A chemical perspective on the recreational use of geothermal waters

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The potential of geothermal waters for tourism and recreation in New Zealand dates back at least to colonial times, with visits by Prince Albert to the Pink and White Terraces in 1870 and by a subsequent visit of the Duke and Duchess of Cornwall to Rotorua in 1901. Public bathing at the Te Aroha baths overtook their private therapeutic use after 1907,[1] and in Rotorua, the opening of the Blue Baths in the 1930s for recreational swimming was incorporated into a Government strategy of the time to encourage tourism (Fig.1).[2,3]

Nearly a hundred natural hot springs and commercial pools using warm waters from geothermal resources that are currently used for recreation in New Zealand have been described,[6] and this compilation is reflected in the NZ Hot Springs website.[7] This website also provides the opportunity for visitors to the 107 springs and pools listed to provide comment and give a rating. Although there is no indication given as to how these ratings are determined, it would be expected that the characteristics of the waters, the ambience of the setting, and the quality of the service at commercial pools, are factors that would influence the rating. As is shown for the currently closed Waingaro Hot Springs, the quality of service can vary considerably over time (Fig. 2), but more usually the ratings tend to show little variation over time (Fig. 3).

A research project by the University of Waikato and GNS Science is undertaking a survey of hot springs and hot pools aimed at determining the microbial and physicochemical diversity of geothermal features, an archive of microbial diversity and genetic potential, and an 'environmental indicator' ('uniqueness' metric prediction), in which the microbial and physicochemical diversity data will be assessed via a set of criteria that ranks ecosystem 'uniqueness'.[8] As a prelude to the microbiological work, the researchers are measuring selected physicochemical properties of the springs and pools they are sampling, viz., temperature, pH, redox potential (Eh), conductivity, dissolved oxygen, and turbidity.[9] The variations between Eh and pH, conductivity and pH, and Eh with temperature are shown for the hot springs and pools in Rotorua's Kuirau Park in Fig. 4, Fig. 5 and Fig. 6, respectively.

There is no obvious correlation between either dissolved oxygen or turbidity with the other physicochemical parameters.

At the time of writing this article about 800 samples had been gathered, although the hot springs and pools for which information is displayed on the 1000 Springs database include comparatively few of those on the Hot Springs website. These are shown in Table 1.

The trends of the physiochemical properties with ratings are given in Table 2. The low correlation coefficients mean that the trends are indicative rather than definitive; but it appears that visitors to the springs and pools prefer waters that are warmer, more basic (higher pH, see Fig. 7), and with low turbidity (see Fig. 8). These trends may be confirmed or countered when additional physiochemical data for further hot springs and pools become available from the 1000 Springs Project.

Fig.1. The changing face of tourism: from spectacle to recreation. *Left:* Eruption of the Wairoa Geyser on a booklet cover in 1912 [Photo: Alexander Turnbull Library, Eph-A-TOURISM-Rotorua-1912-02-front].[4] *Right:* Rotorua's newly opened Blue Baths featured on the cover of a 1930s Tourist and Publicity Department booklet [Photo: Alexander Turnbull Library, Eph-A-TOURISM-1930s-02-cover].[5]

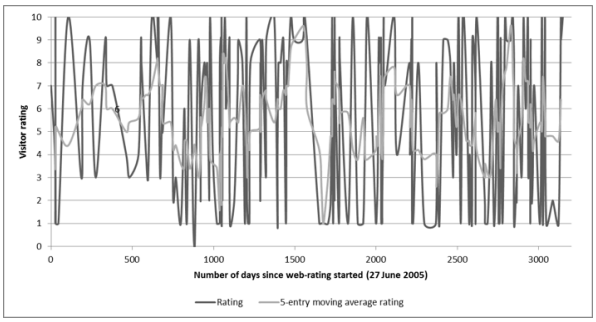

Fig. 2. Variation in the 348 visitor ratings of Waingaro Springs (near Hamilton) from 27 June 2005 to 8 February 2014

