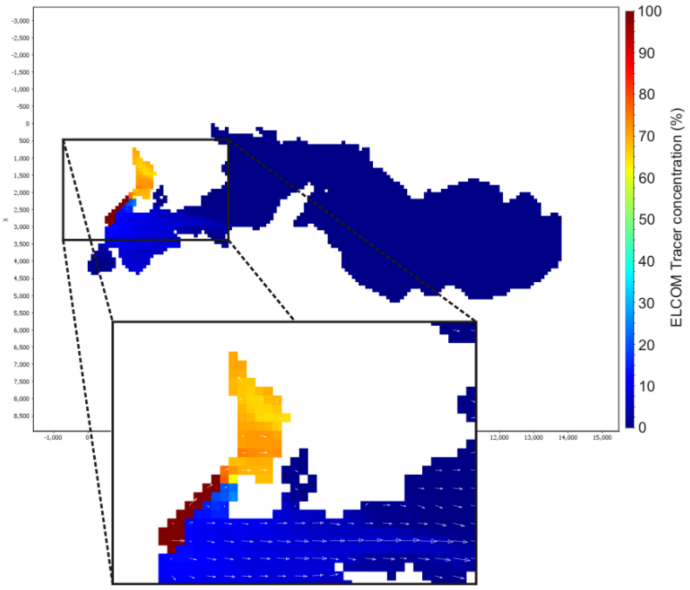
Facilitating rafting on the Kaituna River: The effect of manipulating Lake Rotoiti outflow on the function of the Ohau diversion wall



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Executive Summary

The University of Waikato was requested by Bay of Plenty Regional Council to quantify the effectiveness of the Ohau diversion wall when controlling the Kaituna River outflow during high and low flows. The Ohau diversion wall was constructed to divert nutrient-enriched water from Lake Rotorua away from the main basin of Lake Rotoiti and towards the Kaituna River outflow. Bay of Plenty Regional Council wished to determine whether controlling the Lake Rotoiti outflow to enable rafting on the Kaituna River would impact on the efficacy of the Ohau diversion wall.

The Kaituna River is used for commercial and recreational white-water rafting and kayaking, and is a proposed venue for the 2013 World Rafting Championships. However, control of the Kaituna outflow to regulate the water level in the lake may conflict with the use of the Kaituna River for rafting, which requires discharge to be between minimum and maximum raftable flows (13 $m^3\ s^{-1}$ and 26 $m^3\ s^{-1}$, respectively). Outflow from the lake may be controlled so that flows in the river are within the raftable range for a number of hours a day, and then adjusted for the remainder of the day to prevent high or low water levels. However, it is possible that this may affect the efficacy of the Ohau diversion wall, leading to concerns that this mode of operation could impact on the water quality in Lake Rotoiti. To address these concerns, three-dimensional hydrodynamic modelling was used to quantify the transfer of water from the Ohau channel to Lake Rotoiti under scenarios that facilitated rafting operations. The model was set up so that a tracer (transported by water flow) would be released in the Ohau inflow for the duration of the simulation. Tracer concentrations were output from the model simulations as depth profiles for five stations in the lake to quantify the transport of water from the Ohau channel into Lake Rotoiti.

Tracer concentrations at the five stations in Lake Rotoiti were compared between the baseline scenario (i.e. measured inflow and outflow data for October-November 2010) and flow and rafting scenarios. These involved high (29 $m^3\ s^{-1}$) or low (8 $m^3\ s^{-1}$) flows through the Ohau channel (that would be above or below the maximum or minimum raftable flows, respectively), and manipulation of the Rotoiti outflow for 4 hours each day to facilitate rafting on the Kaituna River. Tracer concentrations output from model simulations indicate that there is potential for significant transfer of Lake Rotorua water to the main basin of Lake Rotoiti under sustained high flows through the Ohau channel. For example, at the Narrows, the tracer concentration under high flows was 0.5% above the baseline after 1 week, but nearly 4% above baseline after 8 weeks. In contrast, sustained low flows result in less water transported to the main basin of Lake Rotoiti than under the baseline scenario (c. 5% below baseline after 8 weeks). However, the influence of manipulating the outflow (for 4 hours each day) to facilitate rafting operations appears to be relatively minor, compared to the effect of the high or low flows. The difference in mean tracer concentration between the high flow scenario and the rafting, combined with high flows, was $< 0.12\%$ for all stations. Similarly, the difference between the low flow scenario and the rafting combined with low flows was $< 0.10\%$ for all stations.

