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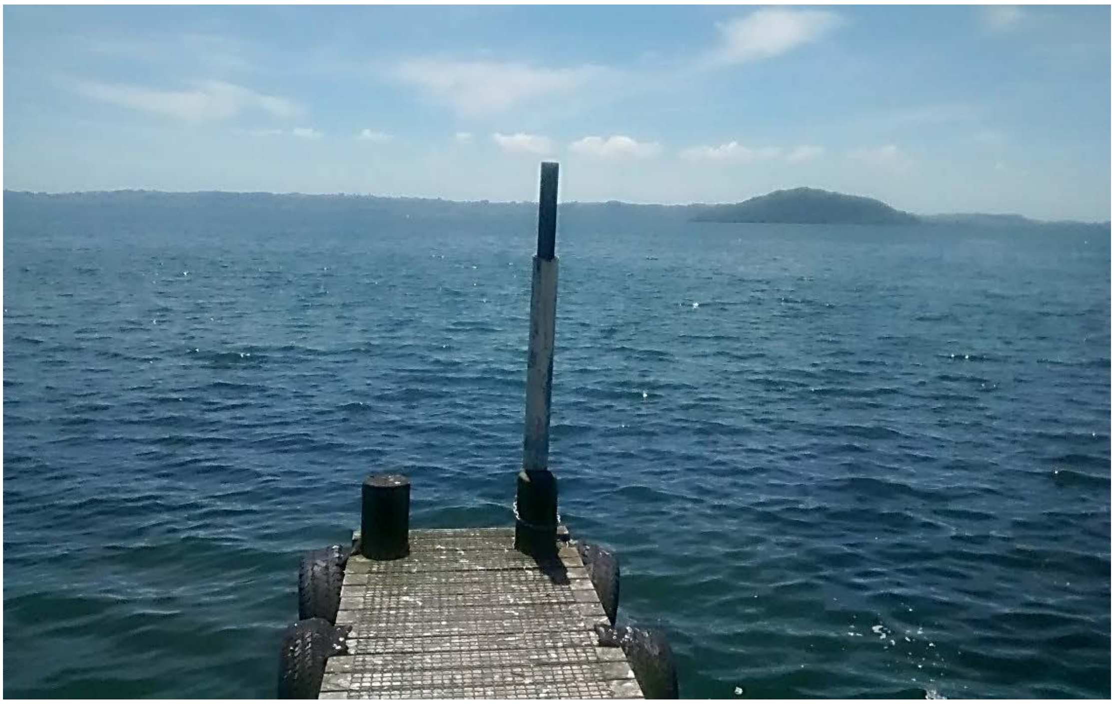
# Assessment of Effects of Proposed Treated Wastewater Discharge to the Te Arikiroa Thermal Channel and Sulphur Bay (Lake Rotorua)



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Client report prepared for Rotorua Lakes Council

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Cover: View across Lake Rotorua from Sulphur Bay (Photo: Christopher Dada).

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# EXECUTIVE SUMMARY

After 2019, irrigation operations at the Land Treatment System (LTS) in the Whakarewarewa Forest are scheduled to cease. A number of options and locations have been considered for the discharge of the treated wastewater when the current discharge consent ceases. Following consultations and technical assessments, the preferred option of Rotorua Lakes Council is to upgrade the existing plant to a full Membrane Bioreactor Plant with the addition of an Ultraviolet Disinfection System (or alternative treatment to achieve an equivalent performance in terms of treated wastewater quality). Under this arrangement, wastewater would be subjected to biological, chemical and physical treatment processes, and the treated wastewater discharged through Te Arikiroa Thermal Channel to Sulphur Bay. Rotorua Lakes Council is thus undertaking an environmental impact assessment study to determine the effects of discharging treated wastewater to the thermal channel and Puarenga Bay (Lake Rotorua), with particular reference to aesthetic, water quality and ecological considerations. These considerations include potential effects related to faecal indicator bacteria, nutrient concentrations, metals, dissolved oxygen, and taonga species (native species of cultural significance).

The assessment focused on:

(i) The projected treated wastewater characteristics;

(ii) Existing conditions of the receiving water;

(iii) The sensitivity of the receiving water and the impact of the proposed discharge on water quality and taonga species (native species of cultural significance) in Te Arikiroa Thermal Channel and Sulphur Bay.

The main techniques used to inform the assessment in this study were:

1) Analysis of historical water quality data, 2011-2014;
2) Collection of additional water quality data at Te Arikiroa Thermal Channel and Sulphur Bay and along a transect to quantify spatial variability (sampling in 2016 and 2017);
3) Mass balance dilution modelling to predict water quality in the Te Arikiroa Thermal Channel and Sulphur Bay (Lake Rotorua), at a site outside of the assumed mixing zone;
4) Lake ecosystem modelling conducted by Abell et al. (2015) to assess effects related to eutrophication;
5) Background review of biological information and field investigations for taonga species at Sulphur Bay and Te Arikiroa Thermal Channel (2017).

For mass balance dilution calculations, it was assumed that mean baseline discharge (flow rate) of the thermal channel is 0.01 $m^3\ s^{-1}$ and the mean daily discharge of treated wastewater is 0.2756 $m^3\ s^{-1}$. Thus, following implementation of the proposed option, the flow in the thermal channel was assumed to comprise 27.56 parts treated wastewater to 1 part baseline thermal channel water. The smaller discharge of the thermal channel relative to the treated wastewater means that the treated wastewater will completely dominate the quality of the water in the thermal channel following implementation of the proposed option. Estimation of baseline conditions in the Te Arikiroa Thermal Channel was informed by the results of grab sampling undertaken in January 2017. To predict water quality in the lake, mass balance dilution calculations were used to predict water quality at a monitoring site ('Site 4') 250–300 m north of the Puarenga Stream mouth, outside of an assumed mixing zone that comprises the area within a 250 m radius of the mouth of the thermal channel. This area may be considered a "zone of reasonable mixing", and was identified following: consideration of baseline data; previous hydrodynamic modelling results, and; consideration of the magnitude of the projected discharge and the morphology of the receiving bay. To estimate the extent that lake water will dilute the treated wastewater, results were analysed from a previous study that used a three-dimensional hydrodynamic model (ELCOM) to simulate the mixing and dilution of treated wastewater from a shoreline site to the west of the Puarenga Stream mouth, in the vicinity of the mouth of the Te Arikiroa Thermal Channel (Abell 2015, Abell et al. 2015). Results for two representative one-month modelling periods in winter and summer showed that the proportion of treated wastewater present at the surface (0–2 m depth) ranged from 0.1–4.0% (median = 0.7%) at Site 4, with a 95th percentile proportion wastewater of 3.0%. Consistent with a precautionary approach, the 95th percentile value (3.0%) was used for mass balance dilution calculations to predict lake water quality, i.e., the treated wastewater was assumed to mix in the lake to yield a mixture that comprises three parts wastewater to 97 parts ambient lake water. This approach is conservative because it is based on the 95th percentile value (i.e., the modelling predicted that the proportion of treated wastewater would be lower than 3% for 95% of the time) and the concentration of treated wastewater is expected to be considerably lower in the main body of the lake, relative to conditions at Site 4 at the edge of the mixing zone. Estimation of baseline water quality at Site 4 in Lake Rotorua was based on the results of monthly sampling during July 2011 to June 2016 conducted as part of an Alum Dosing Monitoring Survey, supplemented with the results of additional sampling undertaken in November 2016 to inform this assessment (to measure nutrients, metals, faecal indicator bacteria, and water column chlorophyll *a*).

Results of the assessment for individual indicators are as follows:

### *Microbiological characteristics*

Potential impacts on microbiological characteristics of receiving waters were assessed based on modelled concentrations of *E. coli*, which is an indicator of faecal contamination. Projected *E. coli* concentrations in the treated wastewater are very low, reflecting the high level of proposed treatment, which will include an Ultraviolet Disinfection System. Concentrations of *E. coli* measured in November 2016 (2 CFU 100 mL$^{-1}$) were used for the mass balance calculations, although this is conservative as concentrations following the upgrades are expected to be lower due to more stringent treatment. Projected concentrations are lower than background concentrations in the Te Arikiroa Thermal Channel and Lake Rotorua. The mass balance dilution modelling therefore showed that the proposed discharge option is predicted to reduce *E. coli* concentrations in the receiving environment, thus providing improved water quality with regard to this indicator. Further assessment of microbial risk will be provided in a separate study conducted by MWH/NIWA that involves modelling the fate of faecal bacteria and provides a Microbial Risk Assessment. No consideration has been given to other factors that could compromise the predicted microbial concentrations.

### *Eutrophication (including macrophytes and periphyton)*

Relative to operation of the LTS, the proposed option will increase nitrogen and phosphorus loads to Lake Rotorua. In isolation, this will contribute to adverse water quality and ecological effects associated with eutrophication. Projected total nitrogen and total phosphorus concentrations in the treated wastewater equate to maximum loads of 40 t N yr$^{-1}$ and 3.0 t P yr$^{-1}$.

The effects of the proposed option on eutrophication in Lake Rotorua were considered in detail by Abell et al. (2015) by applying a one-dimensional lake ecosystem model (DYRESM-CAEDYM). Those modelling results for Option 6a surface discharge (most comparable to the preferred option considered here), showed that the mean 8-year TLI$_3$ would be 0.02 TLI$_3$ units higher than the modelled baseline scenario (no discharge). This difference is small relative to model error, and is negligible to low from an ecological perspective. The model predictions showed no change to the baseline Attribute States for chlorophyll *a* (B), total nitrogen (B) and total phosphorus (C) that are defined in the National Policy Statement for Freshwater Management (2014) for protection of ecosystem health in lakes and rivers (in relation to toxicity). The version denoted as 2014 includes amendments to water quality standards made in 2017; the referencing format is specified by the Ministry for the Environment.

Although the predicted long-term effects on lake trophic status are minor (negative), there is potential for more pronounced localised effects on productivity. These could include local increases in phytoplankton biomass in the southern area of the lake during periods when background nutrient concentrations in the lake are at limiting concentrations, e.g., during stratified periods in the summer. Such conditions could also occur some distance from the outfall, in areas where dominant mixing process cause the discharged treated wastewater to accumulate. Three-dimensional modelling showed that discharge to Sulphur Bay could result in accumulation of treated wastewater in the vicinity of Rotorua lakefront following prolonged NE winds (Abell 2015, Abell et al. 2015). Thus, there is potential for localised and temporary increases in phytoplankton biomass in this area during specific weather conditions.

Potential impacts to periphyton and macrophytes were not considered in the assessment due to the geothermal characteristics of the thermal channel and Sulphur Bay (unsuitable habitats).

### *Metals and pH*

A suite of 31 metals was considered, based on those that have potential to cause ecological or human health risks. Projected concentrations in treated wastewater were estimated based on three flow-weighted samples of the existing treated wastewater that were collected in November 2016. Projected concentrations in treated wastewater are higher than baseline concentrations of nine metals in the Te Arikiroa Thermal Channel and 20 metals in the lake, measured at Site 4 in Sulphur Bay, outside of the assumed mixing zone. In the Te Arikiroa Thermal Channel, projected metal concentrations in treated wastewater are higher than baseline concentrations of antimony, bismuth, cadmium, molybdenum, nickel, selenium, sodium, tin and silver. The modelled concentrations of cadmium, nickel, selenium and silver in the thermal channel are less than the 99% ANZECC and ARMCANZ (2000) trigger values. No trigger values are defined for the remaining five metals.

In Sulphur Bay, projected metal concentrations in treated wastewater are higher than baseline concentrations of antimony, bismuth, cadmium, calcium, chromium, cobalt, copper, lead, magnesium, molybdenum, nickel, potassium, selenium, sodium, strontium, tin, uranium, vanadium, zinc and silver. The modelled concentrations of cadmium, lead, copper, nickel, selenium and sulphur in Sulphur Bay are less than the 99% ANZECC and ARMCANZ (2000) trigger values. The modelled concentrations of chromium and zinc in the thermal channel are less than the 95% ANZECC and ARMCANZ (2000) trigger values but greater than the 99% values. No trigger values are defined for the remaining 12 metals.

In Sulphur Bay, the only metal for which the modelled concentration exceeds a defined 90% trigger value is aluminium. This reflects background conditions and not the proposed discharge.

The projected mean pH of the treated wastewater (6.94) is higher than the baseline pH of Te Arikiroa Thermal Channel (~5.60) and Sulphur Bay (4.16 at Site 4). Therefore the proposed discharge will increase the pH in the thermal channel and cause a localised increase in pH in Sulphur Bay; modelled pH was 6.89 in the thermal channel and 4.24 in Sulphur Bay.

### *Nutrients (assessment of potential for toxicity)*

Projected ammoniacal nitrogen concentrations in the treated wastewater (2.0 mg N $L^{-1}$) are lower than measured concentrations in the Te Arikiroa Thermal Channel (5.6 mg N $L^{-1}$) but higher than measured concentrations in Sulphur Bay at Site 4 (0.04 mg N $L^{-1}$). The modelling therefore predicts that the discharge will cause ammoniacal nitrogen concentrations to decrease in the Te Arikiroa Thermal Channel (1.16 mg N $L^{-1}$) but increase slightly at the edge of the mixing zone in Sulphur Bay (0.07 mg N $L^{-1}$).

Comparisons were made with Attribute States defined in the National Policy Statement for Freshwater Management (2014) for protection of ecosystem health in lakes and rivers (in relation to toxicity), which assigns an ‘attribute state’ of A to D based on concentration. Comparisons were made using criteria based on median concentrations, although we recognise that criteria based on other metrics (annual maxima or 95th percentiles) have also been defined. Consideration of median concentrations was deemed most appropriate due to the limited extent of baseline sampling. Baseline Attribute States (based on estimated median concentrations) are D in the Te Arikiroa Thermal Channel and B in Sulphur Bay (Lake Rotorua).

The proposed discharge is predicted to improve the Attribute State to C in Te Arikiroa Thermal Channel and cause no change to the Attribute State in Lake Rotorua. The modelled concentration for Lake Rotorua is at the low end of the range for Attribute State B, which corresponds to conditions associated with occasional impacts on the most sensitive species. The toxicity of ammonia depends strongly on pH, although no pH adjustments were made for this assessment, which provides for a conservative approach given the low pH of Sulphur Bay. The proposed discharge is therefore not predicted to substantively increase ecological risks associated with ammonia toxicity.

Projected nitrate-nitrogen concentrations in the treated wastewater (2.0 mg N $L^{-1}$) are higher than measured concentrations in the Te Arikiroa Thermal Channel (<0.01 mg N $L^{-1}$). The modelling therefore predicts that the discharge will cause nitrate-nitrogen concentrations to increase in the Te Arikiroa Thermal Channel (1.93 mg N $L^{-1}$). Comparisons were made with Attribute States defined in the National Policy Statement for Freshwater Management (2014) for protection of ecosystem health in rivers (in relation to toxicity). The Attribute State (based on estimated median concentrations) in the Te Arikiroa Thermal Channel is A under baseline conditions and B following the projected discharge. Attribute State B corresponds to conditions associated with growth effects on up to 5% of species. This modelling result should be considered in the context of the negligible to low ecological value of the Te Arikiroa Thermal Channel, and the expected high contribution that other baseline factors (e.g., low pH) make to limiting growth. Nitrate is also likely to undergo denitrification in the low-oxygen conditions of the thermal channel, thus reducing concentrations relative to model predictions which assume conservation of mass. Baseline and modelled Attribute States were not calculated for Lake Rotorua because the Attribute States relate to rivers. However, based on consideration of the projected nitrate concentrations in the treated wastewater, and the expected dilution in the lake, the proposed discharge is not expected to increase ecological risk in the lake due to nitrate toxicity.

### *Water temperature*

The projected flow rate of the proposed discharge (0.2756 $m^3\ s^{-1}$) is substantially higher than the baseline flow rate in the Te Arikiroa Thermal Channel (0.01 $m^3\ s^{-1}$). Therefore, following implementation of the proposed discharge, the water temperature of the thermal channel will be closely aligned with the projected water temperature of the treated wastewater (16–18°C). Seasonal variability in baseline water temperature of the Te Arikiroa Thermal Channel is not precisely known; however, given the geothermal influence on the channel, it is likely that the proposed discharge will result in lower water temperatures in the channel.

Based on measure baseline water temperatures at the edge of the assumed mixing zone in Sulphur Bay, the proposed discharge is expected to cause a localised increase in water temperatures in the winter and a small localised decrease in water temperatures in summer. The relatively low volume of the proposed discharge means that any localised temperature changes in Sulphur Bay are expected to be ameliorated before treated wastewater mixes with the wider lake.

### *Suspended solids, colour, clarity and visual/aesthetic values*

Baseline turbidity is high in the Te Arikiroa Thermal Channel (460 NTU, *n*=1) and Sulphur Bay (mean of 163.5 NTU at Site 4, *n* = 29), reflecting the geothermal influence. Turbidity in the treated wastewater is not precisely known but it will be substantially lower than the baseline turbidity in the receiving environments, partly due to the use of ultra-filtration, which will remove the contribution of particulate material to turbidity. Accordingly, the proposed discharge is predicted to cause a decrease in turbidity in the thermal channel, and a localised decrease in Sulphur Bay.

Similarly, suspended sediment concentrations are projected to be negligible in the treated wastewater due to the use of ultra-filtration. The proposed discharge is therefore not predicted to cause an increase in suspended sediment concentrations in receiving waters unless there is an initial scouring of the channel with the large volume of wastewater discharge. The removal of particulate material means that no issues are expected related to increased deposition of sediments.

The colour of the receiving waters or the treated waters is not precisely known. Generally, the treated wastewater is expected to have considerably higher clarity than the receiving waters that are geothermally influenced and of high turbidity. The discharge has potential to cause a localized reduction in the milky hue of Sulphur Bay, most likely during winter when the treated wastewater is likely to be warmer than the off-shore areas of the bay and thus positively buoyant, i.e., it will float and therefore have higher potential to affect visual appearance at the surface. However, there is uncertainty about this prediction due to the relatively low flow rate of the proposed discharge and localised mixing, i.e., a visible change might not be apparent.

### *Emerging organic contaminants*

The proposed wastewater discharge has potential to increase concentrations of emerging organic contaminants in receiving waters. These analytes were sampled during baseline data collection undertaken for this study, at sites inside and outside of the assumed mixing zone (site 4 and 5). Analysis of these data and associated assessment outcomes are provided in a separate study conducted by Northcott Research Consultants Ltd (Northcott 2017).

### *Taonga species (including macroinvertebrates and fish)*

Taonga species (fish, kōura and kākahi) are currently expected to be absent from the Te Arikiroa Thermal Channel. The large geothermal-influence most likely eliminates the potential for taonga species to colonise the channel. Accordingly, there is considered to be no effect of the proposed wastewater discharge on these taxa in the Te Arikiroa Thermal Channel or perhaps a higher likelihood of their colonisation of the Thermal Channel.

Previous biological monitoring of Sulphur Bay suggests that, apart from wildfowl (not considered in this assessment), chironomids (family: Chironomidae) are the only aquatic organisms present. Based on evaluation of the water quality modelling results, taonga species are not expected to colonize Sulphur Bay following implementation of the proposed discharge. Accordingly, there is also assessed to be no effect of the proposed wastewater discharge on taonga species in Lake Rotorua.

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## GLOSSARY

| | |
|---|---|
| Bardenpho | A biological nutrient removal system that comprises a series of tanks with alternating anoxic/aerobic conditions to remove both N and P. Added to the Rotorua WWTP in 1991. |
| BoPRC | Bay of Plenty Regional Council |
| Chl *a* | Chlorophyll *a*. A plant pigment that is used as an indicator of phytoplankton biomass. |
| DRP | Dissolved reactive phosphorus |
| *E.coli* | *Escherichia coli*. A bacterium that is commonly used as an indicator of faecal contamination in water. |
| LTS | Land Treatment System. Treated wastewater is currently spray–irrigated at the LTS, located to the south of Lake Rotorua. |
| MBR | Membrane bioreactor. A nutrient removal system that combines biological treatment and membrane separation. Added to the Rotorua WWTP in 2012. |
| N | Nitrogen. |
| $NH_4$ | Ammonium. Part of the inorganic nitrogen which is required by plants |
| P | Phosphorus. |
| Phytoplankton | Microscopic aquatic plants that are suspended in the water column |
| Q | Stream discharge |
| RDC | Rotorua District Council |
| TLI | Trophic Level Index. The metric is termed $TLI_3$ when it is calculated without Secchi depth data as values are based on three (rather than four) water quality variables. |
| TN | Total nitrogen |
| TP | Total phosphorus |
| UV | Ultra–violet |
| WWTP | Waste water treatment plant |

## INTRODUCTION

Currently, wastewater from the city of Rotorua is collected and treated at the Rotorua Wastewater Treatment Plant (WWTP). The resulting wastewater is pumped to the Land Treatment System (LTS) in the Whakarewarewa Forest for subsequent irrigation onto approximately 300 ha of plantation forest. Whakarewarewa Forest is irrigated with treated wastewater as permitted by the resource consent for the discharge of treated municipal wastewater to land. This disposal method will be discontinued in around 2020. A court-mediated agreement was reached between the Rotorua Lakes Council, Bay of Plenty Regional Council and landowners in the LTS area to find an alternative to the current discharge system before the end of the current resource consent in 2021.

