

# PROTECTING LAKE ROTORUA FROM HELLS GATE – THE TIKITERE GEOTHERMAL STREAM DIVERSION

*Gloria Vega (AWT), Jason Ewert (AWT), Greg Manzano, (Rotorua District Council)*

---

## ABSTRACT

Rotorua District Council (RDC) own and operate the wastewater network and treatment plant for the urban area of Rotorua. As part of providing this service to the District, and in partnership with other stakeholder groups, RDC are committed to minimising nutrient discharges into Lake Rotorua.

The geothermal field at Tikitere has been identified as contributing a significant portion of nitrogen into the Lake Rotorua catchment. The four geothermal streams are contributing approximately 30 tonnes of nitrogen per year to the lake, with an average daily flow of 4400 m<sup>3</sup>/day.

The feasibility and limitations of capturing the “Hells Gate” Tikitere geothermal nitrogen source and conveying it through the new Okawa Bay/Mourea pipeline to the Rotorua Wastewater Treatment plant for biological nitrogen removal are discussed in this paper.

This paper presents the findings of the geothermal stream characterisation, inhibition potential and fatal-flaw analysis assessing the effect of conveying the geothermal fluid through pipework and treating it at the Rotorua WWTP. Treatment of the geothermal stream at the WWTP was evaluated in terms of capacity and treatability, highlighting increased methanol dosing, aeration, clarification and landfill disposal requirements.

## KEYWORDS

**Geothermal treatment, nitrification inhibition test, respirometry, wastewater treatment plant, fatal-flaw**

## 1 INTRODUCTION

The Rotorua area is part of the active volcanic plateau region in New Zealand’s North Island. Geothermal activity releases Hydrogen Sulphide into the atmosphere and also significant nitrogen discharges into local streams and waterways. Rotorua has approximately 66,000 permanent residents and a large tourist industry with a Population Equivalent of 20,000.

The geothermal field at Tikitere has been identified as contributing approximately 30 tonnes of Nitrogen into the Lake Rotorua catchment. Given the high Nitrogen concentration in the Tikitere geothermal stream (20 mgN/L) and its proximity to existing reticulation infrastructure, the Council would like to investigate the possibility of capturing this geothermal nitrogen source and conveying it through the new Okawa Bay/Mourea pipeline to the Rotorua WWTP for Biological Nitrogen removal.

For treatment to occur, it would first involve either collection of the geothermal stream at source and the design and construction of a pipeline to take the stream to the new Okawa Bay pipeline, or alternatively to collect the geothermal water from a local waterway closer to the pipeline. This has the disadvantage that storm water would be included from the upstream catchment.

However, before any method of conveyance or treatment can occur, the geothermal stream first needs to be fully evaluated in terms of the potential impact on conveying the geothermal fluid through pipework and treating it at the Rotorua WWTP.

The feasibility and limitations of capturing the “Hells Gate” Tikitere geothermal nitrogen source and conveying it through the new Okawa Bay/Mourea pipeline to the Rotorua Wastewater Treatment plant for biological nitrogen removal have been studied as part of a broader plan for the restoration of the Rotorua lakes.

This paper presents information relating to the geothermal stream characterisation, inhibition potential and fatal-flaw analysis assessing the effect of conveying the geothermal fluid through pipework and treating it at the Rotorua WWTP, to determine whether the stream can be treated by the plant.

Currently the Rotorua Wastewater Treatment Plant (WWTP) processes an average wastewater flow of 19,000 m<sup>3</sup>/day with a peak flow of 34,000 m<sup>3</sup>/day. Rotorua WWTP was upgraded in 1988 to a 5 stage Bardenpho Process. This was the first full biological nitrogen and phosphorus removal process used for municipal wastewater in New Zealand and was implemented to eliminate point source nutrient discharges from sewage to Lake Rotorua. A subsequent upgrade, completed in 2005 increased the capacity of the plant and added methanol in order to reduce TN in the plant discharge. Following treatment final effluent is irrigated to a dedicated irrigation system in Whakarewarewa Forest with groundwater movement to Lake Rotorua. This is the largest lake in the area with a surface area of 56 square kilometres.

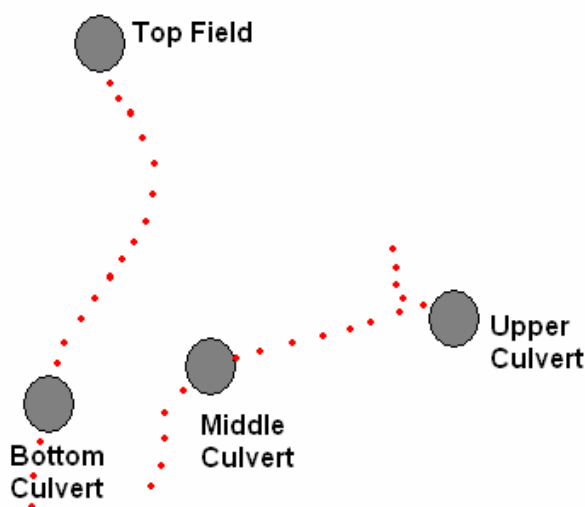
## 2 GEOTHERMAL STREAM AND TREATMENT PLANT ASSESSMENT

### 2.1 GEOTHERMAL STREAM CHARACTERISATION

The Tikitere geothermal field is located on SH 30 about 4km east of the junction with SH 33, approximately 8km from the Rotorua Urban area. The geothermal field at Tikitere straddles the catchment boundary between Lakes Rotorua and Rotoiti, and has two main areas of surface discharges, both of which have been developed as a Tourist Attraction (Hells Gate). The field naturally drains to the Waiohewa Stream which discharges to Lake Rotorua.

