

"Mini-Superfund" Site in Kawerau, New Zealand: A Closer Look at Water Quality

by

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Abstract

In 1954 New Zealand's government passed the Tasman Pulp and Paper Enabling Act, which gave the Tasman company carte blanche to do everything necessary to create the Pulp and Paper Mill's waste disposal site on Maori Trust land. Consequently, the former Lake Rotootipaku has become Tasman Pulp and Paper's primary disposal site. This area has been described as "one of the worst locations one could contrive for a waste disposal site". Geologically, the waste site is situated on highly permeable young rocks, with active fault traces traversing it and a high groundwater surface. In addition, the site sits atop an active geothermal area and is within 100 meters of the Tarawera River. Previous site assessments have identified groundwater and soil contamination at levels that exceed national and international guidelines for drinking water, agricultural use, and ecological health and protection. Additionally, Lake Rotootipaku is no longer a waterway for migratory fish and eels, geothermal surface features and hot springs have been destroyed, ponds that have formed behind large constructed embankments are suffering ecologically, and contamination has migrated offsite.

The previous environmental site assessments thoroughly investigate soil, groundwater and solid waste contamination in the area. Yet, limited water quality analysis exists for the site's neighboring surface water bodies, *i.e.* A8 pond, Urupa pond, and the Tarawera River. Results from surface water investigation suggest that the ponds are contaminated with boron, arsenic, cadmium, chromium, mercury, lead, and zinc. Geothermal activity in the area is targeted as the cause for this heavy metal contamination.

An unmet need to fully characterize surface water contamination in the principle surface water bodies neighboring the former Lake Rotootipaku has shaped the objectives of this Masters Project. One primary objective of this project is to investigate the nature and extent of the inorganic contamination in principle water bodies neighboring Lake Rotootipaku. Additionally, this project uses chemical and isotopic fingerprinting to distinguish between geothermal and anthropogenic sources of contamination. This project is based on systematic fieldwork and sampling of several key water sources in the area.

None of the inorganic constituents measured in A8 pond, Urupa pond, or Tarawera River exceed the ANZECC guideline values for recreational water use. Therefore we conclude that the water quality is acceptable, with regard to inorganic contamination, for recreational purposes. Hydrogen and oxygen isotopic fingerprints and conservative mixing calculations suggest that geothermal waters have mixed only with the Tarawera River, but not with A8 and Urupa ponds. Iron, manganese, and copper concentrations in A8 pond, Urupa pond, and the Tarawera River are greater than the concentrations measured in pristine and geothermal waters. However, we attribute the relatively high levels of iron and manganese to organic contamination of the surface water that triggered oxidation, created reducing conditions, and consequently enhanced the reductive dissolution of manganese and iron from the sediments. Thus, the evidence suggests that there is no source of inorganic anthropogenic contamination, *i.e.* inorganic contamination originating from the pulp and paper mill, in the principle surface water bodies. Further research is necessary to explore potential sources of organic contaminants in A8 pond, Urupa pond, and the Tarawera River.

Table of Contents

ABSTRACT	2
INTRODUCTION	4
BACKGROUND.....	6
<i>SURVEY OF PULP AND PAPER MILL CONTAMINANTS</i>	<i>6</i>
<i>General Water Quality Parameters</i>	<i>9</i>
<i>Organic and Inorganic Contamination.....</i>	<i>9</i>
<i>SITE DESCRIPTION.....</i>	<i>11</i>
<i>LEASE AGREEMENT.....</i>	<i>15</i>
<i>HISTORICAL AND CULTURAL SIGNIFICANCE.....</i>	<i>16</i>
<i>GEOHERMAL ACTIVITY</i>	<i>16</i>
PREVIOUS SITE ASSESSMENTS.....	17
<i>GROUNDWATER CONTAMINATION.....</i>	<i>17</i>
<i>SOIL CONTAMINATION.....</i>	<i>18</i>
<i>A8 AND URUPA POND SEDIMENTS AND SURFACE WATERS</i>	<i>19</i>
<i>LEACHATE.....</i>	<i>21</i>
METHODS.....	21
<i>DATA COLLECTION</i>	<i>21</i>
<i>DATA ANALYSIS.....</i>	<i>23</i>
<i>CHARGE BALANCE ERRORS</i>	<i>25</i>
RESULTS.....	26
<i>GEOHERMAL MIXING</i>	<i>33</i>
<i>GEOHERMAL MIXING</i>	<i>34</i>
<i>LITHIUM/CHLORIDE RATIOS.....</i>	<i>34</i>
<i>HYDROGEN AND OXYGEN ISOTOPES</i>	<i>35</i>
<i>PERCENT MIXING CALCULATIONS</i>	<i>36</i>
<i>HYDROCHEMICAL FACIES: X-Y PLOTS</i>	<i>37</i>
<i>ANZECC GUIDELINES FOR RECREATIONAL USE</i>	<i>37</i>
DISCUSSION.....	37
<i>ISOTOPIC FINGERPRINTING.....</i>	<i>37</i>
<i>GEOHERMAL CONTRIBUTION.....</i>	<i>38</i>
<i>Lithium/Chloride Ratios.....</i>	<i>38</i>
<i>ANTHROPOGENIC CONTAMINATION</i>	<i>39</i>
<i>WATER QUALITY.....</i>	<i>40</i>
SUMMARY AND CONCLUSIONS	41
RECOMMENDED FUTURE WORK.....	41
ACKNOWLEDGEMENTS	42
REFERENCES	43
APPENDIX A: X-Y PLOTS FOR CONSERVATIVE CONSTITUENTS.....	45