Model output of surface tracer concentrations indicates there may be an effect of controlling the Rotoiti outlet flow for rafting in the vicinity of the diversion wall. This output indicates there may be some backflow around the Ohau diversion wall (into the Rotoiti main basin) under high flows, during the period of time when outflow is controlled for rafting. This effect is short-lived and there is no evidence that it has a significant effect on tracer concentrations in the stations in the lake. However, the model scenarios cannot indicate the effect of controlling the outflow for more than 4 hours on potential backflow around the diversion wall. Overall, model scenarios indicate that, although

sustained high flows do result in increased transfer and backflow around the Ohau diversion wall, controlling the outflow to facilitate rafting for 4 hours per day is unlikely to contribute large increase in volume of Lake Rotorua water to Lake Rotoiti.

Acknowledgements

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Introduction

The University of Waikato was requested by Bay of Plenty Regional Council to quantify the effectiveness of the Ohau diversion wall in Lake Rotoiti when controlling the Kaituna River outflow during high and low flows. The Ohau diversion wall was constructed to divert nutrient-enriched water from Lake Rotorua towards the Okere Arm in Lake Rotoiti (and then the Kaituna River outflow), thereby by-passing the main basin of Lake Rotoiti. Water quality has improved in Lake Rotoiti since the installation of the Ohau diversion wall; prior to wall construction the lake was classified as eutrophic, but is now mesotrophic (Scholes, 2011). Bay of Plenty Regional Council wished to determine whether controlling the Lake Rotoiti outflow to enable rafting on the Kaituna River would impact on the efficacy of the Ohau diversion wall, potentially affecting water quality in the main lake basin.

The Kaituna River is the only surface outflow from Lake Rotoiti. It is used for commercial and recreational white-water rafting and kayaking, and is a proposed venue for the 2013 World Rafting Championships (13-24 November 2013). Control of the Kaituna outflow at the Okere gates regulates the water level in Lake Rotoiti to within a 400 mm consented range, thereby regulating the discharge from Lake Rotoiti to the Kaituna River (e.g. Britton and Wickramanayake, 2010). Operation of the Okere gates for these objectives may conflict with use of the Kaituna River for rafting, which requires discharge to be between 13 m^3 s^{-1} (the minimum raftable flow) and 26 m^3 s^{-1} (the maximum raftable flow). For example, during flood events, the outflow from Lake Rotoiti may be increased to prevent undesirably high lake levels, resulting in flows in the Kaituna River that are above the maximum raftable flow, preventing rafting operations. Previously, outflow through the Okere gates has been controlled so that flows in the river are below the maximum raftable discharge for a number of hours a day to allow rafting, and then increased above the maximum raftable discharge for the remainder of the day to prevent high water levels (Figure 1). However, it is possible that this may result in backflow of water from the Ohau channel around the diversion wall and into the main body of Lake Rotoiti (during the period of time when outflow is restricted to be below the maximum raftable flow), leading to concerns that this type of manipulation of the outflow to facilitate rafting operations could impact on the water quality in Lake Rotoiti.