The Tikitere geothermal field has four streams that are contributing approximately 30 tonnes of nitrogen per year to the Lake Rotorua catchment with an average daily flow of 4,400 m<sup>3</sup>/day. This relates to an average nitrogen content of 20mgN/L, which is approximately half of that found in typical domestic wastewater. The location of each stream and confluence is detailed in a simplified diagram in Figure 1 below.

Figure 1: Geothermal Sources and Confluence



Results of the analysis of sampling data provided by RDC for the period 21 April 2004 to 6 December 2004 is detailed in Table 1.

Table 1: Average Mass Loads Tikitere Geothermal Streams

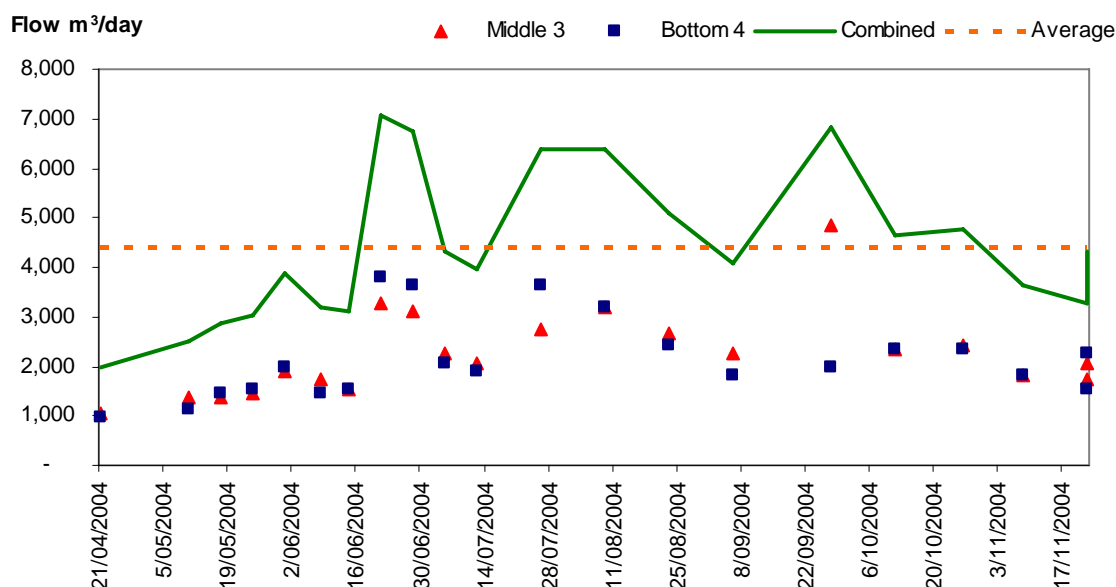
Source	DRP	NH <sub>4</sub> -N	pH	SS	Temp.	TKN	TOXN	TP	Total N	Flow
	kg/d	kg/d	pH	kg/d	°C	kg/d	kg/d	kg/d	kg/d	(l/s)
Middle Culvert	0.07	17	3.8	15	17	19	1.89	0.13	20.6	26
Bottom Culvert	0.01	57	2.9	57	28	62	0.15	0.13	62.5	25

Discharges from the Tikitere fields are high in nitrogen mainly in the Ammonium form. The average temperature of the streams from the Top Field and Bottom Culvert are higher than ambient air temperature indicating there is natural heating present. None of the geothermal streams contribute a notable phosphorous discharge, with the average around 0.13 kg/day.

Findings from a study by Williamson and Cooke (1982) in the Hell's Gate area described the water as "acid (pH 2-4) ammonium sulphate drainage water".

Figure 2 presents the fluctuations in flow from the Middle and Bottom geothermal streams over the course of one year with the total flow ranging between 1980 and 7000 m<sup>3</sup>/day. The average flow from these two streams over the monitoring period was 4385 m<sup>3</sup>/day.

Figure 2: Fluctuations in daily flow from the Middle and Bottom Culvert geothermal streams



Samples taken from April to June 2004 were tested by RDC for a range of heavy metals. The maximum values from the Middle and Bottom stream are compared against background contaminant concentrations of water samples measured in the Ohau Channel and Okere Falls (Stephens & Clearwater, 2005) in Table 2 below.

