A desktop assessment of geothermal well testing impacts on Rotorua Airport operations

Prepared for Rotorua Regional Airport Limited

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Executive summary

Rotorua Airport has a sensitivity to cloud and visibility conditions and its operations are often impacted by low cloud base, fog, and reduced visibility. Rotorua Airport is thus concerned about the potential impact of the planned Tāheke geothermal plant activities, including well-testing plumes and steam plumes from cooling towers, on its airport operations.

A screening review of historic 1970s and 1980s meteorological observation campaigns of geothermal plume activity under various atmospheric conditions has been undertaken. Those campaigns included photographic analysis and plume rise/spread modelling analysis.

The screening analysis indicated that under certain atmospheric conditions steam plumes from well-testing may rise to around 2000 ft (600 m) and the horizontal extent could reach 2.5 km downwind. However, some uncertainty around these figures exists due to model bias and difficulty in representing all processes leading to visible plume formation.

An initial investigation has been made into the two cooling tower options based on source parameters provided by the developer. The air-cooled condenser is expected to have little impact as the maximum vertical extent of plume is likely to be around half that for well-testing and air-cooled condensers trap steam in tubes so emit little steam. However, for the mechanical draft wet cooling tower, the screening analysis indicated maximum vertical extent of the plumes could be as high as for well-testing under some conditions.

It is likely that the Civil Aviation notification thresholds of 4.3 m/s at 60 m above the ground and at 172 m (the estimated height of the obstacle limitation surface above the nearest well) may be exceeded.

To strengthen the conclusions here, it is recommended that a more detailed justification and presentation of results of a visible plume modelling analysis (or relevant observations) from cooling towers and well-testing be done. This would include the assumptions made in that modelling where it was concluded plumes from the mechanical wet draft cooling towers would only reach 500 ft (150 m). It is also advisable that modelling with the ATCOOL model also be undertaken, as this is recommended for visible plumes in the "Good practice guide for Atmospheric Dispersion" published by the Ministry for the Environment.

Further investigation may also be warranted around the issue of the strength of vertical velocities in plumes from both the well-testing and the cooling towers.

Finally, NIWA is happy to make material (observations and reports – where permitted) available for inspection at its Wellington offices to either the Tāheke developers or Rotorua Airport.

1 Background

Rotorua Airport is concerned about the potential impact of the planned Tāheke geothermal plant development (near Okere Falls) on its airport operations. In particular, Rotorua Airport are concerned about effects on visibility and vertical motions particularly during periods of well-testing as well as from wet-cooling tower plumes. Rotorua Airport has a sensitivity to cloud and visibility conditions and often reports low cloud bases, fog and reduced visibility (see Figure A- 1 in Appendix A). In this report an initial assessment of literature and past field observations of geothermal plumes is carried out. Additionally, this report contains a review of assumptions and methods used in modelling done by Air Quality Consultants New Zealand Limited for the plant developer.