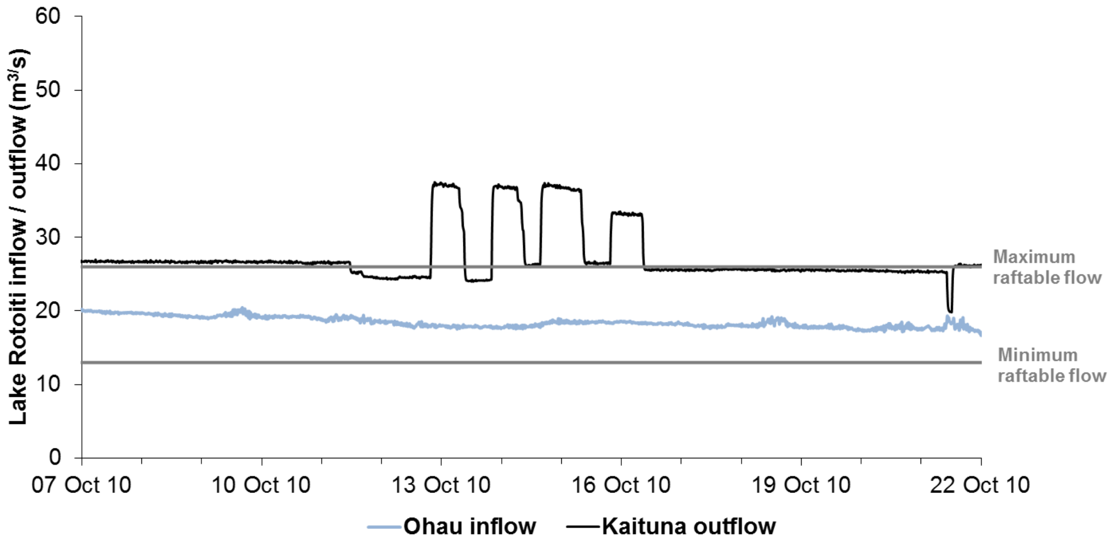

Figure 1: Lake Rotoiti inflow (through Ohau channel) and outflow (measured data) showing manipulation of Kaituna outflow to be below the maximum raftable flow for several hours each day between 13/10/2010 and 15/10/2010.

The aim of this study was to use three-dimensional hydrodynamic modelling to quantify the transfer of water from the Ohau channel to Lake Rotoiti under scenarios that facilitated rafting operations. 3D hydrodynamic modelling of Lake Rotoiti has previously been applied to determine the implications of different operation water level regimes on the operation of the Ohau channel diversion wall (Muraoka et al., 2010). This report summarises the results of simulations using a similar model setup as used in Muraoka et al (2010).

Methods

Study site

Lake Rotoiti is a large (surface area 34.6 km^2), deep (max. depth 124 m, mean depth 31 m), monomictic, mesotrophic lake located c. 279 m above sea level (m a. s. l.) in the Bay of Plenty region of New Zealand (von Westernhagen et al., 2010). Surface inflows are derived from coldwater or geothermal springs, except for the main surface inflow, which flows into the western basin of Lake Rotoiti through the Ohau channel from eutrophic Lake Rotorua (Scholes, 2009). The only surface outflow from Lake Rotoiti is the Kaituna River, at the northern end of the western basin. The Lake Rotoiti catchment is predominantly in exotic forestry (46%) and indigenous forest/scrub (36%), with smaller amounts of pasture (16%) and urban (2%).

Model description and setup

In this study the three-dimensional (3D) model ELCOM (Estuary, Lake and Coastal Ocean Model) was used to simulate hydrodynamics in Lake Rotoiti. ELCOM was developed by the Centre for Water Research in Western Australia and is based on the unsteady, viscous Navier-Stokes equations for incompressible flow (Hodges and Dallimore, 2011). The Lake Rotoiti ELCOM model was set up as in a previous application (Muraoka et al., 2010), but with finer grid resolution (100 x 100 m *cf.* 200 x 200 m).

