Effect of different operational regimes of Okere Gates on the effectiveness of the Ohau Channel diversion wall in Lake Rotoiti

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Prepared for Environment Bay of Plenty

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Executive Summary

The Centre for Biodiversity and Ecology Research was requested by Environment Bay of Plenty (EBoP) to present model results that demonstrate the water flow implications of four different water level operational regimes in Lake Rotoiti. The aim was to quantify the proportion of nutrient-enriched Lake Rotorua water being transported from Ohau Channel around the diversion wall and into Lake Rotoiti. Environment Bay of Plenty did not wish to compromise the effectiveness with which the wall diverted this nutrient-enriched water from Rotorua directly to the Kaituna River.

Lake Rotoiti water level is regulated by Okere Gates which control water flowing into Kaituna River, and to a lesser extent by the Ohau Channel weir. The proposed consented levels and ranges (all levels as RL Moturiki Datum) include a maximum consented level of 279.40 m minimum consented level 279 m thus a 400 mm consented range. The proposed operational strategy allows for operational levels to rise above 279.25 m for a maximum of 5% of each year in extreme events and with a target operational range of 200 mm between 279.05 m and 279.25 m, with the following distribution:

- 5-10% of each year between 279.20 and 279.25 m.
- At least 80% of each year between 279.10 and 279.20 m.
- 5-10% of each year between 279.05 and 279.10 m in the months of May to July.

The three dimensional water quality model, ELCOM-CAEDYM, was used to simulate the four different operational schemes. Inputs include inflows and outflows provided by EBoP, rainfall, amd wind speed and direction, solar radiation, air temperature, cloud cover and relative humidity. The inflows and outflows varied in accordance with each of the operational regimes; 'Status Quo' representing the current scheme, the 'Preferred' option which involved a modest amount of water level variation both seasonally and over shorter time scales driven by variation in Ohau Channel flow, the 'Natural' scenario where no structures were in place and a 'Low Weir' option. For the simulations, a tracer was used to track the flow of Rotorua water into Lake Rotoiti. Concentrations were measured at four lake stations and immediately at the end of the wall within the Okere Arm. The tracer was released within the Ohau Channel. The model simulation outputs included water levels and tracer concentrations within the lake.

With a Low Weir in place, Lake Rotoiti would receive the least water from Lake Rotorua (0.02-0.025% for five selected stations throughout the lake) of all four options with this regime producing low water levels and wide fluctuations (0.51-0.71m). Water levels were within the target ranges for

the proposed operational strategy for only 23% of the time and below the target range for 72% of the time.

Under the Natural scenario, a small proportion of Lake Rotorua water entered Rotoiti (0.07-0.11%) but more than the Low Weir option. The water level was generally high and there were also large fluctuations (0.5 to 0.71 m). Water levels were within the proposed target range for 49% of the time and above the target range for 36% of the time.

The current operational regime, Status Quo, allowed more Rotorua water into Lake Rotoiti (0.25-0.5%) than any other scenario but the maximum proportion was 3.2% of the original. Under this scheme, water levels underwent smaller fluctuations (0.24-0.35 m) and were within the target ranges for the proposed operational strategy for 96% of the time, but there was a greater proportion in the lower part of this range.

The Preferred option allowed less Rotorua water into Lake Rotoiti (0.21-0.39%) than the Status Quo case, yet more than the Natural and Low Weir scenarios. Also, the level of fluctuation (0.24-0.43 m) was greater than those experienced at present but not as extreme as those of the other two schemes. Water levels were maintained within the target range for 93% of the time and above the target range for 7% of the time. Of all scenarios, this option was the closest match to the proposed operational ranges. Water level fluctuations were less than for the Natural and Low Weir scenarios but were slightly greater than those experienced at present.

Whilst the Preferred option increased fluctuations in water level, the fluctuations were not as exaggerated as those produced by the Low Weir and Status Quo scenarios. This option further reduces the quantity of Lake Rotorua water going into Lake Rotoiti which in turn should reinforce the effects of the diversion wall in improvements in water quality of Lake Rotoiti over time. Cultural, ecological and socio-economic effects are beyond the scope of this report, but we recognise that the assessment we present here should be considered alongside those effects.

Introduction

The Centre for Biodiversity and Ecology Research was requested by Environment Bay of Plenty to present model results that demonstrate the water flow implications on the operation of the Ohau Channel diversion wall of different water level operational regimes in Lake Rotoiti. The Ohau Channel diversion wall was completed in mid-July 2008 (Hamilton et al., 2009). The wall is 1,275 m in length and diverts nutrient-enriched water from Lake Rotorua towards the Okere Arm in Lake Rotoiti, and is intended to short-circuit water in the Ohau Channel into the Kaituna River, by-passing the main basin of Lake Rotoiti. Water quality of Lake Rotoiti has been adversely affected by deterioration in water quality of Lake Rotorua which became evident in the 1960s (Vincent, 1984; Hamilton, 2004). With the diversion wall in place a large fraction of the water from Rotorua goes directly to the Kaituna River. Thus there is an estimated reduction of nutrient loads of 17 tonnes TP yr^{-1} and 164 tonnes TN yr^{-1} (Hamilton, 2004). Water quality improvements have been reported since the completion of the Ohau Channel wall, with Lake Rotoiti now classified as mesotrophic, an improvement from its eutrophic state immediately prior to the wall construction (Scholes, 2009).

Lake Rotoiti water level is regulated by Okere Gates (constructed in 1982) which controls the water flowing into Kaituna River and to a much lesser extent by the Ohau Channel weir (constructed in 1989) where water leaves Lake Rotorua. The Okere Gates are at the northern end of the Okere Arm. Prior to the gates being built, the outflow from Lake Rotoiti was controlled only by a rock ledge weir approximately 35 m downstream of the present gates. Under the terms of resource consent 02 4504, Environment Bay of Plenty operates the Okere Gates so that the water level in Lake Rotoiti is maintained within a target level of 279.150 ± 0.075 m, with a maximum limit of 279.44 m and minimum limit of 278.89 m above Moturiki Datum or mean sea level. Currently, the level is generally maintained so that the monthly variation is c. 0.05-0.1 m, whereas prior to 1982 inter-annual variation was commonly around 0.2-0.5 m and seasonal variations were approximately 0.2 m (Hawes, 2003). The proposed consented levels and ranges (all levels in metres RL Moturiki Datum) comprise a maximum consented level of 279.40 m, minimum consented level 279.0 m, thus 400 mm consented range. The proposed operational strategy allows for operational levels to rise above 279.25 m for a maximum of 5% of each year in extreme events and will a target operational range of 200 mm between 279.05 and 279.25 m with the following distribution:

- 5-10% of year between 279.20 and 279.25 m.
- At least 80% of year between 279.10 and 279.20 m.
- 5-10% of year between 279.05 and 279.10 m in the months of May to July.

The resource consent for the current regime of operation of the Okere Gates expired on 30 June, 2010. Environment Bay of Plenty wishes to examine different potential operational regimes that would affect water levels in Lake Rotoiti. These regimes include re-establishment at varying degrees of the natural seasonal lake level fluctuations (prior to 1982) that may allow reformation to some extent of the natural sandy shoreline (Aurecon, 2009). For whatever water level and flow regime adopted, it is of fundamental importance that the investment in the wall infrastructure and its apparent effectiveness in improving water quality of Lake Rotoiti (Hamilton et al., 2009) are not compromised through a water level operational regime that allows substantial quantities of water from the Ohau Channel to flow around the diversion wall and into the main basin of Lake Rotoiti.

This report summarises the results of a three dimensional hydrodynamic model simulation which was used to examine the fate of water from the Ohau Channel and its potential to affect water quality in Lake Rotoiti, in response to four different operational regimes for Okere Gates over four years which included years with differing quantities of rainfall (Figure 1).

Methods

1.1 Study site

Lake Rotoiti (38°S, 176°E) is a large (area = 34.6 km^2), long (max. length = 13.24 km) lake with a mean depth of 31 m. It is located within the Okataina Volcanic Centre of central North Island, New Zealand (Nairn, 2002), a volcanically active region which contributes to a geothermal influence. In addition to water entering from the Ohau Channel, Lake Rotoiti receives water from its immediate catchment through coldwater and geothermal springs. The latter enter in specific marginal areas of the lake as well as in a geothermally active region of the deeper lake bed. The Kaituna River is the only outflow from Lake Rotoiti (Vincent, 1984; Priscu et al., 1986).

1.2 Data sources and scenarios

Three years were selected to represent different rainfall years: 1998 and 2001 as wet years, 1999 as an average year, and 2000 as a dry year (Figure 1).

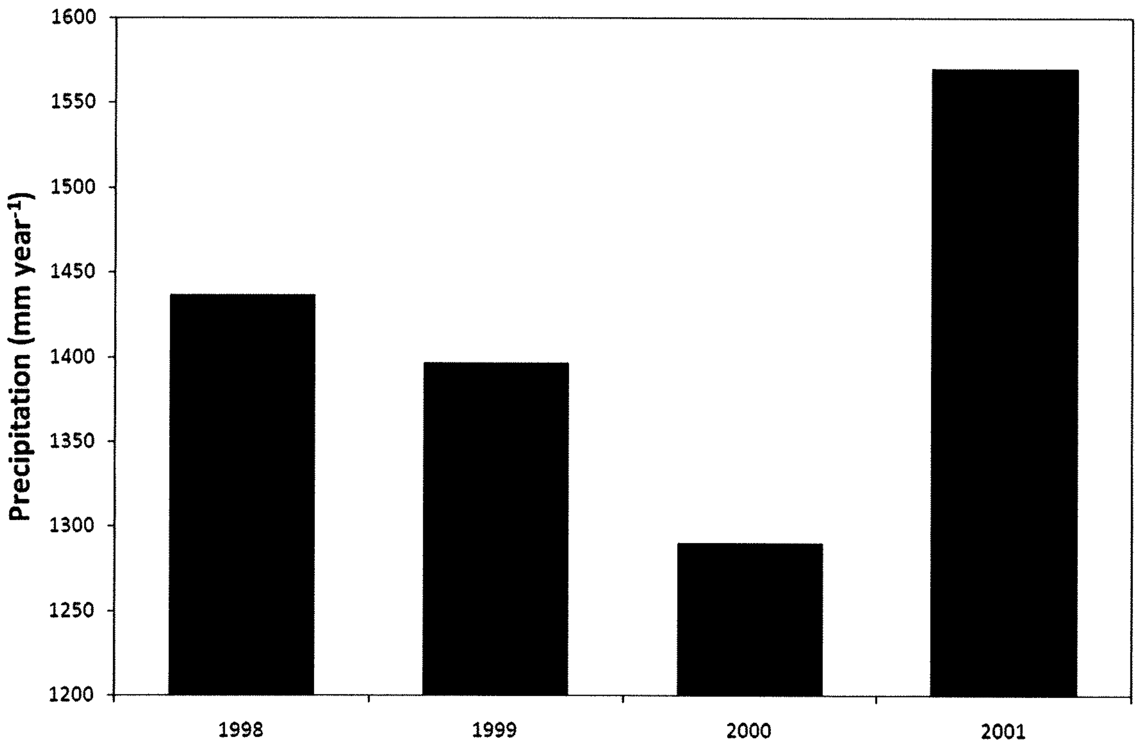

Figure 1. Total annual rainfall for 1998, 1999, 2000 and 2001. Data from Rotorua Aero automated weather station.