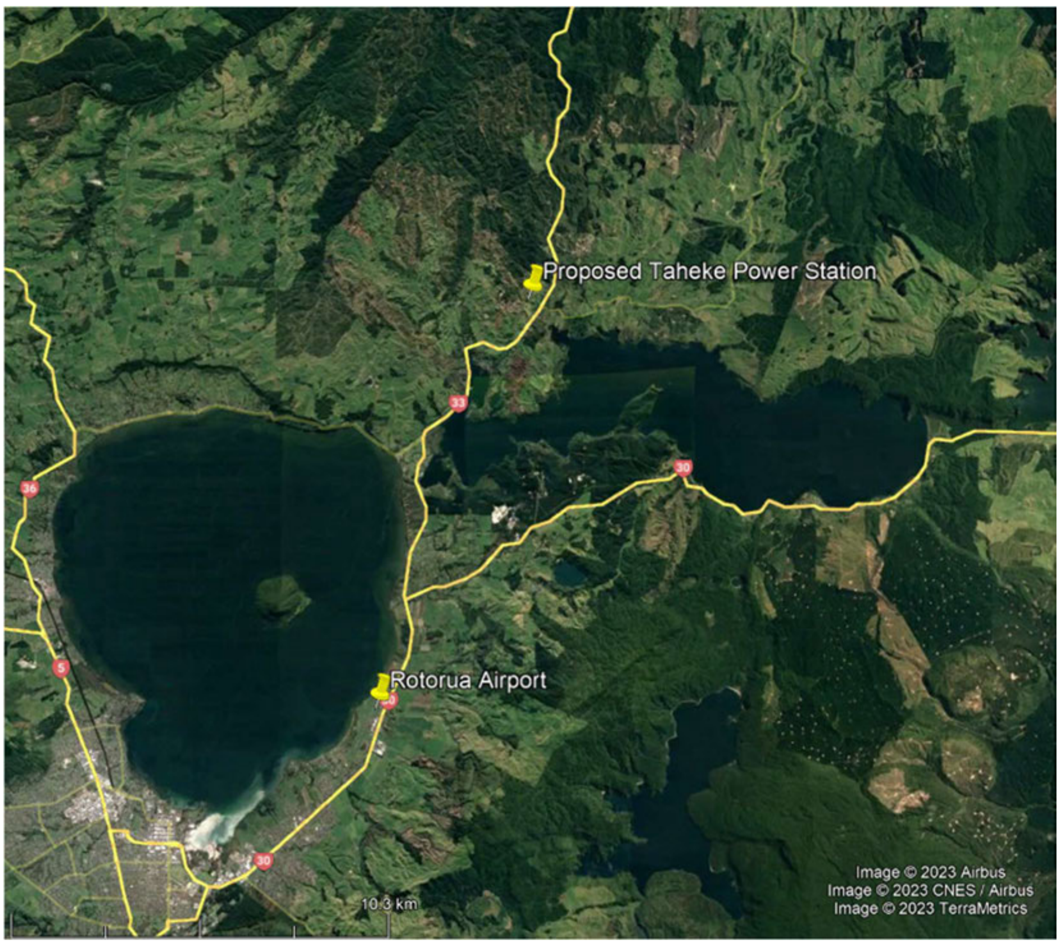

Figure 1: Google Earth image of area showing location of the proposed Tāheke Power station relative to Rotorua Airport which is around 11.5 km to the SSW.

Well (or bore) testing and steam emitted from wet tooling towers of geothermal plants can cause large visible plumes of steam (Hanna, 1976) that can extend many hundreds of metres into the boundary-layer and several kilometres downwind. The extent does depend on many factors and these include atmospheric stability, height of boundary-layer inversions, ambient humidity profiles, exit velocities, stack height, and stack diameter among others. Visible plumes from cooling towers have often been reported to cause local issues when relative humidities exceed 80% and dry-bulb temperatures are less than 15°C and these conditions do occur reasonably frequently at Rotorua, totalling around 800 hours per year in daytime (See Figure A- 2 Appendix A).

2 Plume-rise and downwind extent.

2.1 Past field studies of geothermal plumes and source characteristics

In the 1970's and 1980's MetService staff conducted field monitoring campaigns investigating steam plumes from geothermal developments in the Taupo area (Table 1). These included making observations of atmospheric temperature and humidity profiles, photographic analysis and sodar imaging of plumes (see Figure 2) The results from those studies are relevant here as the climate and elevation of both areas is generally similar (Chappell, 2013). In the analysis of the field results plume models such as PLUME (Clarkson and Simpson, 1984) and ATCOOL (Hanna, 1976) were used.