Inflow data was derived from measured inflow (for the Ohau channel) and outflow, with minor surface inflows calculated from an otherwise complete water balance (Muraoka et al., 2010). Hourly meteorological data (i.e. rainfall, wind speed and direction, solar radiation, air temperature, relative humidity and cloud cover) were acquired from NIWA's Cliflo service (National Institute of Water and Atmospheric Research National Climate database, http://cliflow.niwa.co.nz) for the Rotorua Aero Automated Weather Station. The model was run at a 150 s time step for a nine-week period between 01/10/2010 and 02/12/2010, and there was good agreement between measured and modelled water level under this baseline scenario (R^2 0.99; MAE 0.003 m; Figure 2).

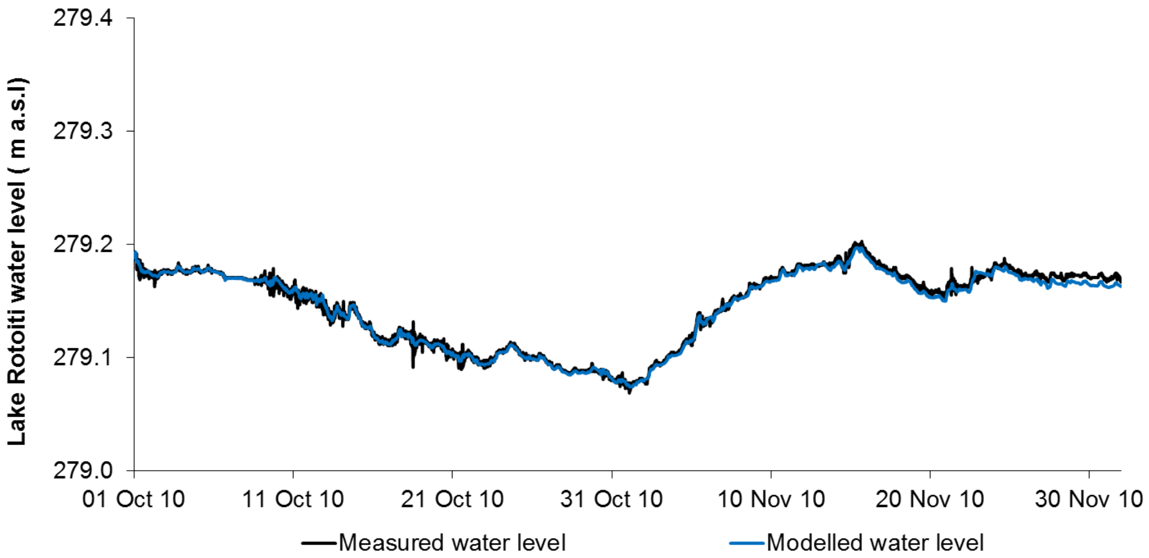

Figure 2: Measured and modelled (ELCOM) water level in Lake Rotoiti between 01/10/2010 and 02/12/2010 under the baseline scenario

ELCOM allows provision for simulation of a tracer that is transported by water flows, and the model was set up so that a tracer would be released in the Ohau inflow for the duration of the simulation. As in the previous study by Muraoka et al. (2010), tracer concentrations were output from the ELCOM simulations as depth profiles for five stations in the lake to quantify the transport of water from the Ohau channel into Lake Rotoiti (Figure 3).