Four different water level operational scenarios were provided by Environment Bay of Plenty. The first, 'Status Quo', corresponded to the current operational regime. The 'Low Weir' scenario represented a low weir located where the Okere Gates are at present and was used to simulate pre-structure Lake Rotoiti levels with water levels slightly lower than the current values, and the third, 'Preferred' option to a scenario using a modest amount of water level variation both seasonally and over shorter time scales driven primarily by variations in the Ohau Channel flow. The fourth scenario, 'Natural', was one with no structures in place. Each of these flow scenarios was run from 1998 to 2001, which included different volumes of rainfall for each year, thus including natural variability. The average inflow and outflow data used for the model input over the four years (1998-2001) was provided by Environment Bay of Plenty (Figure 2).

For the purposes of the model simulation, rainfall, wind speed and direction, solar radiation, air temperature, cloud cover and relative humidity were acquired from Rotorua Aero Automated Weather Station through Cliflo service of NIWA (National Institute of Water and Atmospheric Research National Climate Database, http://cliflo.niwa.co.nz/).

1.3 Water balance

A water balance equation was used to adjust the direct catchment inputs to Lake Rotoiti, as the only unknown term, to match the prescribed water level scenarios in the lake. The data sources for the components of the water balance are summarised in Table 1

$$\text{Inflow from Ohau channel}\left(\frac{m^3}{d}\right) + \text{Minor stream inflows}\left(\frac{m^3}{d}\right) + \text{Rainfall}\left(\frac{m^3}{d}\right)$$
$$= \Delta\,\text{Lake surface volume}\left(\frac{m^3}{d}\right) + \text{Evaporation}\left(\frac{m^3}{d}\right) + \text{Outflow to Okere}\left(\frac{m^3}{d}\right)$$

Evaporation was calculated from air temperature and pressure, relative humidity, wind speed and surface water temperature. Daily inflow data were smoothed through use of a running average over three days. The resulting inflow was split into the geothermal component, which was held constant, and a coldwater component which was varied as part of the water balance. Daily surface water temperature was calculated from interpolations between monthly measurements. The ELCOM-CAEDYM model, which predicts surface water temperature at a sub-daily time ste was run until a satisfactory match was obtained with the water levels provided for each year (1998, 1999, 2000 and 2001) by Environment Bay of Plenty.

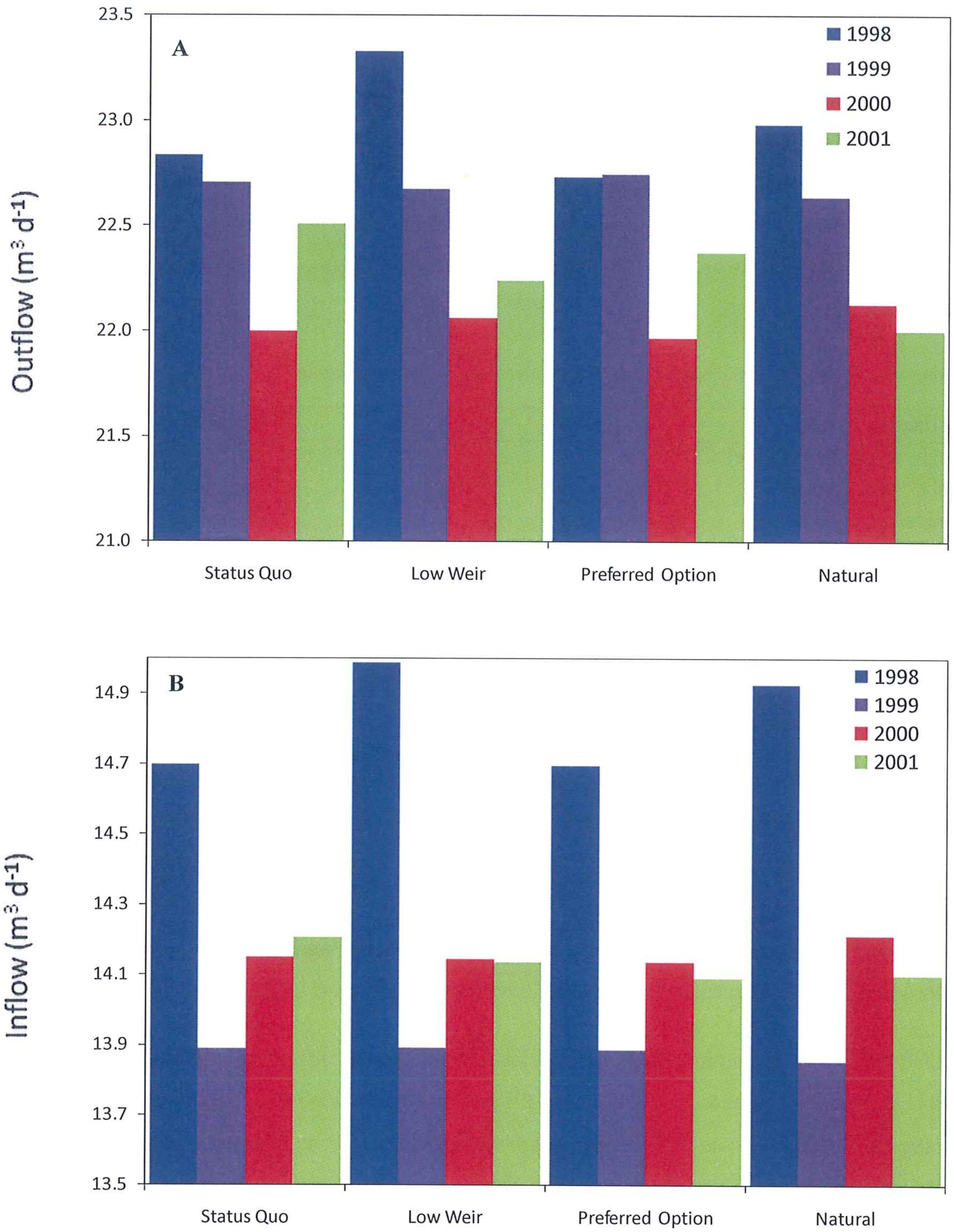

Figure 2. Average daily outflows from Lake Rotoiti at Taheke recorder downstream from Okere Gates (A) and average daily inflow from Lake Rotorua at Ohau Channel (B) under four different operational regimes (Status Quo, Low Weir, Preferred Option and Natural) using rainfall inputs from 1998-2001.

Additional input data were required for running the ELCOM-CAEDYM model. Cloud cover, used to calculate long wave radiation input, was calculated from shortwave radiation. A polynomial regression (third-order) yielded a positive relationship ($R^2 = 0.9729$) between buoy data and Rotorua Aero Automated Weather Station air temperature data from 13/07/2007 to 30/06/2008. This equation was used to acquire the lake air temperature input needed for the model and provided a more accurate input of conductive heat exchange than the air temperature taken on land. Water temperature at Okere Gates was calculated using the respective mass and temperature of Lake Rotoiti water and Lake Rotorua water.

Table 1. Data sources for the components of the water balance for Lake Rotoiti.

Variables	Method
Inflow from Ohau channel	Recorded
Minor stream inflows	Estimated
Rainfall	Recorded
Δ Lake Surface level change	Recorded
Evaporation	Estimated
Outflow from Okere	Recorded

1.4 ELCOM-CAEDYM and operation

ELCOM (Estuary, Lake and Coastal Ocean Model), a three dimensional hydrodynamic model, coupled with aquatic ecosystem model, CAEDYM (Computational Aquatic Ecosystem Dynamics Model) was used for this project. ELCOM-CAEDYM was developed by the Centre for Water Research in Western Australia (Hodges & Dallimore, 2006; Robson & Hamilton, 2004). ELCOM simulates hydrodynamics of lake and temperature temporally and spatially (Hodges & Dallimore, 2006) and CAEDYM calculates ecological dynamics and transport (Robson & Hamilton, 2004).

ELCOM-CAEDYM output set-up was an important step. In this study, we allocated stations in strategic locations around Lake Rotoiti and Ohau Channel. Station names and locations are illustrated in Figure 3. Station 1 was a mid-lake station at 'The Crater' more than 90 m deep, half way along Lake Rotoiti. Station 2 was located at 'The Narrows', a narrow part of the lake between the western and the main eastern basin, Station 3 was a mid-lake station in Okawa Bay, Station 4 was situated just outside of the Ohau Channel wall in the Okere Arm and Station 5 was at Te Weta Bay, in the northern part of the western basin.

A simulated tracer dye, used as a measure of Lake Rotorua water dispersal, was 'released' in the Ohau Channel and was expected to be transported by the water flow. Concentrations of the tracer were measured through the lake profile at the five stations. The values were averaged when stratification was not observed. These concentrations were used to support understanding of the transport of the Ohau Channel water in Lake Rotoiti.

The ELCOM-CAEDYM model output using derived inflows, calculated as above, was calibrated to return a close match to the observed lake surface level fluctuations. It should be noted that although the inputs for water inflow and outflow provided by Environment Bay of Plenty were from 1998-2001, the model output was based on the present configuration with the diversion wall in place.