Introduction

Until the early 1960s Lake Rotootipaku in Kawerau, New Zealand was a shallow lake with active hot springs and sinter terraces on its southern shore. It was fed by a natural spring and was rich in fish (particularly eels) that were a vital source of food for the local people. However, in 1954 New Zealand's government passed the Tasman Pulp and Paper Enabling Act that essentially gave the Tasman company carte blanche to do anything and everything necessary to construct and operate a pulp and paper mill waste disposal site on Maori Trust land. Despite landowners' protests, the government appointed a group of Responsible Trustees (none of which were landowners) who agreed to lease the area to Tasman Pulp and Paper in 1971, with the lease expiring in 2013. Consequently, Lake Rotootipaku has become Tasman Pulp and Paper's primary disposal site for solid paper-mill waste. The Responsible Trusteeship for Lake Rotootipaku has been restored to the landowners and Norske Skog Tasman Limited now owns the pulp and paper mill. Yet, Lake Rotootipaku is no longer a waterway for migratory fish and eels, geothermal surface features and hot springs have been destroyed, ponds that have formed behind large constructed embankments are suffering ecologically, and contamination has migrated offsite.

Several environmental site assessments have been conducted on behalf of the Responsible Trustees and Norske Skog to ascertain the magnitude of contamination and the potential environmental hazards. Over the last 10 years the investigations have explored soil and groundwater contamination; geotechnical engineering properties of the landfill embankments; geothermal risks; hydro-geological characteristics of the landfill; and overall environmental risk of the landfill ((GES, 2002);(GES,2004); (SKM, 2004); (SKM, 2005); (SKM, 2007)). The resulting reports present data and analysis for onsite groundwater, soil, and solid waste contamination. Additionally, limited data and analysis is provided for the contiguous surface water bodies, *i.e.* A8 and Urupa ponds; namely pond sediment and surface water concentrations for selected heavy metals. Contaminant concentrations in the leachate waters are also assessed.

Collectively Sinclair Knight Merz (SKM), Gwilym Environmental Services (GES), and Gulf Resource Management (GRM) confirm contamination in the groundwater, soil, waste, pond water, pond sediment, and embankments on and around the waste disposal site. These site assessments identify contamination levels that exceed Australia and New Zealand Conservation Council (ANZECC) guidelines for drinking water, agricultural use, and ecological health and protection. Table 1 below lists the sample mediums and the contaminants that exceed relevant ANZECC guidelines. Latter sections of this paper (see Previous Site Assessments) present contaminant concentrations for each sample medium and the corresponding ANZECC guideline levels.

Parameter	Groundwater	Soil	Pond Sediments	Pond Waters	Leachate Waters
Sodium	X				
Sufate	X				
Ammoniacal Nitrogen	X	X			
Phosphate	X				
Sulfide	X				
Mercury	X	X	X		
Manganese	X	X			
Arsenic	X	X	X		
Boron	X	X	X	X	X
Lithum	X				
Barium	X				
Cadmium	X				
Chromium	X			X	
Nickel	X				
Lead	X	X	X		
Zinc	X	X	X		
Copper	X			X	X

Table 1. Sample Mediums and Contaminants that exceed relevant ANZECC guidelines

While it is essential to understand the nature and extent of groundwater, soil, and waste contamination onsite and on neighboring land plots, it is also critical to fully characterize the water chemistry in the principal surface water bodies, *i.e.* A8 pond, Urupa pond, and the Tarawera River, contiguous to the waste disposal site. Such characterization enhances our understanding of contaminant migration and also assists in developing appropriate remediation strategies. SKM (2007) claims that heavy metal contamination in pond sediments and surface waters is attributable to mixing with geothermal waters but provides meager scientific evidence to support this claim. Thus, an unmet need has arisen to determine if the principal surface water

bodies have mixed with geothermal waters and also to identify any inorganic anthropogenic contamination sources.

This Master's Project primarily seeks to synthesize previous site assessments; characterize the water chemistry for the principal surface water bodies; and distinguish between geothermal and anthropogenic contamination sources, if any. In the proceeding pages, I provide pertinent background information, including a description of the site; discuss the results of previous site assessments; describe my methods; and finally, provide my results and discussion.