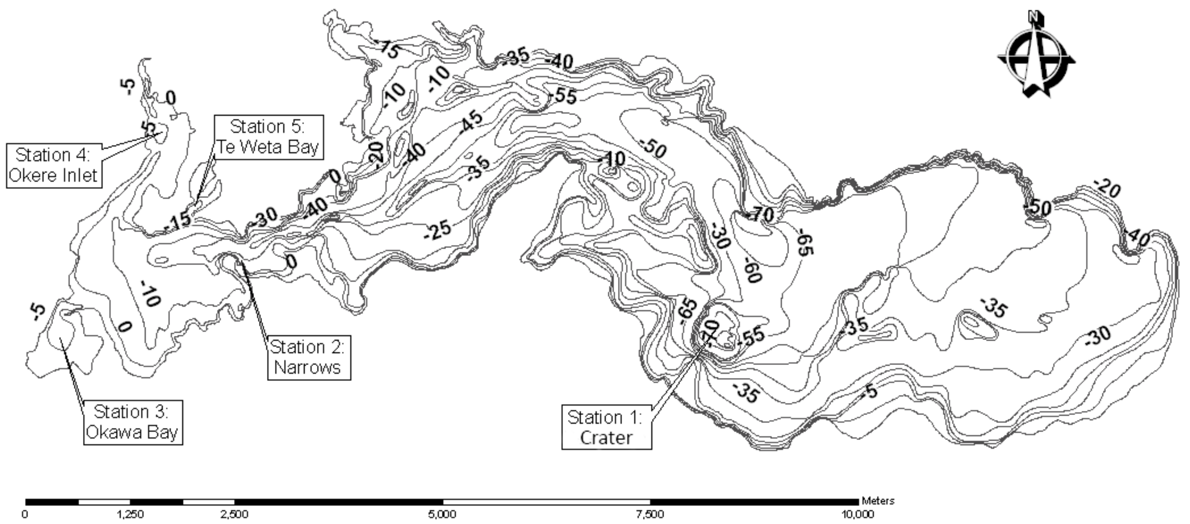

Figure 3: Lake Rotoiti bathymetry and location of stations output from ELCOM model simulations (from Muraoka et al., 2010).

Scenarios

Bay of Plenty Regional Council requested scenarios to be simulated that involved high or low flows through the Ohau channel (that would be above or below the maximum or minimum raftable flows, respectively), and manipulation of the outflow for 4 hours a day to facilitate rafting on the Kaituna River. Four scenarios were conceptualised as follows:

1) **No rafting with Ohau high flow scenario.** This scenario assumes flow through the Ohau channel is 29 $m^3 s^{-1}$ and calculates outflow for the Kaituna River based on a water balance to prevent water levels exceeding consent limits.
2) **No rafting with Ohau low flow scenario.** This scenario assumes flow through the Ohau channel is 8 $m^3 s^{-1}$ and calculates outflow for the Kaituna River based on a water balance to prevent water levels exceeding consent limits.
3) **Rafting with Ohau high flow scenario.** This scenario assumes flow through the Ohau channel is 29 $m^3 s^{-1}$ and prescribes an outflow of 26 $m^3 s^{-1}$ (i.e. the maximum raftable flow on the Kaituna River) for 4 hours per day. Outflow for the remaining 20 hours is calculated based on a water balance to prevent water levels exceeding consent limits.
4) **Rafting with Ohau low flow scenario.** This scenario assumes flow through the Ohau channel is 8 $m^3 s^{-1}$ and prescribes an outflow of 13 $m^3 s^{-1}$ (i.e. the minimum raftable flow on the Kaituna River) for 4 hours per day. Outflow for the remaining 20 hours is calculated based on a water balance to prevent water levels exceeding consent limits.

Each scenario was simulated with a 1 week model "warm up" period with baseline data (from 01/10/2010 0:00 h to 07/10/2010 23:59 h), with a further 8 weeks under scenario conditions (from 08/10/2010 0:00 h to 03/12/2010 0:00 h). Comparison of the "no rafting" and "rafting" scenarios under both high and low flows should allow separation of the effect of the high/low flows from the effect of the high/low flows combined with manipulation of the outflow for rafting.

Results and discussion

Tracer concentrations at stations in Lake Rotoiti

Tracer concentrations for each station are illustrated in Figure 4. Mean tracer concentrations (Table 1) show that, compared to the baseline scenario, the Ohau high flow scenario (without rafting) does result in more water being transported from the Ohau channel to Lake Rotoiti. The Ohau low flow scenario (without rafting) results in less water being transported to Lake Rotoiti, than under the baseline scenario. This is consistent with results in Muraoka et al. (2010) which indicated higher tracer concentrations in wet years (i.e. high flows), compared to dry years (i.e. low flows). Therefore, sustained high flows through the Ohau channel have the potential for significant transfer of Lake Rotorua water to Lake Rotoiti. For example, at the Narrows, the tracer concentration under high flows was 0.5% above the baseline after 1 week, but nearly 4% above baseline after 8 weeks (Table 2). However, the influence of manipulating the outflow (for 4 hours a day) to facilitate rafting operations appears to be relatively minor, compared to the effect of the high or low flows. The difference in mean tracer concentration between the high flow scenario and the rafting, combined with high flows, was < 0.12 % for all stations. Similarly, the difference between the low flow scenario and the rafting combined with low flows was < 0.10% for all stations.