After assessment of a large number of possible discharge options, a preferred option was identified by Rotorua Lakes Council for further detailed assessment. This option involves treating wastewater to a high level and then discharging it to Lake Rotorua at Sulphur Bay, via Te Arikiroa Thermal Channel. To support further detailed assessment of this preferred option, Rotorua Lakes Council engaged the Environmental Research Institute, University of Waikato to lead water sampling and undertake additional analysis that builds on previous studies. Specifically, objectives were to:

- Conduct water quality sampling along a transect perpendicular to the mouth of the Te Arikiroa Thermal Channel;
- Analyse available water quality data and provide assessment outcomes in the context of attribute states defined in the National Policy Statement for Freshwater Management 2014 (amended 2017; NPS-FM (2014));
- Consider the potential for the proposed discharge to impact taonga species (species of cultural significance), including macroinvertebrates and freshwater fish.

This report addresses the objectives listed above, and is complimentary to a separate Microbial Risk Assessment conducted by MWH /NIWA, and a study of emerging organic contaminants undertaken by Northcott Research Consultants Ltd (Northcott 2017).

## BACKGROUND

### 1.1. GENERAL ENVIRONMENTAL EFFECTS OF DISCHARGING TREATED WASTEWATER

While it is generally accepted that conventional wastewater treatment reduces the concentrations of contaminants and pathogens, the extent to which this occurs varies widely depending on the treatment process. For example, although treatment at WWTPs largely reduces biochemical oxygen demand and pathogen load, the treatment does not generally ensure that the characteristics of the wastewater match the water quality of the receiving waters (USEPA 2011). Previous studies of the effects of WWTP wastewaters elsewhere have reported the following:

1. increased nutrient loading and eutrophication (Gücker et al. 2006, Waiser et al. 2011);
2. increased antibiotic resistance in bacteria (Amos et al. 2014, Bouki et al. 2013);
3. persistence of non-indigenous microorganisms in the receiving water (Dury et al 2013);
4. emerging organic contaminant loading (Stewart et al. 2014);
5. heavy metal loading (Stewart et al. 2014, WSL 2011, Wilkison et al 2002),and;
6. changes in flora and fauna distribution, abundance and community structure (WSL 2011).

The impact of the proposed option on eutrophication (bullet point 1) in Lake Rotorua was assessed by Abell et al. (2015), although local effects of the proposed discharge on nutrient concentrations in Sulphur Bay and the Te Arikiroa Thermal Channel are considered in this report. Microbial effects (bullet points 2 and 3) will be considered in detail in a Microbial Risk Assessment conducted by MWH /NIWA, although potential effects of the proposed option on faecal indicator bacteria concentrations are considered in this report. Emerging organic contaminants will be considered separately by Northcott Research Consultants Ltd. (bullet point 4). Bullet points 5 and 6 are considered in this report.

## 1.2. LAKE ROTORUA

### 1.2.1. Setting

Lake Rotorua is a large (80.8 km$^2$), relatively shallow (mean depth 10.8 m) lake of volcanic origin (Figure 1). It has a terrestrial catchment area of approximately 425 km$^2$ with complex hydrogeology including large unconfined aquifers that retain groundwater for long and variable periods (Hamilton et al. 2015). Lake Rotorua is geologically separate from nearby lakes and was formed in a caldera (crater caused by a volcanic eruption) about 200,000 years ago (teara.govt.nz). Lake Rotorua is nationally iconic and a major asset to the city of Rotorua. It is a lake of great cultural significance to Māori and the lake lies within the tribal area of Te Arawa. Lake Rotorua also provides important recreational and tourism opportunities such as such as boating, kayaking, swimming, as well as a trout fishery.

Lake Rotorua flows into Lake Rotoiti via the Ōhau Channel at the northeastern corner of the lake. The Ōhau Channel Diversion Wall, constructed in 2008, prevents water from Lake Rotorua mixing with Lake Rotoiti and instead diverts flow to the Kaituna River, which flows into the Pacific Ocean near Maketu. Owing to the geothermal activity, areas around the lake have a high sulphur content. This gives Lake Rotorua a yellowish-green hue in Sulphur Bay, which is an example of Rotorua's famous geothermal environment, with characteristic silica flats, rocky terraces, and sulphur ledges that lie alongside active boiling mud pools and steam vents. Mokoia Island, close to the centre of the lake, is a rhyolite dome.

### 1.2.2. Hydrology and land use

Lake Rotorua has nine major sub-catchments that contribute approximately 66% of the inflow to the lake (Hoare 1980). Rainfall to the lake surface contributes approximately 22% of the inflow, while minor streams and ungauged sources contribute approximately 12% (Hoare 1980). The WWTP is situated in the Puarenga Stream sub-catchment, which is the second-largest stream inflow based on volume and has a mean discharge of 1.95 $m^3 s^{-1}$ (2007–2014 data; Abell et al. 2015). The projected mean flow rate of the treated wastewater discharge is 0.276 $m^3 s^{-1}$ (Mott MacDonald 2017).

The predominant land use in the wider Lake Rotorua catchment is pasture, although this varies among sub-catchments (Figure 2). Pasture (dairy and dry stock) comprised approximately 13% of the catchment in 1940 but now comprises approximately 50% (Rutherford et al. 2011), with intensification greatest in the past 3-4 decades (Hamilton et al. 2015). Land use in the Puarenga Stream sub-catchment predominantly consists of plantation forestry, dairy support pastoral activities, and native forest and scrub plantations (Figure 2).

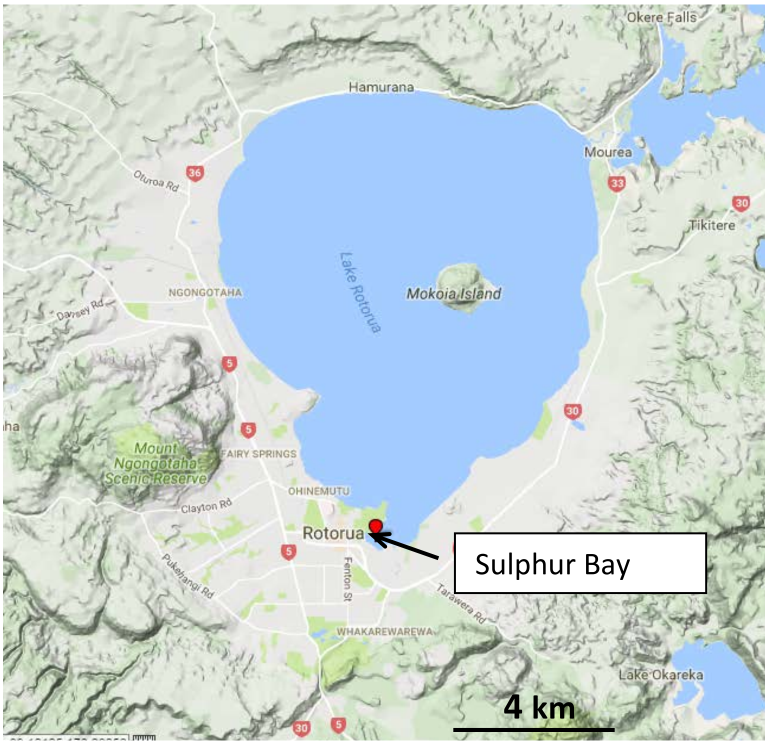

**Figure 1** **Map of Lake Rotorua (created using GPS Visualizer). The Te Arikiroa Thermal Channel enters the lake at the southern end of Sulphur Bay.**

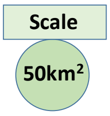

**Figure 2** **Land use within the Lake Rotorua Catchment. Size of the pie charts is scaled to the area of the catchment (Source: Tempero et al. 2015)**

### 1.2.3. Water quality

Lake Rotorua is eutrophic (highly productive). This is caused by excessive inputs of nitrogen and phosphorus, which have impaired water quality relative to pre-1960s conditions. Since 2010, the water quality of Lake Rotorua has improved relative to the previous two decades, reflecting a range of environmental management actions (Smith et al. 2016).

Lake water quality is monitored using the Trophic Level Index (TLI), which is a metric of trophic status that integrates mean annual measurements of Secchi depth, and concentrations of total nitrogen (TN), total phosphorus (TP) and chlorophyll *a* (Burns et al. 1999). The 2014/15 TLI value for the lake is 4.4 TLI units, which is slightly higher than the target of 4.2 but lower than the majority of the values that were measured during the 1990s and 2000s (Scholes & Hamill 2016).

The land use in the lake catchment affects the quality of water that enters the lake. In particular, intensive pastoral agriculture is a significant source of nitrogen and phosphorus to the lake, although there has been a lag between intensification and increased loads to the lake, particularly for nitrogen (Rutherford 1984, Morgenstern et al. 2015). The expansion of agricultural development and co-incident urbanisation in the Lake Rotorua catchment have largely been implicated in the decline of Lake Rotorua water quality particularly between the 1960s and mid- 2000s (e.g., Fish 1969; Rutherford et al. 1996; Burger et al. 2007a, 2008).

Figure 3 and Figure 4 show mean external nitrogen and phosphorus loads to Lake Rotorua. For context, the estimated loads associated with the proposed treated wastewater discharge are also presented on these figures; these are discussed further in Section 1.3.2. Internal loads from the lake bed have also been shown to be historically significant, particularly for phosphorus (Burger et al. 2008). There is evidence that these loads have declined in the last decade (e.g., Figure 1 in Abell et al. 2016), which likely largely reflects alum dosing operations (Smith et al. 2016) and, potentially, some decline of legacy nutrient loads in the lake bed sediments.

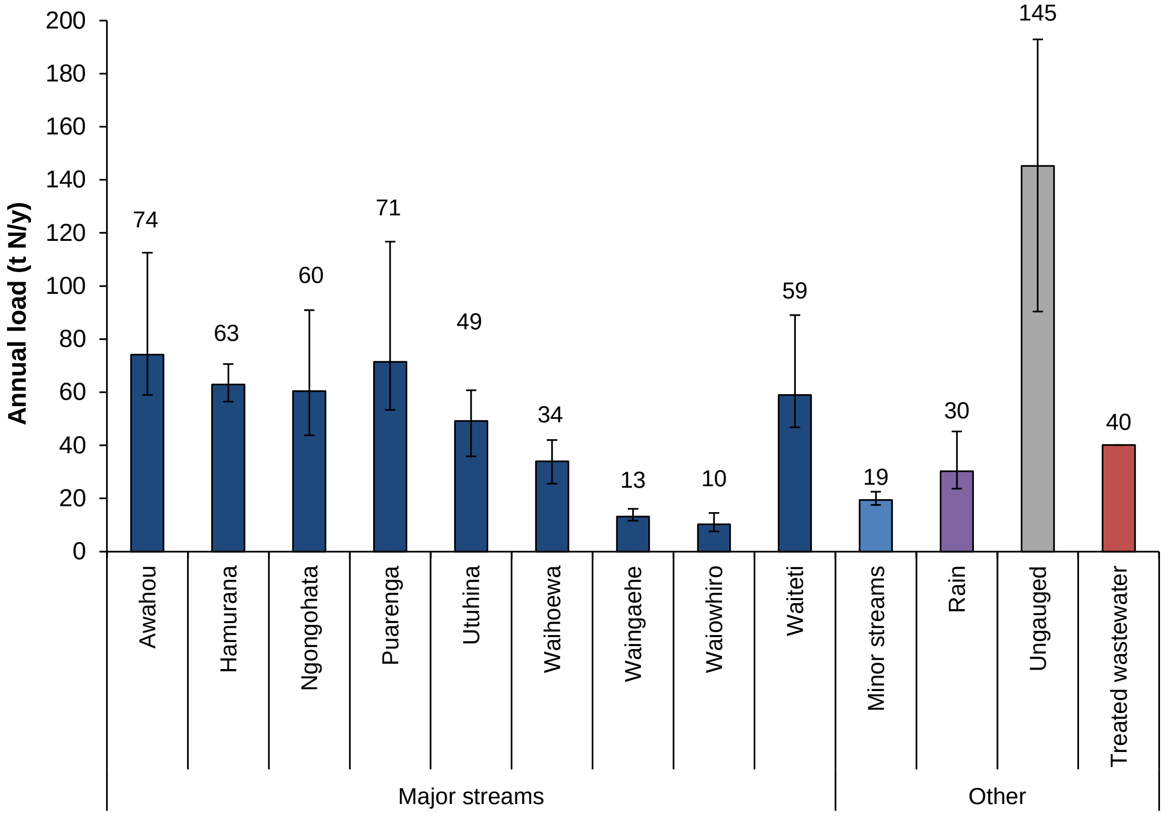

**Figure 3. Estimated mean external nitrogen loads to Lake Rotorua. Estimates are based on the period 2007–2014. Vertical lines show the minimum and maximum annual loads. Estimates are presented for the range of wastewater treatment options that were considered during an earlier assessment stage. The TN load for the current preferred option corresponds to Option 2b (mean TN concentration = 4.62 mg $L^{-1}$). Reproduced from Abell et al. (2015).**

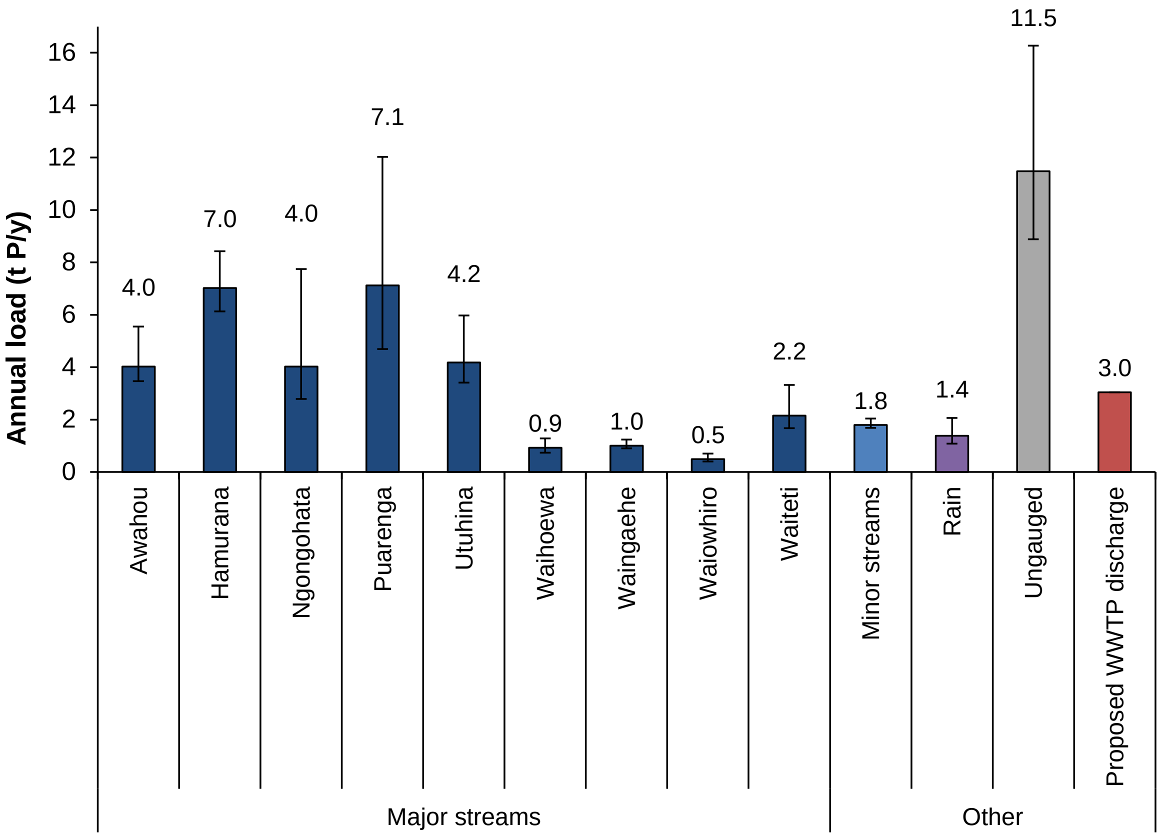

**Figure 4.** **Estimated mean external phosphorus loads to Lake Rotorua. Estimates are based on the period 2007–2014. Vertical lines show the minimum and maximum annual loads. Estimates are presented for the range of wastewater treatment options that were considered during an earlier assessment stage. The TP load for the current preferred option corresponds to Option 6a (up to 3.0 t P $y^{-1}$). Reproduced from Abell et al. (2015).**

## 1.3. WASTEWATER DISCHARGE IN THE LAKE CATCHMENT

### 1.3.1. History of wastewater discharge in the lake catchment

Before 1991, secondary-treated wastewater was discharged to Lake Rotorua. This contributed to the accumulation of nutrients (particularly phosphorus) in the bed sediments, in addition to inputs from other sources such as farmland, in turn contributing to eutrophication and associated algal blooms and periods of water quality decline in the 1970s and 1980s (Tomer et al 1997, 2000, Rutherford 1984; Rutherford et al. 1989). To address this point source, treated wastewater was re-directed to the LTS in October 1991, an area which covers over 193 ha in the Whakarewarewa Forest of the Puarenga subcatchment to the south of the lake (Hu et al., 2007). In the same year, (1991), the treatment plant was upgraded to include an activated-sludge (Bardenpho) process for nutrient removal (Water Environment Federation 1992, Tomer et al 2000). Treated wastewater from Rotorua city is then spray-irrigated in the Whakarewarewa Forest to minimise wastewater-derived nitrogen (N) and phosphorus (P) entering Lake Rotorua. Water quality monitoring of the outflow stream (Waipa Stream) from the LTS, indicates that a major portion of the N and P loads is retained or attenuated (denitrified), meaning that the implementation of the LTS has considerably reduced N and P input to the lake from wastewater sources (Tomer et al. 1997, Hu et al 2007).

### 1.3.2. Proposed option for wastewater discharge in the lake catchment

The Resource Consent for the Rotorua LTS expires in 2021, warranting the need to consider alternative wastewater disposal systems. As a result, various stakeholders (Bay of Plenty Regional Council, Toi Te Ora, Te Arawa Lakes Trust, Rotorua Lakes Community Board, CNI, Timberlands and representatives from all hapū around the lake) were invited following a workshop to participate in the Rotorua Project Steering Committee (RPSC). The RPSC had an objective to identify and evaluate alternative options to the LTS. At least six different options, involving varying grades of treatment were considered (Abell et al. 2015, Mott Macdonald 2015). A number of potential discharge sites to water were also identified, including discharge to the Puarenga Stream, the lake bed, or the shoreline of Sulphur Bay. Following consultations and technical assessments, the RPSC's preliminary preferred option was to upgrade the existing plant to provide a full Membrane Bioreactor Plant, with the addition of an Ultraviolet Disinfection System (or alternative treatment to achieve an equivalent performance in terms of treated wastewater quality). Under this arrangement, wastewater would be subjected to a rigorous array of biological, chemical and physical treatment processes (Figure 5). The highly treated wastewater would then be discharged through a land contact treatment area (earth beds) to an existing constructed drain at Sulphur Bay (Te Arikiroa). Treated wastewater would then flow into the Te Arikiroa Thermal Channel, which is a natural channel that drains the geothermal area.