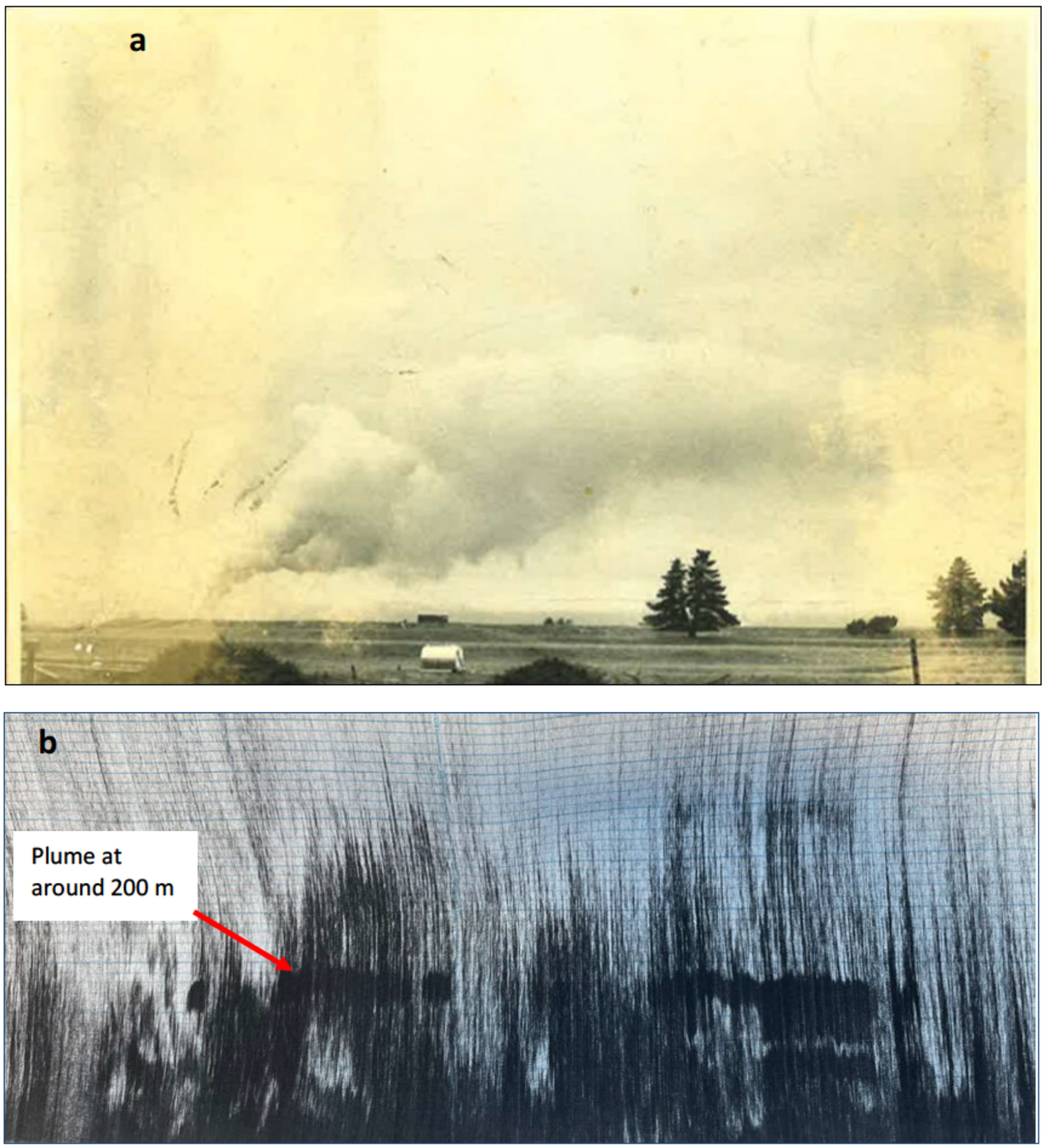

Figure 2: Sample Photos taken during MetService Studies of steam plumes from a) Bore 35 taken at Ōhaaki Bore 35 on 3 May 1979 and b) sodar imaging of temperature variance at Broadlands on 22 June 1977.

Table 1: Listing of locations and periods of some past Meteorological Service monitoring studies of geothermal plumes in the Taupo area along with brief comments

Location	Period	Comments
Broadlands	1975-1979	Lowlift rawinsonde data, pibal profiles, theolodite winds, and sodar imaging of thermal variations to detect steam plumes.
Tauhara	15-26 July 1985	Investigation of plume dispersal under light winds and inversion conditions. Only 24 July was suitable. Met Monitoring Tethersondes, airsondes, observations of steam plumes and fog. (Wratt et al., 1986)
Tauhara	1996	Met Monitoring – surface station at site, plus Taupo Aero Cloud obs, plus 1 year of dispersion modelling and plume rise modelling (using ATCOOL) –
Ōhaaki	1975-1978	Theolodite winds and sodar imaging of thermal variations to detect plumes.
Ōhaaki	1979	SF6 Tracer experiment for plume dispersal.
Ōhaaki	May 1980	Photography of plumes, wind and temperature profiles and modelling of plume rise using PLUME. (Clarkson and Simpson, 1984)

2.2 Source characteristics and assumptions

Typical source parameters ascertained from the field campaign research notes and summary reports from the Ōhaaki 1980 field campaign and a Tauhara 1996 study (Clarkson and Belberova, 1997) are provided in the upper half of Table 2. These are useful to compare against those provided for Tāheke (Air Quality consulting NZ report and personal communication with Peter Stacey of Air Quality Consulting NZ) as they provide insight as to what the expected height and horizontal extent visible plumes may reach from Tāheke (lower half of Table 2).

Table 2: Emission source parameters for bore testing and cooling towers referred to in this report.

Plant	Ōhaaki Bore 35 1980	Ōhaaki Bore 19 1980	Tauhara 1997 (Mechanical Forced Draft)
Mass flow	60,000 kg/hr	53,000 kg/hr	
Steam Flow	48,000 kg/hr	53,000 kg/hr	300,000-400,000 kg/hr (vapour)
Liquid Water Flow	12,000 kg/hr	0 kg/hr	
Temperature	99 C	99 C	25 C (Dry bulb)
Stack Height	5 m	5 m	13 m
Stack Diameter	2 m	2 m	10 m
Exit Velocity			10.5 m/s
RH Exit			70%
	Tāheke Well Testing[1]	**Tāheke ORC - air cooled condenser[1]**	**Tāheke - Condensing Steam Turbine - Mechanical Draft Wet Cooling Tower[1]**
Mass flow		18,000,000 kg/hr (Provided as Air flow of 4,380 m3/s)	11,000,000 kg/hr (Provided as Air flow of 2,875 m3/s)
Steam Flow	500,000 kg/hr (Approx)	Steam condensed - negligible	
Liquid Water Flow			
Temperature	100 C	27 C	35 C
Stack Height	4.6 m	14 m	6 m
Stack Diameter	5.9 m	6.1 m	9.0 m
Exit Velocity	8.6 m/s	5.0 m/s	11.3 m/s
Effective Stack Height			

1 – As provided in Air Quality NZ Report

2.3 Observed and modelled visible plume characteristics.

A broad summary of the observed characteristics of the visible plumes and modelled plumes from the Ōhaaki and Tauhara studies are provided in Table 3 and Table 4. The results selected include stable, neutral and unstable weather conditions. With respect to well-testing at Tāheke the temperature and stack characteristics are somewhat similar to the Ōhaaki bores but the steam discharge is apparently around ten times the rate. The Tāheke well-testing discharge rate is similar to that assumed in Clarkson's Tauhara 1997 study of plumes from a mechanical forced draft cooling tower, but the temperature is lower.