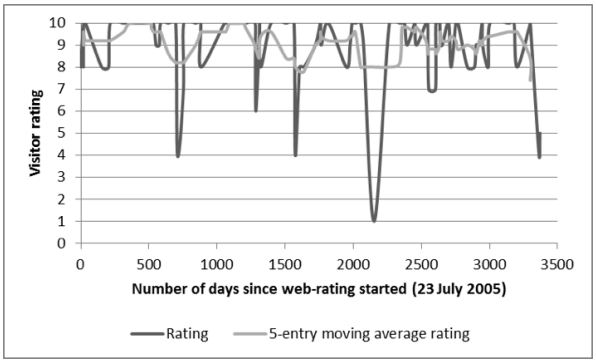

Fig.3. Variation of the 97 visitor ratings for Kerosene Creek (a stream associated with the Waiotapu Geothermal Field, near Rotorua) from 23 July 2005 to 13 October 2014

Table 1. Comparison of hot pool physicochemistry and visitor ratings

Thousand Springs Database									Hot Pools Database		
System	Location	Feature	Physicochemical properties						**Average Visitor rating* *V***	Number of ratings	Spring/Pool
			Temp, T/°C	Acidity pH	Redox potential Eh/mV	Conductivity σ/mS cm^{-1}	Dissolved oxygen O_2/mgL^{-1}	Turbidity r/FNU			
Tikitere	Hells Gate	Tikitere #76 (Hurutini)	42.1	2.24	69.2	3048	40	99.1	6.8	4	Hell's Gate
Rotorua	Kuirau Park	Features 26, 30, 31, 33†	42.8	7.18	-74.4	1702	2.12	13.1	7	6	Kuirau Park Footbaths
Waikite	Waikite Thermal Valley Pools	Feature #5	74.8	8.46	-0.6	1083	2.01	0.9	9.5	63	Waikite Valley Thermal Pools
Waiotapu	Waiotapu	Champagne Pool	74.5	5.29	-222.2	7464	4.93	5.9	8.1	10	Waterfall Spout Bath, Waiotapu
									9	97	Kerosene Creek
									8.6	34	HotnCold (Waiotapu Stream)
									8.6‡	141	Waiotapu
Wairakei-Tauhara	Spa Park	Otumuheke Stream Feature #1	37.5	7.68	79.2	758	3.13	1.5	7.9	16	Otumuheke Stream, Spa Park
	Wairakei Terraces	Bathing Pool 1-4	39.2	8.44	165.7	7015	4.05	1.5	9.4	5	Wairakei Terraces
	Wairakei Thermal Valley	Feature #2	46.7	6.95	62.1	749	3.84	1.4	9	2	Honeymoon Pool (Te Kiri o Hine Kai Stream
Turangi	Tokaanu	Features #31, #34¶	33.5	6.05	146.3	4782	2.92	7.4	8.7	47	Tokaanu Thermal Pools

*Visitor ratings are on a scale of 1 through 10 (10 is best).

†The values of the physiochemical properties are averaged over the four features closest to the footbaths

‡Rating averaged over three pools in streams draining Waiotapu thermal area, considered to be similar to Champagne Pool

¶Physiochemical properties are averaged over the two pools stated to be in Tokaanu

Table 2. Linear regression between visitor ratings and physiochemical parameters

Linear regression parameters*	P						
	Temperature (T)	Acidity (pH)	Redox potential (Eh)	Conductivity (σ)	Dissolved oxygen (O_2)	Turbidity (r)	Log Turbidity (log r)
Slope: M	+5.777	+1.243	+21.993	+662.6	+0.0679	-22.58	-0.533
Intercept: C	0.581	-3.861	-155.8	-2216	2.8071	202.5	5.113
Correlation coefficient	0.133	0.391†	0.0321	0.0608	0.0048	0.465	0.657‡

*For equation ***P*** = M.***V*** + C, where ***V*** is visitor rating; † See Fig. 7; ‡ See Fig. 8

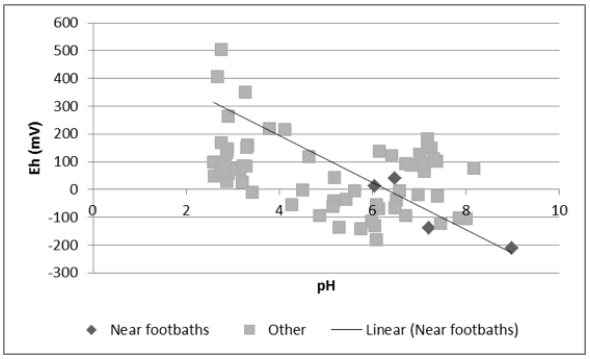

Fig.4. Variation of redox potential, Eh, with pH for hot springs and pools in Kuirau Park, Rotorua. Although a number of reactions contribute to Eh, the data accord with theoretical expectations that Eh decreases with increasing pH