In summary, the proposed upgrade will involve the following features (Mott MacDonald 2017):

- upgrades to the inlet structure;
- a large increase in capacity to fully treat 72ML d-1;
- upfront flow-balancing;
- a potential option to bypass primary settling tanks to divert carbon into secondary treatment to reduce carbon dosing requirement;
- no changes to the existing extended secondary treatment tank (i.e., the current capacity to fully nitrify and denitrify will remain);
- capacity for phosphorus flocculation (likely with aluminium sulphate [alum])at several locations in the secondary treatment tank at a number of points;
- installing a new tank for ultra-filtration using a 0.02–0.04 µm pore size filter;
- post-filtration UV treatment, prior to consent compliance testing;
- capacity for beneficial reuse, and;
- discharge to earth beds.

The preferred treatment option is projected to result in treated wastewater with a TN concentration of ≤4.62 mg $L^{-1}$ and a TP concentration of approximately 0.35 mg $L^{-1}$ (see options 2b and 6a in Abell et al. 2015[1]). Based on a mean treated wastewater discharge rate of 0.276 $m^3$ $s^{-1}$, these concentrations correspond to an annual TN load of 40 t N $yr^{-1}$ (Figure 3) and an annual TP load from treated wastewater of 3.0 t P $yr^{-1}$ (Figure 4). These projected loads will be lower than the loads that are currently applied to the LTS and they are comparable with loads from a major stream inflow (Figure 3, Figure 4). The projected composition of the treated wastewater is considered further in Section 1.5.

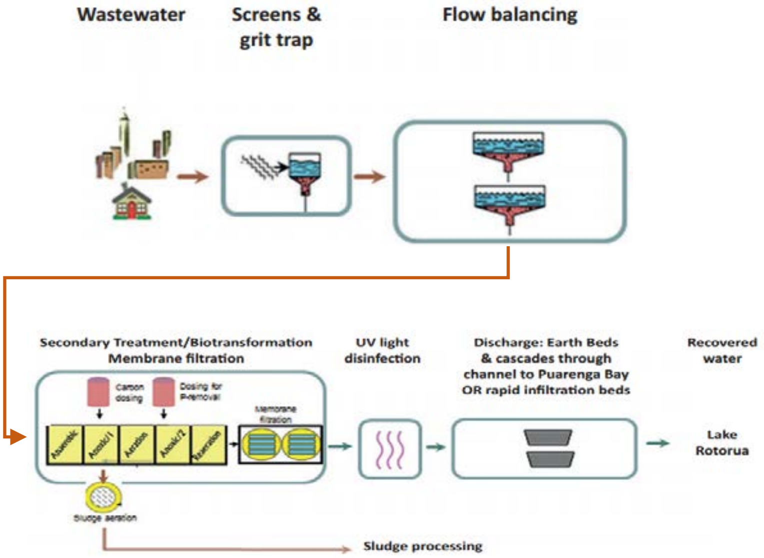

**Figure 5** **Schematic representation of Rotorua's Proposed Upgraded WWTP treatment process. The figure indicates the level of treatment that is expected, although the specifications may differ.**

Technical assessments that informed the selection of the preferred option captured the available treatment and discharge options. To inform environmental risks, Abell et al. (2015) completed a water quality assessment of six main options for enhanced wastewater treatment at seven proposed discharge locations. The assessment included: 1) mass balance calculations; 2) 1-D lake modelling, and; 3) 3-D lake modelling. The assessment considered impacts to lake trophic status and involved comparing predicted lake water quality with Attribute States based on the National Policy Statement for Freshwater Management 2014. A key finding of this study was that effects associated with each treatment option on lake trophic status would be neutral to minor (negative). This was based on using a 1-D model to simulate mean TLI for an eight-year period, which showed that predicted changes in mean TLI values were minor (<0.01 to 0.02 units) and within the range on model error. This indicates that the proposed discharge options

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[1] These concentrations were based on a spreadsheet ('Load data.xlsx') sent to C. McBride (University of Waikato) by e-mail on 10 June 2015 from K. Brian (Engineer, Mott MacDonald).

would have a small effect on average lake trophic status. The 3-D lake modelling predicted how treated wastewater would be diluted and dispersed in the lake following discharge to either the Puarenga Stream or the lake bed. An extension of this work considered discharge to the west of the Puarenga Stream mouth, directly north of the existing Rotorua Wastewater Treatment Plant (Abell 2015).

The effect of the proposed treated wastewater discharge on eutrophication in Lake Rotorua was assessed by Abell et al. (2015). However, following selection of the preferred option, there is now a need to conduct further assessment that reflects additional data collection and considers: microbial contaminants, heavy metals, pH, clarity, dissolved oxygen, emerging organic contaminants, and; changes in flora and fauna distribution, abundance and community structure.

## MATERIALS AND METHODS

### 1.4. OVERVIEW

To assess the environmental effect of discharge of treated wastewater into Lake Rotorua through Sulphur Bay/Thermal Channel, our study focused on four main issues:

(i) the proposed discharge water characteristics

(ii) the environmental and ecological condition of the receiving water

(iii) the sensitivity of the receiving water to changes in key water quality variables due to the proposed discharge of treated wastewater, including consideration of a zone of reasonable mixing.

(iv) effects of the treated wastewater discharge on taonga species.

### 1.5. CHARACTERISTICS OF TREATED WASTEWATER

The quality of the treated wastewater following the upgrades was estimated as follows:

**Faecal indicator bacteria and metals**: Concentrations of these analytes were assumed to be consistent with current concentrations. This is a conservative assumption because the proposed Ultraviolet Disinfection System is expected to further reduce concentrations of faecal indicator bacteria, while additional treatment (e.g., ultra-filtration) is expected to further reduce metal concentrations.

Concentrations were characterized by collecting three 24-hr composite samples of treated wastewater from the current WWTP on 23, 24 and 25 November 2016. The composite samples were formed by combining two or more samples collected at different locations. These samples were flow-proportional, i.e., the samples were collected at a frequency that was proportional to the treated wastewater flow rate. Flow-proportional sampling allows for the accurate measurement of pollutant loads when both the flow rate and pollutant concentration vary over the sampling period (Ort et al 2010). These samples, in addition to samples described below in

Section 1.6, were analysed at Hill Laboratories (Hamilton, accredited) using standard techniques.

**Nutrients**: Nutrient concentrations are based on projected concentrations presented in Mott MacDonald (2017), and generally correspond to projected phosphorus concentrations for Option 6a and projected nitrogen concentrations for Option 2b that were considered in Abell et al. (2015)[1].

**pH**: This was assumed to be consistent with the current pH because the proposed upgrades are not expected to change pH from current conditions. pH was characterised based on measurements collected at the MBR site by Rotorua Lakes Council from July 2015 to March 2016.

**Water temperature**: The treated wastewater temperature was assumed to follow an annual sinusoidal trend with a maximum of 18 °C and a minimum of 16 °C (K. Brian, pers. comm. 2015). This is consistent with Abell et al. (2016).

**Suspended solids, colour and clarity**: The proposed upgrades involve installing an ultra-filtration system (Section 1.3.2) which will remove suspended solids. This is expected to result in high clarity. The projected colour of the treated wastewater is not precisely known (e.g., in True Colour Units). However, the extent of colour is expected to be considerably less than that of Sulphur Bay.

Wastewater data were compared with applicable guidelines (Section 1.7.3).

## 1.6. CHARACTERISTICS OF RECEIVING WATER

### 1.6.1. Receiving Water: Te Arikiroa Thermal Channel (January 2017)

The Te Arikiroa Thermal Channel is a locally and geothermally influenced stream channel that flows into the southern end of Sulphur Bay, Lake Rotorua (Figure 1). To characterise the water quality of the receiving Te Arikiroa Thermal Channel, a grab sample was collected from the thermal channel in January 2017. Thermal channel water was analysed to determine concentrations of nutrients, metals, *E.coli* and faecal coliforms. Turbidity was measured using a turbidity meter.

### 1.6.2. Receiving Water: Sulphur Bay Water Quality (2011-2016)

The water quality of Sulphur Bay was characterised based on measurements collected during 2011–2016 at sampling stations along a transect within Sulphur Bay. The transect was aligned in a NE–SW direction (Figure 6), reflecting a gradient of increasing influence by lake water and declining influence from the Puarenga Stream and geothermal water. Data were collected as part of two studies:

1. Monthly sampling during July 2011 to June 2016 conducted as part of an Alum Dosing Monitoring Survey. This survey measured temperature, turbidity, conductivity, pH, and concentrations of phosphorus and aluminium.

2. Sampling was conducted in November 2016 to inform this assessment. Samples were analysed to determine concentrations of nutrients, metals, faecal indicator bacteria, and water column chlorophyll *a*.

The mixing zone for the proposed wastewater discharge was assumed to encompass an area of approximately 250 m from the proposed discharge location (see rationale in Section 1.7.2.2).

Sampling sites included a site approximately 100 m from the discharge (site 6, within the mixing zone), 250 m from the discharge (site 5, edge of the mixing zone) and four further sites located along the transect (1–4). Site 7 was sampled to the north west of Sulphur Point (Figure 6) to represent a control site outside of Sulphur Bay.

## 1.7. MASS BALANCE DILUTION MODELLING

### 1.7.1. Overview

Projections of the water quality of the treated wastewater (Section 1.5) were combined with quantitative water quality data for receiving waterbodies (Section 1.6) to predict how implementing the proposed discharge option will affect water quality. Separate water quality predictions were made for: 1) the Te Arikiroa Thermal Channel; 2) Lake Rotorua, based on predictions for a site in Sulphur Bay, immediately outside of the assumed mixing zone. Predictions for Lake Rotorua (Sulphur Bay) were based on projections of the concentration (%) of treated wastewater that were derived using a 3-D hydrodynamic model by Abell et al. (2015). Water quality predictions were compared with Attribute States in the National Policy Statement for Freshwater 2014, with consideration of updates made in 2017 (NPS-FM (2014); New Zealand Government 2017) and the ANZECC and ARMCANZ (2000) guidelines. We recognise that the proposed option includes capacity to provide beneficial reuse of treated wastewater (Section 1.3.2), e.g., a portion of the treated wastewater may be diverted for uses such as irrigation of recreational sites. This capacity was not considered and therefore the estimated contaminant loads provide ‘worst case’ predictions in this regard because some attenuation is expected if treated wastewater is diverted to land.

**Figure 6** **Locations sampled along a transect from the estimated mixing zone (sites 5 and 6) to sites that represent increased influence from the wider lake (sites 1–4). A control sample was collected at Site 7. Red line (right-hand figure) denotes the treated discharge water. Right-hand figure: Google Earth.**

### 1.7.2. Modelling

#### *1.7.2.1. Te Arikiroa Thermal Channel*

Projected concentrations of analytes following the proposed discharge to the Te Arikiroa Thermal Channel were estimated as follows:

$$C_{i,channel} = \frac{\left(C_{i,baseline} \cdot Q_{baseline}\right) + \left(C_{i,TW} \cdot Q_{TW}\right)}{Q_{baseline} + Q_{TW}}$$

where: $C_{i,channel}$is projected concentration of analyte *i* in the thermal channel; $C_{i,baseline}$ is mean baseline (no discharge of treated wastewater) concentration of analyte *i* (in the channel); $C_{i,TW}$,is projected concentration of analyte *i* in the treated wastewater; $Q_{baseline}$ is mean baseline discharge (flow rate) of the thermal channel (0.01 $m^3$ $s^{-1}$; BoPRC 2015), and; $Q_{TW}$ is the mean daily discharge of treated wastewater (0.2756 $m^3$ $s^{-1}$; Mott MacDonald 2017). Concentrations were expressed as mg $L^{-1}$.

This approach assumes: 1) conservation of mass; 2) complete mixing, and; 3) that water quality measurements and projections are accurate and representative.

#### *1.7.2.2. Lake Rotorua (Sulphur Bay)*

To predict water quality in Sulphur Bay, it was necessary to estimate the proportion of treated wastewater that would be present in Sulphur Bay following implementing the preferred option. This was done by analysing predictions from the 3-D hydrodynamic model (ELCOM) configured by Abell et al. (2015) and Abell (2015). Readers should consult these studies for details of the 3-D modelling. In brief, the transport and dispersion of treated wastewater in Lake Rotorua was modelled by simulating propagation of a conservative tracer. Discharge was simulated separately at a range of sites, including discharge from a shoreline site to the west of the Puarenga Stream mouth in the vicinity of the mouth of the Te Arikiroa Thermal Channel. The model application required simplifying lake morphology by discretising the water column into 3–D cells with dimensions: $x$ = 50 m, $y$ = 50 m and $z$ = 0.5 – 2 m. Treated wastewater concentrations were simulated for each cell at sub-hourly frequency. Two separate one-month modelling periods were simulated in summer and winter to reflect a range of background conditions that can affect mixing processes in the lake (e.g., wind, inflow stream discharge).

For this study, the mixing zone where discharge from the Te Arikiroa Thermal Channel mixes with Lake Rotorua was assumed to comprise the area within a 250 m radius of the mouth of the thermal channel. This area may be considered a “zone of reasonable mixing”. This assumption was based on:

1. Analysis of the 3-D modelling results presented by Abell et al. (2015) and Abell (2015);
2. Water quality data collected along the transect in Sulphur Bay (Section 1.6.2), with consideration of the dispersion/dilution of analytes of geothermal origin, and;

3. Expert opinion, with consideration of the projected discharge and the morphology of the receiving bay.

Accordingly, modelled surface water (0–2 m depth) treated wastewater concentrations were analysed for the model cell that overlaps with Site 4, which lies 250–300 m north of the Puarenga Stream mouth (Figure 6). This site was the closest to the proposed discharge point that was located outside of the assumed mixing zone (Figure 6). For context, modelled surface water (0–2 m depth) treated wastewater concentrations were also analysed for the model cell that overlaps with Site 5, which lies at the edge of the mixing zone. Modelled concentrations were higher inside the mixing zone, with similar values modelled during summer and winter at individual sites (Figure 7). Median concentration at Site 5 at the edge of the mixing zone was 21.1% (range of values: 3.0–41.2%) while median concentration at Site 4 outside the mixing zone was 0.7% (range of values: 0.1–4.0%; Table 1).

Projected concentrations of analytes in Sulphur Bay following the proposed discharge were calculated as:

$$C_{i,lake} = \frac{\left(C_{i,baseline} \cdot k\right) + \left(C_{i,TW} \cdot (100 - k)\right)}{100}$$

where: $C_{i,lake}$ is the projected concentration of analyte *i* in the lake; $C_{i,baseline}$ is mean baseline (no discharge of treated wastewater) concentration of analyte *i* (in the lake), based on measurements collected at Site 4; $C_{i,TW}$,is projected concentration of analyte *i* in the treated wastewater; and; *k* is the modelled concentration of treated wastewater in ambient surface lake water at Site 4. Concentrations of analytes were expressed as mg $L^{-1}$ and the modelled concentration of treated wastewater was expressed as %, e.g., 1% is equivalent to one part treated wastewater to 99 parts lake water. As a precautionary approach, the 95th percentile concentration (3.0%) was used for the calculations (i.e., *k* = 3.0; Table 1). Thus, the calculations are expected to approximate the worst-case scenario, based on model predictions.

This approach assumes: 1) conservation of mass; 2) that water quality measurements at Site 4 are representative of conditions just outside of the mixing zone; 3) projections of treated wastewater quality are accurate, and; 4) model predictions are representative of mixing processes. When the above assumptions are met, the analysis provides a conservative assessment of projected water quality impacts in the lake because it is based on 95th percentile predictions for a site near the edge of the mixing zone, and the treated wastewater will be diluted to a greater extent elsewhere in the lake.

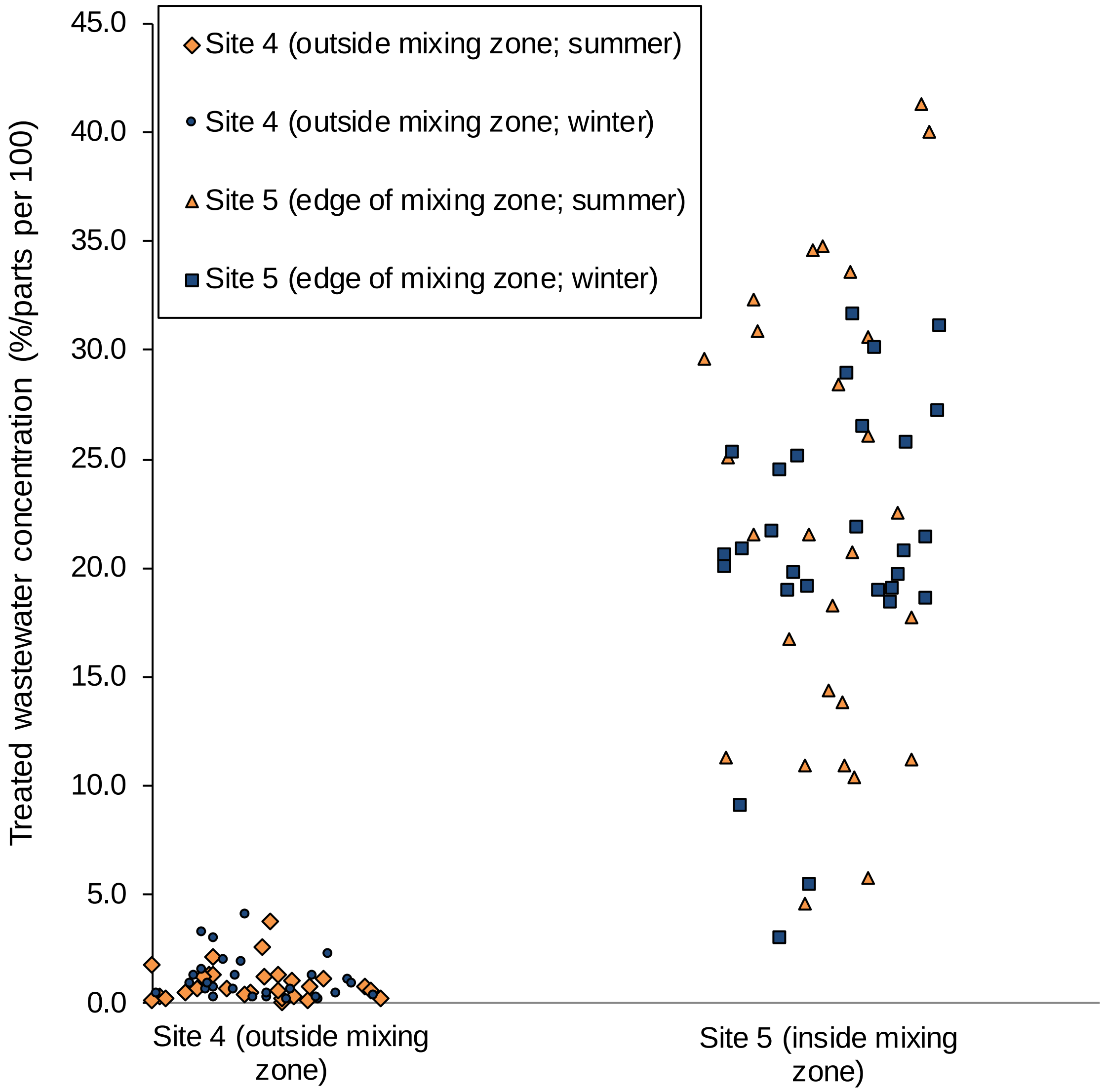


**Figure 7.** **Projected range in treated wastewater concentrations at sites in Sulphur Bay at the edge (Site 5) and just outside (Site 4) of the assumed mixing zone (Figure 6). Projections are based on 3-D modelling of two representative 1-month periods in summer and winter (Abell et al. 2015). Each value represents the modelled concentration at 09:00 on each day of the modelling periods. Points have been jittered on the *x*-axis to minimise over-plotting.**

**Table 1.** **Summary of modelled concentrations (% of wastewater) shown in Figure 7.**

| Statistic | Site 5 (edge of mixing zone) | Site 4 (outside mixing zone) |
|---|---|---|
| Minimum (%) | 3.0 | 0.1 |
| 25th %ile (%) | 18.2 | 0.3 |
| 50th %ile (%) | 21.1 | 0.7 |
| 75th %ile (%) | 27.5 | 1.3 |
| 95th %ile (%) | 34.6 | 3.0 |
| Maximum (%) | 41.2 | 4.0 |

### 1.7.3. Assessment guidelines

#### *1.7.3.1. NPS-FM (2014) Attribute States*

The NPS-FM (2014) sets out the objectives and policies for freshwater management under the Resource Management Act 1991. The NPS-FM (2014) also sets national thresholds and bottom lines for freshwater quality, and designates a range of attributes that correspond to different Ecosystem Health Attribute States, covering ecosystem health and human health for recreation. The NPS-FM (2014) includes amendments made in 2017 but the document remains with a publishing date of 2014 following recommendations of the Ministry for the Environment. Attribute States have been defined for protection of human health (recreation) for *E. coli* (Table 2) in lakes and rivers. For lakes, Attribute States for the protection of Ecosystem Health have been defined for ammoniacal nitrogen (lakes and rivers; toxicity), total nitrogen, total phosphorus (trophic state), and phytoplankton (chlorophyll a) (Table 2) in lakes and rivers. For lakes, Attribute States for the protection of Ecosystem Health have been defined for ammoniacal nitrogen (lakes and rivers; toxicity), total nitrogen, total phosphorus (trophic state), and phytoplankton (chlorophyll *a*) (to Table 7). For rivers, Attribute States have been defined for nitrate (toxicity; Table 4) and dissolved oxygen (Table 8).