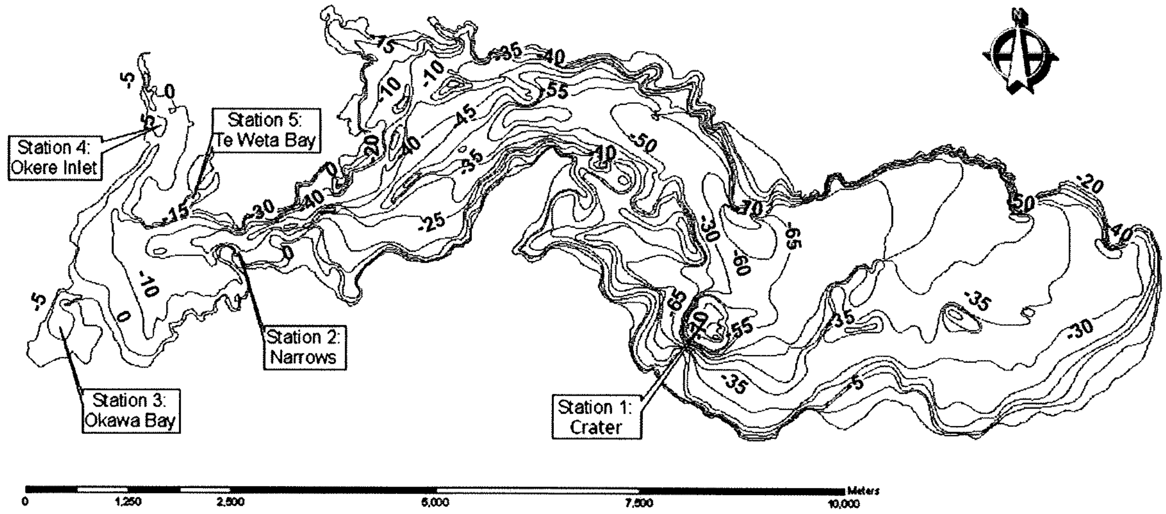

Figure 3. Bathymetric map of locations of stations on Lake Rotoiti: Station 1 (The Crater), Station 2 (The Narrows), Station 3 (Okawa Bay), Station 4 (Okere Arm), Station 5 (Te Weta Bay).

Results

1.5 Lake level fluctuations

Modelled lake level changes for all the scenarios and for the observed fluctuations are shown in

Figure 4. The water levels output simulated for the current structure (Status Quo) and the measured fluctuation match very well. The Low Weir and Natural scenarios produced the largest fluctuations over the greatest range (Table 2). The Preferred Option produced less fluctuations than the Natural and Low Weir scenarios and was most like Status Quo (

Figure 4; Table 2).

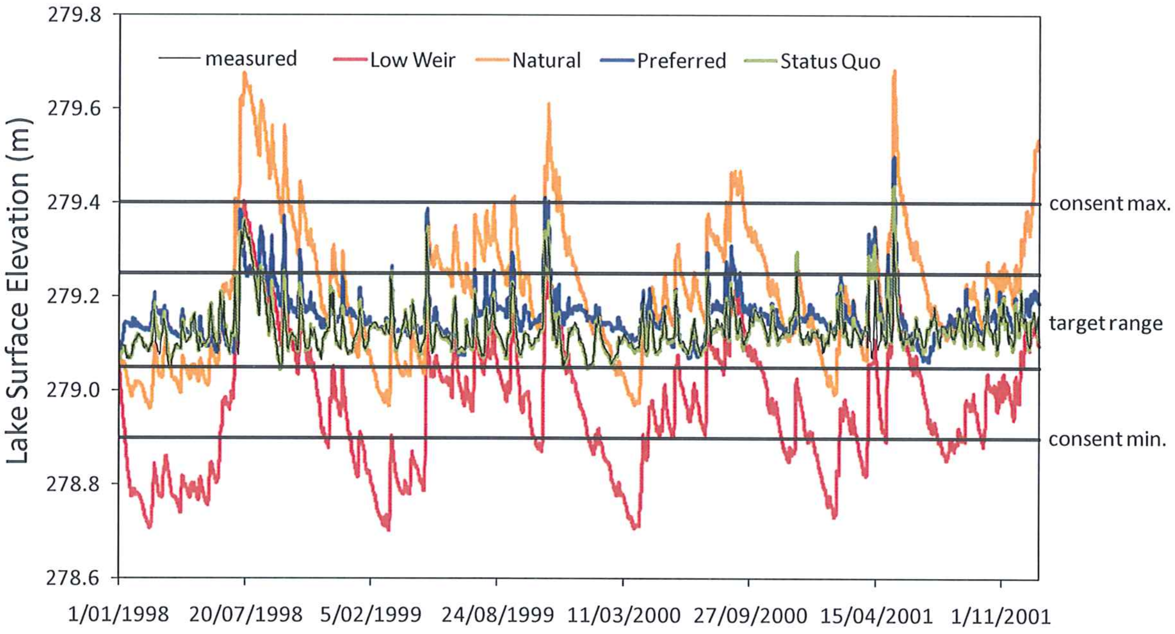

Figure 4. Modelled scenarios (Status Quo, Low Weir, Preferred, Natural) and measured lake level fluctuations of Lake Rotoiti using rainfall inputs from 1998-2001.

Table 2. Range of lake level fluctuation for each scenario (Status Quo, Low Weir, Preferred, Natural) from 1998-2001.

	Status Quo	Preferred	Low Weir	Natural
1998	0.32 m	0.31 m	0.7 m	0.71 m
1999	0.31 m	0.32 m	0.65 m	0.64 m
2000	0.24 m	0.24 m	0.51 m	0.5 m
2001	0.35 m	0.43 m	0.71 m	0.69 m

1.5.1 Performance of each scenario in relation to proposed operational limits

The proposed operational strategy is to maintain the water levels between 279.40 and 279.0 m (above Moturiki Datum) but to also operate within a target range 279.05 m and 279.25 m. Within the target operational range there is a further breakdown of the target range to 5-10% of each year between 279.20 and 279.25 m, at least 80% the of year between 279.10 and 279.20 m and 5-10% of year between 279.05 and 279.10 m in the months of May to July, with an allowance of 5% of the year allowed above 279.25, to account for extreme events. The percentage of time that water level was above, below and within the various proposed operational ranges for each scenario over the four years is shown in Table 3. Appendix 2 gives more in-depth analyses, including monthly averaged percentages. The Status Quo and Low Weir scenarios exceeded 279.25 m for less than 5% of the time whereas the Preferred scenario and Natural scenario were above that limit for 7% and 24% of the time, respectively. The Preferred and Status Quo scenarios stayed within the target range for at least 93% of the time, but the Status Quo was more often in the 279.05-279.10 range than the Preferred option. For the Low Weir scenario, the water level was within the target range 23% of the time and it was at, or below, 279.0 m for 72% of the time. The Natural option stayed within the target range for 49% of the time with higher than proposed periods of time between 279.20-279.25 m and 279.05-279.1 m. For 14% of the time the Natural option was at or below the target range and above it for 36% of the time.

Table 3. Average percentage of time that the water level was above, below and within the proposed target operational ranges for each scenario (Status Quo, Low Weir, Preferred, Natural) from 1998-2001. The grey band denotes the target range.

Range	Status Quo	Preferred	Low Weir	Natural
>279.4	0	0	0	10
279.35-279.40	0	1	1	5
279.30-279.35	1	2	1	11
279.25-279.30	2	4	1	10
279.20-279.25	4	8	2	16
279.15-279.20	14	38	4	12
279.10-279.15	53	40	6	12
279.05-279.10	25	8	11	9
279.00-279.05	1	0	11	10
<279.00	0	0	61	4

The average percentage of time above, within and below the proposed target range is shown in Table 4. For each scenario, the proportion that falls within the target range is similar for each rainfall regime with the exception of the Natural scenario for which the water level was within the target range for a greater duration. Otherwise the proportions above the target range tended to decrease in the year.

Table 4. Averaged percentage of time of water levels above, within and below the proposed target range for each scenario (Status Quo, Low Weir, Preferred, Natural) during wet (1998 and 2001), average (1999) and dry (2000) years. The grery bar denoted the target level.

Range	Status Quo			Preferred			Natural			Low Weir		
	wet	average	dry	wet	average	dry	wet	average	Dry	Wet	average	dry
Above target	6	4	1	8	6	3	35	45	30	6	1	0
Within target	94	96	98	92	94	97	48	41	60	22	27	24
Below target	0	0	1	0	0	0	18	14	11	72	72	76

1.6 Rotorua water influence on tracer concentrations

Tracer concentrations for each station site are illustrated in Figure 5. Mean tracer concentrations are summarised in Table 5. Mean tracer concentration results show that the Preferred Option will transfer up to half as much of the Lake Rotorua water to Lake Rotoiti at Stations 1, 2, 4 and 5 as the current structure (Status Quo scenario). However, the Natural and Low Weir scenarios would transport even less water into Lake Rotoiti than the Preferred option (Table 5). For all scenarios it took the tracer six months before it reached its maximum concentration at Station 1 (The Crater), the most distant from the origin of the tracer. Tracer concentrations then remained fairly stable and at a very low concentration (Figure 5). The maximum concentration at Station 1 was around 0.27% of the original concentration and this was represented by the Status Quo scenario (Figure 6).

Table 5. Mean percentage of tracer concentrations based on input from the Ohau Channel (100%) for stations (Station 1 - Crater, Station 2 - the Narrows, Station 3 - Okawa Bay, Station 4 - Okere Arm, Station 5 – Te Weta Bay) for four scenarios (Status Quo, Low Weir, Preferred, Natural) from 1998-2001.

Location: Method:	Station1 Surface	 Bottom	Station 2 mean	Station3 mean	Station 4 mean	Station5 mean
Status Quo	0.44	0.25	0.44	0.5	65.24	0.44
Preferred	0.21	0.21	0.36	0.39	65.04	0.34
Low Weir	0.02	0.02	0.025	0.02	63.68	0.02
Natural	0.07	0.07	0.11	0.1	64.1	0.1

Once a near-steady state was reached at Stations 2 (The Narrows), Station 3 (Okawa Bay) and Station 5 (Te Weta Bay) tracer levels tended to be punctuated by seasonal fluctuations in tracer concentrations, with concentrations increasing from January to April and then decreasing again by July to remain stable for the intervening months. This trend was most marked in 1998 and 2001, the wet years, and peak concentrations were lowest during the year 2000, the dry year. There was a consistent pattern at Stations 1, 2, 3 and 5 with the Low Weir scenario producing the lowest concentrations of tracer, then increasingly higher concentrations in the Natural, Preferred and then Status Quo scenarios (Figure 5).