A simple preliminary screening analysis using the Holland formula for effective stack height was carried out. Effective stack height (H_{ES}) equates to where a plume rise would level off and is given by

$$H_{ES} = H + \left(d\frac{v_s}{u}\right)\left(1.5 + 0.00268\,p\,d\frac{\Delta T}{T_s}\right),$$

where $\boldsymbol{H}$ is stack height (m), $\boldsymbol{d}$ is stack diameter (m), $\boldsymbol{v_s}$ is exit velocity (m/s), $\boldsymbol{u}$ is wind speed (m/s), $\boldsymbol{p}$ is pressure (mb), $\Delta\boldsymbol{T}$ is difference between stack temperature (K) and ambient dry bulb temperature, and $\boldsymbol{T_s}$ is stack temperature (K). This analysis indicated that Tauhara Mechanical Draft Cooling tower would be expected to have much higher plume rise than Ōhaaki Bores (note, exit velocity was not available, but assumed to be similar as Tāheke) by a factor of around 3-4. This is roughly in line with the observations and model projections where plume rise for Tauhara were often estimated to be in the range 350 to 560 m (Table 4) and for Ōhaaki between 80 and 320 m (Table 3Table 3). This screening analysis indicated that plume rise from the Tāheke well testing would be expected to be about the similar or higher than as was estimated for Tauhara, i.e., approximately 600 m, and this number is consistent with presentations made to Rotorua Airport by the developers in December 2022. Based on the Air Quality Consultants report and personal communication with Peter Stacey of Air Quality Consultants it seems their conclusions may be based on results of CALPUFF model equations/options where a buoyant line source was assumed. Note, CALPUFF does have a limited cooling-tower module, but the report provided does not mention that and visible plumes are not mentioned. With respect to the two cooling tower options at Tāheke, the plume rise for the air-cooled-condenser would be around 50% of what was estimated for Tauhara and for the wet mechanical draft wet cooling tower option it would be similar but slightly higher than Clarkson and Belberova's (1997) calculations for Tauhara's mechanical draft tower. This is somewhat higher than the 150 m figure indicated in presentations made to Rotorua Airport by the developers in December 2022. However, the current screening analysis does not account for newer technology which may reduce steam and vapour content, especially so for the air-cooled condenser where little, if any, visible plumes are anticipated.

It should also be noted that it is difficult to model visible plumes since these are sensitive to small changes in temperature and humidity conditions and it has been reported that the Briggs type formulations which PLUME, ATCOOL and CALPUFF formulations are based can underestimate plume rise and extent especially for small stacks (Clarkson and Simpson, 1984 and Gordon et. al. 2018), so some conservatism needs to be applied to estimates presented in this report.

Note also, that the Ōhaaki analysis here was for bores not the Ōhaaki cooling tower. Clarkson (in notes for a consent application) has noted that the Ōhaaki cooling tower would be expected to create larger and more highly visible plumes than the Tauhara cooling tower since Ōhaaki uses a convective (or natural draft) cooling tower and it was 2.5 times larger than Tauhara.

Table 3 and also show observations and estimates of horizontal extent of the visible plume and it is expected that maximum horizontal visible plume extent from well-testing at Tāheke would be similarly greater than that observed and modelled for the Ōhaaki bores and again be similar or slightly higher than that modelled with ATCOOL for Tauhara by Clarkson and Belberova (1997) (see Hanna, 1976 for a description of ATCOOL). Thus, it is not expected that the visible horizontal extent of plumes from any Tāheke well testing would be more than around 2.5 km from source and would be much less for either of the proposed Tāheke cooling tower option, but especially so for the air-cooled condenser option.

Table 3: Table of key meteorological conditions and observed plume characteristics from Ōhaaki Bores 35 and 19 as derived from photographic analysis during the May 1980 monitoring period (numbers for Bore 19 are shown in square brackets). Also included are PLUME model predictions of Clarkson and Simpson (1984). For plume rise and extents the numbers quoted are the upper uncertainty limits, i.e., if 100 m ± 20m was quoted, that is reported here as 120 m.

	Ōhaaki Bore 35[19]			
Date	14/05/1980	14/05/1980	17/05/1980	18/05/1980
PG Stability Class	B Unstable	E Stable	D Neutral	D Neutral-windy
Wind Speed	1.6 m/s	0.8 m/s	2 m/s	6 m/s
RH	86%	73%	83%	79%
Temperature	14.1 C	12.7 C	10.7 C	12.7 C
Max plume rise (camera)	230 m [270 m]	85 m [120 m]	320 m [360 m]	80 m
Max plume rise (PLUME model)	200 m [220 m]	110 m [130 m]	120 m [160 m]	50 m
Visible downwind extent (camera)	250 m [240 m]	180 m [200 m]	320 m [370 m]	260 m
Visible downwind extent (PLUME model)	66 m [40m]	70 m [50 m]	110 m [100 m]	90 m
Plume width	40 m [40 m]	40 m [45 m]	60 m [80m]	35 m

Table 4: Table of key meteorological conditions (observed) in at Tauhara and plume characteristics as modelled using ATCOOL for a selection of 8 cases in 1996 and 1997.