Comparisons were made using criteria based on median concentrations, although we recognise that criteria based on other metrics (annual maxima or 95th percentiles) have also been defined. Consideration of median concentrations was deemed most appropriate due to the limited extent of baseline sampling.

**Table 2 Lake and river *E. coli* concentrations corresponding to Human Health for Recreation Attribute States designated in the NPS-FM (2014).**

| | | | | | |
|---|---|---|---|---|---|
| **Value** | Human health for recreation | | | | |
| **Freshwater Body Type** | Lakes and rivers | | | | |
| **Attribute** | *Escherichia coli (E. coli)* | | | | |
| **Attribute Unit** | *E. coli* 100 mL$^{-1}$ (number of *E. coli* per hundred millilitres) | | | | |
| **Attribute State**[1] | **Numeric Attribute State** | | | | **Narrative Risk Descriptor** |
| | % exceedances over 540 cfu 100 mL$^{-1}$ | % exceedances over 260 cfu 100 mL$^{-1}$ | Median concentration (cfu 100 mL$^{-1}$) | 95th percentile of *E. coli* 100 mL$^{-1}$ | Description of risk of Campylobacter infection (based on *E. coli* indicator) |
| **A (Blue)** | <5% | <20% | ≤130 | ≤540 | For at least half the time, the estimated risk is <1 in 1000 (0.1% risk). The predicted average infection risk is 1% |
| **B (Green)** | 5-10% | 20-30% | ≤130 | ≤1000 | For at least half the time, the estimated risk is <1 in 1000 (0.1% risk). The predicted average infection risk is 2% |
| **C (Yellow)** | 10-20% | 20-34% | ≤130 | ≤1200 | For at least half the time, the estimated risk is <1 in 1000 (0.1% risk). The predicted average infection risk is 3% |
| **D (Orange)** | 20-30% | >34% | >130 | >1200 | 20-30% of the time the estimated risk is ≥50 in 1000 (>5% risk). The predicted average infection risk is >3% |
| **E (Red)** | >30% | >50% | >260 | >1200 | For more than 30% of the time the estimated risk is ≥50 in 1000 (>5% risk). The predicted average infection risk is >3% |

**Table 3 Ammoniacal-nitrogen concentrations (mg N L-1) corresponding to Ecosystem Health Attribute States designated in the NPS-FM (2014), with considerations given to a range of pH and temperature following wastewater discharge.**

| | | | |
|---|---|---|---|
| **Value** | Ecosystem health | | |
| **Freshwater Body Type** | Lakes and rivers | | |
| **Attribute** | **Ammonia (Toxicity)** | | |
| **Attribute Unit** | mg $NH_4$-N $L^{-1}$ (milligrams ammoniacal-nitrogen per litre) | | |
| **Attribute State** | **Numeric Attribute State** | | **Narrative Attribute State** |
| | **Annual Median** | **Annual Maximum** | |
| **A** | ≤0.03 | ≤0.05 | 99% species protection level: No observed effect on any species tested |
| **B** | >0.03 and ≤0.24 | >0.05 and ≤0.40 | 95% species protection level: Starts impacting occasionally on the 5% most sensitive species |
| **C** | >0.24 and ≤1.30 | >0.40 and ≤2.20 | 80% species protection level: Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species) |
| **National Bottom Line** | **1.30** | **2.20** | |
| **D** | >1.30 | >2.20 | Starts approaching acute impact level (i.e. risk of death) for sensitive species |

**Table 4** **Nitrate-nitrogen concentrations (mg N L-1) corresponding to River Ecosystem Health Attribute States designated in the NPS-FM (2014).**

| **Value** | Ecosystem health | | |
|---|---|---|---|
| **Freshwater Body Type** | Rivers | | |
| **Attribute** | Nitrate (Toxicity) | | |
| **Attribute Unit** | mg $NO_3$-N $L^{-1}$ (milligrams nitrate-nitrogen per litre) | | |
| **Attribute State** | **Numeric Attribute State** | | **Narrative Attribute State** |
| | **Annual Median** | **Annual 95th Percentile** | |
| **A** | ≤1.0 | ≤1.5 | High conservation value system. Unlikely to be effects even on sensitive species. |
| **B** | >1.0 and ≤2.4 | >1.5 and ≤3.5 | Some growth effect on up to 5% of species. |
| **C** | >2.4 and ≤6.9 | >3.5 and ≤9.8 | Growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects. |
| **National Bottom Line** | 6.9 | 9.8 | |
| **D** | >6.9 | >9.8 | Impacts on growth of multiple species, and starts approaching acute impact level (i.e. risk of death) for sensitive species at higher concentrations (>20 mg $L^{-1}$). |

**Table 5** **Total nitrogen concentrations (mg $L^{-1}$) corresponding to Lake Ecosystem Health Attribute States designated in the NPS-FM (2014).**

| | | | |
|---|---|---|---|
| **Value** | Ecosystem health | | |
| **Freshwater Body Type** | Lakes | | |
| **Attribute** | Total Nitrogen (Trophic state) | | |
| **Attribute Unit** | mg $m^{-3}$ (milligrams per cubic metre) | | |
| **Attribute State** | **Numeric Attribute State** | | **Narrative Attribute State** |
| | Annual Median | Annual Median | |
| | Seasonally Stratified and Brackish | Polymictic | |
| **A** | ≤160 | ≤300 | Lake ecological communities are healthy and resilient, similar to natural reference conditions. |
| **B** | >160 and ≤350 | >300 and ≤500 | Lake ecological communities are slightly impacted by additional algal and/ or plant growth arising from nutrient levels that are elevated above natural reference conditions. |
| **C** | >350 and ≤750 | >500 and ≤800 | Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions. |
| **National Bottom Line** | **750** | **800** | |
| **D** | >750 | >800 | Lake ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state, (without native macrophyte/ seagrass cover) due to impacts of elevated nutrients leading to excessive algal and/or plant growth, as well as from losing oxygen in bottom waters of deep lakes. |

**Table 6** **Total phosphorus concentrations (mg $L^{-1}$) corresponding to Lake Ecosystem Health Attribute States designated in the NPS-FM (2014).**

| | | |
|---|---|---|
| **Value** | Ecosystem health | |
| **Freshwater Body Type** | Lakes | |
| **Attribute** | Total Phosphorus (Trophic state) | |
| **Attribute Unit** | mg $m^{-3}$ (milligrams per cubic metre) | |
| **Attribute State** | **Numeric Attribute State** | **Narrative Attribute State** |
| | **Annual Median** | |
| **A** | ≤10 | Lake ecological communities are healthy and resilient, similar to natural reference conditions. |
| **B** | >10 and ≤20 | Lake ecological communities are slightly impacted by additional algal and plant growth arising from nutrient levels that are elevated above natural reference conditions. |
| **C** | >20 and ≤50 | Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions. |
| **National Bottom Line** | **50** | |
| **D** | >50 | Lake ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state (without native macrophyte/seagrass cover), due to impacts of elevated nutrients leading to excessive algal and/or plant growth, as well as from losing oxygen in bottom waters of deep lakes. |

**Table 7** **Phytoplankton concentrations expressed as chlorophyll *a* ($\mu g\ L^{-1}$) corresponding to Lake Ecosystem Health Attribute States designated in the NPS-FM (2014).**

| | | | |
|---|---|---|---|
| **Value** | Ecosystem health | | |
| **Freshwater Body Type** | Lakes | | |
| **Attribute** | Phytoplankton (Trophic state) | | |
| **Attribute Unit** | $mg/m^3$ (milligrams chlorophyll-a per cubic metre) | | |
| **Attribute State** | **Numeric Attribute State** | | **Narrative Attribute State** |
| | Annual Median | Annual Maximum | |
| **A** | ≤2 | ≤10 | Lake ecological communities are healthy and resilient, similar to natural reference conditions. |
| **B** | >2 and ≤5 | >10 and ≤25 | Lake ecological communities are slightly impacted by additional algal and/or plant growth arising from nutrient levels that are elevated above natural reference conditions. |
| **C** | >5 and ≤12 | >25 and ≤60 | Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrient levels that are elevated well above natural reference conditions. Reduced water clarity is likely to affect habitat available for native macrophytes. |
| **National Bottom Line** | **12** | **60** | |
| **D** | >12 | >60 | Lake ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state (without native macrophyte/seagrass cover), due to impacts of elevated nutrients leading to excessive algal and/or plant growth, as well as from losing oxygen in bottom waters of deep lakes. |

**Table 8 Dissolved oxygen concentrations (mg L$^{-1}$) corresponding to River Ecosystem Health Attribute States designated in the NPS-FM (2014) in relation to dissolved oxygen.**

| **Value** | Ecosystem health | | |
|---|---|---|---|
| **Freshwater Body Type** | Rivers (below point sources) | | |
| **Attribute** | **Dissolved Oxygen** | | |
| **Attribute Unit** | mg L$^{-1}$ (milligrams per litre) | | |
| **Attribute State** | **Numeric Attribute State** | | **Narrative Attribute State** |
| | 7-day mean (Summer Period: 1 Nov to 30 Apr) | 1-day minimum (Summer Period: 1 Nov to 30 Apr) | |
| **A** | ≥8.0 | ≥7.5 | No stress caused by low dissolved oxygen on any aquatic organisms that are present at matched reference (near-pristine) sites. |
| **B** | ≥7.0 and <8.0 | ≥5.0 and <7.5 | Occasional minor stress on sensitive organisms caused by short periods (a few hours each day) of lower dissolved oxygen. Risk of reduced abundance of sensitive fish and macroinvertebrate species. |
| **C** | ≥5.0 and <7.0 | ≥4.0 and <5.0 | Moderate stress on a number of aquatic organisms caused by dissolved oxygen levels exceeding preference levels for periods of several hours each day. Risk of sensitive fish and macroinvertebrate species being lost. |
| **National Bottom Line** | **5.0** | **4.0** | |
| **D** | <4.0 | <4.0 | Significant, persistent stress on a range of aquatic organisms caused by dissolved oxygen exceeding tolerance levels. Likelihood of local extinctions of keystone species and loss of ecological integrity. |

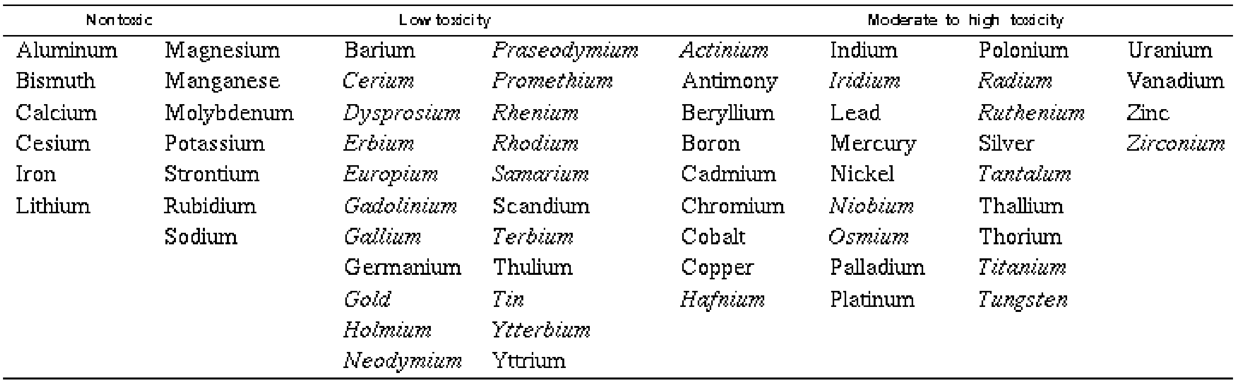
### *1.7.3.2. ANZECC and ARMCANZ (2000) guidelines*

Projected in-stream and in-lake metal concentrations following discharge of treated wastewater were evaluated by making comparisons with ANZECC and ARMCANZ (2000) guidelines. Two main categories of metals were considered in this study. The heavy metals (e.g., iron, lead, and copper) which typically have densities five times greater than water, and the light metals (e.g., sodium, magnesium, and potassium) which generally have lesser densities. Although their toxicities differ, several heavy metals, like cadmium, lead, and mercury, are highly toxic at relatively low concentrations, and can accumulate in body tissues over long periods. A list of metals according to their toxicities is presented in Table 9.

The guidelines provide a framework for assessing water quality based on 'trigger values', which are concentrations of an analyte that have the potential to cause an environmental risk if exceeded (Hickey & Pyle 2001). Trigger values for chemical stressors are based on analysis of statistical distributions and are provided for differing levels of nominal aquatic community protection (e.g., 99%, 95%, 90%). Table 10 presents a general framework for applying levels of protection for toxicants to different ecosystem conditions. Generally, the trigger values for 99% protection relate to the narrative of "no adverse effects" and would apply to protection of pristine areas. Trigger values for 95% protection however, apply to a "no significant adverse effect" guideline (Hickey 2007).

Some chemicals have the potential to bio-accumulate (e.g., cadmium, chromium, lead and zinc). In such instances it is recommended that site-specific investigations of residue levels in appropriate organisms may provide additional evidence for whether or not bioaccumulation is an issue at the site under study. In the absence of such local data, a higher level of protection is recommended (e.g., 99% protection for slightly-moderately disturbed systems instead of 95%). In this study, no attempt was made for site-specific investigations of residue levels in appropriate organisms, hence the 99% protection level for slightly–moderately disturbed systems, instead of 95%, is suggested as most applicable. However, for context, concentrations of metals following discharge in this study are compared with three of the protection levels (99%, 95% and 90%).

## Table 9 Classification of naturally occurring metals according to their toxicity and availability in the hydrologic environment (Garbarin et al 1995)



| Nontoxic | | Low toxicity | | Moderate to high toxicity | | | |
|---|---|---|---|---|---|---|---|
| Aluminum | Magnesium | Barium | *Praseodymium* | *Actinium* | Indium | Polonium | Uranium |
| Bismuth | Manganese | *Cerium* | *Promethium* | Antimony | *Iridium* | *Radium* | Vanadium |
| Calcium | Molybdenum | *Dysprosium* | *Rhenium* | Beryllium | Lead | *Ruthenium* | Zinc |
| Cesium | Potassium | *Erbium* | *Rhodium* | Boron | Mercury | Silver | *Zirconium* |
| Iron | Strontium | *Europium* | *Samarium* | Cadmium | Nickel | *Tantalum* | |
| Lithium | Rubidium | *Gadolinium* | Scandium | Chromium | *Niobium* | Thallium | |
| | Sodium | *Gallium* | *Terbium* | Cobalt | *Osmium* | Thorium | |
| | | Germanium | Thulium | Copper | Palladium | *Titanium* | |
| | | *Gold* | *Tin* | *Hafnium* | Platinum | *Tungsten* | |
| | | *Holmium* | *Ytterbium* | | | | |
| | | *Neodymium* | Yttrium | | | | |

## Table 10 General framework for applying levels of protection for toxicants to different ecosystem conditions.

| Category | Ecosystem condition | Level of protection |
|---|---|---|
| A | High conservative/ecological value systems | • For anthropogenic toxicants, detection at any concentration could be grounds for source investigation and management intervention; for natural toxicants background concentrations should not be exceeded.<br>• Where local biological or chemical data have not yet been gathered, apply the 99% protection levels (table 3.4.1) as default values. Any relaxation of these objectives should only occur where comprehensive biological effects and monitoring data clearly show that biodiversity would not be altered. In the case of effluent discharges, Direct Toxicity Assessment (DTA) should also be required on the effluent.<br>• Precautionary approach taken to assessment of post-baseline data through trend analysis or feedback triggers. |
| B | Slightly to moderately Disturbed ecosystems | • Always preferable to use local biological effects data (including DTA) to derive guidelines.<br>• *If local biological effects data unavailable*, apply 95% protection levels as default, low-risk trigger values. b 99% values are recommended for certain chemicals that have the potential to bioaccumulate<br>• Precautionary approach may be required for assessment of post-baseline data through trend analysis or feedback triggers.<br>• In the case of effluent discharges Direct Toxicity Assessment (DTA) may be required.<br>• In the case of effluent discharges, Direct Toxicity Assessment (DTA) may be required on the effluent |
| C | Highly disturbed ecosystems | • Apply the same guidelines as for slightly–moderately disturbed systems. However, the lower protection levels provided in the Guidelines may be accepted by stakeholders.<br>• DTA could be used as an alternative approach for deriving site-specific guidelines |

### 1.8. LAKE ECOSYSTEM MODELLING OF EUTROPHICATION EFFECTS

One-dimensional lake ecosystem modelling (using DYRESM-CAEDYM) was conducted by Abell et al. (2015) to simulate mean annual values of a Trophic Level Index (TLI) to assess impacts on lake trophic status. The model was used to simulate water quality effects of discharging treated wastewater, relative to a baseline period (2007–2014) that was assumed to be representative of current conditions. Measured and modelled concentrations of total nitrogen, total phosphorus and chlorophyll *a* were also compared with Lake Ecosystem Health Attribute State values defined in the National Policy Statement, to assess the implications of the proposals relative to defined attribute states.

Readers should consult Abell et al. (2015) for further details of methods.

### 1.9. EFFECT OF TREATED WASTEWATER ON TAONGA SPECIES

Healthy waterways have always been prized by Māori, and are essential for gathering kai, preserving the mauri of a waterway, and maintaining the mana of the tangata whenua (Kusabs and Shaw 2008). Consideration was thus given to the potential of discharge water to negatively affect population dynamics, physiology and health of freshwater fish, macroinvertebrates (e.g. kōura and kākahi), and macrophytes.

This component of the assessment was undertaken by conducting a background review and then collating and summarizing expert opinions on the potential impact of treated wastewater on taonga species, including kōura and kākahi. Expert opinions were provided by:

- Dr B. Hicks (report author; Professor of Biological Sciences at University of Waikato)
- Dr N. Ling (report author; Associate Professor of Biological Sciences at University of Waikato)
- Dr I. Kusabs (fisheries biologist with extensive experience conducting research on the Te Arawa lakes)

Additional field investigations in February 2017 were used to support this component of the assessment. These investigations were based on a survey of approximately 400 m of the shallow littoral area from Sulphur Point through to the wetlands on the western side of the Sulphur Point Boat Ramp.

The background review included consideration of reports based on the monitoring of alum dosing into the Puarenga Stream (Landman and Ling 2008, 2009; Ling 2014, 2016).

Potential effects on birds were not considered. This assessment did not include a historical or cultural assessment. Potential impacts to periphyton and macrophytes were scoped out from consideration in the assessment due to the geothermal characteristics of the thermal channel and Sulphur Bay (unsuitable habitats).

# RESULTS AND DISCUSSION

## 1.10. CHARACTERISTICS OF TREATED WASTEWATER

### 1.10.1. Microbiological Characteristics

Concentrations of three faecal bacterial indicators measured in the composite samples of treated wastewater were very low (Figure 8). Consistent concentrations were measured on each date: concentrations of faecal coliforms and *E. coli* were 2 CFU 100 mL$^{-1}$; concentrations of enterococci were 1 CFU 100 mL$^{-1}$. These concentrations are comparable with the *E. coli* concentrations that were considered by Abell et al. (2015), which were based on additional measurements (*n* = 277) collected following treatment with the current MBR system (median = 0, mean = 5.6; 95th percentile = 6.2; units are CFU 100 mL$^{-1}$)[2]. These concentrations are much lower than ambient concentrations in the Puarenga Stream (Abell et al. 2015) and at beaches around Lake Rotorua (Dada & Hamilton 2016).