Surface contour plots of tracer concentrations over time for each scenario are given in Appendix 1. They provide an alternate representation of the data presented in Figure 5.

Distance from Ohau Channel was represented by difference in magnitude in the tracer concentrations i.e., Station 1 (Crater) which had very low concentrations of tracer as compared to Stations 2, 3 and 4 (Figure 5). Morphological differences (i.e., relatively closed bays, Station 3 (Okawa Bay) and Station 5 (Te Weta Bay) did not reduce the tracer concentrations but concentration was less variable than at Station 2 (The Narrows; Figure 5).

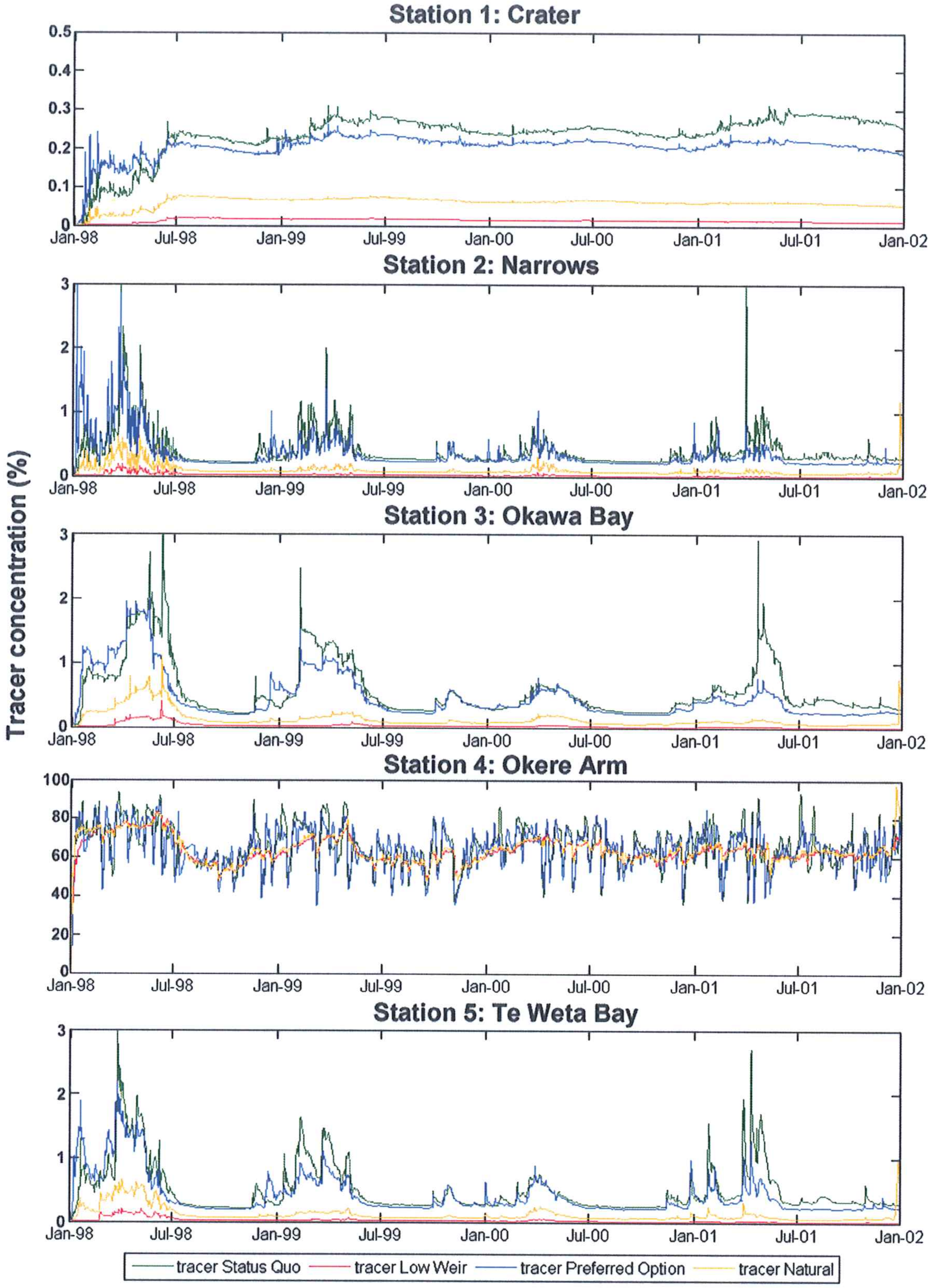

Figure 5. Tracer concentration as a percentage of input from the Ohau Channel (100%) at Station 1 - Crater, Station 2 - the Narrows, Station 3 - Okawa Bay, Station 4 - Okere Arm, Station 5 – Te Weta Bay for each scenario (Status Quo, Low Weir, Preferred, Natural) for 1998-2001.

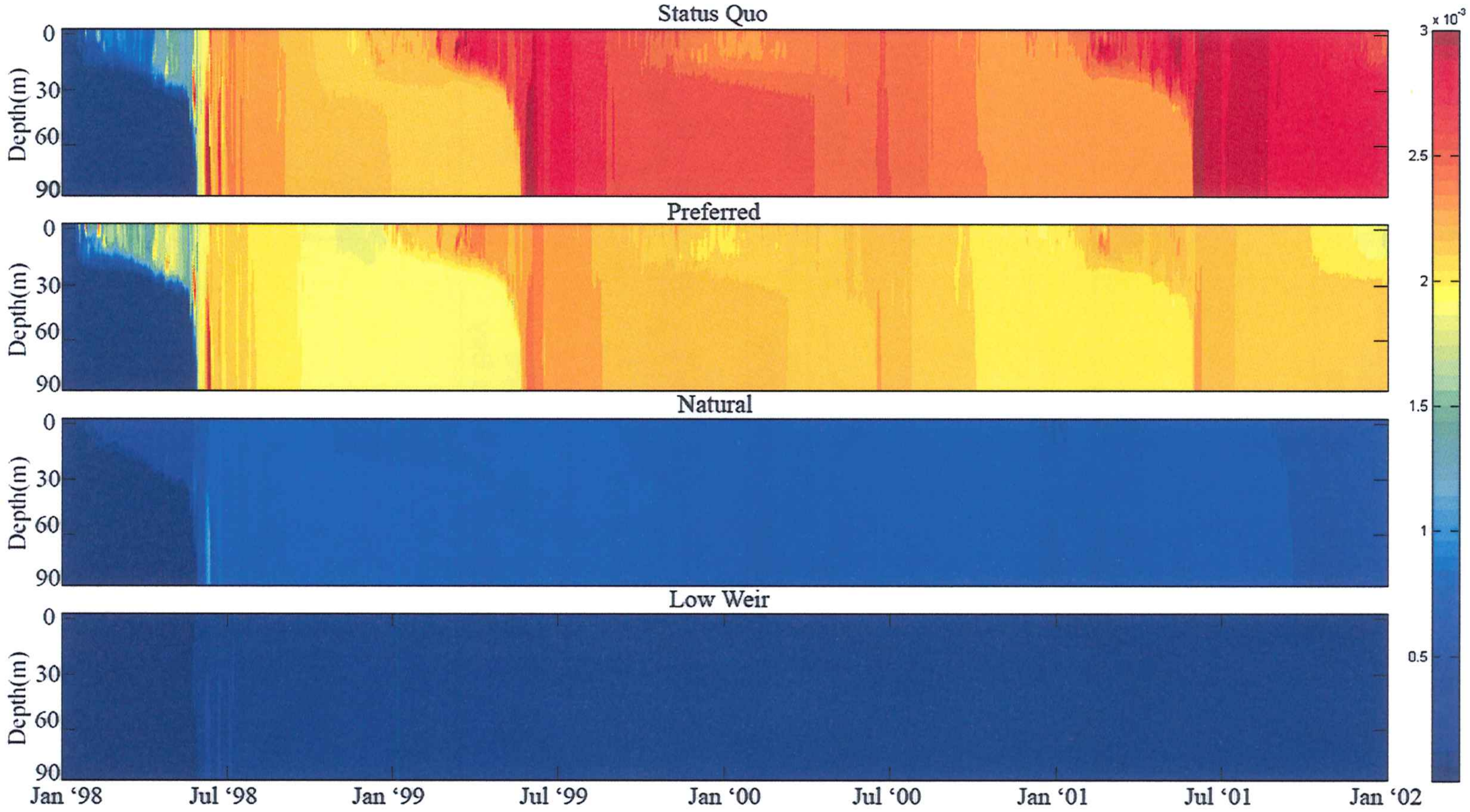

Figure 6. Tracer concentrations at Station 1 (Crater station) as a fraction of input from the Ohau Channel (100%) for each scenario (Status Quo, Low Weir, Preferred, Natural) 1998-2001.

Discussion

The aim of this report was to quantify the proportion of Lake Rotorua water being transported from Ohau Channel around the diversion wall and into Lake Rotoiti. We discuss the findings for the various options below.

None of the simulated scenarios is likely to change the water quality of Lake Rotoiti appreciably as a result of Lake Rotorua water flowing around the diversion wall and into Lake Rotoiti. For each scenario, only a small proportion of Lake Rotorua water, ranging from 0.02-0.5%, reached Station 1 (The Crater), the station farthest from the tracer source of Ohau Channel (Table 5). The maximum tracer concentration simulated at any station was 3.2% of that in the Ohau Channel, which was for the Status Quo scenario at Station 2 (The Narrows). More water from Lake Rotorua enters Lake Rotoiti during summer than in winter, and bays tend to have a longer response time. The proportion of water from Lake Rotorua that enters Lake Rotoiti tends to increase under higher rainfall which leads to higher flows through the Ohau Channel.

The Low Weir scenario had the lowest amount of water from Lake Rotorua entering Lake Rotoiti (average of 0.02-0.025% across each of the stations 1, 2, 3 and 5); less than any of the other scenarios. This scenario did not match the proposed operational ranges for considerable periods of time, however, as it produced low water levels that were below the target range for 72% of the time. This scenario showed large fluctuations in water level (0.51-0.71 m).