Table 2: Heavy Metals Concentrations Comparison

Heavy Metal	Middle Field µg/L Maximum	Bottom Culvert µg/L Maximum	Ohau Channel µg/L Background	Okere Falls µg/L Background
Antimony	2.6	1.8	-	-
Arsenic	15.0	10.0	7	6
Beryllium	0.0	0.3	-	280
Boron	3570	1290	310	-
Cadmium	0.0	0.0	0.025	2200
Caesium	8.6	2.9	-	0.25
Chromium	0.6	0.7	0.25	-
Copper	0.5	1.7	0.6	0.6
Lead	0.3	1.7	0.05	0.05
Lithium	63.3	22.6	134	119

Heavy Metal	Middle Field µg/L Maximum	Bottom Culvert µg/L Maximum	Ohau Channel µg/L Background	Okere Falls µg/L Background
Mercury	1.3	14.6	0.05	0.05
Nickel	0.0	0.0	0.05	0.05
Selenium	<1	<1	-	-
Silver	<0.1	<0.1	-	-
Thallium	0.0	0.1	-	-
Zinc	13	12	5	0.5

Table 2 indicates that heavy metals concentrations of the geothermal streams are elevated above those concentrations measured in non-geothermal streams. The possible effect of heavy metals on accumulation in the wastewater treatment plant sludge is discussed in the section below.

An extensive literature review has revealed no published information on treatment of geothermal water in biological wastewater treatment plants. However many articles and reports have been written on geothermal water characterisation.

Ellis and Mahon (1977) noted that geothermal water characteristics change over time, due to changing temperatures, pressures, inflows of cold water, or other geothermal sources, therefore continual sampling of the water is required to obtain an understanding of these variations.

## 2.2 BIOLOGICAL PROCESS INHIBITION POTENTIAL

Table 3 presents a comparison of known nitrification inhibition concentrations with concentrations of parameters measured in the Tikitere geothermal waters.

Table 3: Heavy Metals Concentrations Comparison

Known Inhibitor	Minimum Concentration for Inhibition (mg/L)	Measured Concentration in Geothermal Wastewater (mg/L)			
		Top Field	Upper Culvert	Middle Culvert	Bottom Culvert
Cr <sup>3+</sup>	118 <sup>a</sup> - 10.0 <sup>b</sup>	0.002	<0.0005	0.006	0.007
Cu	150 <sup>a</sup> - 230 <sup>b</sup>	0.0059	<0.0005	0.0005	0.0017
Ni	5 <sup>b</sup>	0.0012	<0.0005	<0.0005	<0.0005
Pb	0.5 <sup>b</sup>	0.0059	<0.0001	0.0002	0.0017
Zn	11 <sup>b</sup>	0.02	0.002	0.013	0.012
CS <sub>2</sub>	35 <sup>b</sup>	-	-	-	-
H <sub>2</sub> S	50 <sup>b</sup>	-	-	-	-
Sulphides	5 <sup>b</sup>	-	-	-	-

<sup>a</sup>Henze et al. (1983)

<sup>b</sup>Water Environment Federation (1998)

From Table 3 it appears that the concentrations measured in the Rotorua geothermal waters to date, are lower than the minimum inhibition concentrations stated in the literature. However, sulphates and sulphides are known to inhibit bacterial processes in wastewater treatment plants (Water Environment Federation, 1998) and have not been historically measured.

Given that it is not possible to measure the actual synergistic effect of the geothermal water on the biological activity of the activated sludge by desktop assessment alone, treatability trials (respirometry testing) were conducted under standard scientific experimental protocols (including appropriate control experiments) to measure the actual effects (if any) that the inclusion of the Tikitere geothermal fluid might have on the biological processes at the Rotorua WWTP.

## 2.2.1 INHIBITION RESPIROMETRY TESTS

Bench scale respirometry testing was conducted during March and April 2007, to determine if the addition of the Tikitere geothermal flows will have any effect on the respirometry rate of the activated sludge at the Rotorua WWTP and quantify that effect in terms of treatment plant performance if any effect is measured.

The procedure used for evaluating both heterotrophic and nitrification inhibition was based on the standard UK Standing Committee of Analysts (1982) and OECD (1984) inhibition testing methods. The methods provide a high level of confidence for potential acute toxicity effects and represent a relatively fast and simple means of investigating general acute nitrification inhibition. It was conducted using standard laboratory apparatus, and can be set up to test several samples concurrently.

The procedure to assess potential inhibition relies on a known sludge mass with a known or measured activity. The trial involved adding a sample of the Tikitere geothermal fluid to a primary treated effluent sample from the Rotorua WWTP at the volumetric proportions that it would enter the Rotorua WWTP, in order to simulate the effect that the Tikitere fluid would have on the Rotorua WWTP if the geothermal diversion is put in place.

The solutions were aerated to maintain solids suspension and incubated for a 3 hour period. The Oxygen uptake rate (OUR) of the continuously agitated solutions was measured by using an auto trace DO probe. The trace recorded the decline in DO as a function of time, representing the respiration rate. Once the linear section of the trace approached 50% of the initial value, 1.5mL of 2.5g/L Allythiourea (ATU) solution was injected into the bottle to inhibit nitrification. Deflections in the respiration rate were noted, and the trace continued until a sufficient linear length was recorded.