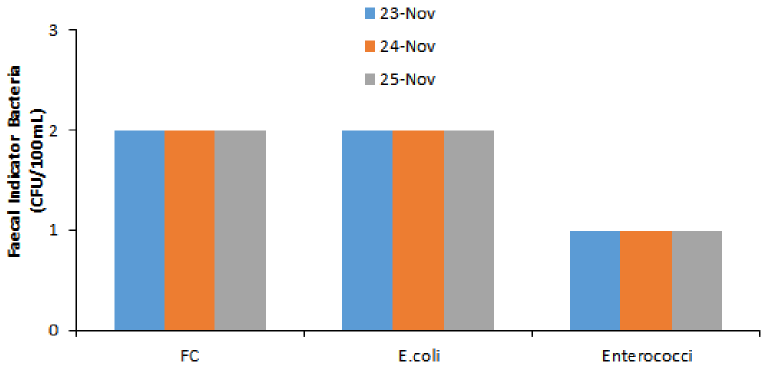


**Figure 8** **Concentrations of faecal coliforms (FC), *E. coli* and enterococci (b) faecal coliforms measured in composite samples of treated wastewater collected in November 2016.**

Although there is often some variability in the raw wastewater constituents, literature suggests that raw sewage contains high levels of *E. coli*, typically within the range of 5 million to 10 million CFU 100 mL$^{-1}$. Consistent post-treatment concentrations of less than 2 CFU 100 mL$^{-1}$attest to the effectiveness of the current membrane bioreactor in removing >99% of faecal bacteria from the raw sewage. Concentrations of faecal bacterial indicators in treated wastewater are expected to decrease further following the upgrades, which involve addition of

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[2] These data are also comparable to 2016 monitoring data (n = 33, min. = 1 CFU, max. = 8 CFU, median = 1 CFU, mean = 1.7 CFU).

an Ultraviolet Disinfection System. However, a conservative approach was taken of assuming that the concentrations presented in Figure 8 are representative of concentrations following the proposed upgrades.

### 1.10.2. Metals

A suite of 31 metals was considered, based on those that have potential to cause ecological or human health risks. Based on an assessment of metal concentrations in three flow-weighted, 24-hour composite samples collected from the existing WWTP, metal concentrations exhibit little or no daily variability (the exception was sodium, which is not included in the ANZECC and ARMCANZ (2000) guidelines and does not pose an environmental risk at the levels that were measured). Accordingly, mean values based on the three samples were used to characterize metal concentrations in existing treated wastewater, which were assumed equivalent to metal concentrations following the proposed upgrades.

Measured metal concentrations in treated wastewater are presented in Section 1.1.3, where values are compared with baseline and modelled concentrations.

### 1.10.3. Nutrients

Projected nutrient concentrations in the treated wastewater are (Mott Macdonald 2017):

TP and dissolved reactive phosphorus (DRP) = 0.1 to 0.35 mg $L^{-1}$

TN ≤ 4.62 mg $L^{-1}$

Dissolved organic nitrogen (DON) = 0.90–1.62 mg $L^{-1}$

Nitrate and nitrite nitrogen (NOx-N) = 2.00 mg N $L^{-1}$

Ammoniacal nitrogen ($NH_4$-N) = 1.00 mg N $L^{-1}$

Particulate nutrients will be removed by filtration.

Projected phosphorus concentrations are consistent with Option 6a that was considered in Abell et al. (2015) while projected nitrogen concentrations are broadly consistent with Option 2b that was considered in Abell et al. (2015)[3].

### 1.10.4. pH

The pH values measured at the MBR site by Rotorua Lakes Council during July 2015 to March 2016 are shown in Figure 9. Measurements were based on non-acidified samples and were

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[3] Projected TN concentrations are the same but the projected distribution among the dissolved fractions is different. Dissolved inorganic nitrogen concentration for Option 2a was 3.28 mg N/L and 3.00 mg N/L here.

assumed to be representative of treated wastewater following the proposed upgrades. These measured pH values range from 6.45 to 7.35 (mean = 6.94; median -= 6.89; *n* = 31).

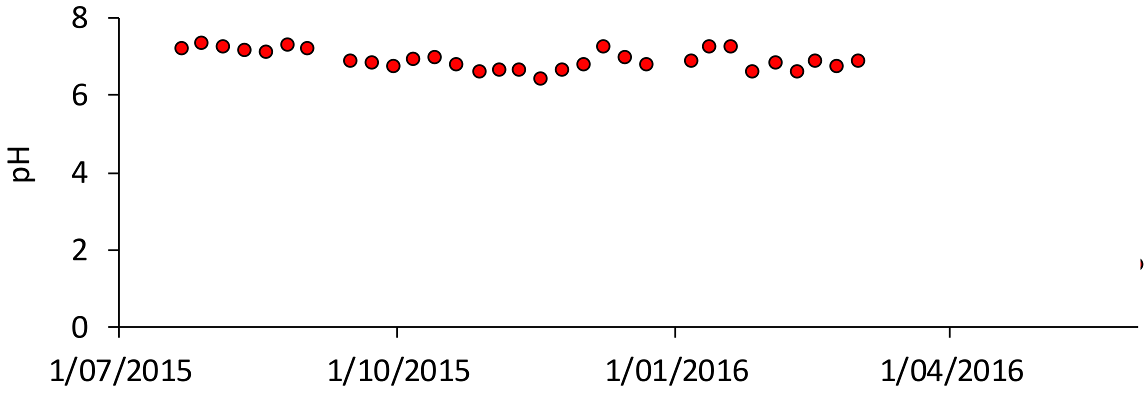

**Figure 9** **pH of treated discharge water (July 2015-June 2016). Values measured after March 2016 reflect sample preservation, not ambient conditions.**

### 1.10.5. Water Temperature

The treated wastewater temperature is expected to be in the range 16–18 °C (K. Brian, pers. comm. 2015; Figure 10).

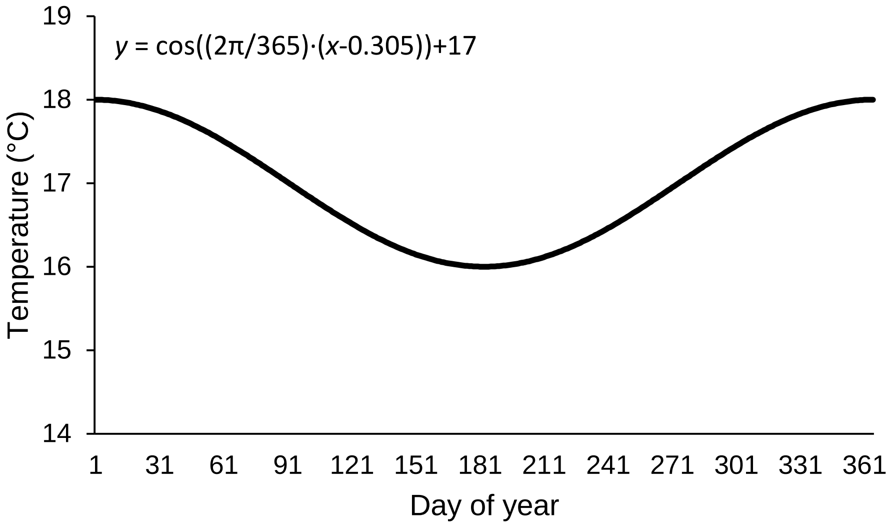

**Figure 10** **Projected annual variability in treated wastewater temperature. Based on values assigned in modelling conducted by Abell et al. (2015).**

### 1.10.6. Suspended solids, colour and clarity

Total suspended sediment concentrations are expected to be negligible in the treated wastewater due to the use of an ultra-filtration system (Section 1.3.2). Clarity is expected to be high and colour is expected to be lower than in the mixing zone of Sulphur Bay. The implications of this are considered further in Section 1.1.5.

### 1.10.7. Dissolved oxygen

The projected dissolved oxygen concentration of the treated wastewater is not precisely known. Potential worst-case changes to dissolved oxygen concentrations were evaluated by assuming a dissolved oxygen concentration of 2 mg $L^{-1}$, as was assumed by Abell et al. (2015) for comparable calculations in relation to the Puarenga Stream.

This value is appropriate because dissolved oxygen is added to the aeration basin during wastewater treatment to enhance the oxidation process. Although these microorganisms require at least 0.1 to 0.3 mg $L^{-1}$ dissolved oxygen to metabolise food and to reproduce, most WWTPs maintain about 2 mg $L^{-1}$ of dissolved oxygen so that microorganisms are maintained in an aerobic phase (Rosemount Analytical 2009).

## 1.11. RECEIVING WATER QUALITY

### 1.11.1. Te Arikiroa Thermal Channel

#### *1.11.1.1. E. coli*

*E. coli* concentrations for the limited sampling at Te Arikiroa Thermal Channel showed that levels of *E. coli* were relatively high (see Section 1.11.1.1 for data for recreational sites, which provide some context). A median *E. coli* count of 400 CFU 100 $mL^{-1}$ was recorded for water samples collected from Te Arikiroa Thermal Channel. This indicates that, under current baseline conditions, the Te Arikiroa Thermal Channel could potentially contain pathogens and the water is not suitable for recreational use. Based on the *E. coli* attribute states in the NPS (2014; Table 2), this median concentration corresponds to category E (red; median concentration > 260 CFU 100 $mL^{-1}$), which corresponds to a narrative risk descriptor of: "For more than 30% of the time the estimated risk is ≥50 in 1000 (>5% risk).

The predicted average infection risk is >7%". Baseline data have not been compared with other criteria in the NPS (e.g., based on the 95th percentile) due to a lack of data. Based on the three-tier (traffic light) management framework defined for results of *E. coli* in freshwaters, when freshwater contains concentrations of *E. coli* between 260 and 540 CFU 100 $mL^{-1}$, people are exposed to a low risk of infection (less than 1% risk) from contact with such water during activities with occasional immersion and some ingestion of water (such as wading and boating).

### *1.11.1.2. Nutrients*

Nutrient concentrations in Te Arikiroa Thermal Channel based on the limited sampling in November 2016 are presented in Table 11. Total nitrogen concentrations in Te Arikiroa Thermal Channel are very high (12.0 mg $L^{-1}$) and exceed the projected concentration of nitrogen in the treated wastewater. About half of the total nitrogen was made up of ammonium that is predominantly geothermally derived. Like nitrogen, total phosphorus in Te Arikiroa Thermal Channel is also considerably higher than phosphorus concentrations in both Sulphur Bay and the treated wastewater (Table 11). The DRP: TP ratio was 0.0023 in Te Arikiroa Thermal Channel so phosphorus was almost all in particulate form (Table 11), unlike the treated wastewater for which particulates will be removed.

### *1.11.1.3. Metals and pH*

Heavy metal analysis of the receiving water and trigger values corresponding to 99%, 95% and 90% species protection levels are presented in Section 1.1.3. Current levels of many metals in the Te Arikiroa Thermal Channel are quite high, often-exceeding concentrations designated to offer 90% protection level (for instance, aluminium). Concentrations of several metals are higher than in the treated wastewater, which reflects the geothermal influence to the stream.

The pH of Te Arikiroa Thermal Channel is approximately 5.6. This acidic condition reflects the geothermal influence. pH exerts an important control on the solubility of metals, which has implications for bioavailability and associated toxicity. Figure 11 illustrates how pH affects the solubility of six metal species that are important from an environmental risk perspective.

As noted above, for most of the metals considered in this study, current levels of analytes in the Te Arikiroa Thermal Channel water are also higher than levels in the proposed discharge water. There are, however, two important considerations. First, these metal concentrations were not corrected for hardness. Water hardness, a measure of the major cations (predominantly calcium and magnesium), is an important parameter in freshwaters, which tends to have a major effect on the toxicity of metals. In this study, water hardness (measured as mg $CaCO_3$ $L^{-1}$) was 101 mg $L^{-1}$ for Te Arikiroa Thermal Channel, but can typically range from <1 (very soft) to >400 mg $L^{-1}$ (very hard). Second, the guidelines presented in ANZECC and ARMCANZ (2000) are typically based on total concentrations and therefore the toxicity will depend on the proportion of the metal in the dissolved phase, since only a fraction of the total concentration will generally be bioavailable, for example in the case of copper and zinc. In such situations, it is important to measure the bioavailable metal fraction (ANZECC and ARMCANZ 2000). This was not done in this study.

**Table 11** **Nutrient concentrations measured in Te Arikiroa Thermal Channel, compared with mean concentrations measured in Sulphur Bay and projected concentrations in treated wastewater.**

| Analyte | Te Arikiroa Thermal Channel (mg $L^{-1}$) | Sulphur Bay (mg $L^{-1}$)* | Treated wastewater (mg $L^{-1}$)** |
|---|---|---|---|
| Total nitrogen | 12.00 | 0.37 | <4.62 |
| $NH_4$-N | 5.60 | 0.0395 | 1.00 |
| Nitrate-N + Nitrite-N | <0.10 | 0.145 | 2.00 |
| Total Kjeldahl nitrogen | 11.90 | 0.265 | 1.90–2.30 |
| Dissolved reactive phosphorus | <0.004 | 0.009 | 0.10–0.35 |
| Total phosphorus | 1.72 | 0.038 | 0.10–0.35 |

* Mean concentrations, multi-site sampling in Sulphur Bay (2011-2015)

** Projected concentrations for Option 6a

#### *1.11.1.4. Water temperature*

Baseline water temperature in the Te Arikiroa Thermal Channel is not precisely known but it is expected to exceed ambient lake water temperatures, reflecting the geothermal influence.

#### *1.11.1.5. Suspended sediments, colour and clarity*

Baseline turbidity in the Te Arikiroa Thermal Channel is high and was measured as 460 NTU in 2017.

#### *1.11.1.6. Dissolved oxygen*

Baseline dissolved oxygen concentration in the Te Arikiroa Thermal Channel is uncertain. For the purpose of evaluating changes to dissolved oxygen in Sulphur Bay using mass balance dilution modelling, it was conservatively assumed that the water in the thermal channel is anoxic (0 mg $L^{-1}$).

### 1.11.2. Sulphur Bay Water Quality

#### *1.11.2.1. Overview*

Figure 12 summarises water quality data collected along the transect (Figure 6) as part of the Alum Dosing Monitoring Survey (2011-2014). The sections below provide further details regarding baseline concentrations of individual analytes in Sulphur Bay.

A B

C D

E F

**Figure 11** **Graphs to show how the solubility of specific metals is controlled by pH (Ayres et al. 1994).**

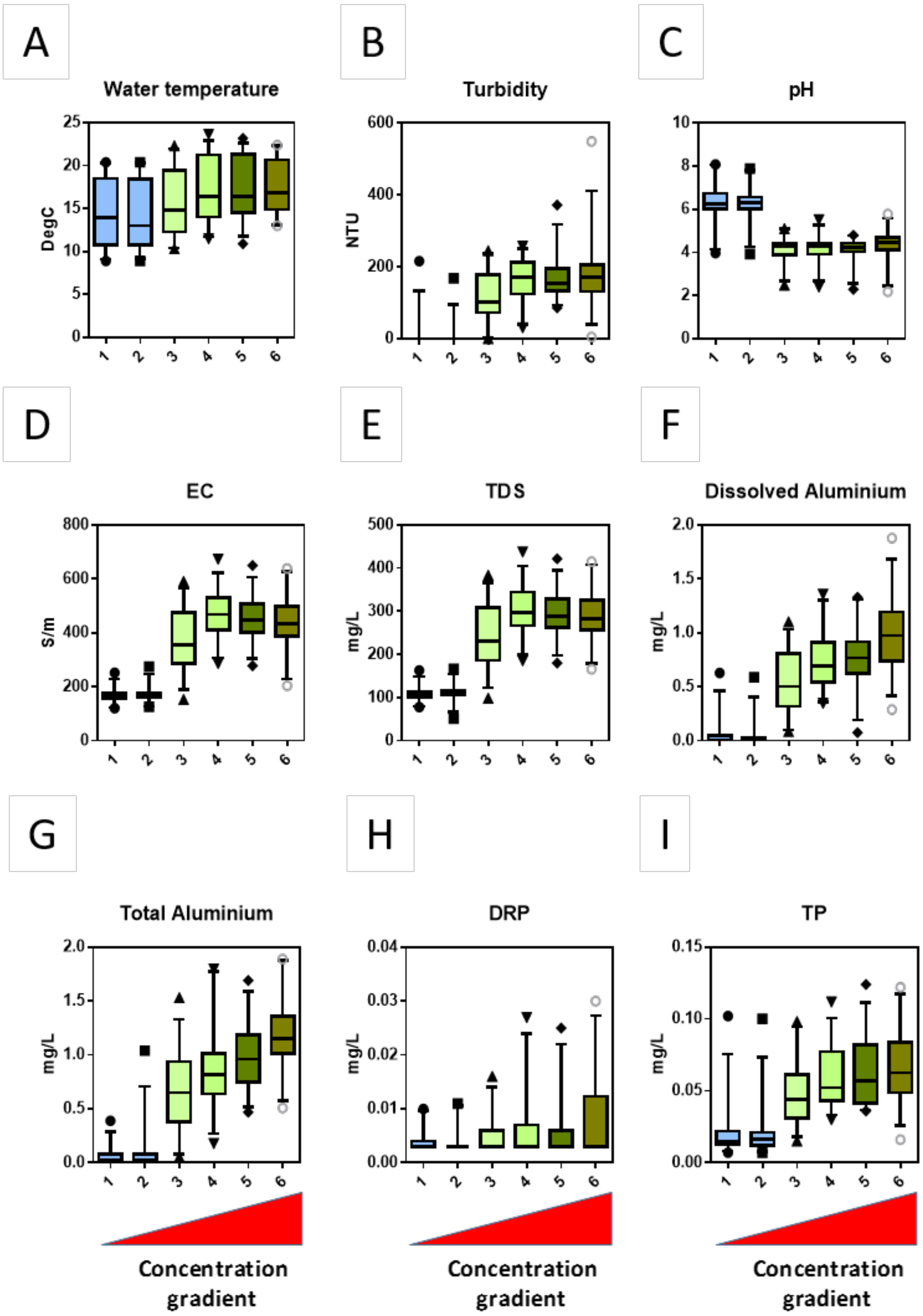

**Figure 12** Box plots of water quality data collected along a transect in Sulphur Bay as part of an Alum Dosing Monitoring Survey (2011-2014). Sites are shown on Figure 6; sites lie along a projected concentration gradient of treated wastewater, with sites 6 and 5 closest to the proposed point of discharge, within the assumed mixing zone.

#### 1.11.2.2. *E.coli*

Compared to other sampling sites in Lake Rotorua, there is a dearth of historical *E. coli* data from Sulphur Bay area. Historical data only exist for spot sampling on five different occasions in this area of the lake (Table 12). Based on the limited sampling in this study, water samples generally presented with low faecal indicator bacteria (FIB) concentrations (< 2 CFU 100 $mL^{-1}$). One sample collected from the southern-most part of the bay had a concentration of 13 CFU 100 $mL^{-1}$. These *E.coli* concentrations are generally very low, e.g., relative to concentrations in stream inflows. The high levels of sulphur, high temperatures and acidic pH in Sulphur Bay area likely inhibit the proliferation of faecal indicator bacteria (van Elssa et al 2007), while mixing with lake water from pelagic areas will dilute concentrations.

A comparative assessment of monitoring reports on surface water quality at the Sulphur Bay area and proximal recreational sites generally captures historical trends in the environmental and ecological conditions of the lake prior to the proposed discharge (Figure 13). During the baseline period, the *E. coli* Attribute State for the Sulphur Bay area was 'A', while that of proximate recreational sites (e.g., Ngongotaha, Holden's Bay and Ohinemutu) was generally A for most years (Figure 13). Attribute State A corresponds to concentrations associated with instances when people are exposed to only a very low risk of infection (less than 0.1% risk) from contact with water during activities with occasional immersion and some ingestion of water (such as wading and boating)".