The Natural scenario produced a similar range of water level fluctuations (0.5 to 0.71 m) to the Low Weir scenario. In the Natural scenario, however, water levels were generally higher and were above the proposed operational range for 36% of the time. This regime would not fulfil the proposed operational strategy as the water levels were within the proposed targeted range for less than 50% of the time. The difference between the Natural option (0.07-0.11% across each of the stations 1, 2, 3 and 5) and the Low Weir option (0.02-0.025%) was small and would be unlikely to lead to a detectable difference in water quality between these two scenarios.

The current regime (Status Quo) appears to be the least favourable of the four options in terms the proportion of Lake Rotorua water that would enter Lake Rotoiti. The average percentage of Lake Rotorua water entering Lake Rotoiti in this case ranges from 0.25-0.5% and the maximum is 3.2%. This scenario had low fluctuations in water levels (0.24–0.35 m) compared with any of the other three scenarios and levels remained within the proposed target operational range for 96% of the time. There was a high percentage of time (average 25% over 4 years) where water levels were within the

279.05-279.10 m water level range, well above the proposed 5-10% frequency for the months of May to July.

The Preferred option, on average, resulted in 16-52% less water from Lake Rotorua entering Lake Rotoiti than the Status Quo option. Water level fluctuations were slightly greater (0.24–0.43 m) than for the Status Quo option (0.24-0.35 m). Water levels were maintained within the proposed target range for 93% of the time.

The proposed changes in operation of the Okere Flood gates and Ohau Channel weir are not anticipated to compromise the efficiency of the diversion wall for any of the scenarios but there are subtle differences between the scenarios and a possibility of small variations in water quality in the western end of the lake including the embayments. The Low Weir option produced the least input of water from Ohau Channel into Lake Rotoiti followed by the Natural option, the Preferred option, and then the Status Quo. Our results suggest that differences between the scenarios in terms of backflow of water around the diversion wall, are likely to be small, and that other effects of water level variations can now be focused upon in terms of their ecological, cultural and socio-economic effects.

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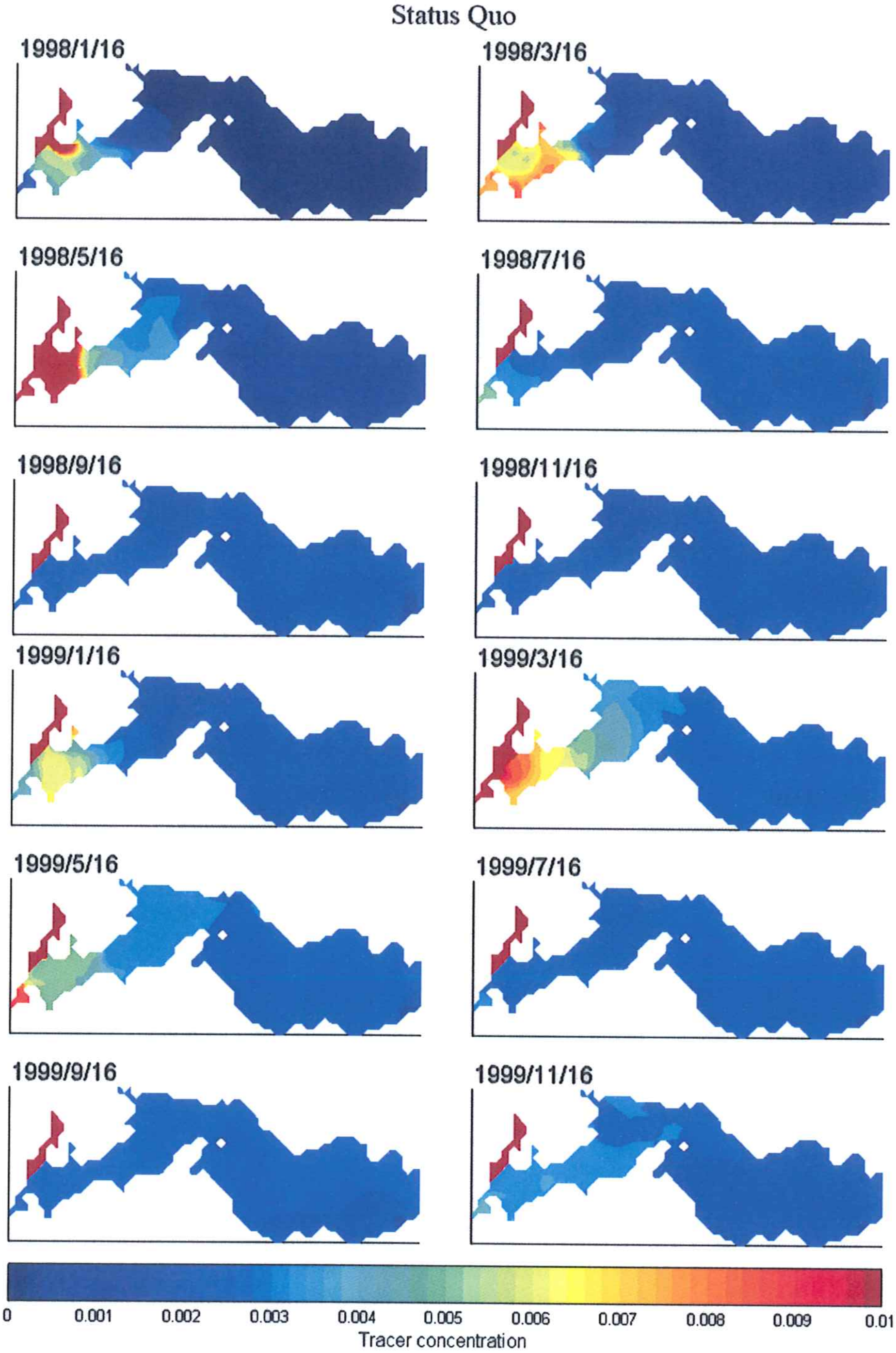
Appendices

Appendix 1. Fraction of tracer (as a percentage) in Lake Rotoiti as a percentage of inputs in the Ohau Channel (Status Quo, Low Weir, Preferred, Natural) at two-monthly intervals from 1998-2001.



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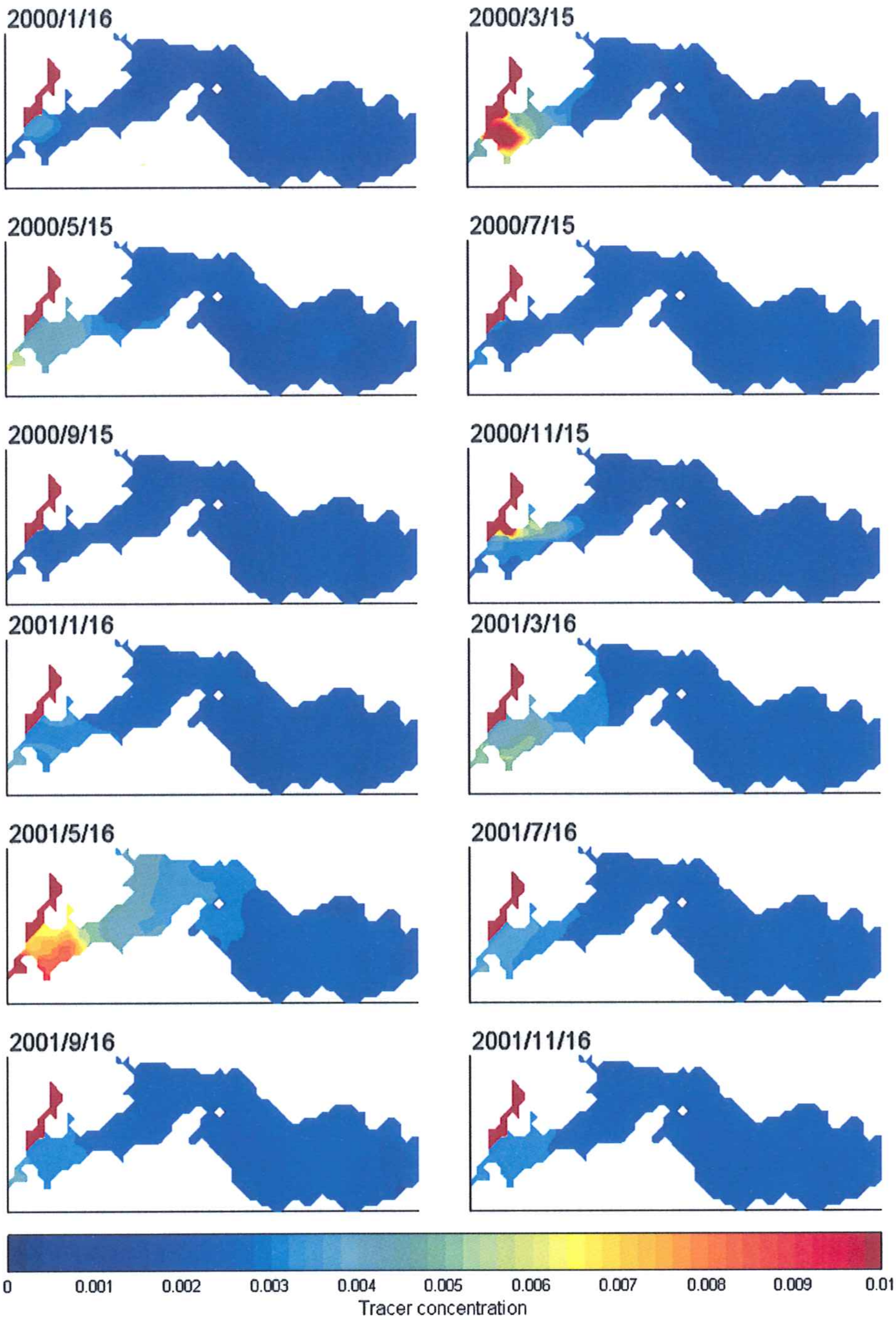
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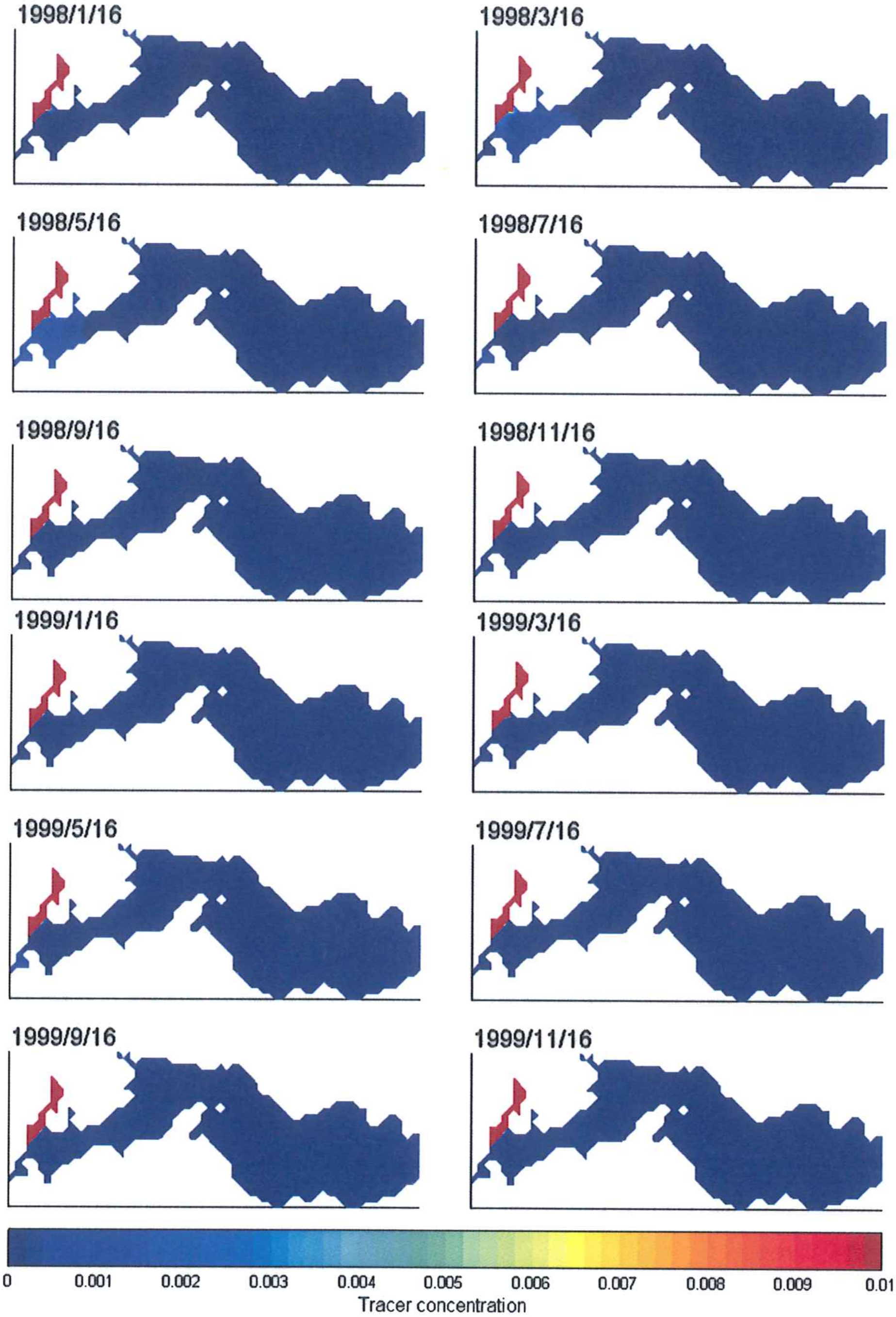
2000/3/15
2000/5/15
2000/7/15
2000/9/15
2000/11/15
2001/1/16
2001/3/16
2001/5/16
2001/7/16
2001/9/16
2001/11/16
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
Tracer concentration