Respirometry (OUR) tests were completed for two solutions and three controls. When all measurements were completed the angle of deflection,  $\alpha$ , caused by the addition of ATU, was determined as shown in Table 4. This deflection represents the contribution that nitrification makes to overall respiration, that is made up of nitrogenous and carbonaceous components. Figure 3 and Figure 4 show the resulting OUR curves over time for one solution (Sample 2) and one control (Control 3), respectively.

Figure 3: Solution Oxygen Uptake Rate – Sample 2

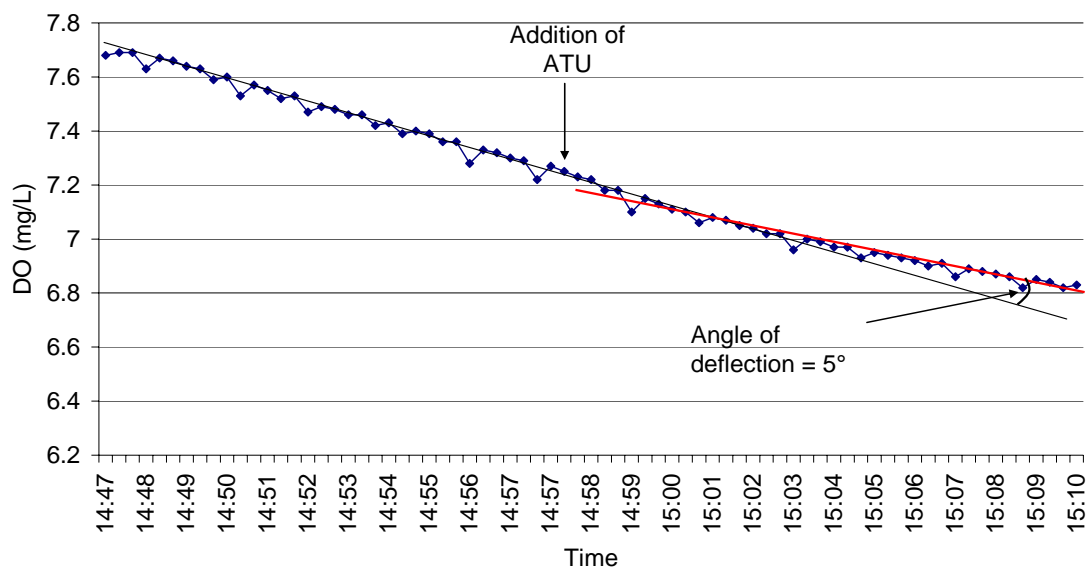


Figure 4: Control Uptake Rate – Control 2

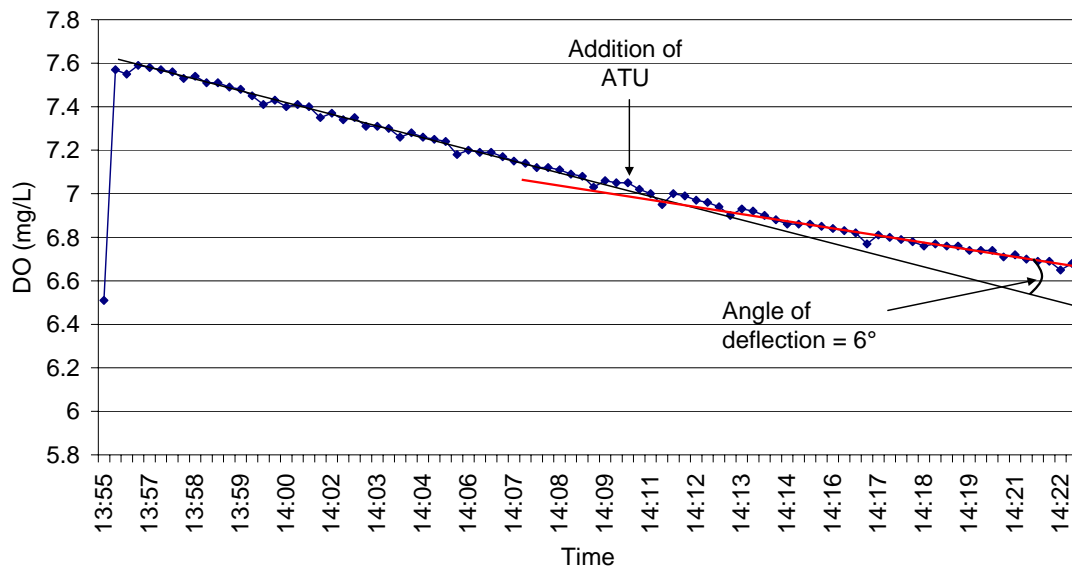


Table 4: *Respirometry (OUR) Tests Results*

Sample	Angle of Deflection (°)	Mean Angle of Deflection (°)	Percentage Inhibition(%)
Control 1	4.5	5.7	11.8
Control 2	6.5		
Control 3	6		
Sample 1	5	5	
Sample 2	5		

The average value for the controls,  $\alpha_c$ , was  $5.7^\circ$ . The average value for the samples containing geothermal fluids  $\alpha_g$ , was  $5.0^\circ$ . An estimate of percentage inhibition was approximated by the following equation and interpreted as per the criteria set out in Table 5 below.

$$\frac{\alpha_c - \alpha_g}{\alpha_c} = 100 \quad (1)$$

Table 5: *Criteria for Nitrification Inhibition Percentage Interpretation*

Percentage Inhibition Range	Interpretation
51% - 100%	Partial to full inhibitory effect. Further investigation should be carried out using definitive method.
15% - 50%	Partial inhibitory effect. Further screening to be conducted to determine the extent of inhibition.
1% - 15%	No inhibitory effect. Percentage considered as an acceptable level of experimental noise.
0%	No inhibitory effect.

