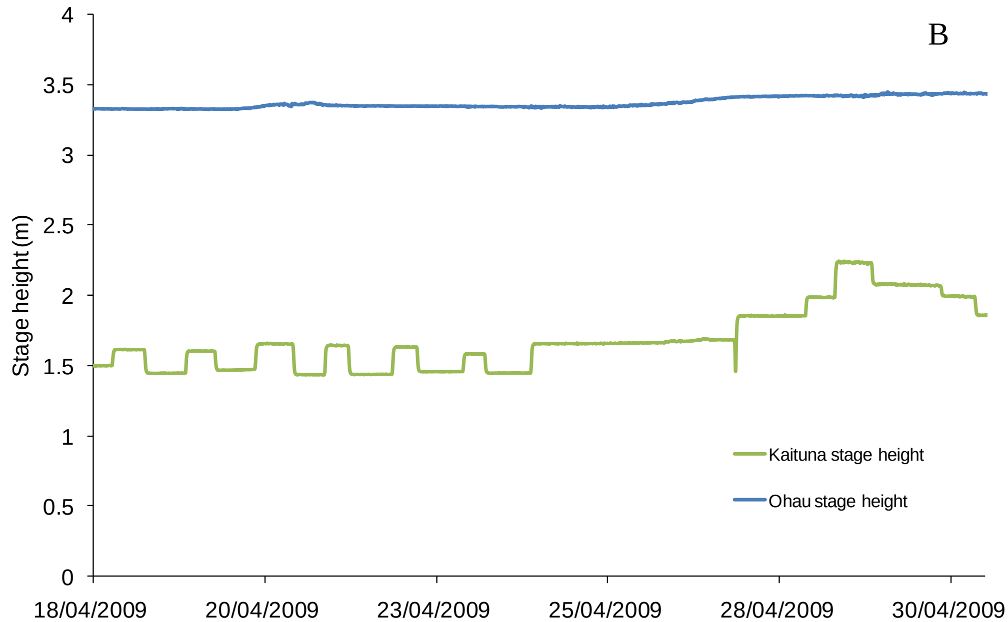


Figure 18. Flow (A) and stage height (B) measured in Kaituna River and Ohau Channel, 17 April to 1 May 2009.

Flow in Ohau Channel ranged between 11 and 15m^3s^{-1} and 9.5 and 30.9m^3s^{-1} for Kaituna River (Figure 18A). Flows in Ohau Channel were lowest at the beginning of our study and increased on 20 and 21 April, peaking at $12.5m^3s^{-1}$. The flow steadily increased from 25 April with peak flow on 29 April at $15m^3s^{-1}$. Flows in Kaituna River were stepped due to the flood gates opening and closing but the overall trend was similar to that in the Ohau Channel with peak flow on 28 and 29 April at $30\text{-}31m^3s^{-1}$. Stage height at the Ohau monitoring site was around 3.33m for 17-19 April, then increased on 20 April and peaked at 3.37m on 21 April, decreased for a while and steadily increased from 24 to 29 April when it reached 3.45m. The difference between the lowest and highest stage height was 12.6 cm. As with the flows, a similar trend occurred with the Kaituna River stage heights (Figure 18B).

Discussion

It is evident from the data collected during this study that water was flowing from the Okere Arm towards the main basin of Lake Rotoiti periodically during April 2009. There are a few possible explanations for the water flowing in the SW to SE direction, towards the lake from the Okere Arm rather than the expected NW to NE direction towards Kaituna River. Wind-induced return-flow may have produced this effect. This is where the current flow just above the lake bed flows ‘into the wind’ in response to wind-stress and it is commonly found in stratified lakes (Webster & Hutchinson, 1994; Stevens and Imberger, 1996). Another possible driver is an underflow produced by a temperature differential. This involves cooler, denser water flowing into warmer and more buoyant receiving water sank and moving downslope just above the bed as an underflow (e.g., Pickrill & Irwin, 1982). A further reason may be increase in water level during winter months producing an increase in the volume of water entering the Okere Falls. At full capacity, that water may back up into the Okere Arm, the diversion channel, Lake Rotorua and Lake Rotoiti.