Background

Survey of Pulp and Paper Mill Contaminants

The wide varieties of pulp and paper mills use an array of processes and chemicals, and wastewater treatment options. Each pulp and paper mills likely falls into one of the following general categories: market pulp mills, non-integrated mills, integrated mills, converting facilities, de-inked pulp mills (USEPA, 2002). The Norske Skog Tasman Limited Pulp and Paper Mill uses both kraft and themomechaical pulping processes. The mill furnish is largely softwood, with infrequent pulping of Eucalyptus sp. (Van Den Heuvel, 2002). The kraft pulp is chlorine bleached with sodium hypochlorite or chlorine dioxide (Van Den Heuvel, 2002).

The three primary processes associated with all pulp and paper manufacture include pulping, bleaching and papermaking. In most processes, chlorinated and organic compound, nutrients, and metals are all discharged into pulp and paper mill effluent wastewaters. Table 2 below lists the common contaminants associated with each stage.

Pulping	Bleaching	Paper Manufacture
Sodium Hydroxide Residues	Hydrogen Peroxide	Waste sludge
Sulfuric/sulfurous Acid	Elemental Chlorine	Bleaching and Pulp Contaminants
Hydrochloric Acid	Chlorinated Compounds	SVOCs
Hydrogen Sulfide	Sodium Hydrosulfite	VOCs
Ammonia	Polychlorinated Biphenils (PCBs)	Slimicides Chlorinated Phenols
Lead	Dioxins and Furans	Aminos and Quarternary Ammonium Compounds
Cyanide		Organosulfur Compounds
Zinc		Silver Compounds
Chromium		Titanium Residues
Resin		Oil and Grease Discharges
Unnatural Fatty Acids and Chlorinated Analogs		Polychlorinated Biphenyls, pesticides, dyes, asbestos fibers from agricultural residues

Table 2. Common contaminants associated with each stage of the paper manufacturing process

In order to specify common contaminants associated with pulp and paper manufacture, I synthesized a handful of relevant literature sources. Robinson et al. (1994) examined the relationship between environmental responses at pulp mill sites and the pulping process, effluent treatment, and bleaching technology used by pulp mills; their study took place throughout Canada's Great Lakes Drainage Basin. Chandra et al. (2006) studied the seasonal physico-chemical and microbial quality of the Gola River downstream of a pulp and mill discharge point. Poykio (2007) extracted heavy metals from biosludge whose origin was a Finnish pulp and papermill biological wastewater treatment plant. Wang et al. (2005) reported effluent concentrations of selected contaminants from a New Zealand thermo-mechanical pulp mill. Finally, data from SKM (2005) represents contaminant concentrations in the groundwater underlying a pulp and paper mill waste disposal.

Tables 3, 4, and 5 below present a data compilation of general pulp and paper effluent characteristics (Table 3), organic contaminants and their concentration ranges (Table 4), and inorganic contaminants and their concentration ranges (Table 5). In most cases, each source surveyed or tested a pulp and paper mill effluent/waste from a number of different sources. Therefore the results reported for each source are a range of concentrations, or mean concentrations from a number of pulp and paper mills.

	Parameter	Robinson et al. (1994)	Chandra et al. (2006)	Poykio et al. (2007) (total extractable from biosludge)	Wang et al. (2005)	SKM (2005)
Long-term effluent characteristics	Effluent Flow (m ³ /d)	47276-173931	-	-	-	-
	Water Use (m ³ /tonne)	51-171	-	-	-	-
	Total Hardness (mg/L)	-	-	-	-	24-790
	TDS (mg/L)	21-317	7-173	-	-	52-2540
	TSS (mg/L)	<0.1-19	5.20-1173	-	-	-
	COD (mg/L)	-	29-5068	-	-	<6- 230
	BOD (kg/d)	1689-55817	13-2666	-	-	<1 to 8 (mg/L)
	Alkalinity (mg/L)	19-79	-	-	-	<1-840
	Conductivity (mS/m)	54-480	-	-	-	10.1-331
	DO (mg/L)	4.4-10.8	-	-	-	-
pH	7.3-8	7.10-7.76	8.3	5.1-7.2	2.8-7.0	