**Table 12 Historical *E.coli* concentrations, Sulphur Bay area, Lake Rotorua, 2003-2015. Figure 13 provides context for these data by drawing comparisons with other sites and Attribute States.**

| Sampling point | Sampling date | CFU/100mL |
|---|---|---|
| Motutara Point (Sulphur Point) | 11/11/03 | 27 |
| Motutara Point (Sulphur Point) | 05/01/04 | 7 |
| Motutara Point (Sulphur Point) | 04/02/04 | 100 |
| Sulphur Point | 20/02/2006 | 4 |
| Sulphur Point | 10/03/2014 | 6 |

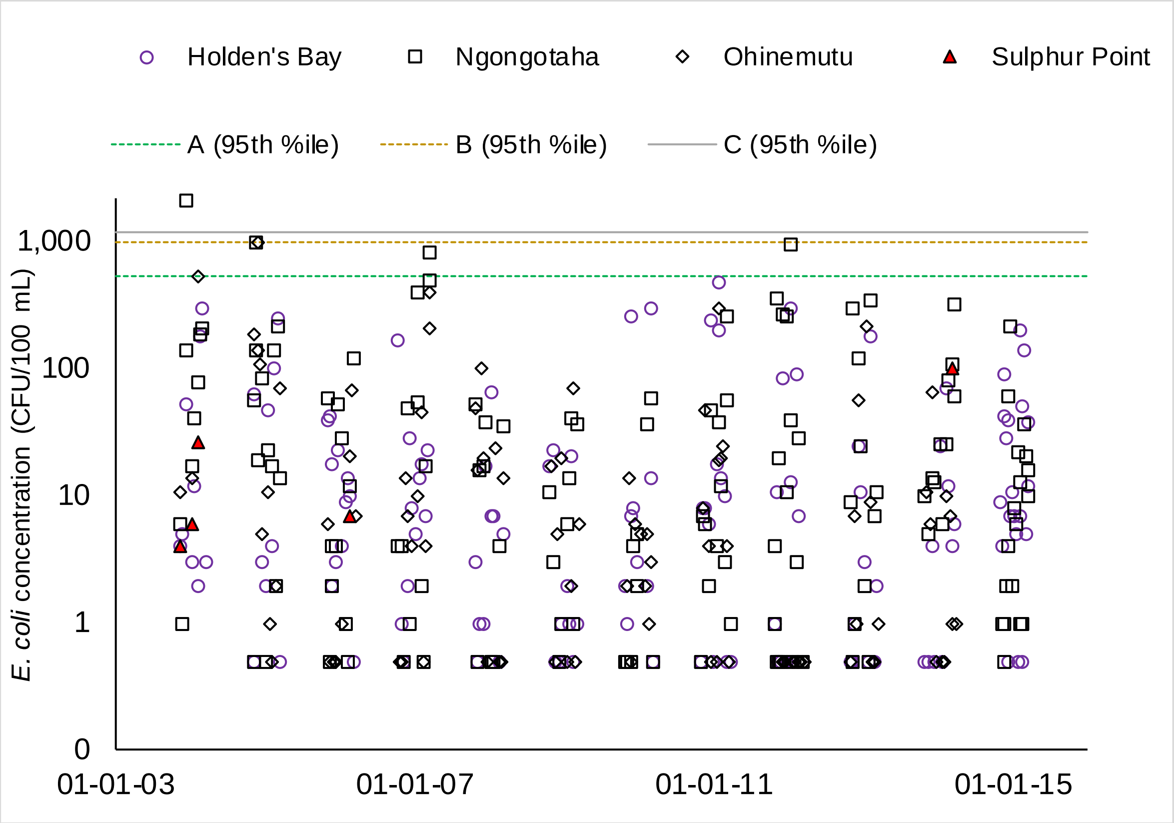

**Figure 13** Monthly measurements of *E.coli* concentration (logarithmic scale) in samples collected from Sulphur Bay area, as well as from recreational sites proximal to the proposed discharge site. Dashed lines denote values (defined as annual 95th percentiles) that correspond to Attribute States defined in the National Policy Statement for Freshwater Management 2014. Precise 95th percentile values are not defined for Attribute States D and E (the criterion is '>1200' for both states).

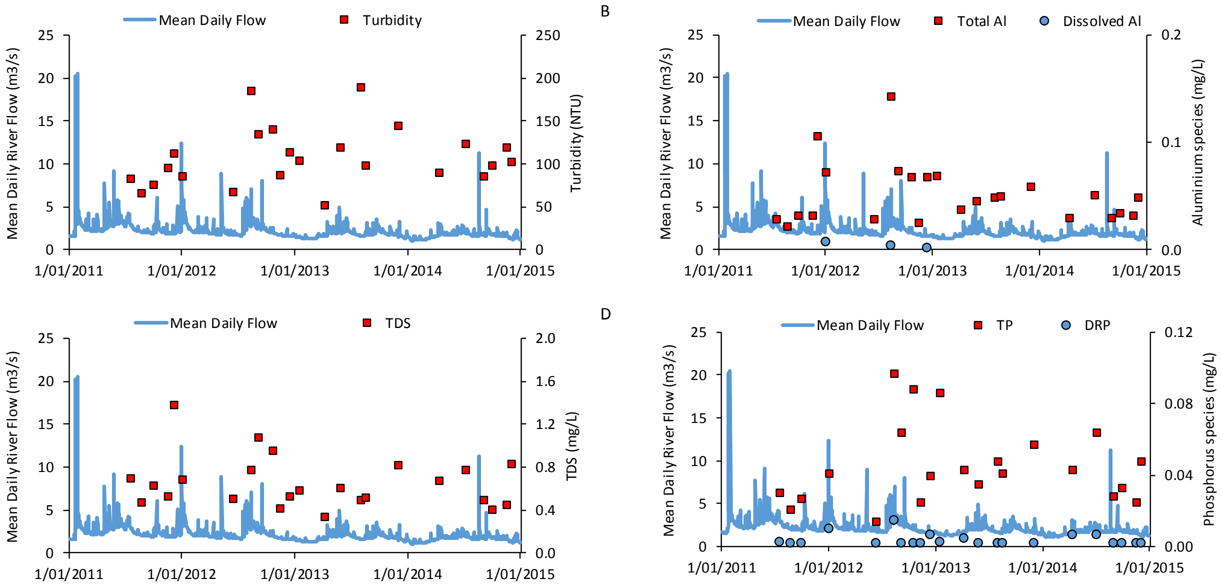

**Figure 14** Water quality, Sulphur Bay area, Lake Rotorua (2011-2014).

### *1.11.2.3. Nutrients and turbidity*

Monitoring records (2011–2015) of water quality within Sulphur Bay are presented in

Figure 14. Mean turbidity of water samples (n=169) collected at several sites in Sulphur Bay in the period (2011-2014) generally ranged between 53 and 189 NTU. Puarenga Stream was not the main driver of turbidity in Sulphur Bay given that turbidity in Sulphur Bay area showed little or no correlation with Puarenga Stream flow (Figure 15). The presence of dissolved sulphur species is a major cause of high turbidity in the geothermally influenced Sulphur Bay.

Total dissolved solids (TDS) of water samples collected from the mixing zone, Sulphur Bay area, were negatively correlated with Puarenga flow (Figure 20) indicating that the Puarenga Stream inflow plays an important role in diluting dissolved solids in this part of the lake. Dissolved and total aluminium generally increased with increasing Puarenga streamflow (

Figure 14 and Figure 15), consistent with alum treatment application at the inflow. The dissolved reactive phosphorus in Sulphur Bay region were generally low (<0.02 mg $L^{-1}$), as most of the TP in Sulphur Bay water was in particulate form. It is also noteworthy that up to 82.5% of the particulate phosphorus load from the Puarenga sub-catchment is anthropogenic in origin, i.e., above reference levels indicative of pre-human conditions (Tempero et al 2015). Sulphur Bay water quality data generated from the limited sampling in 2016 was also consistent with the historical data. Based on data from the limited sampling (2016), ammonium, nitrate and total nitrogen concentrations in Sulphur Bay range from 0.025 – 0.1 mg N $L^{-1}$, 0.21 – 0.24 mg N $L^{-1}$ and 0.14 – 0.65 mg N $L^{-1}$, respectively (Figure 16). Concentrations of nitrogen and phosphorus measured in November 2016 typically declined with increasing distance from the proposed discharge location (Figure 16), reflecting mixing between the streams with relatively high concentrations (Puarenga Stream and minor geothermal streams) and the lake with relatively low concentrations. An exception was DRP, which was slightly higher outside of the assumed mixing zone (Figure 16). The low DRP concentrations reflect the influence of aluminium sulphate dosing to an extent that the concentration gradient along the transect is reversed, i.e., with concentrations increasing with distance away from the Puarenga Stream alum dosing influence.

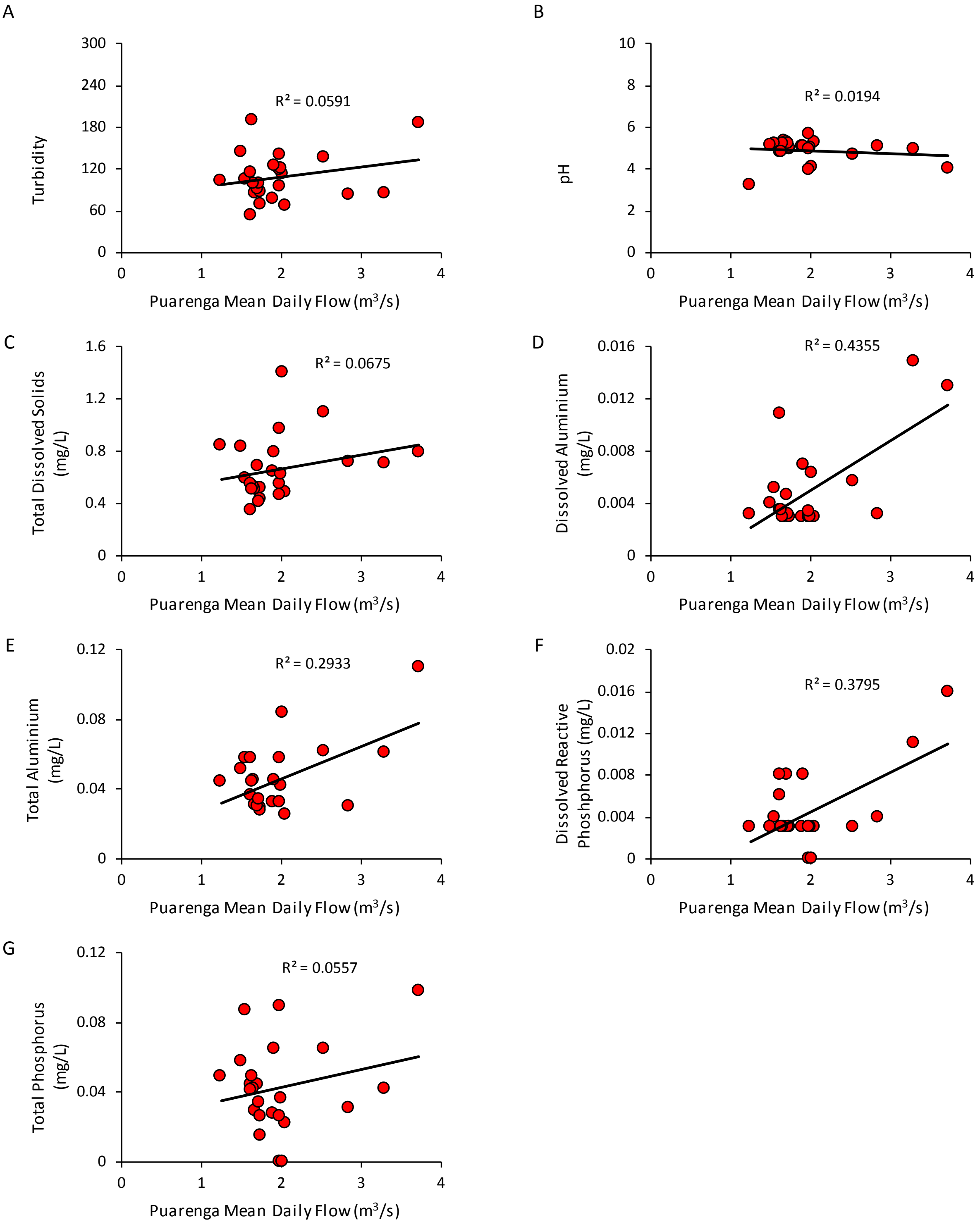

**Figure 15** **Correlation between Puarenga Stream mean daily flow and water quality, Sulphur Bay, Lake Rotorua (2011-2014). Correlations of each analyte with Puarenga flow were mostly weak ($R^2$ <0.5).**

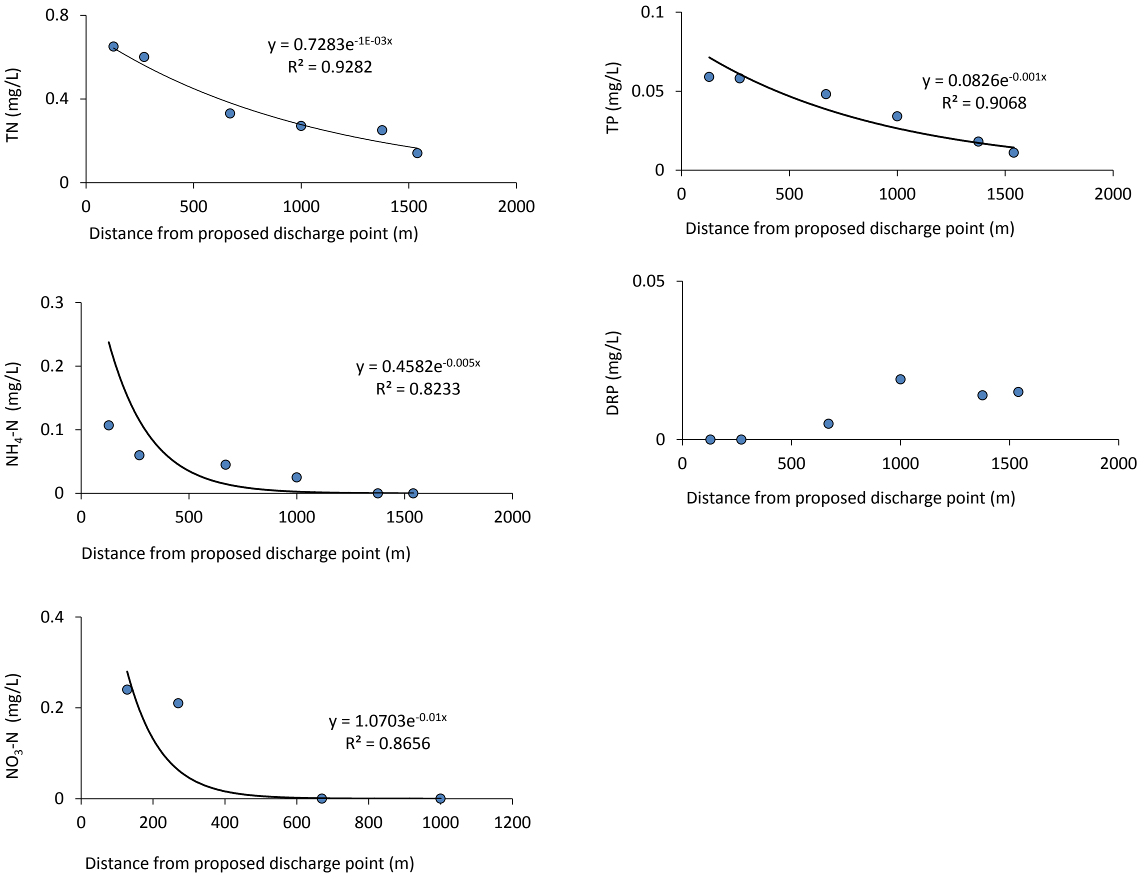

**Figure 16.** **Nitrogen (left) and phosphorus (right) concentrations measured at sites in Sulphur Bay (Figure 6) during the survey conducted in November 2016. Exponential decay curves of best fit are included where appropriate.**

### *1.11.2.4. Metals and pH*

Metal concentration in water samples collected at Sulphur Bay reflect contributions from the lake, the geothermally influenced area, and other inflows, principally the Puarenga Stream. Concentrations generally decline with increasing distance from the shoreline, reflecting declining contribution from geothermal sources (Figure 18). Geothermal materials in the form of fine suspensions in the mineral-enriched waters are responsible for high levels of metals including sodium, potassium, copper, zinc, molybdenum, iron and other metals in Sulphur Bay (Figure 18).

Bismuth, silver, cadmium, uranium, chromium, nickel, tin and vanadium were either not present or present at levels below standard detection limits in water samples collected from Sulphur Bay. It is important to note that current mean baseline levels of metal concentrations were within the range that offers 99% protection level for sensitive species in the Sulphur Bay, except for arsenic, aluminium, boron and zinc. Arsenic and boron were both present at concentrations within the range that offers 90% protection level for sensitive species in Sulphur Bay. Aluminium concentrations were present at levels within the range that offers a much lower level of protection level for sensitive species in the Sulphur Bay. The Bay of Plenty Regional

Council has adopted alum dosing at conservative levels as an effective way to help meet water quality targets for lakes Rotorua, Rotoehu and Okaro, considering that alum can chemically bind both suspended particles and dissolved phosphorus before settling to the lake bed, in a process known as flocculation.

While there is a general dearth of toxicity studies on the effect of aluminium on aquatic species, Tempero et al. (2015) argued that considering the conservative rates of application, there is little evidence in support of aluminium passing up the food chain. A concern was, however, highlighted in the report. This relates to uncertainties around the possibilities of a potentially large shift in lake pH, which can potentially dissolve the alum floc, causing the release of aluminium and phosphorus back into the lake. The effect of treated wastewater on the pH of the Sulphur Bay is described in Section 1.1.3. Sulphur Bay water pH was generally low. Apart from a single instance when a maximum pH value of 5.7 was recorded, water pH for the entire historical data (2011-2015) was less than 5.4 (95th percentile pH = 5.31). Lower pH values were generally recorded for water samples collected in the southernmost part of the bay, accounting for most of the pH values below the 5th percentile (pH 3.98) of the data. Considering the low pH observed during baseline conditions, theoretically, metals would not form hydroxide precipitates in the bay but would remain mostly in dissolved state (see theoretical solubility plots in Figure 11).

Mean pH measured at Site 4 (outside of the mixing zone, Figure 6) during July 2011 to May 2015 was 4.16 (*n*=25; range of values = 2.41–5.54; median = 4.21; Figure 17). This mean value was used to characterize baseline conditions at this site for mass balance calculations.