Table 1: Mean percentage of tracer concentration based on input from the Ohau Channel (100%) for five stations in Lake Rotoiti for the baseline scenario (01/10/2010 – 02/12/2010), Ohau high flow and Ohau low flow scenarios, and rafting combined with Ohau high flow and Ohau low flow scenarios.

Scenario	*Station 1 Crater - surface*	*Crater - bottom*	*Station 2 Narrows*	*Station 3 Okawa Bay*	*Station 4 Okere Inlet*	*Station 5 Te Weta Bay*
Baseline	0.88	0.45	7.50	6.67	48.56	5.09
Ohau high flow	1.02	0.55	9.29	7.59	62.96	5.59
Ohau low flow	0.67	0.31	5.41	5.19	36.10	4.03
Rafting and Ohau high flow	1.01	0.56	9.27	7.52	62.86	5.71
Rafting and Ohau low flow	0.67	0.32	5.42	5.22	36.19	4.04

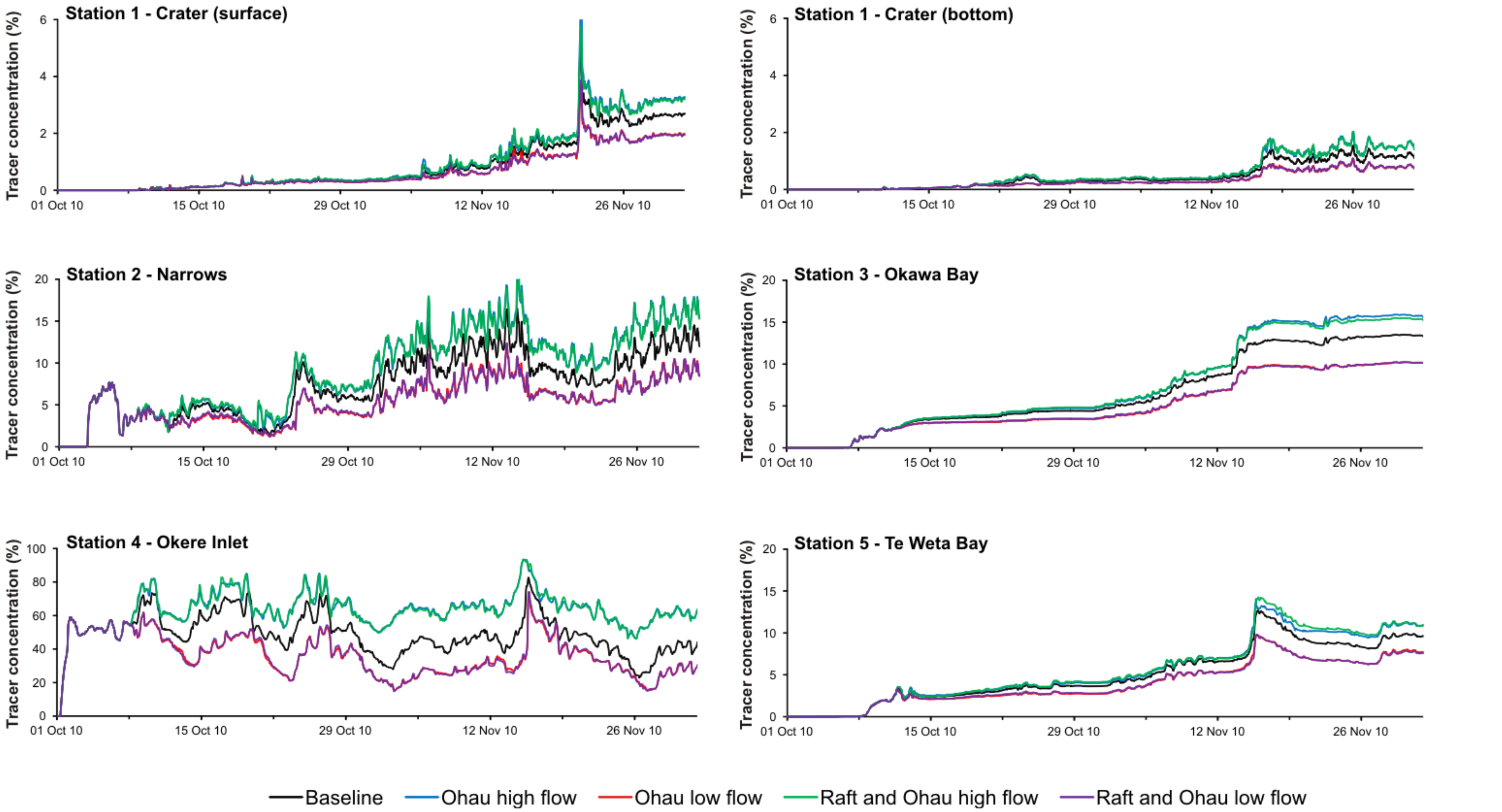

Figure 4: Tracer concentration as a percentage of input from the Ohau Channel (100%) at five stations in Lake Rotoiti for baseline scenario (black lines), Ohau high flow scenario (blue lines), Ohau low flow scenario (red lines), rafting combined with high flows (green lines) and rafting combined with low flows (purple lines). N.B. For flow and rafting scenarios the first week of the simulation used baseline data to provide a model "warm up" period.

Tracer concentrations close to the Ohau diversion wall

The only indication of an effect from controlling the flow for rafting is in the vicinity of the diversion wall. Model output of surface sheet tracer concentration and current velocity indicate that there may be small differences in tracer concentration near the northern end of the Ohau diversion wall between the high flow scenario and the rafting combined with high flow scenario (Figure 5). The rafting scenarios were setup to control the outflow each day