Table 3. Long term pulp and paper mill effluent characteristics

	Parameter	Robinson et al. (1994)	Chandra et al. (2006)	Poykio et al. (2007) (total extractable from biosludge)	Wang et al (2005)	SKM (2005)
Range of concentrations for selected chlorophenolic compounds (ng/L).	AOX (kg/d)	169-4128	-	-	-	0.044-1.7 (mg/L)
	246-TCP	<1-500	-	-	-	-
	2346-TeCP	<0.5-52	-	-	-	-
	45-DCG	<3-350	-	-	-	-
	346-TCG	<1-130	-	-	-	-
	345- TCG	<1-350	-	-	-	-
	456- TCG	<1-260	-	-	-	-
	TeCG	0.71-230	-	-	-	-
	6-MCVan	<1-190	-	-	-	-
	55-DCVan	<1-57	-	-	-	-
Range of concentrations for selected resin acids (ng/L)	Pimaric	<60-720	-	-	-	All resin acids were below detection limit of 0.0005 mg/L
	Sandaracimparic	<50-360	-	-	-	-
	Isopimaric	<40-1900	-	-	-	-
	Abietic	<30-8400	-	-	-	-
	Dehydroabietic	<60-7400	-	-	-	-
	Beta-Chlorodehydroabietic	<20-440	-	-	-	-
Range of concentrations for selected fatty acids (ng/L)	Myristic	<30-560	-	-	-	Below detection limit for VFA (5 mg/L) IPBC (0.01 mg/L), DDAC (0.005 mg/L), EDTA (0.05 ma/L)
	Palmitic	69-2200	-	-	-	-
	Heptadecanoic	<80-250	-	-	-	-
	Oleic	<80-11000	-	-	-	-
	Total Organic Carbon (mg/L)	2.2-20	-	-	983-1537	2.7-61
Miscellaneous Organic Compounds	Phenol	-	3-1914.52	-	-	Below detection level
	Lignin	-	11-265	-	-	-
	PCP (mg/L)	-	-	-	-	<0.00001-0.00006
	PCB (mg/L)	-	-	-	-	0.0002-0.003
	OCDD (ng I-TEQ/L)	-	-	-	-	0.0.000247-0.520
	Formaldehyde (mg/L)	-	-	-	-	0.06-6.3

Table 4. Pulp and Paper Mill Waste Disposal Organic Contaminants and Concentration Ranges

Parameter	Robinson et al. (1994)	Chandra et al. (2006)	Poykio et al. (2007) (total extractable from biosludge)	Wang et al. (2005)	SKM (2006)
N (mg/L)	0.3-7	0.22-9	16 (g/kg)	5.6-9.0	<0.01-39.7
P (mg/L)	0.003-0.109	1-43.5	0.3 (g/kg)	3.1-6.1	0.015-2.88
Cl (mg/L)	1.2-82	4-358	-	0-0.46	-
SO ₄ (mg/L)	2.7-25	0.03-3.33	1.7 (g/kg)	12.4-17.3	<0.002-15.6
Na (mg/L)	1.5-57	4-254	5.4 (g/kg)	13.8-30.4	-
K (mg/L)	0.5-1.5	0.07-4	1 (g/kg)	39-83.6	-
Al (ug/L)	21-2550	-	-	-	-
Ba (ug/L)	8 to 34	-	332 (mg/kg)	-	0.0224-1.14
Fe (ug/L)	17-2510	-	2433 (mg/kg)	0.2-0.6	-
Mn (ug/L)	2-122	-	1660 (mg/kg)	0.2-0.4	0.0559-10.7
Sr (ug/L)	21-54	-	-	-	-
Zn (ug/L)	0.4-14	-	193 (mg/kg)	-	<0.001-2.59
Ca (mg/L)	-	-	99 (g/kg)	40.9-52.9	-
Mg (mg/L)	-	-	2.2 (g/kg)	9.3-12.4	-
Cu (mg/L)	-	-	10 (mg/kg)	-	below detection limit
Cd (mg/L)	-	-	1.2 (mg/kg)	-	0.0006
Cu (mg/L)	-	-	32 (mg/kg)	-	-
Pb (mg/L)	-	-	8.3 (mg/kg)	-	0.0001-0.107
Cr (mg/L)	-	-	47 (mg/kg)	-	0.012-0.002
Ni (mg/L)	-	-	21 (mg/kg)	-	<0.0005-0.0533
Co (mg/L)	-	-	2 (mg/kg)	-	-
As (mg/L)	-	-	1.5 (mg/kg)	<0.001-0.724	-
V (mg/L)	-	-	25 (mg/kg)	-	-
Hg (mg/L)	-	-	0.05 (mg/kg)	-	<0.00008-0.356
B (mg/L)	-	-	-	-	0.009-13.7
Li (mg/L)	-	-	-	-	0.003-4.29
Sn (mg/L)	-	-	-	-	0.0005

Table 5. Pulp and Paper Mill Waste Disposal Inorganic Contaminants and Concentration Ranges

General Water Quality Parameters

The various water quality parameters listed in Table 3 above can be used to assess the cleanliness of a water body. From examination of the results in Table 3 it is obvious that water quality is poor in waters bodies that have mixed with pulp and paper mill effluent. This is mainly attributable to the elevated values of BOD, COD, TSS, DO, and alkalinity. For example, waters with BOD levels of 100 mg/L or greater are considered exceedingly polluted with organic waste (Stanko and Angus, 2006). BOD levels in pulp and paper mill effluent contaminated waters reach 2666 mg/L. The study by Chandra et al. (2006) revealed that pulp and paper mill effluent into the Gola River has enhanced the pollutant load of BOD, COD, TDS, and TSS by at least twenty times after mixing with pulp and paper waste.