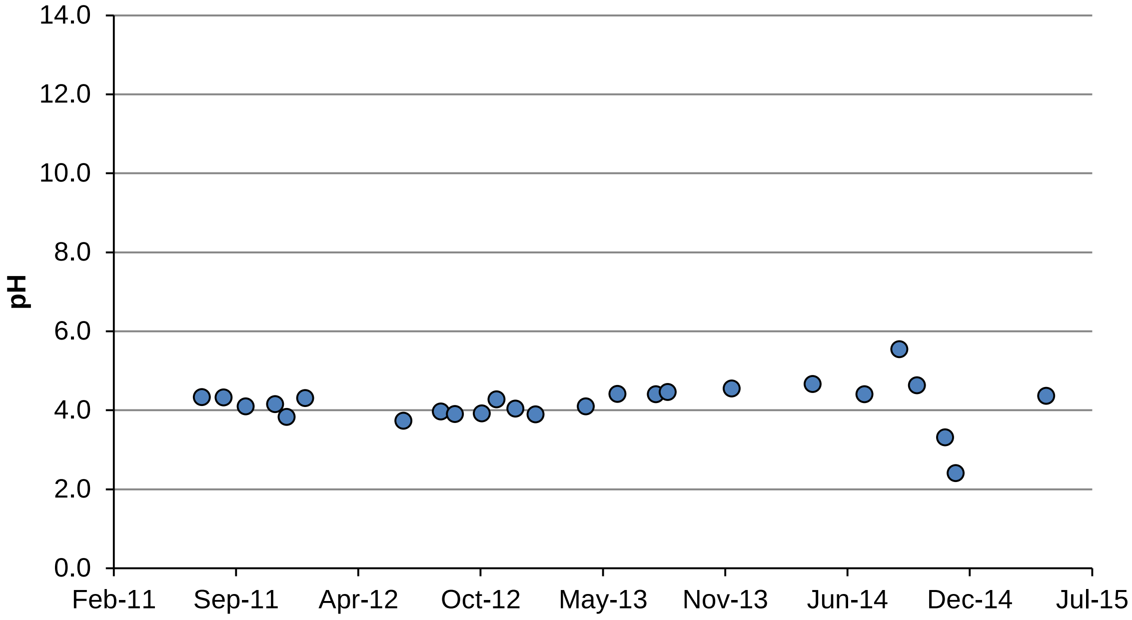

**Figure 17** pH in Sulphur Bay at Site 4 (Figure 6; 2011–2015).

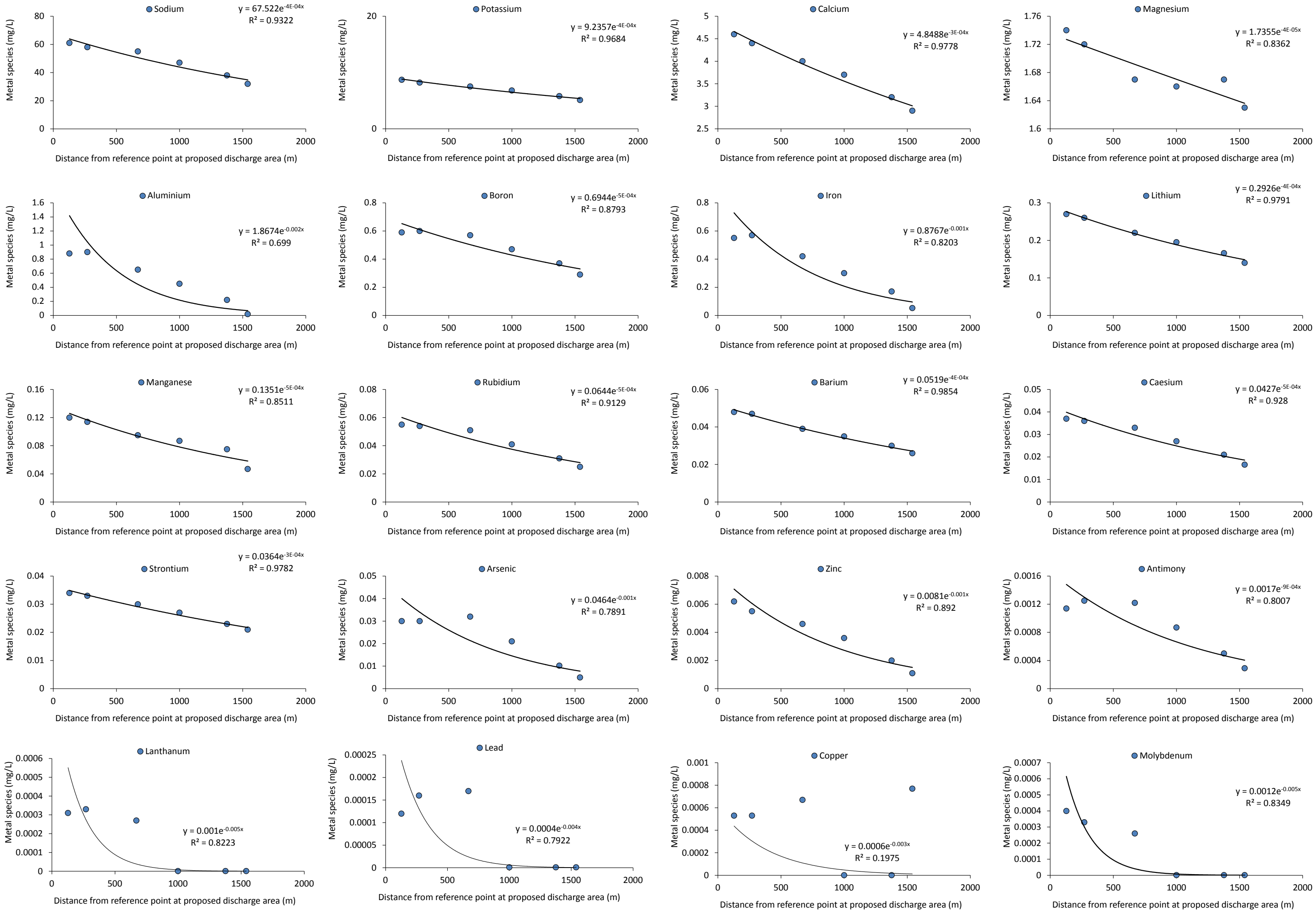

**Figure 18** Metal concentrations measured at sites in Sulphur Bay (Figure 6) during the survey conducted in November 2016. Exponential decay curves with distance away from the inflow are shown.

#### *1.11.2.5. Water temperature*

Water temperature varies seasonally in Sulphur Bay. During winter, water temperature declines with increasing distance from the shore, reflecting mixing between geothermal water and cooler lake water. Water temperature measured at Site 4 (Figure 6) during 2011–2015 ranged from 11.5 °C to 23.7 °C (mean = 17.2, *n* = 29).

#### *1.11.2.6. Suspended sediments, colour and clarity*

Sulphur Bay has high turbidity, reflecting the geothermal influence. Mean turbidity measured at Site 4 (Figure 6) during 2011–2015 was 163.5 NTU (range of values: 31–258 NTU, *n* = 29).

#### *1.11.2.7. Dissolved oxygen*

Dissolved oxygen concentration measured at Site 4 during the November 2016 transect survey was 9.33 mg $L^{-1}$ (102.3%, water temperature = 19.51 °C, sampling time = 12:26).

## 1.1. MASS BALANCE DILUTION MODELLING

### 1.1.1. Microbiological characteristics

Projected *E. coli* concentrations in the treated wastewater are very low, reflecting the high level of proposed treatment. Projected concentrations are lower than background concentrations in the Te Arikiroa Thermal Channel and Lake Rotorua. The mass balance dilution modelling therefore shows that the proposed discharge option is predicted to reduce *E. coli* concentrations in the receiving environments, thus providing improved water quality with regards to this indicator (Table 13).

Comparisons were made with Attribute States defined in the National Policy Statement for Freshwater Management 2014 (amended in 2017) for protection of human health for recreation in lakes and rivers (Table 2). This comparison has greater relevance when considering effects in the lake, as the geothermal characteristics of Te Arikiroa Thermal Channel limit the potential for contact recreation. The baseline concentration measured in the Te Arikiroa Thermal Channel (400 CFU 100 $mL^{-1}$) corresponds to Attribute State E (red), based on comparison with the median concentration criterion (260 CFU 100 $mL^{-1}$). The baseline median concentration measured in Sulphur Bay (7 CFU 100 $mL^{-1}$) corresponds to the low end of the range for Attribute States A–C (blue to yellow), based on comparison with the median concentration criterion (≤ CFU 130 $mL^{-1}$; note that the median concentration is the same for the three lowest attribute states). The proposed discharge is predicted to substantially reduce the *E. coli* concentrations in Te Arikiroa Thermal Channel, resulting in *E. coli* concentrations that correspond to the low end of the range for Attribute States A–C (blue to yellow). Following the proposed discharge, the median modelled concentrations in Sulphur Bay are not projected to change.

This analysis is limited by the moderate extent of baseline data. This meant that it was not possible to make robust comparisons with other numeric Attribute State classes (e.g., based on the 95th percentile; (Table 2). However, this limitation is not expected to adversely change the assessment outcomes, given the very low projected *E. coli* concentrations in the treated wastewater. This analysis assumes that the projected *E. coli* concentrations in the treated wastewater are representative. Further assessment of microbial risk will be provided in a separate study conducted by MWH/NIWA that involves modelling the fate of faecal bacteria and provides a Microbial Risk Assessment.

**Table 13 Baseline and projected *E.coli* concentrations. Comparisons are made to Attribute States defined in the National Policy Statement for Freshwater Management (2014) for protection of human health for recreation in lakes and rivers.**

| Site | *E. coli* (CFU 100 mL$^{-1}$) | Details | Attribute State (median concentration) |
|---|---|---|---|
| Te Arikiroa Thermal Channel baseline | 400 | One sampling date, November 2016) | E |
| Sulphur Bay (Lake Rotorua) baseline | 7 | Median value ($n$ = 5) | A-C |
| Treated wastewater (projected) | 2 | Median (and maximum) value ($n$ = 3) | - |
| Te Arikiroa Thermal Channel modelled | 16 | | A-C |
| Sulphur Bay (Lake Rotorua) modelled | 7 | | A-C |

## 1.1.2. Nutrients

### *1.1.2.1. Ammoniacal nitrogen*

Projected ammoniacal nitrogen concentrations in the treated wastewater are lower than measured concentrations in the Te Arikiroa Thermal Channel but higher than measured concentrations in Sulphur Bay at Site 4. The modelling therefore predicts that the discharge will cause ammoniacal nitrogen concentrations to decrease in the Te Arikiroa Thermal Channel but increase slightly at the edge of the mixing zone in Sulphur Bay.

Comparisons were made with Attribute States defined in the National Policy Statement for Freshwater Management 2017 for protection of ecosystem health in lakes and rivers (in relation to toxicity). Comparisons were made based on median concentrations (sample size was insufficient to make comparisons based on 95th percentile values). Baseline Attribute States (based on estimated median concentrations) are D in the Te Arikiroa Thermal Channel and B in Sulphur Bay (Lake Rotorua). The proposed discharge is predicted to improve the Attribute State to C in Te Arikiroa Thermal Channel and cause no change to the Attribute State in Lake Rotorua. The modelled concentration for Lake Rotorua is at the low end of the range for Attribute State B, which corresponds to conditions associated with occasional impacts on the most sensitive species.

The attribute states in

Table 14 are based on pH of 8 and water temperature of 20 °C. No pH adjustments have been made in this assessment. Ammonium toxicity increases with increasing temperature and pH

(Wetzel 2001). Sulphur Bay is acidic and therefore the decision to use uncorrected Attribute State classifications represents a precautionary approach.

Based on the above, the proposed discharge is not predicted to substantively increase ecological risks associated with ammonia toxicity.

**Table 14 Baseline and projected ammoniacal nitrogen concentrations. Comparisons are made to Attribute States defined in the National Policy Statement for Freshwater Management 2017 for protection of ecosystem health in lakes and rivers (based on toxicity).**

| Site | $NH_4$-N (mg $L^{-1}$) | Details | Attribute State (median concentration) |
|---|---|---|---|
| Te Arikiroa Thermal Channel baseline | 5.60 | One sampling date (November 2016) | D |
| Sulphur Bay (Lake Rotorua) baseline | 0.04 | One sampling date (November 2016) | B |
| Treated wastewater (projected) | 2.00 | Projected | - |
| Te Arikiroa Thermal Channel modelled | 1.16 | | C |
| Sulphur Bay (Lake Rotorua) modelled | 0.07 | | B |

#### *1.1.2.2. Nitrate-nitrogen*

Projected nitrate-nitrogen concentrations in the treated wastewater are higher than measured concentrations in the Te Arikiroa Thermal Channel. The modelling therefore predicts that the discharge will cause nitrate-nitrogen concentrations to increase in the Te Arikiroa Thermal Channel.

Comparisons were made with Attribute States defined in the National Policy Statement for Freshwater Management 2017 for protection of ecosystem health in rivers (in relation to toxicity). The Attribute State (based on estimated median concentrations) in the Te Arikiroa Thermal Channel is A under baseline conditions and B following the projected discharge (Table 15). Attribute State B corresponds to conditions associated with growth effects on up to 5% of species.

This modelling result should be considered in the context of the negligible to low ecological value of the Te Arikiroa Thermal Channel, and the contribution that other baseline factors (e.g., low pH) make to limiting growth. Nitrate may be minimally denitrified in the stream, thus reducing concentrations relative to the model predictions, which assume conservation of mass.

Baseline and modelled Attribute States were not calculated for Lake Rotorua because the Attribute States relate to rivers. However, based on consideration of the projected nitrate concentrations in the treated wastewater, and the expected dilution in the lake, the proposed discharge is not expected to increase ecological risk in the lake due to nitrate toxicity.

**Table 15** **Baseline and projected nitrate-nitrogen concentrations. Comparisons are made to Attribute States defined in the National Policy Statement for Freshwater Management 2017 for protection of ecosystem health in rivers (based on toxicity).**

| Site | $NO_3$-N ($mg\ L^{-1}$) | Details | Attribute State (median concentration) |
|---|---|---|---|
| Te Arikiroa Thermal Channel baseline | <0.01 | One sampling date (November 2016) | A |
| Treated wastewater (projected) | 2.00 | Projected | - |
| Te Arikiroa Thermal Channel modelled | 1.93 | | B |

### *1.1.2.3. Total nitrogen and total phosphorus*

The NPS (2014) defines Attribute States for total nitrogen and total phosphorus. These states are intended to manage ecological risks associated with eutrophication. This aspect has been assessed by Abell et al. (2015) and is considered in Section 1.2.

### 1.1.3. Metals and pH

Projected metal concentrations in treated wastewater are higher than baseline concentrations of nine metals in the Te Arikiroa Thermal Channel and 20 metals in the lake, measured at Site 5 in Sulphur Bay (Table 16). In Te Arikiroa Thermal Channel, projected metal concentrations in treated wastewater are higher than baseline concentrations of antimony, bismuth, cadmium, molybdenum, nickel, selenium, sodium, tin and silver. The modelled concentrations of cadmium, nickel, selenium and silver in the thermal channel are less than the 99% ANZECC and ARMCANZ (2000) trigger values. No trigger values are defined for the remaining five metals.

In Sulphur Bay, projected metal concentrations in treated wastewater are higher than baseline concentrations of antimony, bismuth, cadmium, calcium, chromium, cobalt, copper, lead, magnesium, molybdenum, nickel, potassium, selenium, sodium, strontium, tin, uranium, vanadium, zinc and silver. The modelled concentrations of cadmium, lead, copper, nickel, selenium and sulphur in Sulphur Bay are less than the 99% ANZECC and ARMCANZ (2000) trigger values. The modelled concentrations of chromium and zinc in the thermal channel are less than the 95% ANZECC and ARMCANZ (2000) trigger values but greater than the 99% values. No trigger values are defined for the remaining 12 metals. In Sulphur Bay, the only metal for which the modelled concentration exceeds a defined 90% trigger value is aluminium. This reflects background conditions and not the proposed discharge.

The projected mean pH of the treated wastewater (6.94) is higher than the baseline pH of Te Arikiroa Thermal Channel (~5.60) and Sulphur Bay (4.16 at Site 4; Table 17). Therefore, the proposed discharge will increase the pH in the thermal channel and cause a localised increase in pH in Sulphur Bay; modelled pH was 6.89 in the thermal channel and 4.24 in Sulphur Bay (Table 17).

## Table 16 Baseline and modelled metal concentration, with comparisons to ANZECC and ARMCANZ (2000) guidelines.

| Metal | Baseline conc. in Te Arikiroa Thermal Channel (mg/L) | Baseline conc. in Sulphur Bay (Site 4; mg/L) | Projected conc. in treated wastewater (mg/L) | Modelled conc. in Te Arikiroa Thermal Channel (mg/L) | Modelled conc. in Sulphur Bay (Site 4; mg/L) | ANZECC and ARMCANZ (2000) trigger values for freshwater (mg/L) | | | Modelled change[b] (thermal channel) | Modelled change[b] (lake) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 99% | 95% | 90% | | |
| Aluminium[a] | 10.3000 | 0.6500 | 0.0440 | 0.4031 | 0.6318 | 0.027 | 0.055 | 0.08 | -96% | -3% |
| Antimony | 0.0003 | 0.0012 | 0.0045 | 0.0044 | 0.0013 | ID | ID | ID | 1304% | 8% |
| Arsenic | 0.0079 | 0.0320 | 0.0039 | 0.0040 | 0.0312 | 0.0008 | 0.013 | 0.042 | -49% | -3% |
| Barium | 0.2000 | 0.0390 | 0.0150 | 0.0215 | 0.0383 | N/A | N/A | N/A | -89% | -2% |
| Bismuth | BDL | BDL | 0.0001 | 0.0001 | 0.0000 | ID | ID | ID | ↑ | ↑ |
| Boron | 0.4700 | 0.5700 | 0.2500 | 0.2577 | 0.5604 | 0.09 | 0.370[c] | 0.680[c] | -45% | -2% |
| Cadmium | 0.0000 | BDL | 0.0001 | 0.00005 | 0.00000 | 0.00006 | 0.0002 | 0.0004 | ↑ | ↑ |
| Caesium | 0.0320 | 0.0330 | 0.0100 | 0.0108 | 0.0323 | N/A | N/A | N/A | -66% | -2% |
| Calcium | 101.0000 | 4.0000 | 9.7000 | 12.8968 | 4.1710 | N/A | N/A | N/A | -87% | 4% |
| Chromium | 0.0070 | BDL | 0.0023 | 0.0025 | 0.0001 | 0.00001 | 0.001[c] | 0.006[a] | -65% | ↑ |
| Cobalt | 0.0006 | BDL | 0.0003 | 0.0003 | 0.0000 | ID | ID | ID | -40% | ↑ |
| Copper | 0.0125 | BDL | 0.0093 | 0.0094 | 0.0003 | 0.001 | 0.0014 | 0.0018[c] | -25% | ↑ |
| Iron | 3.2000 | 0.4200 | 0.0500 | 0.1603 | 0.4089 | ID | ID | ID | -95% | -3% |
| Lanthanum | 0.0055 | 0.0003 | 0.0001 | 0.0003 | 0.0003 | ID | ID | ID | -95% | -2% |
| Lead | 0.0044 | 0.0002 | 0.0019 | 0.0020 | 0.0002 | 0.001 | 0.0034 | 0.0056 | -55% | 31% |
| Lithium | 0.1320 | 0.2200 | 0.0850 | 0.0866 | 0.2160 | N/A | N/A | N/A | -34% | -2% |
| Magnesium | 9.5000 | 1.6700 | 2.1000 | 2.3591 | 1.6829 | N/A | N/A | N/A | -75% | 1% |
| Manganese | 1.8700 | 0.0950 | 0.0570 | 0.1205 | 0.0939 | 1.2 | 1.90[C] | 2.50[C] | -94% | -1% |
| Molybdenum | 0.0004 | 0.0003 | 0.0009 | 0.0009 | 0.0003 | ID | ID | ID | 99% | 7% |
| Nickel | 0.0020 | BDL | 0.0077 | 0.0075 | 0.0002 | 0.008 | 0.011 | 0.013 | 275% | ↑ |
| Potassium | 17.6000 | 7.5000 | 16.0000 | 16.0560 | 7.7550 | N/A | N/A | N/A | -9% | 3% |
| Rubidium | 0.0730 | 0.0510 | 0.0370 | 0.0383 | 0.0506 | N/A | N/A | N/A | -48% | -1% |
| Selenium | BDL | BDL | 0.0011 | 0.0011 | 0.0000 | 0.005 | 0.011 | 0.018 | ↑ | ↑ |
| Sodium | 53.0000 | 55.0000 | 65.0000 | 64.5798 | 55.3000 | N/A | N/A | N/A | 22% | 1% |
| Strontium | 0.4600 | 0.0300 | 0.0460 | 0.0605 | 0.0305 | N/A | N/A | N/A | -87% | 2% |
| Thallium | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | ID | ID | ID | -11% | -1% |
| Tin | BDL | BDL | 0.0006 | 0.0005 | 0.0000 | ID | ID | ID | ↑ | ↑ |
| Uranium | 0.0001 | BDL | 0.0000 | 0.0000 | 0.0000 | ID | ID | ID | -64% | ↑ |
| Vanadium | 0.0041 | BDL | 0.0011 | 0.0012 | 0.0000 | ID | ID | 0.05 | -71% | ↑ |
| Zinc | 0.3700 | 0.0046 | 0.0550 | 0.0660 | 0.0061 | 0.0024 | 0.008[c] | 0.015[c] | -82% | 33% |
| Silver | BDL | BDL | 0.0001 | 0.00010 | 0.00000 | 0.00002 | 0.00005 | 0.0001 | ↑ | ↑ |

[a] at ph >6.5, at pH<6.5, there are insufficient data to derive trigger value

[b] Change expressed as percent change from baseline value.
Arrows indicate direction of change when baseline value is BDL.