	Tauhara 1997			
Stability Class	C/D Neutral-Unstable	F Stable (Cold)	D Neutral	E Slightly stable
Wind Speed Sfc	1.3 m/s	0.5 m/s	4.5 m/s	2.8 m/s
Wind Spd 50 m	1.5 m/s	2.3 m/s	5.3 m/s	5.3 m/s
RH	100%	100%	100%	100%
Temperature sfc	10 C	-1 C	8 C	-1 C
Temperature 50m	0 C	1 C	0 C	0 C
Max plume rise (ATCOOL)	400 m	510 m	150 m	560 m
Visible downwind extent (ATCOOL)	1600 m	600 m	850 m	730 m
Max plume rise (model ATCOOL)	440 m	410 m	200 m	345 m
Visible downwind extent (ATCOOL)	532 m	504 m	2600 m	361 m
	Tauhara 1996			
Stability Class	A Very Unstable	F Stable Cold	E Stable Windy	F Stable
Wind Speed Sfc	0.4 m/s	0.5 m/s	9.9 m/s	2.0 m/s
Wind Spd 50 m	2.5 m/s	2.5 m/s	11 m/s	2.5 m/s
RH	95%	95%	95%	85%
Temperature sfc	6 C	0 C	10 C	-1 C
Temperature 50m	-2 C	2 C	2 C	1 C
Max plume rise (ATCOOL)	440 m	410 m	200 m	345 m
Visible downwind extent (ATCOOL)	532 m	504 m	2600 m	361 m
Max plume rise (model ATCOOL)	440 m	410 m	200 m	345 m
Visible downwind extent (ATCOOL)	532 m	504 m	2600 m	361 m

2.4 Vertical Motions

Civil Aviation rules on discharges of efflux state that anyone proposing to discharge efflux at a velocity in excess of 4.3 m/s through an airport's "obstacle limitation surface" (See Figure 3) or at a velocity in excess of 4.3 m/s at a height higher than 60 m above ground level must notify the director of Civil Aviation. For the closest well-testing site of the Tāheke development the height of the obstacle limitation surface has been estimated as being 172 m.

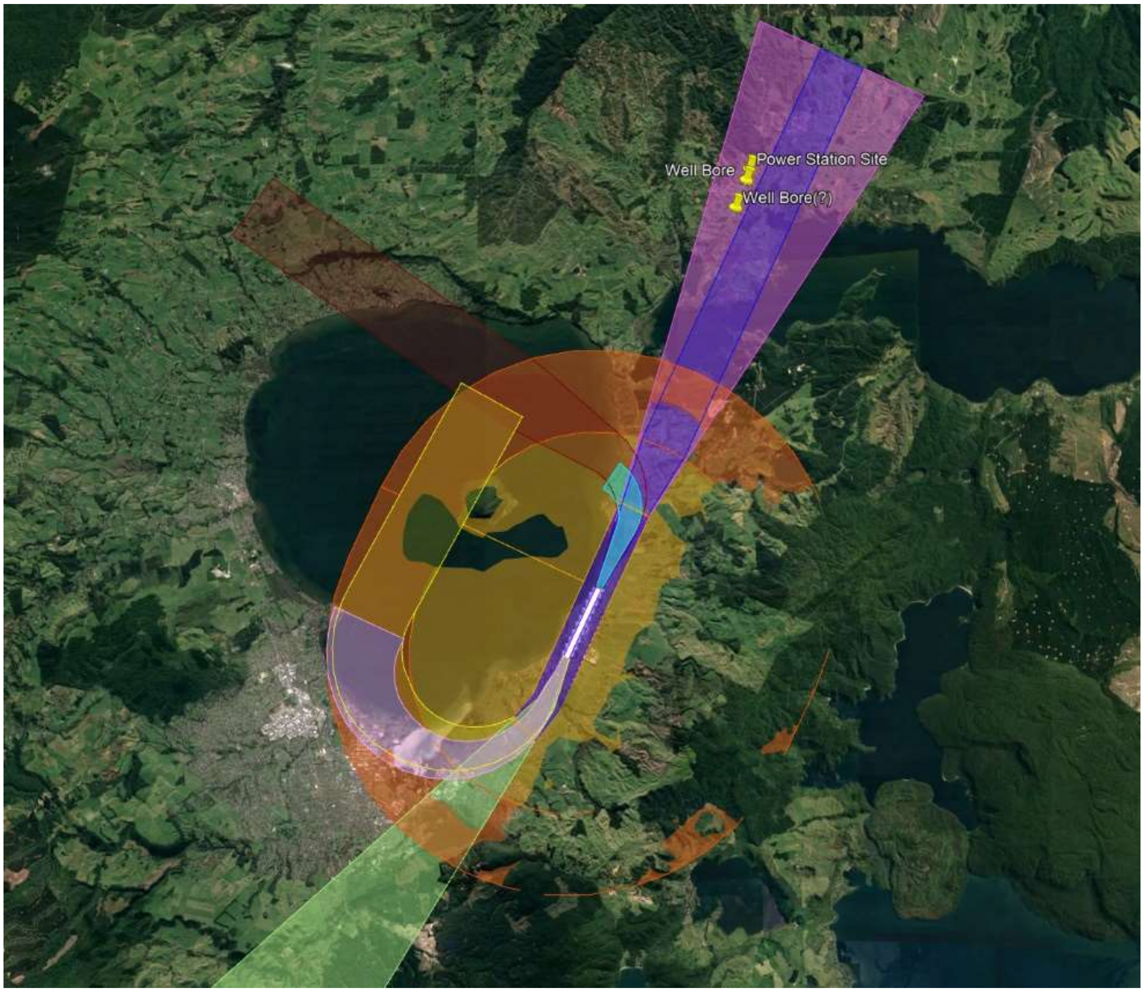

Figure 3: Approximate Obstacle limitation surface for Rotorua Airport as provided by Rotorua Airport Limited. The height of this surface above ground for the closest bore site is 172 m.