Organic and Inorganic Contamination

A considerable number of organic contaminants are associated with pulp and paper manufacture including chlorinated compounds, resin acids and fatty acids. The presence of organic matter is important from an environmental standpoint because it tends to form soluble or

insoluble complexes with toxic heavy metals, to migrate or be retained in the soil (Poykio, 2007). The organic compounds reported by SKM (2005) were generally all below detection levels and available Australian and New Zealand Environment Conservation Council (ANZECC) guideline levels. Additionally, many of the organic compounds reported in other studies were present at low or non-detectable levels. Yet relatively high values were reported for some organic compounds (chlorinated compounds, resin acids and fatty acids), which could pose threats to human and ecological health.

A variety of heavy metals and other inorganic contaminants are associated with pulp and paper manufacture (refer to Table 5 for a complete list). The concentrations of calcium and magnesium reported by Poykio et al. (2007) were 62 and 11 times here, respectively, than the typical values in arable land in Central Finland. The study by Chandra et al. (2006) revealed that pulp and paper mill effluent into the Gola River has enhanced the pollutant load of sulphate, chloride, sodium, nitrate, potassium, lignin, and phenol by at least twenty times after mixing with pulp and paper mill waste. Additionally, many of the inorganic constituents reported by SKM (2005) exceed the ANZECC guidelines for groundwater quality. These constituents include mercury, manganese, boron, arsenic, ammoniacal-N, phosphorus, sulphide. A general trend observed from the data compilation is that excessive nutrients result from pulp and paper mill waste, which is attributable to woodwaste.

Many of the organic and inorganic contaminants found can pose human health and ecological risks, even at very low concentrations. For example, dioxins and furans have been reported to cause adverse effects on the liver, immune system, reproduction, and development in humans (Stanko and Angus, 2006). Additionally dioxin and furan exposure has been linked to cardiovascular disorders and carcinogenic effects (Stanko and Angus, 2006). Thompson et al. (2001) reported impaired liver function, delayed sexual maturity, smaller gonadas, changes in fish reproduction, and depression in secondary sexual characteristics in fish exposed to effluent from both bleached and unbleached Kraft pulp effluents.

The above literature synthesis provides the reader with a general of idea of the contaminants associated with pulp and paper manufacture. A large number of contaminants are associated with pulp and paper manufacture, including chlorinated compounds, resin acids, fatty acids, lignins, phenols, PCPs, PCBs, inorganic contaminants, and a considerable list of heavy metals. The chlorinated organic compounds mainly result from the bleaching processes while

heavy metals are used as complexing agents to remove other transition metals present within the wood. Most toxicity studies of pulp and paper mill effluent address the effects of chlorinated organic compounds because they can be toxic, persistent, bioaccumulating, and biomagnifying. Typically heavy metals are present at levels below those in domestic sewage and therefore, are not cause for concern (Stanko et al., 2006, Thompson et al, 2001). When assessing the potential environmental risks posed to the environment from a particular mill, it is imperative to consider contaminant concentrations and the documented environmental effects for each contaminant.

Site Description

Tasman Pulp and Paper Mill is located approximately 300 meters to the east of the Tarawera River in Kawerau, Bay of Plenty, New Zealand (see Figure 1). Figure 2 shows an aerial view of the primary solids waste site and the surrounding area including the Te Wai U o Tuwharetoa spring (TWT spring), A8 pond, A8/Western Embankment, Upper Embankment, Urupa pond, primary solids disposal area, Primary Solids/Eastern Embankment, and the Tarawera River. This figure does not illustrate the locations of the pulp and paper mill processing plants or aeration ponds (used to treat liquid waste).

The former Lake Rotoitipaku is shown in Figure 2 and can be identified by the label "Pond 1944". The solid waste disposal site for the Tasman Pulp and Paper Mill is located several kilometers to the northwest of the Mill in Kawerau and approximately 3 kilometers to the west of the Tarawera River. This disposal area is not specifically labeled in Figure 2 but is located towards the southern end of the valley that contains the waste disposal area and is distinguishable by its tan color. Constructed embankments in the west (up gradient) and the east (down gradient) enclose the solid waste disposal area.