Low Weir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1998/3/16
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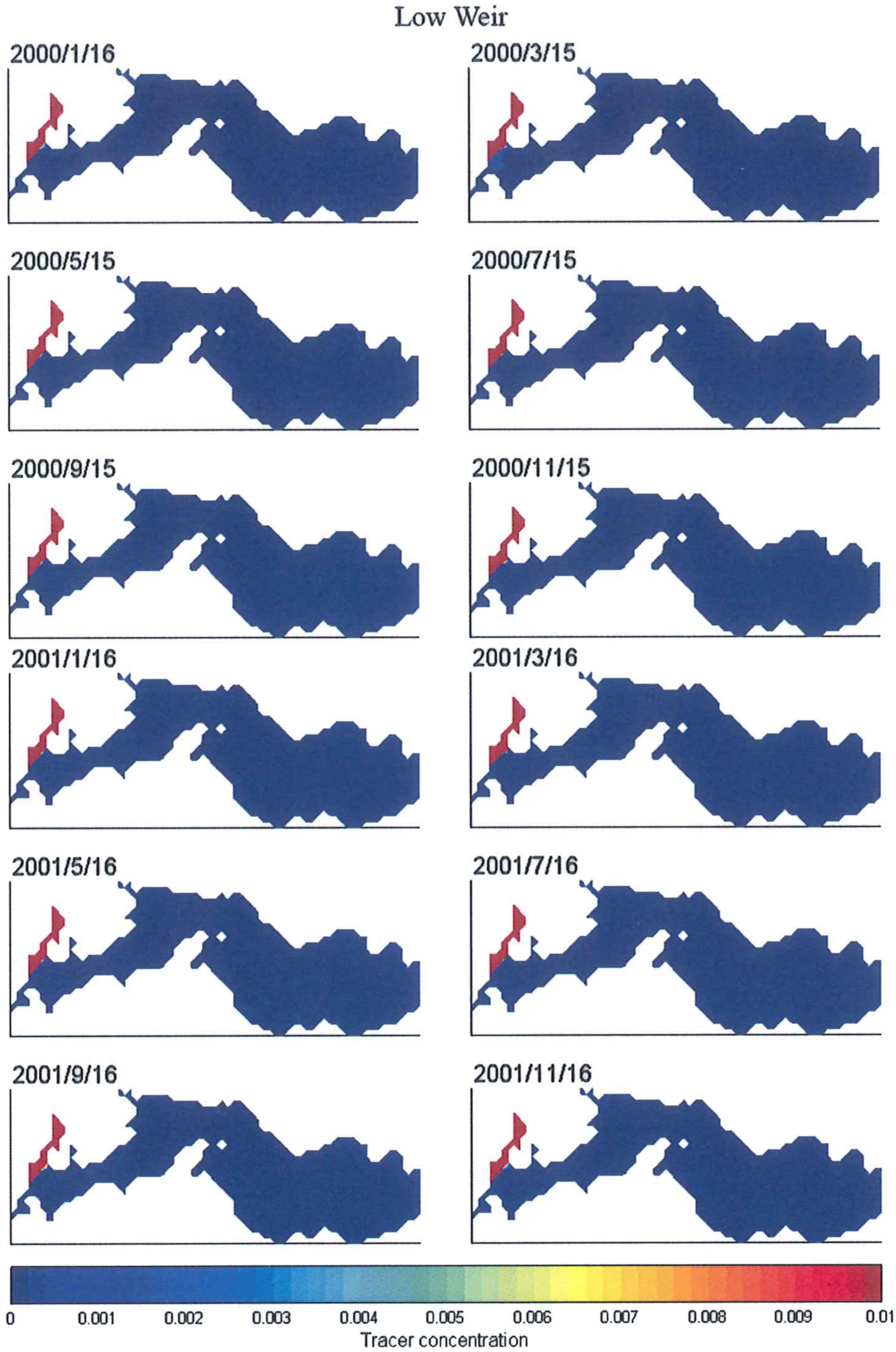
1998/9/16
1998/11/16
1999/1/16
1999/3/16
1999/5/16
1999/7/16
1999/9/16
1999/11/16
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
Tracer concentration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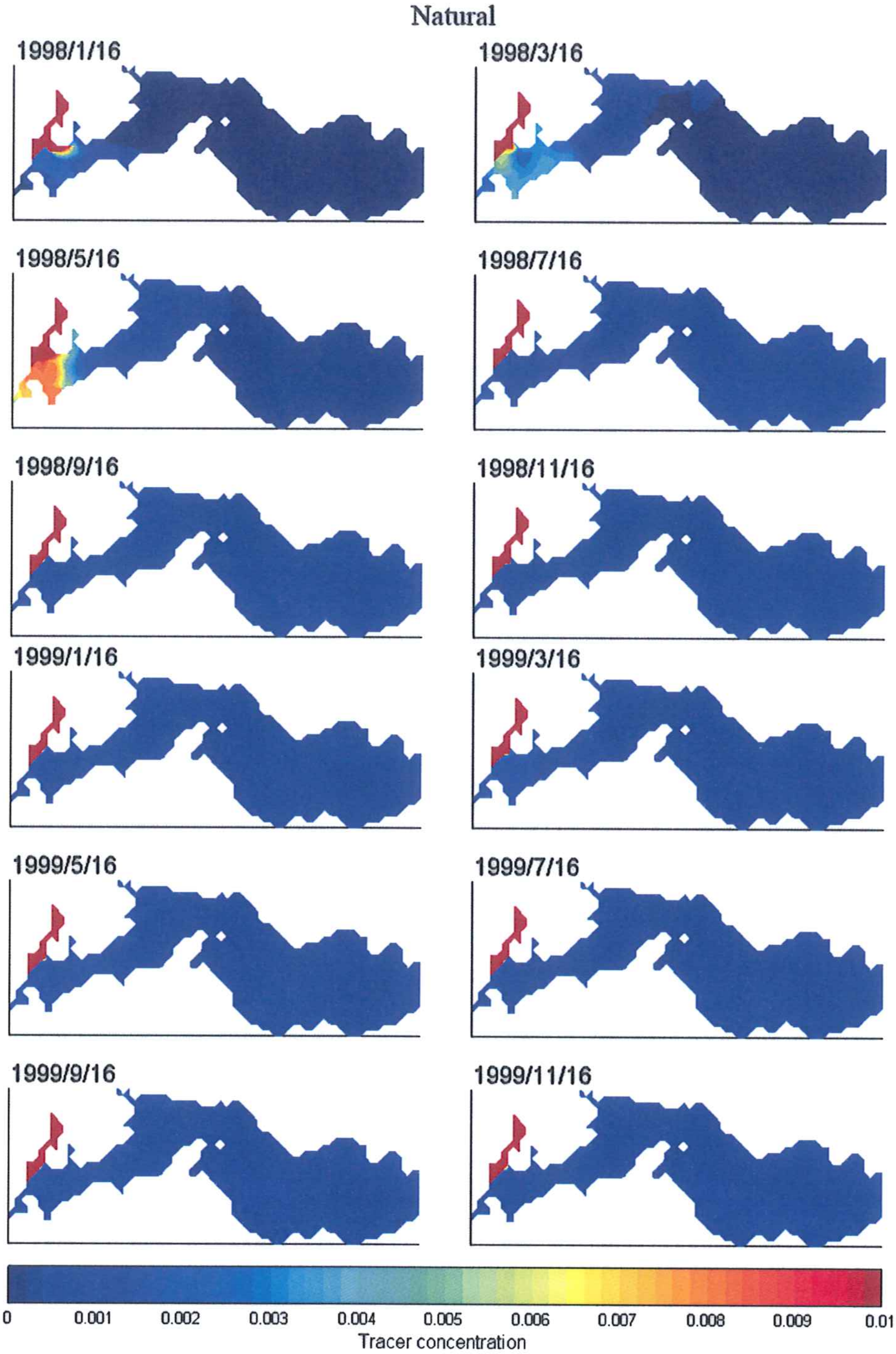
2000/3/15
2000/5/15
2000/7/15
2000/9/15
2000/11/15
2001/1/16
2001/3/16
2001/5/16
2001/7/16
2001/9/16
2001/11/16
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
Tracer concentration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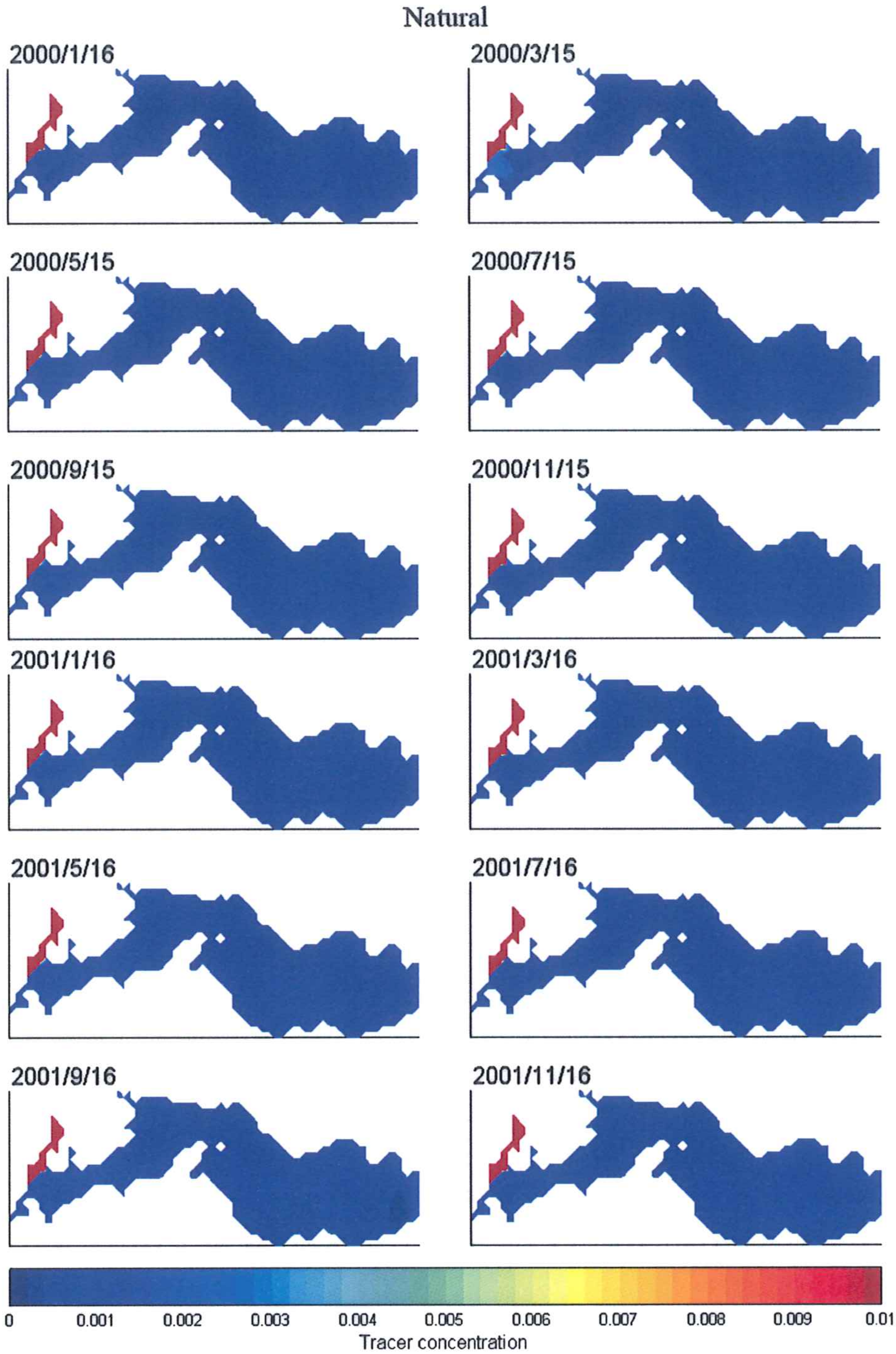
1998/3/16
1998/5/16
1998/7/16
1998/9/16
1998/11/16