[c] Figure may not protect key test species from chronic toxicity

BDL- Below detection limit

| Key | Metal concentration in relation to ANZECC and ARMCANZ (2000) freshwater trigger levels (mg/L) |
|---|---|
| 🟦 | ≤ 99% trigger value |
| 🟨 | > 99% and ≤ 95% trigger value |
| 🟧 | > 95% and ≤ 90% trigger value |
| 🟥 | > 90% trigger value |
| ⬛ | Not applicable or insufficient data to derive a reliable trigger value |

**Table 17 Baseline and modelled pH**

| Site | pH | Details |
|---|---|---|
| Te Arikiroa Thermal Channel baseline | 5.6 | One sampling date, November 2016) |
| Sulphur Bay (Lake Rotorua) baseline | 4.16 | Mean value (2011-2015; n=25) |
| Treated wastewater (projected) | 6.94 | Mean value (2015-2016; *n* = 31) |
| Te Arikiroa Thermal Channel modelled | 6.89 | |
| Sulphur Bay (Lake Rotorua) modelled | 4.24 | |

### 1.1.4. Water temperature

The projected flow rate of the proposed discharge (0.2756 $m^3$ $s^{-1}$) is substantially higher than the baseline flow rate in the Te Arikiroa Thermal Channel (0.01 $m^3$ $s^{-1}$). Therefore, following implementation of the proposed discharge, the water temperature of the thermal channel will be closely aligned with the projected water temperature of the treated wastewater (16–18°C; Figure 10). Seasonal variability in baseline water temperature of the Te Arikiroa Thermal Channel is not precisely known; however, given the geothermal influence on the channel, it is likely that the proposed discharge will result in lower water temperatures in the channel.

Based on measured baseline water temperatures at the edge of the assumed mixing zone in Sulphur Bay, the proposed discharge is expected to cause a localised increase in water temperatures in the winter and a small localised decrease in water temperatures in summer. The relatively low volume of the proposed discharge means that any localised temperature changes in Sulphur Bay are expected to be ameliorated before treated wastewater mixes with the wider lake.

### 1.1.5. Suspended sediments, colour and clarity

Baseline turbidity is high in the Te Arikiroa Thermal Channel (460 NTU, *n*=1) and Sulphur Bay (mean of 163.5 NTU at Site 4, *n* = 29), reflecting the geothermal influence. Turbidity in the treated wastewater is not precisely known but it is expected to be lower than the baseline turbidity in the receiving environments, partly due to the use of ultra-filtration, which will remove the contribution of particulate material to turbidity. Accordingly, the proposed discharge is predicted to cause a decrease in turbidity in the thermal channel, and a localized decrease in Sulphur Bay.

Similarly, suspended sediment concentrations are projected to be zero or negligible in the treated wastewater due to the use of ultra-filtration. The proposed discharge is therefore not predicted to cause an increase in suspended sediment concentrations in receiving waters. The removal of particulate material means that no issues are expected with increased deposition of sediments.

The colour of the receiving waters or the treated waters is not precisely known, e.g., relative to a Pt-Co standard. Generally, the treated wastewater is expected to have higher clarity than the receiving waters that are geothermally influenced. The discharge of treated wastewater has potential to cause a localized reduction in the milky hue of Sulphur Bay, most likely during winter when the treated wastewater is likely to be warmer than the off-shore areas of the bay and thus be positively buoyant, i.e., it will float and therefore have higher potential to affect visual appearance at the surface. However, there is uncertainty about this prediction due to the relatively low flow rate of the proposed discharge, i.e., a visible change might not be apparent.

### 1.1.6. Dissolved oxygen

The projected flow rate of the proposed discharge (0.2756 $m^3\ s^{-1}$) is substantially higher than the baseline flow rate in the Te Arikiroa Thermal Channel (0.01 $m^3\ s^{-1}$). Therefore, following implementation of the proposed discharge, the dissolved oxygen concentration of the thermal channel will be closely aligned with the dissolved oxygen concentration of the treated wastewater. The geothermal characteristics of the thermal channel suggest that the dissolved oxygen concentration is low. Based on this, there would be limited potential for the proposed discharge to adversely affect the dissolved oxygen concentrations in the thermal channel. However, this is speculative as neither the concentrations of the thermal channel nor the treated wastewater are known precisely.

Mass balance dilution calculations were undertaken using a conservative approach that assumed a worst-case scenario concentration (2 $mg\ L^{-1}$) in the treated wastewater and anoxic baseline conditions in the thermal channel. The measurement collected at Site 4 in November 2016 (in early afternoon when concentrations were supersaturated) was used to characterise conditions in Sulphur Bay. This approach provides a suitable basis to evaluate the maximum potential for the proposed discharge to adversely affect dissolved oxygen concentrations in Lake Rotorua.

Results for the modelled scenario described above show that the proposed discharge has potential to cause a small reduction (0.22 $mg\ L^{-1}$) in dissolved oxygen concentrations at the edge of the mixing zone. Comparisons were not made with the dissolved oxygen Attribute State in the NPS-FM (2014) because these Attribute States relate to rivers and not lakes.

**Table 18 Baseline and modelled dissolved oxygen concentrations for a worst case scenario.**

| Site | Dissolved oxygen (mg $L^{-1}$) | Details |
|---|---|---|
| Te Arikiroa Thermal Channel baseline | 0.00 | Assumed worst case |
| Sulphur Bay (Lake Rotorua) baseline | 9.33 | One sampling date (November 2016) |
| Treated wastewater (projected) | 2.00 | Assumed worst case |
| Sulphur Bay (Lake Rotorua) modelled | 9.11 | |

### 1.2. LAKE ECOSYSTEM MODELLING OF EUTROPHICATION EFFECTS

Relative to operation of the LTS, the proposed option will increase nitrogen and phosphorus loads to Lake Rotorua. In isolation, this will contribute to adverse water quality and ecological effects associated with eutrophication.

The effects of the proposed option on eutrophication in Lake Rotorua were considered in detail by Abell et al. (2015). The projected maximum total nitrogen concentration in the treated wastewater (4.63 mg $L^{-1}$; Section 1.10.3) is consistent with Option 2b that was assessed by Abell et al. (2015), while the projected maximum total phosphorus concentration in the treated wastewater (0.35 mg $L^{-1}$; Section 1.10.3) is consistent with Option 6a. These projections equate to maximum loads of 40 t N $yr^{-1}$ (Figure 3) and 3.0 t P $yr^{-1}$ (Figure 4). Relative to the 2029 external nutrient load reduction targets set for Lake Rotorua catchment in the Lakes Rotorua and Rotoiti Action Plan (BoPRC 2009), the maximum loads for the proposed options correspond to 16% of the nitrogen load target (250 t N $L^{-1}$) and 30% of the phosphorus load target (10 t P $y^{-1}$).

Regarding the preferred option considered in this report, it is most relevant to consider the results for Option 6a that Abell et al. (2015) modelled. This corresponded to the highest projected DRP concentration (0.35 mg $L^{-1}$) that was considered, which matches the maximum DRP concentration projected for the current preferred option. This option corresponded to a slightly lower dissolved inorganic nitrogen concentration (2.60 mg N $L^{-1}$) than the maximum projected for the current preferred option (3.00 mg N $L^{-1}$); however, the results are considered comparable. This scenario included current LTS loads although these are projected to decline following implementation of the proposed option, i.e., the modelling is conservative in this regard.

Model performance was satisfactory and the model was considered to provide a suitable tool for assessing eutrophication impacts at a medium-term (≥one-year) resolution. The model did not simulate inter–annual trends in the measured $TLI_3$ well. This suggests that the model may not have been completely responsive to variability in nutrient loading, although the model error likely at least represented issues with accurately representing alum dosing operations. Overall, the eight–year average measured $TLI_3$ for the modelling period was just 0.01 units greater than the modelled value, suggesting good level of model performance at this temporal scale. Readers should consult Abell et al. (2015) for a detailed and quantitative evaluation of model performance.

One-dimensional lake ecosystem modelling showed that the mean 8-year $TLI_3$ for Option 6a (surface discharge) was 4.50, which is 0.02 $TLI_3$ units higher than the modelled baseline scenario (no discharge). This difference is small relative to model error, and is negligible to low from an ecological perspective. Accordingly, the model predictions showed no change to the baseline Attribute States for chlorophyll *a* (B), total nitrogen (B) and total phosphorus (C) that are defined in the NPS-FM (2014).

Although the predicted long term effects on lake trophic status are minor (negative), there is potential for more pronounced localised effects on productivity and there will be an increased load to the lake during the period of 'overlap', when the treated wastewater is discharged to the Thermal Channel but there is a legacy of nutrients from the extant but unused Land Treatment System, which will decline over several years. The localised effects of the discharge could include increases in phytoplankton biomass in the southern area of the lake during periods when background nutrient concentrations in the lake are at limiting concentrations, e.g., during stratified periods in the summer. Such conditions could also occur some distance from the outfall, in areas where dominant mixing process cause the discharged treated wastewater to accumulate. Three-dimensional modelling showed that discharge to Sulphur Bay could result in accumulation of treated wastewater in the vicinity of Rotorua lakefront following prolonged NE winds (Abell et al. 2015, Abell 2015). Thus, there is potential for localised and temporary increases in phytoplankton biomass in this area during specific weather conditions.

## 1.3. EFFECT OF TREATED WASTEWATER DISCHARGE ON TAONGA SPECIES

### 1.3.1. Outcomes of background review and field investigations

#### *1.3.1.1. Te Arikiroa Thermal Channel*

Field investigations conducted in February 2017 revealed no sightings of fish, kōura or kākahi in the heavily geothermally-influenced Te Arikiroa Thermal Channel. Water temperature, pH and calcium concentration are key variables that control the growth and survival of cultured freshwater crustaceans. Considering the high temperature of the geothermally influenced Te Arikiroa Thermal Channel, it is not surprising that kōura was not found in the stream. These observations concur with the findings reported in previous studies (Verhoef and Austin, 1999; Jobling, 2003). In another study on New Zealand kōura, survival of the crayfish declined significantly with increasing temperature as highest mean survival rates of 86% and 92%, respectively, were observed for water temperatures of 14 °C and 16 °C (Hammond et al. 2006). In the Hammond et al. (2006) study, when temperatures exceeded 16 °C, mean survival rates declined progressively from 63% at 18 °C to 27.8% at 22 °C. Apart from affecting kōura survival, temperature also affects the productivity of crayfish, considering that significantly higher biomass increase was associated with optimum temperature of 16 °C than at any of the other temperatures. As kōura normally reside in a restricted home range for several years, cooler winter temperature would not offset high summer temperatures.

Water temperature and calcium concentration are key variables controlling the growth and survival of cultured freshwater crustaceans (Holdwich, 2002), but the effects of calcium, in particular, have been poorly documented in New Zealand. However, the survival of crayfish increases with increasing water calcium levels, partly through a decrease in the number of moult-related deaths because calcium in the water plays an important role in exoskeletal hardening. Calcium concentrations in Te Arikiroa Thermal Channel were very high (>100 mg $L^{-1}$), and Hammond et al. (2006) suggest that calcium concentrations of at least 20–30 mg $L^{-1}$ may be preferable for aquaculture of this species. Despite the high levels of calcium in Te Arikiroa Thermal Channel, the high temperatures in this geothermally influenced stream potentially explain why there are no kōura in the Te Arikiroa Thermal Channel.

#### *1.3.1.2. Sulphur Bay*

Sulphur Bay has highly acidic water with pH 3.4 to pH 6.2 (Landman and Ling 2008), coupled with high concentrations of colloidal sulphur and high water temperatures. The lake shore to the west of Sulphur Point, away from the influence of Sulphur Bay, has been used as a reference site for assessing the effects of alum dosing of Puarenga Stream (Landman and Ling 2008, 2009; Ling 2014, 2016). Field investigations of this reference site in February 2017 were based on a survey of approximately 400 m of the shallow littoral area from Sulphur Point through to the wetlands on the western side of the Sulphur Point Boat Ramp. Common smelt and common bullies were abundant, and kōura (2 large females approx. 40 mm and 30 mm OCL) were found near the wetlands by the boat ramp, where there is little geothermal influence). No kākahi were observed.

The Te Arawa lakes are considered among the most productive kōura fisheries in NZ (Kusabs et al. 2014, 2015). Although the littoral habitat (cobble and gravel) around Sulphur Bay is suitable for kōura, the water quality cannot support them because of the severe geothermal influence. Kōura prefer cool water and high habitat quality (water temperatures of <23°C and dissolved oxygen > 5 mg $L^{-1}$) and are rare in low calcium environments. An explanation of the effects of temperature and water calcium concentrations on growth and survival of freshwater crayfish (*Paranephrops zealandicus*) is presented above in relation to the Te Arikiroa Thermal Channel. Given the high temperature at Sulphur Bay, this environment does not favour this species. Calcium concentration in Sulphur Bay water samples in our study were less than 4 mg $L^{-1}$. These calcium levels are too low to allow for the preponderance of kōura in the Sulphur Bay given that calcium concentrations of at least 20–30 mg $L^{-1}$ are preferable for aquaculture of this species (Hammon et al. 2006). Kōura are known to accumulate arsenic and mercury, particularly in geothermally-influenced waters (Robinson et al. 2003) so they are unlikely to be acceptable for human consumption were they to occur in or near Sulphur Bay (Hicks et al. 2015).

**Figure 19** Kōura (40 mm OCL) found in Lake Rotorua to the west of Sulphur Point in February 2017 (Photo: Ian Kusabs)

The kākahi (freshwater mussels) present in the Te Arawa fisheries area is *Echyridella menziesii*, which is the most widely distributed and abundant species throughout NZ in rivers and lakes. Kākahi are consumed less now than in the past. Their known ability to accumulate pollutants may be a factor in reduced harvest on a large scale by Te Arawa iwi and hapū (Kusabs et al. 2014). Based on field investigations in 2017, the gravel/cobble and clay-pan bed substrate may not be suitable for the proliferation of kākahi. To date, there has been limited research undertaken in New Zealand investigating key drivers influencing presence, distribution, and density of freshwater mussels in lakes. However, given the general decline in their populations, likely causes of declines in freshwater mussels in New Zealand may include influences of bed slope, sediment type, food supply, water quality (pollution and eutrophication), water velocity and presence of fish hosts for the parasitic life stage, which are essential for completion of the kākahi life cycle (McDowall 2002).

Unlike kōura and kākahi, fish can respond quickly to rapid changes in water temperature and quality. This potentially explains the abundance of īnanga (common smelt in this context) at the outer Sulphur Bay to the north of Sulphur Point. Īnanga were first introduced into Lake Rotorua in the 1920s as a food for trout and to help stabilise the rainbow trout fisheries in these lakes. Īnanga soon became the major prey species for trout in most of the large clear lakes, and an important supplementary prey in the smaller, more turbid lakes (Rowe 1984). Īnanga typically mature at one year and occasionally at two years. They spawn from spring to autumn in shallow waters (0.5-3 m deep) on sandy substrates in lakes and in the lower reaches of streams, laying thousands of small eggs (c. 1 mm). The larvae (5 to 6 mm long) hatch and are dispersed throughout the pelagic zone of the lake. The adults then die after spawning. Some īnanga return to streams in spring as transparent, whitebait-like juveniles about 45 mm to 50 mm long, but most remain in the lake, with the juveniles (25-50 mm) occurring in shoals near the lake surface and the adults (51-90 mm) occurring in deeper waters (Kusabs et al. 2014). Their ability to travel during phases of their life cycle could potentially be a reason for their observed preponderance at Sulphur Bay. It seems that given the opportunities for dilution at Sulphur Bay, a phenomenon influenced by prevailing wind and weather conditions, common smelt probably move in and out depending on water quality conditions.

Ability to respond quickly to rapid changes in environmental conditions, including water quality, may also be the reason for the preponderance of common bullies at Sulphur Bay, as observed during the field observation. Common bullies are hardier and can tolerate higher water temperatures (up to 30 $^{o}$C) and lower DO concentrations (3 mg $L^{-1}$). These environmental conditions are typical of Sulphur Bay.

### 1.3.2. Assessment outcomes

#### *1.3.2.1. Effect on Te Arikiroa Thermal Channel taonga species*

During baseline conditions, no fish, kōura or kākahi were observed in the Te Arikiroa Thermal Channel. The large geothermal-influence is assessed to eliminate the potential for taonga species to colonise the channel. Accordingly, we conclude that there will be no effect of the wastewater discharge on these taxa in the Te Arikiroa Thermal Channel.

#### *1.3.2.2. Effect on Sulphur Bay taonga species*

The biological monitoring of Sulphur Bay that has taken place suggests that apart from wildfowl, chironomids (family: Chironomidae) are the only aquatic organisms present (Kanapathippillai 1999). This is entirely predictable given the highly acidic nature of the water, which ranges from pH 3.4 to pH 6.2 (Landman and Ling 2008), and the high concentrations of colloidal sulphur and high water temperatures. Thus, the waters of Sulphur Bay provide a hostile environment for taonga species. Given considerations that the discharge of treated wastewater may change water quality conditions, an integrated approach, which examined the water quality conditions without and during discharge of treated wastewater, based on the mass balance dilution estimates, was necessary. Based on the dilution modelling results of water quality conditions, pH does not change (increase) significantly from a biological perspective following discharge of the treated discharge water through Te Arikiroa Thermal Channel. Also, under baseline conditions, the littoral habitat (cobble and gravel) around Sulphur Bay is suitable for koura but the water quality is not suitable due to the high geothermal influence. Following the discharge of treated wastewater through Te Arikiroa Thermal Channel into the Sulphur Bay, mass balance calculations revealed that there was no major reduction in water temperature at the Sulphur Bay when wastewater was added. This further suggests that relevant background conditions would be largely unchanged following the discharge of treated wastewater. Given that the discharge of treated wastewater might produce a marginal increase in pH and marginal reductions in temperatures, there could be a marginal reduction of geothermal influence on the Sulphur Bay, but this would be insufficient to reverse the low pH or calcium levels. We thus conclude that the wastewater discharge will not transform the aquatic habitat of Sulphur Bay sufficiently to allow taonga species to exist there.

Common smelt are quite mobile in Lake Rotorua and can occupy the outer part of Sulphur Bay north of Sulphur Point when the waters of Lake Rotorua are pushed into the bay by the wind, ameliorating the usually unfavourable acidity levels. Following discharge of treated wastewater, minor increases in pH (Table 17) will be insufficient to allow the survival of common smelt in the inner bay.

Common bullies similarly can occupy the outer limits of Sulphur Bay north of Sulphur Point under favourable wind-driven condition, and can tolerate higher water temperatures (up to 30°C) and lower DO concentrations (3 mg $L^{-1}$) than common smelt. However, they could not exist in the harsh conditions in the inner part of Sulphur Bay because of the low pH (around 3). Discharge of treated wastewater, based on mass balance calculations, will not significantly impair both the dissolved oxygen concentrations and temperature in the inner Sulphur Bay (Section 1.1.6) but also will not improve it sufficiently for fish to exist. Given this reasoning, we conclude that there will be no effect of the wastewater discharge on common bullies in Sulphur Bay.

### 1.4. LIMITATIONS AND UNCERTAINTIES

Key sources of uncertainty are:

- limited baseline data for the receiving environment in the case of analytes that were sampled once (e.g., metals);
- limited information about the projected composition of the treated wastewater for some analytes;
- uncertainties associated with the 1-D lake ecosystem model that are described in Abell et al. (2015).

The implications of these limitations have been described in relevant sections, and a conservative approach has generally been taken where appropriate to manage uncertainty.

It should also be noted that the strain, *E. coli* O157:H7, an intrinsically acid-resistant bacterium that possesses systems for survival at low pH, may survive in acidic environments (Foster and Spector, 1995; Lin et al., 1996; Sang et al., 2000), as is typical for the Te Arikiroa Thermal Channel and Sulphur Bay. *E.coli* analysis in this study, however, did not include a strain classification or microbial risk assessment due to risks associated with *E. coli* O157:H7 in Sulphur Bay. A Microbial Risk Assessment is being prepared separately.

The revised ANZECC and ARMCANZ guidelines (2000) used in this study for the assessment of protection levels provide guidance for establishing appropriate guideline values and comparing measured concentrations with guideline values. There is some uncertainty, however, as to the degree of protection afforded by soluble guideline values to filter feeding organisms (e.g. mussels) and for the protection of sediment-dwelling biota, where particle-associated contaminants settle and accumulate over time.

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