If wind induced return-flow was in force then it could be expected that the water near the surface was flowing in the same direction as the wind, while water further down in the water column would be flowing in an opposing direction as a result of deflection. Our measurements of the water column profile show the direction of flow at LAKE 1 (Figure 6) ranged from SW to SE, throughout the entire water column. During the two periods (20 and 21 April; 25 to 29 April) when the water was flowing fastest (3.5-4.5cm s^{-1}) at LAKE 1 (Figure 7), the water at all depths was flowing into the wind during the first period. During the second period the wind was flowing in the same direction as the water flow at all depths. For LAKE 2, we only have the data for water currents in the bottom water at a discreet depth. With no surface data, we cannot determine whether a return-flow existed there. At this station, two distinct periods (17-24 April and 24 April to 1 May) for wind direction and water current direction coincide (Figures 8 and 12). During the first period, the water current was travelling almost into the wind but during the second period there appears to be no obvious correlation between wind and water flow direction (Figures 8 and 12).

Stephens (2004) predicted that with a diversion wall in place, there could be a 2.5 cm increase at the downstream end of Ohau Channel under normal conditions and that would be transmitted upstream to Lake Rotorua. We found in this study that there was a 12.6 cm variation in stage height for Ohau Channel (Figure 18B). We consider that with this sort of variance the associated increase in water volume is likely to be transmitted upstream from Okere Falls into Okere Arm, up the channel to Lake Rotorua and also into Lake Rotoiti. Rainfall was the likely catalyst for this increase in stage height as faster flow into Lake Rotoiti at LAKE 1 corresponds with a rainfall event on 20 and 21 April and a more prolonged period of rainfall from 25 to 29 April (Figures 17 and 18). This is only true of the first period for LAKE 2 and not the second period.

Greatest temperature differences between Ohau Channel water and Lake Rotoiti water occurred around 21 and 22 April, then again on 24 April (Figure 4). On both occasions the water at LAKE 1 was flowing towards Lake Rotoiti (SSE; Figure 6). On 21 April, the fastest recorded flow was concentrated towards the bottom of the water column (Figures 6 and7), consistent with an underflow. The existence of underflows during April is confirmed by the Bio-Fish data which shows cooler water flowing into the western basin of Lake Rotoiti. This water is cooler than the surrounding epilimnetic water and can only be explained by water coming from Lake Rotorua (Figure 13B). Fluorescence data affirms this, as in the western basin of Lake Rotoiti adjacent to the lake bed and along the top of the thermocline in the surface mixed layer, levels were lower than the ambient water (Figure 15B). This could only occur through addition of water from an outside source into the lake. The position of the plume of lower fluorescence is where an underflow could be expected to occur.

All proposed drivers have been considered in relation to flow from the Okere Arm into Lake Rotoiti during two periods, 20 and 21 April and 25 to 29 April, at both lake stations. High rainfall, strong wind and a temperature differential coincide during the first period whereas during the second period, there was high and prolonged rainfall and strong wind yet a temperature differential was absent. During the first period, strong winds were going in more or less the opposite direction to the current flow at both LAKE 1 and LAKE 2 but for the second period the wind travelled in the same direction as the current at LAKE 1, yet at LAKE 2 the current moved at approximately 90 degrees to wind direction. There is no clear pattern, thus no evidence of return flows suggesting no clear relationship between wind and ‘leakage’ of water from the diversion channel around the wall into Lake Rotoiti. During the periods of high rainfall, water flowed towards Lake Rotoiti at LAKE 1 and LAKE 2 for the first period but during the second period when there was heavier and more prolonged rainfall then water was flowing towards the lake at LAKE 1 but generally towards the Kaituna River at LAKE 2. Thus, excess rainfall may have influenced flow direction at LAKE 1 but not at LAKE 2. Since flow was predominantly in the SW to SE direction at LAKE 1 but faster during the high rainfall periods then it may have been that the station closer to the end of the wall is affected by backflow at this time of the year. Temperature differential is the factor most obviously linked to water entering Lake Rotoiti from the diversion channel end. During the first period when there was a clear temperature differential between the diversion channel water and the Lake Rotoiti water, water was flowing towards Kaituna River from Lake Rotoiti at both LAKE 1 and LAKE 2. At LAKE 1, the position that the water flowed fastest (near the bed) in the direction of Lake Rotoiti (Figure 7) suggests that this was an underflow and this is corroborated by the Bio-Fish data (Figures 13-16).

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