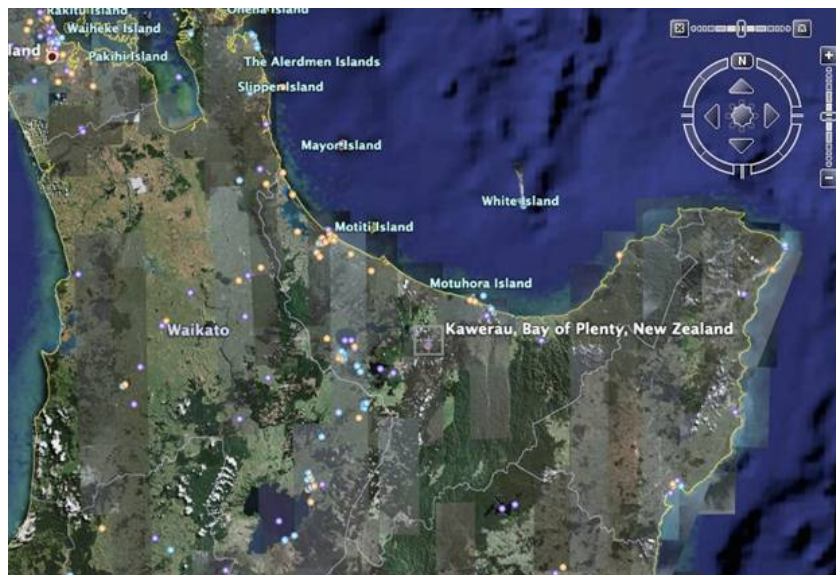


Figure 1. Location of Kawerau, New Zealand. Image obtained from Google Maps



Figure 2. Aerial View of Waste Disposal Site and Surrounding Area

From 1971 until 1995, sludge waste from the pulp and paper mill was dumped into the lake/primary solids landfill. In 1995 a dewatering facility was installed at the mill and since soils have been dewatered and trucked to the primary solids disposal area. Disposal of dewatered waste continues to present day. In addition to solid waste, the mill generates liquid waste that is treated in a series of settling and aeration ponds before being released into the Tarawera River. The solid and liquid wastes are generated from saw milling, pulp and paper milling, geothermal steam exploitation, and other industrial activities that have taken place at the pulp and paper mill. In addition, hazardous materials have been disposed of in the waste disposal area including zinc hydrosulphite (ZnS_2O_4) and asbestos (GRM, 2004).

The TWT spring on the western end of the site feeds the A8 pond, which is located to the east of the spring but to the west of the primary solids disposal area (both upgradient and outside the boundary of the disposal area). An embankment known as the A8 or Western embankment traps surface runoff and natural flow from the spring into the A8 pond. This embankment was constructed using pumice and general mill wastes, including up to ten tonnes of zinc hydrosulphite, in order to prevent encroachment of waste from the primary solids disposal area onto the A8 block.

Water from A8 pond feeds into the Urupa pond. The outlet from the A8 pond is through a culvert that drops about 300 mm into a low gradient channel 400m long to the Urupa Pond. The channel is contained upstream by the A8 embankment and over the downstream by a low angle embankment about 5m high of general mill waste, grading down towards the Urupa Pond on one side and the fiber waste containment on the other. The embankment is well above the water level and containment level. A groundwater drain is installed between the Western Embankment and the Urupa channel in order to pick up any leachate that might be flowing from the Urupa channel. The leachate collected is pumped to the northern end of the containment area (GES, 2002). One feature that is not illustrated on the map is a canal that was built to drain water from the A8 pond directly to the Urupa pond. Water is diverted from the Urupa pond into the Tarawera River.

The Upper Embankment is a former mill waste disposal site that is located just outside the western boundary of the primary solids landfill. The Upper Embankment is a strip of land bounded between the landfill and Urupa channel/pond on its northern end and between the landfill and A8 embankment on its southern end.

The Primary solids or Eastern embankment was built to contain primary solids waste from migrating into the Tarawera River (although there was a breach in 1983). This embankment is east of the primary solids disposal area and runs north to south along the entire waste disposal area. It is made of alluvial pumice gravel and fiber byproducts of the pulp and paper mill process.

The Tarawera River is in the Bay of Plenty region in the North Island of New Zealand. It is 65 kilometers in length and flows from Lake Tarawera, northeastwards across Mount Tarawera (an active volcano), and past the town of Kawerau before turning north, reaching the Bay of Plenty six kilometers to the west of Edgecumbe. Onsite, the Tarawera River flows past the waste treatment ponds in a meandering bend bounded by an alluvial terrace consisting of pumiceous sediments. This river is the key down-gradient receptor of any potential contamination (SKM, 2005).

Lease Agreement

Figure 3 below provides a schematic leased land and neighboring land blocks. A Maori Board of Trustees leases land blocks 39A4, A11, A9, and 990 in Kawerau, New Zealand to Norske Skog Tasman Ltd (NST). Except for land blocks A9 and 990, these blocks are shown in Figure 3. Since 1971 land block 39A4 has been used for waste disposal from the Tasman pulp and paper mills, which is owned by NST. Although land block A8 has not been leased to NST, NST built an artificial embankment along the eastern boundary of the A8 land block to prevent solid waste from encroaching on that A8. Despite these efforts, preliminary sediment and surface water analysis in this pond suggests that contamination has spread to land block A8.



Figure 3. Kawerau A8, 39 A4, and A11 Land Plots

Part of the lease agreement requires that the land be given back to the Trustees "in a state suitable for any agriculture purpose or forestry at the option of the lessor" (GRML, 2004). Clause 15 of the original deed requires that the land be growing healthy pine trees or prepared for agricultural purposes by 2013. An additional deed agreement created in 2003 requires that NST remove all buried drums and hazardous material. In addition, clause 5.14 requires that all work be carried out in a manner that fully protects Te Wai U o Tuwharetoa spring (including but not limited to flooding), any further archaeological sites, and fish and bird wildlife, and enhances the "life force" of the area (GRML, 2004). The termination clause (clause 6) requires that "the land be returned to the Lessors in a fit and proper state and in a form that best suits the then needs of the Lessors and maximizes, to the extent reasonably possible, the restoration of the land" (GRML, 2004). If the agreed conditions are not met, the Trustees have threatened to seek legal action. In 2013, the lease will expire and the land will become the liability of the trustees. Consequently, the Board of Trustees has expressed the urgent need for site remediation, ongoing environmental monitoring, and evaluation.