1999/1/16
1999/3/16
1999/5/16
1999/7/16
1999/9/16
1999/11/16
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
Tracer concentration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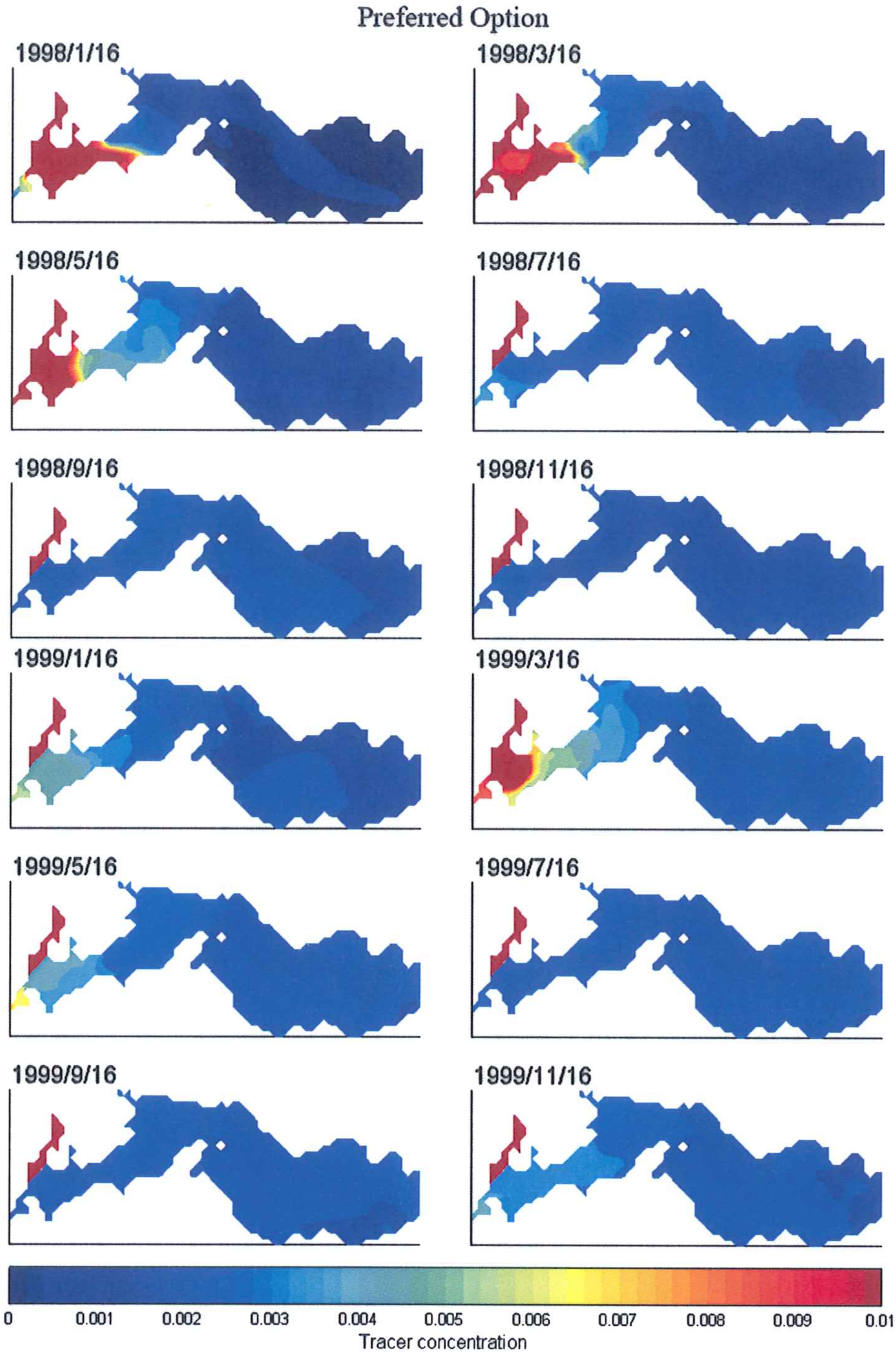
2000/3/15
2000/5/15
2000/7/15
2000/9/15
2000/11/15
2001/1/16
2001/3/16
2001/5/16
2001/7/16
2001/9/16
2001/11/16
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
Tracer concentration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1998/3/16
1998/5/16
1998/7/16
1998/9/16
1998/11/16
1999/1/16
1999/3/16
1999/5/16
1999/7/16
1999/9/16
1999/11/16
0
0.001
0.002
0.003
0.004
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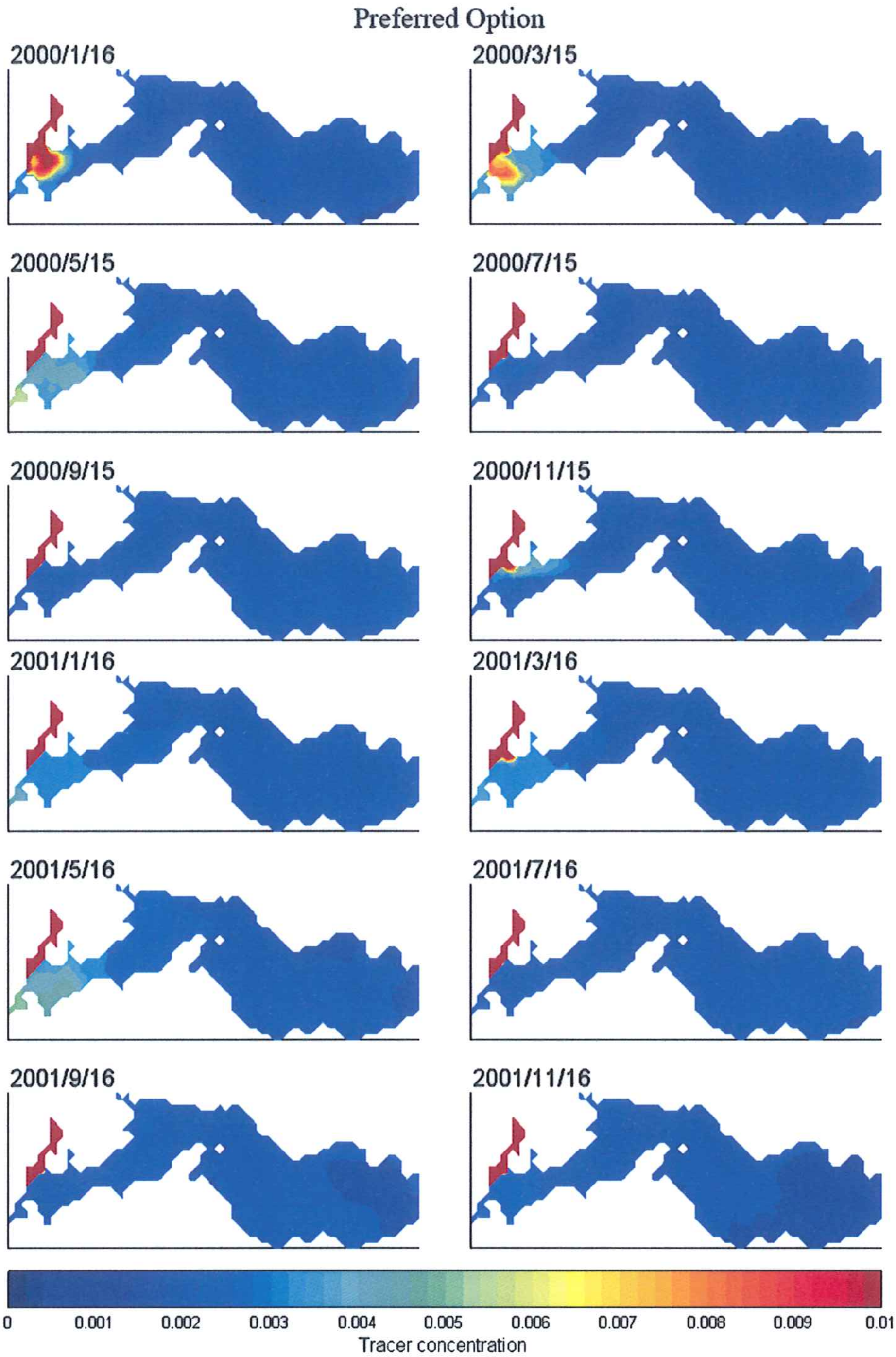
0.007
0.008
0.009
0.01
Tracer concentration