While the Meteorological Monitoring and observational campaigns in the Taupo area do not appear to have recorded the rate of plume rise during the bore testing or investigated the rate of rise in their modelling studies, a staff member involved does recall the very spectacular and rapid ascent of the steam plume. They estimated plumes reached 200 to 300 m above the ground in times well under a minute, with vertical speeds averaging on the order of 4-6 m/s over the ascent. (Tony Bromley, personal communication.)

Vertical motions associated with plume rise, do however, weaken as steam plumes rise to an equilibrium level, i.e., the level where the plume tends to spread out laterally and move downwind. Thus, some deceleration during the ascent does occur. However, if plume heights from the well-testing for the current development do reach up to 2000 ft (600 m) then it is highly likely that vertical plume velocities will exceed 4.3 m/s at both 60 m and 172 m agl. Hanna, 1978 reported for a study of tall and large mechanical draft cooling towers (diameters were 44 m) that average vertical velocities in the plumes were 4.3 m/s.

Hanna, 1978 reports also reported on photographic observations of vortices within cooling tower plumes where 15% of the observed vortex speeds exceeded 4 m/s. The cooling towers in that study were large and mechanically forced and it is not clear whether the same would apply to plumes generated by the two cooling tower options proposed at Tāheke.

Hawkes and Flay, 2017 and Hawkes and Flay, 2018 at the University of Auckland raise the possibility that with mechanical intervention of swirl vanes to manipulate inlet flows, waste heat and moist air from geothermal plants could be used to generate vortices with strong tangential and significant updraft velocities that could extend very high into the atmosphere. Such a vortex would pose a hazard to aviation if formed but it seems unlikely that one of such height could be accidentally or naturally generated and maintained for long enough at Tāheke or in the wider Rotorua area.

Naturally occurring thermals are often generated in areas of strong daytime heating and these could also be favoured to occur in areas where the surface is relatively warm due to geothermal activity, typical vertical motions are in the range of 1-2 m/s (Stull, 1988). Other phenomena such as steam devils can occur in cold air when there are large gradients in temperature between the surface and the atmosphere and these have been reported in areas of geyser activity, however, typically the vertical extent of these features does not exceed 500 m in height.

3 Conclusions and recommendations.

A desktop review of some historic meteorological observation campaigns which included some photographic analysis and subsequent modelling analysis with plume rise models has been undertaken to make a preliminary assessment of whether visible steam plumes from well-testing and cooling towers associated with the Tāheke geothermal development at Okere Falls may affect visibility at operational flight levels around Rotorua Airport.

This analysis indicates that under certain atmospheric conditions steam plumes from well-testing may rise to around 2000 ft (600 m) and the horizontal extent could be 2.5 km downwind. However, some uncertainty around this level exists due to model bias and the complexity in representing all processes leading to visible plume formation.

With respect to the two cooling tower options; based on a screening analysis and the source parameters provided, the air-cooled condenser is likely to have little impact as the maximum vertical extent of plume is likely to be around half that for well-testing and air-cooled condensers trap steam in tubes; however for the mechanical draft wet cooling tower, the screening analysis indicated maximum vertical extent of the plumes could be as high as for well-testing.

In terms of work that could be done to strengthen the conclusions here, it is recommended that a more detailed justification including a written report by the developers and its consultants as to the visible plume modelling from cooling towers and well-testing be done. That report should include assumptions made in that modelling the rise and extent plumes from the well-testing or the mechanical draft wet cooling tower. It is advisable that modelling with the ATCOOL model also be undertaken as recommended by the "Good practice guide for Atmospheric Dispersion" published by the Ministry for the Environment.

Further investigation may be warranted into the strength of vertical velocities in plumes from both the well-testing and the cooling towers as it seems likely that the Civil Aviation notification thresholds of 4.3 m/s at 60 m above the ground and at 172 m (the estimated height of the obstacle limitation surface above the nearest well) may be exceeded.

These investigations could include advanced meteorological monitoring during well-testing where drones could be deployed and the use of modern Large Eddy Simulation models such as PALM, which can realistically simulate turbulence, plumes and vortexes at fine spatial detail, e.g., Giersch, S., Raasch, 2023.

NIWA is happy to make material (observations and reports – where permitted) available for inspection at its Wellington offices to either the Tāheke developers or Rotorua Airport.

4 Acknowledgements

Thanks to Tony Bromley (NIWA) who provided access to the archive of old Meteorological Service field data and reports from the 1970’s and 1980’s.