Historical and Cultural Significance

Lake Rotootipaku and the surrounding land have significant cultural and spiritual significance. Maori beliefs do not allow desecration, destruction, or pollution of the land or its resources. The landowners claim that the block has been ravaged and subjected to continual desecration by Tasman Pulp & Paper Sludge Disposal Operation. Encroachment of sludge onto the A8 block resulted in construction of an embankment without prior consent of the landowners. Furthermore, the sacred spring on the A8 block (Te Wai U o Tuwharetoa) is threatened by flooding.

Geothermal Activity

New Zealand lies at the edge of the Indian plate leading to an abundance of volcanic activity throughout the country. The site of interest lies in the Taupo Volcanic Zone within the Kawerau geothermal field and there are active fault systems in the vicinity of the Tasman waste disposal sites. Thus, it would not be unreasonable to find geothermal sources of contamination on and around the waste disposal site.

The constituents of geothermal fluids are primarily dependent upon temperature, pressure, and the rock composition of the geological system (Sabadell and Axtmann, 1975). The

geothermal waters on New Zealand's North Island are usually low temperature geothermal waters between 20°C and 100°C. Furthermore, the waters on the North Island are commonly found to have elevated levels of chloride, sulfate, arsenic, antimony, boron, thallium, and mercury (Keam, 1982).

McKenzie et al. (2001) characterized the inorganic geochemistry of seven active sinter deposits in the Taupo Volcanic Zone and report low dissolved oxygen levels (typical of geothermal fluids) and trace abundances of arsenic, antimony, boron, thallium, and mercury. More specifically, Christenson (1997) points out that near surface geothermal fluids at Kawerau consist of mixtures of (a) near neutral pH chloride fluid, which represents outflow from the deep reservoir fluid; (b) acid-sulfate condensate, which formed in the oxygenated vadose zone overlying the thermal piezometric surface (largely restricted to high ground around the Onepu Domes); and (c) widespread sodium-bicarbonate waters, formed through the dissolution of a deeply-derived CO₂ gas into shallow aquifer waters; which are all affected, to a varying degree, by dilution from (d) groundwater, of approximately nil chloride concentration.

Previous Site Assessments

Over the last 10 years various investigations have explored soil and groundwater contamination; geotechnical engineering properties of the landfill embankments; geothermal risks; hydro-geological characteristics of the landfill; and overall environmental risk of the landfill. Collectively, Gulf Resource Management Ltd (GRML), Gwilym Environmental Services (GES), and Sinclair Knight Merz Limited (SKM) have investigated the underlying groundwater and soils, A8 and Urupa pond sediments and waters, leachate waters, and primary solids and upper embankment waste. Thus, the sample mediums include soil, waste, groundwater, and surface waters. Selected results from these analyses are discussed in the remainder of this section.

Groundwater Contamination

Groundwater levels in the waste disposal area are within a few meters of the ground surface and therefore directly in contact with the waste. The high groundwater levels are caused by high rainfall infiltration over the flat landfill, low permeability, and poor lateral movement (SKM, 2005). Furthermore, lateral groundwater flow is generally west to east towards the Tarawera River. As can be seen in Table 6 below, some of the groundwater contaminants are

present at concentrations far above ANZECC guidelines. In most cases, the groundwater concentrations are orders of magnitudes higher than the guideline levels, which indicates that groundwater quality in the area is very poor.

Parameter	Range	Median	ANZECC Guidelines
pH (field) (pH units)	2.9-6.5	6.4	6.5-8.51
Conductivity(field)(mS/m)	47-607	125	-
Temperature (field) (CC)	18-54.3	20.7	-
TDS	149-2540	814	10000
Total Chlorine	0.01-0.46	0.06	0.003
Bicarbonate	0-371	371	-
Calcium	12.5-190	68.5	-
Magnesium	1.29-29.3	8.34	-
Total Hardness	36-607	199	500
Sodium	9.86-431	73.5	300
Potassium	3.61-78.6	14.8	-
Chloride	6-259	22.6	400
Sulfate	0-1460	25.4	400
Total Anions	1.29-35.8	14.2	-
Total Cations	1.25-26.5	13.8	-
Total Ammoniacal-N	0.72-5.36	2.87	0.021
Nitrate-N	0-0.04	0.04	0.158
Nitrite-N	0-0.14	0.005	1
Total Phosphorus	0.181-0.71	0.299	0.033
TOC	0-36.3	11.7	-
COD	9-230	27	-
BOD	0-8	3	-
Chlorate	<0.005	-	0.8
Total Sulfide	0.022-15.6	0.518	0.05
Unionised hydrogen sulfide	0.01-16.6	0.396	0.001
Reactive Silica	50.6-326	82.1	-
Total Mercury	0-0.356	0.000755	0.0006
Dissolved Manganese	0.137-3.08	1.37	0.1
Dissolved Arsenic	0.002-0.724	0.007	0.013
Dissolved Boron	0.025-13.7	0.279	0.37
Dissolved Lithium	0.0151-4.29	0.117	1
Dissolved Barium	0.0281-1.13	0.235	0.7
Dissolved Cadmium	0-0.0006	0.0006	0.0002
Dissolved Chromium	0-0.012	0.007	0.001
Dissolved Copper	0-0.588	0.29465	0.0014
Dissolved Nickel	0-0.011	0.004	0.011
Dissolved Lead	0-0.107	0.001	0.0034
Dissolved Selenium	0-0.002	0.002	0.01
Dissolved Zinc	0-2.24	0.089	0.008