between 12 pm and 16 pm. Thus, the output in Figure 5 (15:30 h on 13/10/2010) represents the tracer concentrations and current velocity towards the end of this “outflow controlled” period (and therefore the time at which any potential backflow into the main body of Rotoiti is likely to be greatest). Tracer concentration is slightly higher (c. 30 – 40% cf. 20 – 30%) on the eastern side of the end of the wall when outflow is controlled for rafting. However, this effect is short-lived (there was little difference between the two scenarios just several hours later, when outflow was not controlled) and there no evidence that this minor backflow has a significant effect on tracer concentrations in the stations in the lake (Figure 4). However, it should be noted that under sustained high flows there may be potential for visible backflow of water around the Ohau diversion wall, particularly if the outflow to the Kaituna River is reduced to facilitate rafting. Furthermore, these scenarios cannot indicate the effect of controlling the outflow for more than 4 hours on potential backflow around the diversion wall. Finally, although the current model is likely to be suitable for comparisons between scenarios, the absolute amount of water transferred from the Ohau channel in a model simulation will be a function of both model setup (i.e. grid size and the diversion wall configuration) and inflow volume though the Ohau channel. Future study could be directed towards validating a model grid and configuration with a field tracer study if quantification of the absolute amount of water transferred from the Ohau channel to Lake Rotoiti is deemed an important component of lake management.