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Appendix A Some Climate Statistics for Rotorua Aero

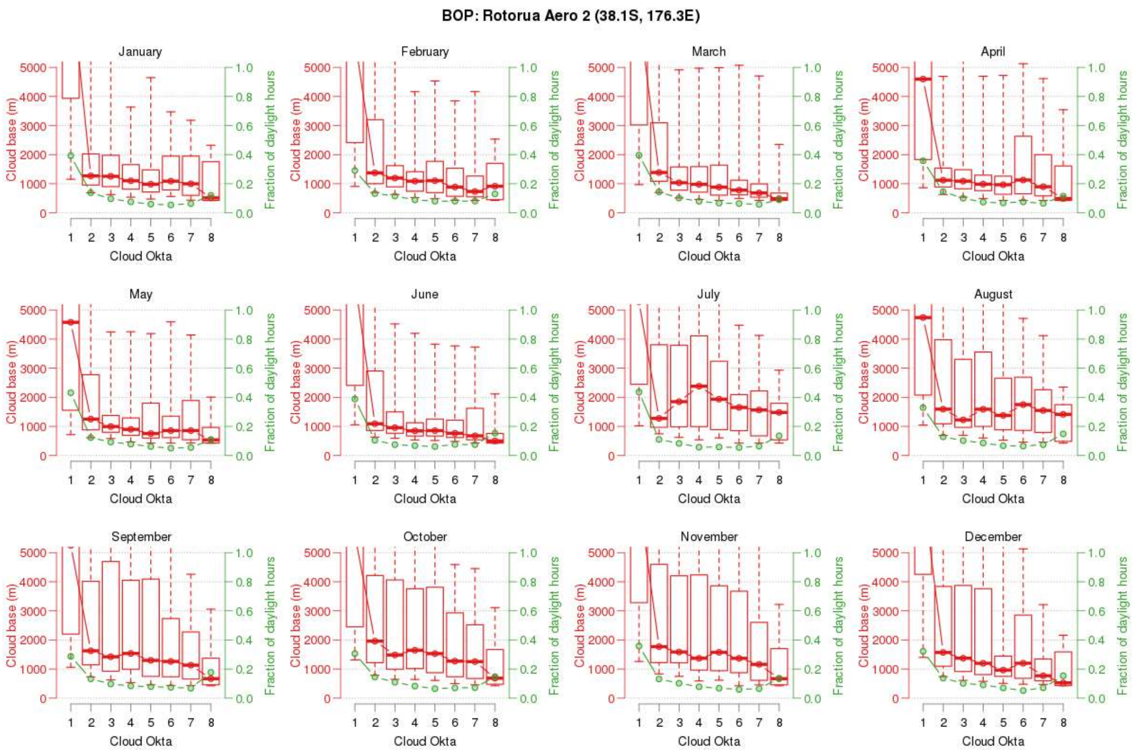

Figure A- 1: Box and whisker (red) plots of estimated cloud base (metres above sea-level) at Rotorua Aero for each month of the year for the 8 different okta classes. The median (50th percentile) is the thick red line, the 25th percentile is the bottom of the red box, the 75th percentile is top of the red box, while the ends of the whiskers are the 5th and 95th percentiles. The green line shows the frequency of occurrence of each okta class. Based on 2 years of NZCSM cloud forecasts April 2018- March 2020.