Preferred Option
2000/1/16
2000/3/15
2000/5/15
2000/7/15
2000/9/15
2000/11/15
2001/1/16
2001/3/16
2001/5/16
2001/7/16
2001/9/16
2001/11/16
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
Tracer concentration

Appendix 2. Average percentage of time of water level within maximum, minimum, mean, median, mode and range for scenarios (Status Quo, Preferred, Natural, Low Weir) for 1998-2001. The grey band denotes the target range.

Averaged percent time in water level ranges for Status Quo for 4 years 1998-2001 (light grey denotes target range)												
Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>279.4	0	0	0	0	1	0	0	0	0	0	0	0
279.35-279.40	0	0	0	0	1	0	3	0	0	0	1	0
279.30-279.35	0	0	0	1	3	0	12	0	0	0	2	0
279.25-279.30	0	0	0	6	2	0	4	4	0	0	4	1
279.20-279.25	0	2	2	4	4	2	5	13	6	2	3	5
279.15-279.20	4	8	6	22	12	15	10	23	12	18	16	18
279.10-279.15	47	58	59	45	54	48	39	58	53	57	61	54
279.05-279.10	45	32	33	23	22	35	28	3	27	23	13	21
279.00-279.05	4	0	0	0	0	0	0	0	2	0	0	1
<279.00	0	0	0	0	0	0	0	0	0	0	0	0

Maximum	279.15	279.18	279.17	279.21	279.29	279.19	279.25	279.22	279.21	279.19	279.24	279.22
Minimum	279.07	279.09	279.08	279.08	279.08	279.08	279.08	279.10	279.07	279.08	279.09	279.08
Mean	279.10	279.12	279.11	279.14	279.14	279.12	279.16	279.15	279.12	279.12	279.14	279.13
Median	279.10	279.11	279.11	279.13	279.12	279.11	279.16	279.15	279.11	279.12	279.13	279.12
Mode	279.08	279.10	279.10	279.09	279.10	279.10	279.15	279.13	279.08	279.13	279.11	279.10
Range	0.08	0.09	0.09	0.13	0.21	0.12	0.17	0.12	0.14	0.10	0.15	0.14

Averaged percent time in water level ranges for Preferred Option for 4 years 1998-2001 (light grey denotes target range)

Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>279.4	0	0	0	0	3	0	0	0	0	0	1	0
279.35-279.40	0	0	0	0	2	0	2	0	1	0	3	0
279.30-279.35	0	0	0	6	2	0	3	7	1	0	3	0
279.25-279.30	0	0	1	5	4	0	11	11	8	2	2	0
279.20-279.25	2	4	2	5	5	1	9	21	22	7	6	13
279.15-279.20	56	21	21	20	24	8	18	47	52	68	42	74
279.10-279.15	40	74	76	64	51	39	25	14	16	24	43	13
279.05-279.10	3	0	0	0	10	52	33	0	0	0	0	0
279.00-279.05	0	0	0	0	0	0	0	0	0	0	0	0
<279.00	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	279.18	279.20	279.20	279.23	279.31	279.18	279.27	279.27	279.29	279.22	279.25	279.23
Minimum	279.12	279.13	279.12	279.12	279.11	279.07	279.07	279.17	279.14	279.14	279.13	279.14
Mean	279.15	279.15	279.14	279.16	279.16	279.11	279.15	279.20	279.19	279.17	279.17	279.17
Median	279.15	279.14	279.13	279.15	279.15	279.10	279.15	279.19	279.18	279.16	279.16	279.17
Mode	279.15	279.13	279.12	279.13	279.12	279.08	279.15	279.18	279.16	279.16	279.13	279.16
Range	0.06	0.07	0.08	0.11	0.20	0.11	0.19	0.11	0.14	0.09	0.12	0.09

Averaged percent time in water level ranges for Natural scenario for 4 years 1998-2001 (light grey denotes target range)

Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>279.4	0	0	0	0	13	0	19	29	31	4	18	10
279.35-279.40	0	0	0	0	5	2	8	8	17	6	2	11
279.30-279.35	0	0	0	10	9	16	15	25	11	23	3	14
279.25-279.30	0	0	0	3	19	27	5	13	7	15	12	22
279.20-279.25	6	6	0	9	6	37	21	0	21	31	29	21
279.15-279.20	16	8	12	11	14	10	24	5	9	11	19	12
279.10-279.15	28	12	12	12	8	1	8	20	4	10	17	10
279.05-279.10	25	20	27	22	9	7	0	0	0	0	0	0
279.00-279.05	22	27	33	28	16	0	0	0	0	0	0	0
<279.00	3	27	16	6	0	0	0	0	0	0	0	0

Maximum	279.15	279.15	279.13	279.19	279.35	279.32	279.41	279.41	279.42	279.33	279.36	279.39
Minimum	279.05	278.99	279.01	279.02	279.10	279.17	279.17	279.27	279.26	279.19	279.14	279.19
Mean	279.10	279.06	279.06	279.11	279.23	279.24	279.31	279.33	279.33	279.26	279.26	279.28
Median	279.09	279.05	279.06	279.12	279.22	279.24	279.32	279.33	279.32	279.26	279.26	279.26
Mode	279.06	279.06	279.04	279.08	279.18	279.21	279.30	279.31	279.29	279.24	279.24	279.22
Range	0.11	0.16	0.13	0.17	0.25	0.15	0.24	0.14	0.16	0.14	0.22	0.20

Averaged percent time in water level ranges for Low Weir scenario for 4 years 1998-2001 (light grey denotes target range)

Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>279.4	0	0	0	0	1	0	0	0	0	0	0	0
279.35-279.40	0	0	0	0	1	0	10	0	0	0	0	0
279.30-279.35	0	0	0	0	2	0	7	5	0	0	2	0
279.25-279.30	0	0	0	0	2	0	0	9	2	0	2	0
279.20-279.25	0	0	0	0	2	0	0	11	7	0	7	0
279.15-279.20	0	0	0	0	6	0	2	5	19	4	7	1
279.10-279.15	0	0	0	1	6	4	11	9	18	6	3	20
279.05-279.10	0	0	0	10	13	19	12	26	14	24	3	14
279.00-279.05	2	0	0	3	16	32	6	10	8	22	15	22
<279.00	98	100	100	86	51	45	51	25	32	44	62	43
Maximum	278.97	278.89	278.88	278.94	279.11	279.08	279.17	279.15	279.17	279.08	279.11	279.10
Minimum	278.80	278.73	278.75	278.76	278.85	278.93	278.93	279.02	279.00	278.93	278.88	278.94
Mean	278.87	278.80	278.81	278.86	278.99	279.00	279.06	279.08	279.07	279.01	279.00	279.02
Median	278.85	278.79	278.81	278.87	278.98	279.01	279.07	279.07	279.07	279.02	279.01	279.01
Mode	278.83	278.76	278.78	278.84	278.94	278.96	279.05	279.07	279.07	278.97	278.96	278.98
Range	0.16	0.16	0.13	0.18	0.25	0.15	0.24	0.14	0.16	0.14	0.23	0.16