An 11.8% inhibition was recorded during the experiment, and therefore attributed to experimental noise as per the Table 5 criteria. It was found from the inhibition tests that the water from the Tikitere Stream does not have an inhibitory effect on the process of nitrification.

## **2.3 WASTEWATER TREATMENT PLANT FATAL-FLAW ANALYSIS**

The evaluation of the impact that the inclusion of the geothermal streams may have on the Rotorua WWTP in terms of capacity and treatability, to determine the feasibility of the operation and its possible limitations, is detailed below.

### **2.3.1 DENITRIFICATION / METHANOL DOSING**

The Rotorua Wastewater Treatment Plant currently adds methanol as a supplemental carbon source for denitrification. The upgrade of the methanol dosing system (methanol dose, sludge production) in order to treat the geothermal stream and meet the current effluent quality requirements of the plant (4-5 mg/L total N) requires consideration of the stoichiometry and kinetics of the growth and decay processes of bacteria under anoxic and aerobic conditions.

#### Methanol dose

During denitrification the addition of methanol is used to provide bacteria with a carbon source for respiration. For every kilogram of nitrate converted to nitrogen gas, approximately 4.5 kilograms of methanol are required.

Assuming that the mass of nitrate to be removed is equivalent to the mass of ammonia nitrified, the additional nitrate loading from Hells Gate would be in the order of 3.5 kg/hour.

The required additional methanol dosing to treat the geothermal stream has been estimated as 380 kg/d, assuming the influent carbon concentration of the geothermal waters is zero.

#### Sludge Management

By treating the geothermal streams at the Rotorua Wastewater Treatment Plant, the increase of flow will result in an increase in sludge production. This arises from the additional suspended solids entering the plant and respiration of denitrifying bacteria.

At average flow and load conditions the suspended solids from the geothermal streams would contribute 70 kg/day of WAS or primary sludge. These solids would be collected in either the primary tank or reactor tanks.

Methanol dosing for nitrate removal will increase biomass growth and WAS production. This will mean larger quantities of sludge, an additional 115 kilograms of WAS per day, will need to be disposed from the plant.

### **2.3.2 SECONDARY CLARIFIERS – CAPACITY AND RISKS ASSESSMENT**

The Activated Sludge process at Rotorua WWTP contains two secondary clarifiers each with a diameter of 30 metres giving a total surface area of 1414 m<sup>2</sup> and basin volume of 7700 m<sup>3</sup>. The Secondary Clarifiers capacity have been identified as a critical aspect that requires detailed analysis, due to potential overloading at peak flow conditions, and the economic implications of the required clarifier system expansion.

#### Capacity Assessment

Given the current population expansion and associated wastewater flow and loads, the existing secondary clarifier system at Rotorua WWTP will require expansion at some point in time in the future, independent of the issues associated with the treatment of the geothermal stream. Therefore, the effect of treating the geothermal stream at Rotorua WWTP was analysed alongside the increments in flow to the treatment plant due to population growth. The estimates for population and visitors growth rates of the Rotorua District Council Growth Model (2005, Harrison Grierson), were used to predict the future wastewater flows to the Rotorua WWTP.

The capacity of the clarifiers is limited to what is termed the Maximum Permissible Solids Loading (MPSL), which relates the inherent settling properties of the sludge, the recycled activated sludge rate and the surface area of the clarifier. If the Applied Solids Loading (ASL) is adequately less than the MPSL the sludge blanket level will remain stationary and the clarifier should operate in a stable manner. Based on the current Clarifiers conditions at Rotorua WWTP, a MPSL of 8.5 kg/m<sup>2</sup>.hour have been assumed as the limit to ensure efficient operation and avoid tank overloading.

The Applied Solids Loading (ASL) and the Maximum Permissible Solids Loading (MPSL) at peak flow conditions, without and with the inclusion of the geothermal stream, are shown in Figure 5.