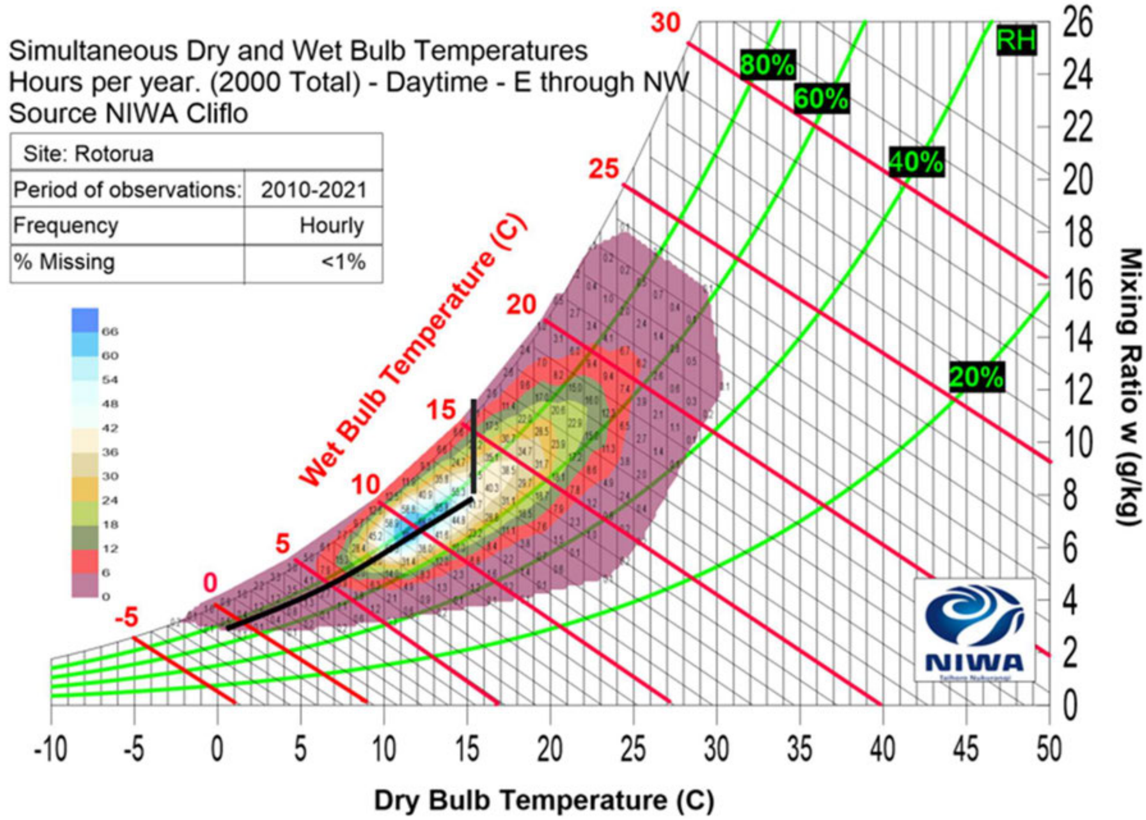

Figure A- 2: Pyschrometric chart for Rotorua Airport (2010-2021) showing frequency (hours per year) of combinations of Air Temperature and humidity for daytime hours when winds are from the sector East through South through Northwest. Above and left of the thick black is the region of > 80% humidity and temperatures < 15 ^{o}C, and occurs for around 800 daytime hours a year, for all wind directions this occurs for around 1430 hours a year.

Jacob Paget

From: Max Gander-Cooper
Sent: Tuesday, 9 May 2023 2:51 pm
To: Fast Track Consenting
Subject: RE: [COMMERCIAL]FW: NIWA report on Taheke Geothermal Project
Attachments: NIWA-desktop-report-Rotorua-Airport-update.pdf

Hey Jake, could you please file this?

From: Fast Track Consenting <fasttrackconsenting@mfe.govt.nz>
Sent: Tuesday, 28 March 2023 1:35 pm
To: Max Gander-Cooper s 9(2)(a)
Cc: Fast Track Consenting <fasttrackconsenting@mfe.govt.nz>
Subject: [COMMERCIAL]FW: NIWA report on Taheke Geothermal Project

Fyi. Worth noting that the comments were also sent to the applicant. Will pdf email below and combine it with attached comments

Many thanks

Jacob

Fast Track Consenting

Ministry for the Environment | Manatū Mō Te Taiao
fasttrackconsenting@mfe.govt.nz | mfe.govt.nz
This email account is monitored by several members of the team, to ensure responses are managed in a timely manner.

Ministry for the Environment
Manatū Mō Te Taiao

From: Jayne Marsh s 9(2)(a)
Sent: Tuesday, March 28, 2023 12:10 PM
To: Stuart McDonnell s 9(2)(a) Fast Track Consenting <fasttrackconsenting@mfe.govt.nz>
Cc: Nicole Brewer s 9(2)(a) >
Subject: NIWA report on Taheke Geothermal Project

MFE CYBER SECURITY WARNING
This email originated from outside our organisation. Please take extra care when clicking on any links or opening any attachments.

Dear Stuart and the Fast Track Consent Team,

As previously mentioned, Rotorua Airport has engaged Richard Turner from NIWA to assess possible effects of the Takeke Geothermal Project on aviation. This is particularly relevant given the plant proposed location is within our Airport Obstacle Limitation Surfaces footprint, directly in the Airport approach and departure flight path areas for aircraft. Please find attached this finalised report from NIWA. Please note, NIWA have requested their permission is sought if this report is shared further, to ensure any potentially confidential data is protected.

From the evidence in this report our concerns remain, that this plant could be a significant hazard to aircraft if a mechanical draft wet cooling tower design were used, and also during well testing. It is likely that aircraft will encounter the plume from this, and the associated vertical updrafts along with decrease in pilot visibility when flying into a discharge cloud would appear hazardous. It would not be possible for an aircraft following an instrument flight procedure to alter its flight path to fly around the cloud. A pilot flying visually may however try and avoid the cloud by going around it, which could also be highly undesirable as low-level manoeuvring of aircraft is to be avoided where possible, and the aircraft might be more likely to encounter other obstacles or terrain when off-track. A pilot flying visually who suddenly loses visual reference in a cloud of any significance is at high risk of spatial disorientation and possible crash, thus flying into a cloud under visual flight rules is not legal. This is potentially very problematic due to the location being on our direct approach / departure path to the North.

The effects on the people inside of an aircraft who would breathe a more concentrated form than the dispersed model when flying directly through a discharge cloud and any information on corrosion or other effects on the aircraft itself have not to date been provided by the project team, such that our concerns on those points remain unaddressed at this time.

We welcome further discussion on any of these matters, please contact myself in the first instance. Now we understand the effects on aviation may be significant we recommend a further aeronautical study be done with consultation of all airport users and the wider aviation community if a wet cooling tower will be used. We also strongly reiterate that Air NZ is consulted as this may significantly affect their operation. The pathway appears much more straight forward if an air-cooled condenser design is used, although the impacts of well testing would still need to be addressed and other hazards associated with aircraft flying over that type of plant are currently unknown.

For clarity, as Requiring Authority in the Rotorua District Plan, Rotorua Airport does not consent to our Obstacle Limitation Surface being breached in excess of Civil Aviation Rules parameters for discharge at this time, which would appear likely to occur from the NIWA report.

Thanks again and wishing you a nice afternoon.

Ngā mihi
Jayne Marsh s 9(2)(a)

SMS and Aeronautical Manager
s 9(2)(a) z

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