Conclusions

In this study, the 3D hydrodynamic model ELCOM was used to simulate the effect of various scenarios on the efficacy of the Ohau diversion wall, which was installed to reduce the transfer of nutrient-enriched water from Lake Rotorua to Lake Rotoiti. The scenarios simulated involved high or low flows through the Ohau channel (that would be above or below the maximum or minimum raftable flows, respectively), and manipulation of the outflow for 4 hours a day to facilitate rafting on the Kaituna River. Overall, model scenarios indicate that, although sustained high flows do result in increased transfer and backflow around the Ohau diversion wall, controlling the outflow to facilitate rafting for 4 hours per day is unlikely to significantly affect the transfer of Lake Rotorua water to Lake Rotoiti.

Table 2: Tracer concentration for the Narrows station for the baseline, flow and rafting scenarios at the beginning of the simulation (time = 0 days) and after time = 7, 14, 28, and 56 days (i.e. 1, 2, 4 and 8 weeks).

	Tracer concentration at Narrows station (%) at time (days)				
Scenario	*0*	7	14	28	56
Baseline	3.61	5.13	2.26	10.17	15.09
High flows	3.61	5.63	2.97	12.47	19.02
Low flows	3.61	3.71	1.62	7.31	10.40
Raft and high flows	3.61	5.68	3.20	12.55	18.89
Raft and low flows	3.61	3.92	1.73	7.47	10.33

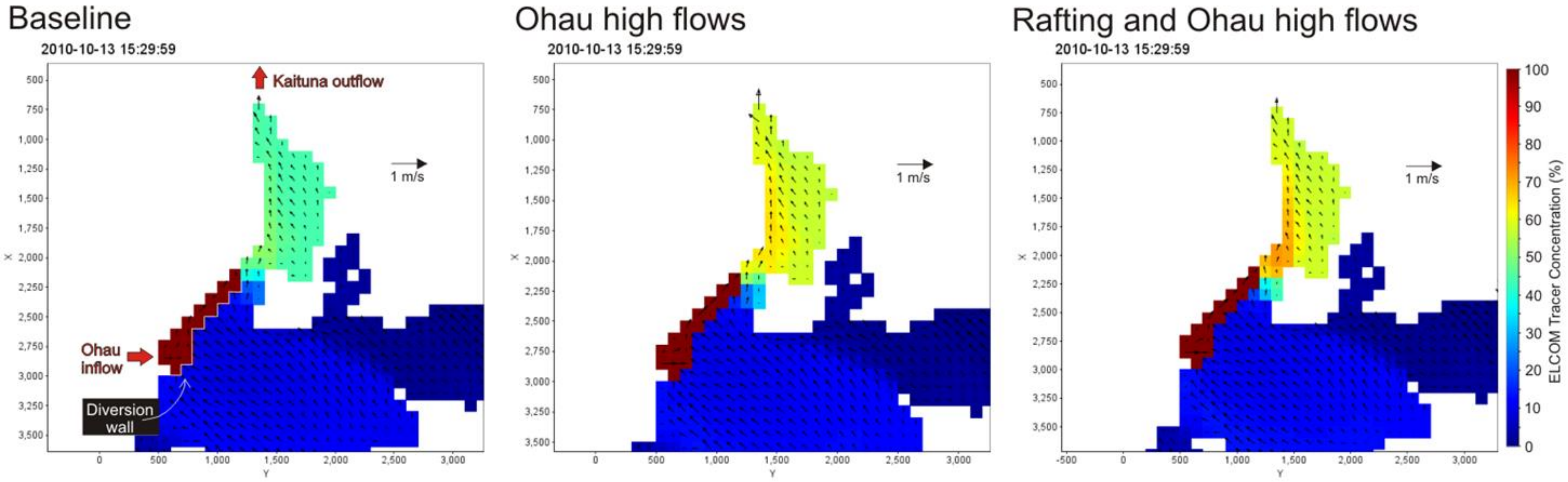

Figure 5: Tracer concentrations in the eastern basin of Lake Rotoiti under the baseline scenario, Ohau high flows scenario and rafting combined with Ohau high flows scenario, for 13th October 2010 at 15:59 (i.e. towards the end of the 4 hour period when outflow was controlled to reduce flow below maximum raftable flow).

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