Figure 5: Peak Flow – Solids Loading Without and With Geothermal Stream

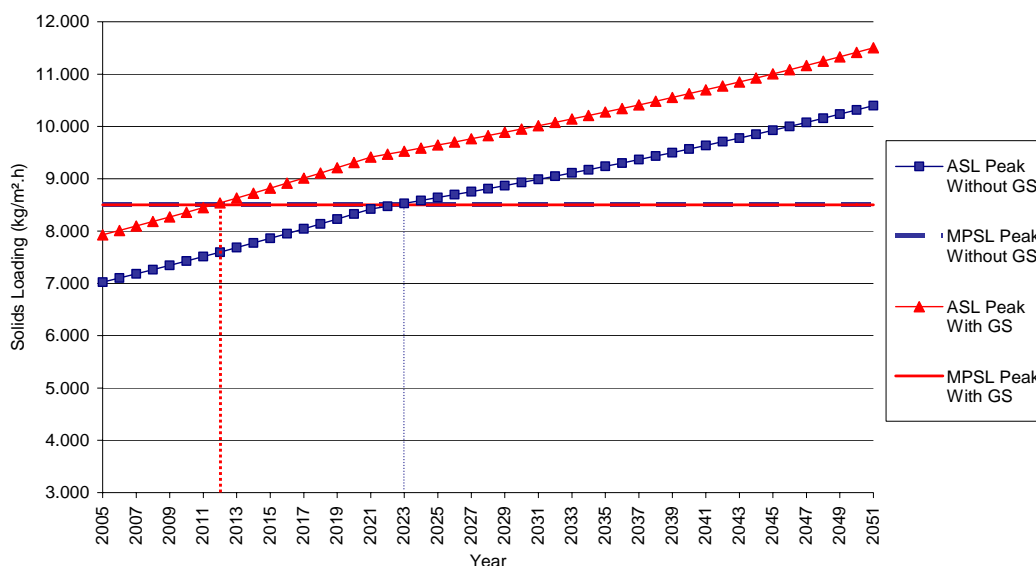


Figure 5 shows that with the existing conditions, the Secondary Clarifier System at Rotorua WWTP is already running close to its design capacity with an ASL of 7.0 kg/m<sup>2</sup>.hour at peak flow. Overloading effects (already reported three to four times per year) are likely to be more severe during the summer holiday season, due to the increased peak flow and loads, and as the plant gets close to or beyond capacity, the clarifier overall performance is likely to further deteriorate.

Figure 5 also shows that critical overloads take place at peak flow (red line) as soon as the geothermal stream is added to the process (i.e. the clarifiers exceed their capacity at peak flow by 2012). Furthermore, increased biomass growth resulting from methanol dosing required for the geothermal stream could potentially increase biomass concentrations and affect the solids loading of the secondary clarifiers, which would increase the risk of overloading.

Risk Assessment

In order to predict the risk escalation with time due to additional flow, the current clarifier performance for average and peak flow was defined as the point of reference. Figure 6 shows the risk of overflow at average and peak flow conditions, without (blue lines) and with (red lines) the inclusion of the geothermal stream. The increasing risk percentage is set from the predicted decreasing difference between the ASL and MPSL.

Figure 6: Risk Analysis - Peak and Average Flow (Without and With Geothermal Stream)

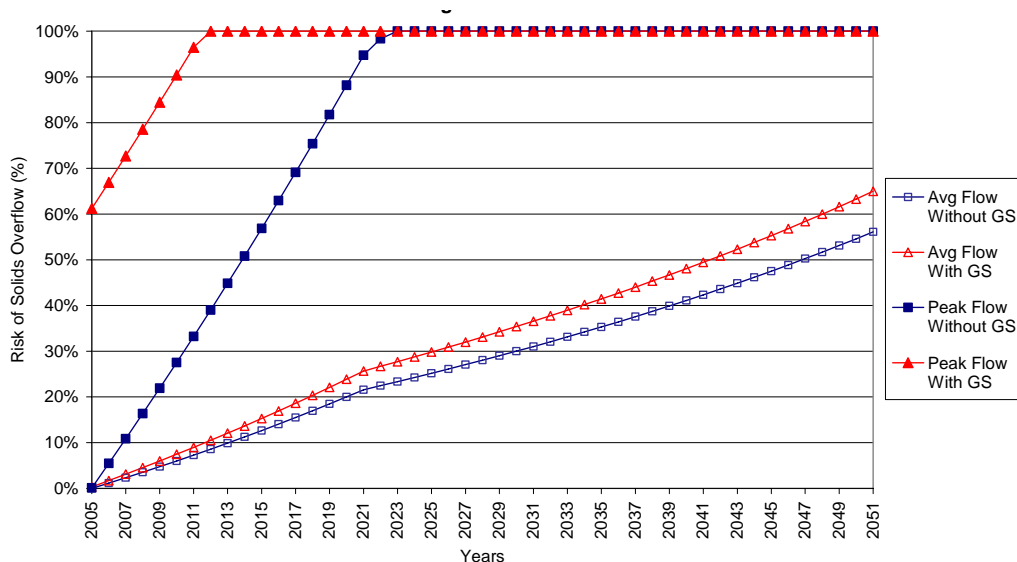


Figure 6 shows that the effect of adding the geothermal stream is estimated to be an overall 30% risk increment at average flow conditions. Also, the assessment indicates that the effect of adding the geothermal stream is significantly larger at peak flow, showing as early as 2012 a 100% risk increment compared with the current conditions.