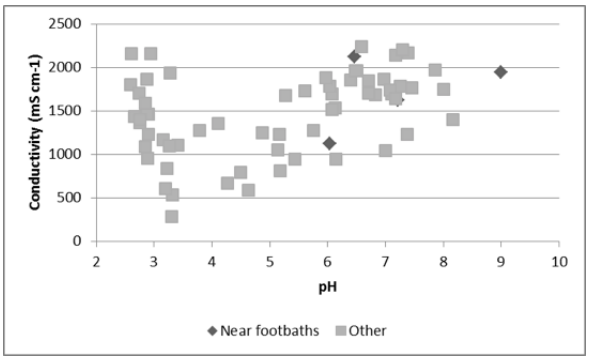

Fig. 5. Variation of conductivity with pH for hot springs and pools in Kuirau Park, Rotorua. The V- shaped distribution results from high conductivity at high pH attributed to chlorides in geothermal water rising from some depth, and high conductivity at low pH resulting from near-surface oxidation processes.

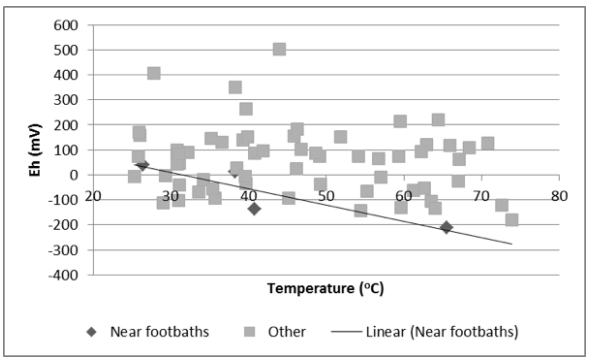

Fig. 6. Variation of redox potential (Eh) with temperature for hot springs and pools in Kuirau Park, Rotorua. Although the data are 'noisy' there is a trend of decreasing Eh as the temperature increases. This is consistent with the higher temperature water being derived from a deep source.

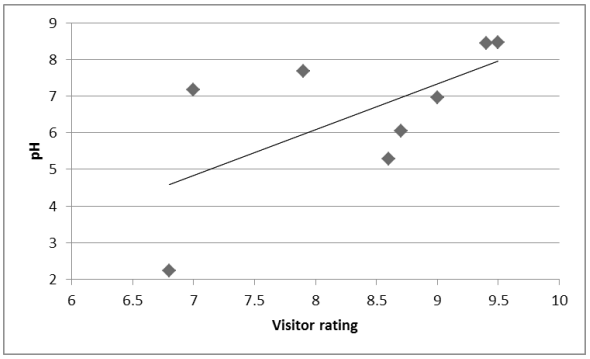

Fig. 7. Variation of pH of hot springs/pools with visitor rating.

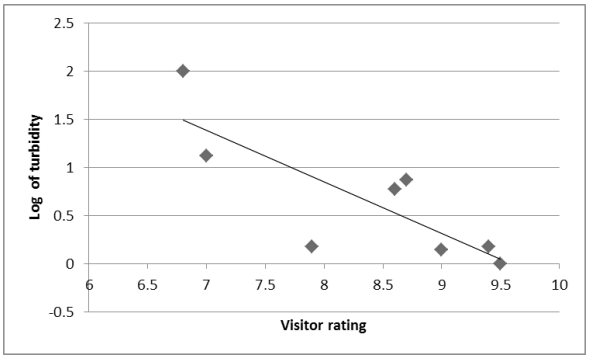

Fig.8. Variation of turbidity (as log *r*) of hot springs/pools with visitor rating.

Notes and References

1. Annual attendance at Te Aroha spa, 1904-1909. Data from *Appendices to the Journal of the House of Representatives*; see Hodder, P. *Chemistry in New Zealand* **2014**, *78*(4), 158-163.
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5. Credit: "Mitchell, Leonard Cornwall, 1901-1971. Mitchell, Leonard Cornwall 1901-1971 :Rotorua and New Zealand's thermal wonderland. [1930s].Ref: Eph-A-TOURISM-1930s-02-cover. Alexander Turnbull Library, Wellington, New Zealand.http://natlib.govt.nz/records/23063926"
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9. *One Thousand Springs: The microbiology of geothermal hotsprings in New Zealand*: http://www.1000springs.org.nz/ (accessed 22 October 2014).