### 2.3.3 HEAVY METALS PRECIPITATION AND ACCUMULATION IN SLUDGE

#### Metal Precipitation

Most metals will form their precipitated state at around pH 4. The pH of the geothermal streams is approximately 3.5. If treatment of the geothermal streams was to occur at the Rotorua Wastewater Treatment Plant, the pH contribution from these streams would be largely diluted by the domestic wastewater and metal precipitation is not thought to be of concern.

#### Metals Accumulation in Sludge

Heavy metals do not pass uniformly through the treatment system to either the biosolids or final effluent. Partition of the metals between these destinations is strongly influenced by the pH and the anions present in the system.

To analyse the effect of heavy metal accumulation in the biosolids, RDC's sampling data has been used to determine the combined contribution to the treatment plant from the geothermal streams based on average flow and concentration, and subsequently calculate the heavy metal concentration in the sludge. It has been assumed 100% of metals accumulate in the primary sludge, of which 2,700 kg/day is produced. The results of this analysis are shown in Table 6.

Table 6: Heavy Metal Accumulation in Sludge Compared with NZWWA limits

Heavy Metal	Combined Load from Geothermal Streams mg/kg	NZWWA Limit for A Grade Sludge** mg/kg
Antimony	2.08	
Arsenic	12	20
Beryllium	0.32	
Boron	3082	
Cadmium	0.08	3
Caesium	9.46	
Chromium	1.05	600
Copper	1.76	300
Lead	1.09	300

Heavy Metal	Combined Load from Geothermal Streams mg/kg	NZWWA Limit for A Grade Sludge** mg/kg
Lithium	70	
Mercury	<b>5.38</b>	2
Nickel	0.81	60
Selenium	1.62	
Silver	0.16	
Thallium	0.10	
Zinc	20.33	600

\*\*The NZWWA limits used are for "Grade A" sludge that is applied to land. These limits are valid until 2012 after which time they will be tightened slightly.

The analysis has shown that the accumulation of mercury could be above the NZWWA guideline limits (NZWWA, 2003).

## 2.4 CONVEYANCE SYSTEM FATAL-FLAW ANALYSIS

Rotorua District Council has constructed a sewerage trunk main to convey wastewater from the Okawa Bay area to link into the existing Rotorua urban wastewater reticulation network. This will enable wastewater from the area to be treated via the existing nutrient stripping plant, thus removing a significant portion of the nitrogen and phosphorous that would have previously gone to the Lake Rotoiti and Lake Rotorua catchments via ground soakage through the continued operation of on-site systems.

The assessment of the effect of conveying the geothermal fluid through the new Okawa Bay/Mourea pipeline to treat it at the Rotorua WWTP, is detailed below.

### Sulphide Damage

Under anaerobic conditions in the sewerage system, all sulphur compounds are susceptible to reduction to sulphide and thus can cause health and safety problems with the volatilisation of hydrogen sulphide gas. This gas can also accelerate sewer corrosion, especially when present in cement based pipes.

The Lake Rotorua Technical Advisory Group engaged GNS to undertake a desktop evaluation to assess the potential for the geothermal flow to for silica and sulphite deposition in the conveyance system. The GNS report concluded that deposition directly from the fluid was unlikely; however deposition from splashing and evaporation would need to be considered.

Long term effects such as corrosion, effects of hydrogen sulphide gas were not evaluated as part of this study.

### Temperature Effects

In pipe conveyance systems, high temperatures can increase the potential for anaerobic conditions to form in the wastewater reticulation system, and this can promote the release of gases such as hydrogen sulphide and ammonia. These consequences can increase the probability of damage to sewer structures.

RDC sampling data previously found that the average temperature of the streams from the Top Field and Bottom Culvert were higher than ambient air temperature, indicating there is natural heating present. However it is considered that these streams will be cooled when combined with the other streams.

### pH Extremes

Extremes of pH can adversely affect the structural integrity of the sewerage system and will alter the chemical equilibrium for a number of parameters in the wastewater such as metals and sulphide. If treatment of the geothermal stream was to occur at the Rotorua WWTP, Council may find that alkalinity dosing would be required to correct the stream to neutral – which will obviously incur costs and further investigation.

### Geothermal Activity

Periodic overflows occur from mud pools in this geothermal area. If this type of geothermal overflow was conveyed to the wastewater treatment plant, there would be elevated temperature, pH, and sulphide concentrations, and very high solids content due to the amount of sediment or mud in the discharge.

This type of flow would therefore place a large risk to the conveyance system and biological treatment plant. Rather than capturing this type of flow, a diversion valve could be installed in the pipeline to divert it back to the natural area. This valve could be connected to a PLC system which would close the valve based on on-line turbidity or temperature measurements.

### Silica Fouling Potential

Table 7 below shows that the contribution of Calcium, SiO<sub>2</sub> and Silica Total are reasonably consistent and significant for each stream.

Table 7: Water Hardness

Water Hardness	Middle Field µg/L Maximum	Bottom Culvert µg/L Maximum
Calcium	9.1	8.5
SiO <sub>2</sub>	92	111
Si-Total	42	528

A report prepared by the Institute of Geological and Nuclear Sciences Limited (Mroczek & Zeamnsky, 2006) suggests that deposition of silica will not be a problem within the pipework, as the sample concentrations show silica is essentially soluble and the geothermal fluids have acidic pH. However the report has highlighted that some scaling due to splash and evaporation could be possible, and that allowances should be made for this in the reticulation design.

The report discusses that the geothermal waters are high in sulphate and calcium concentration; however it suggests that because the pH of the geothermal waters increases within the conveyance system (through reaction of fluids with concrete), scale deposits due to the sulphate and calcium (gypsum) will not increase. Deposition of sulphate would occur as scale due to splash and evaporation of the geothermal fluid.

The report confirms that when the geothermal fluids combine with the domestic flow from the rest of the catchment there will be dilution, and scaling of silica and sulphate minerals is unlikely to occur.

Conveyance system effects, mainly for collecting the geothermal fluid from the Tikitere fields to the WWTP reticulation will need to be considered in detail if the project goes to Stage 2.

## **3 CONCLUSIONS**

Capturing the “Hells Gate” Tikitere geothermal nitrogen source and conveying it through the new Okawa Bay/Mourea pipeline to the Rotorua Wastewater Treatment plant for biological nitrogen removal has been found feasible, and the limitations have been outlined.

Inhibition respirometry tests to measure the actual synergistic effect of the geothermal water on the biological activity of the activated sludge, have indicated that the water from the Tikitere Stream does not have an inhibitory effect on the Rotorua WWTP process of nitrification.

The fatal-flaw analysis assessing the effect of conveying the geothermal fluid through pipework and treating it at the Rotorua WWTP, in terms of capacity and treatability, has highlighted various methanol dosing, aeration, clarification and landfill disposal requirements, including:

Additional 380 kg/d methanol dosing as a supplemental carbon source for denitrification, has been found to be required in order to treat the geothermal stream and meet the current effluent quality requirements of the

plant (4-5 mg/L total N). This will also contribute to the generation of an additional 115 kilograms of WAS per day due to increased biomass growth and WAS production. Also,

Evaluation of the Rotorua Wastewater Treatment Plant has revealed that it appears to be currently operating around its peak design capacity with respect to its primary and secondary clarifiers.

A detailed secondary clarifier risk assessment has indicated that the effect of adding the geothermal stream is estimated to be a 30% overload risk increment at average flow compared with the current conditions. Also, it is estimated that critical overloads will take place at peak flow as soon as the geothermal stream is added to the process, indicating that it is likely that Rotorua WWTP requires expansion of the secondary clarifier system (i.e. add a new secondary clarifier) in the near future if the addition of the geothermal stream flow is to be considered.

Analysis has shown that heavy metal accumulation in biosolids will not prevent sludge disposal to land, with the exception of mercury levels. However, additional heavy metals sampling currently being completed will confirm this.

The assessment of the effect of conveying the geothermal fluid through pipework has indicated that the geothermal fluid will not cause significant deposition due to silica or sulphate minerals, however some scale could occur in pipe work due to splash and evaporation. Scaling is unlikely to occur after the geothermal fluid is mixed with untreated sewage.

## ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of Rotorua District Council and Environment Bay of Plenty with this work.

## REFERENCES

- Arnórsson, et al. (1983) 'The chemistry of geothermal waters in Iceland'. *II. Mineral equilibria and independent variables controlling water compositions. Geochimica et Cosmochimica Acta.* 47: 547-566.
- Ellis A.J. and Mahon, W.A.J. (1977) 'Chemistry and Geothermal Systems' *Academic Press, Inc.* New York.
- Henze et al. (1995) 'Wastewater Treatment: Biological and Chemical Processes'. *Springer-Verlag.* Berlin.
- Harrison Grierson (2005) 'Rotorua District Council Growth Model' New Zealand.
- Mroczek E. and Zemansky G. (March 2006) 'Mixing of Tikitere Geothermal Discharges with Sewage' *Institute of Geological and Nuclear Sciences Ltd (GNS Science) Report, 2006/32.*
- NZWWA (2003) 'Guidelines for the Safe Application of Biosolids to Land in New Zealand' NZWWA
- OECD (1984) 'Test Guideline 209', Paris.
- Standing Committee of Analysts (1982) 'Methods for Assessing the Treatability of Chemicals and Industrial Waste Water and their Toxicity to Sewage Treatment Processes'. London, UK.
- Stephens, S. and Clearwater, S. (2005) 'Water Quality Impacts of a Point Source Discharge of Tikitere Geothermal Water in Lake Rotoiti' *NIWA.*
- Tackas et al. (2007) 'Design of Denitrification Systems Using Methanol' *IWA Nutrient Removal 2007- State of the Art.*
- Water Environment Federation (1998) 'Biological and Chemical Systems for Nutrient Removal: Special Publication' *Water Environment Federation.* USA.

Williamson, R.B. and Cooke, J.G. (1982) 'Water Quality of the Waiohewa Stream, Rotorua, New Zealand'  
*Journal of Marine and Freshwater Research*, 16: 327-337.