*Data is reported in ppm

Table 6. Groundwater Samples: Range, Median, and ANZECC Guideline Concentrations (ppm) for Inorganic Constituents.

Soil Contamination

The most extensive soil analysis was conducted by GES(2004). Forty-seven soil samples from the general mill waste (also known as the Upper Embankment) were collected, analyzed, and documented. Table 7 below presents the concentration ranges and the median concentrations for these 45 samples. Additionally, the relevant ANZECC guidelines values are listed in the

table; guideline values are not listed for magnesium and sodium and therefore are not reported in Table 7. Similar to groundwater, contaminant concentrations in the soils are orders of magnitude higher than ANZECC guideline values. These results suggest that soil quality in the area is very poor.

Parameter	Range	Median	ANZECC Guidelines
Magnesium	110-1990	1230	-
Sodium	175-4890	862	-
Ammoniacal N	<5-72	15	0.9
Boron	<20-67	25	0.37
Manganese	56-304	160.5	1.9
Arsenic	3-122	13	0.013
Mercury	0.1-125	1.3	0.00006
Lead	3.4-110	22.1	0.0034
Zinc	14-1160	69	0.008

*Data is reported in ppm

Table 7. Upper Embankment Soil Samples: Range, Median, and ANZECC Guideline Concentrations (ppm) for Inorganic Constituents.

A8 and Urupa Pond Sediments and Surface Waters

A8 and Urupa ponds are located upgradient of the primary solids disposal area. Additionally, there is poor lateral movement of groundwater in the area (SKM, 2006). Based on this hydrogeological regime, we would not expect contaminant migration from the primary solids disposal area to A8 and Urupa ponds. Yet, the Tasman Solid Waste Permit Application reports that leachate is flowing towards both the A8 and Urupa ponds, against the natural hydraulic gradient. GES (2002) analyzed selected contaminants for the both the soils and waters from A8 and Urupa ponds. The results from this analysis are presented in **Tables 8 and 9** below. Arsenic, boron, mercury, lead and zinc concentrations in pond sediments are orders of magnitude higher than ANZECC guideline values. Boron, chromium, and lead concentrations exceed guideline values in the surface waters.

Parameter	A8 Pond Sediment		Urupa Pond Sediment		ANZECC Guidelines
	Range	Mean	Range	Mean	
Antimony	0.58-0.73	0.63	0.56-0.83	0.68	-
Arsenic	17.2-26.7	22.07	6.6-32.4	21.27	0.013
Boron	<2-6	3.67	<2-8	6.50	0.37
Total Chromium	4.7-11.3	8.10	15.1-105	53.30	-
Copper	5.4-13.1	9.40	8.1-37.7	22.47	-
Mercury	0.5-424	142.67	1.7-16.6	9.13	0.0006
Molybednum	0.64-1.25	0.85	1.23-1.99	1.60	-
Lead	3.34-15.4	9.91	7.52-22.3	16.17	0.0034
Zinc	37.3-102	60.73	50.7-78	62.57	0.008

*Data is reported in ppm

Table 8. A8 and Urupa Pond Sediment Samples: Range, Median, and ANZECC Guideline Concentrations (ppm) for Inorganic Constituents.

Parameter	A8 pond	Urupa Pond	Leachate	ANZECC Guidelines
Magnesium	1.63	1.61	23	-
Sodium	10.3	10.1	121	300
Boron	0.013	0.015	0.761	0.37
Arsenic	0.003	0.003	0.0045	0.013
Cadmium	<0.00005	<0.00008	<0.00005	0.002
Chromium	0.001	<0.0005	<0.0005	0.001
Mercury	<0.00008	<0.00008	0.00004	0.006
Lead	0.0003	0.0001	<0.0001	0.0034
Zinc	0.004	0.001	0.0085	0.008

*Data is reported in mg/L

Table 9. A8 and Urupa Pond Surface Water Samples: Range, Median, and ANZECC Guideline Concentrations (ppm) for Inorganic Constituents.

Leachate

GES (2002) collected and analyzed the leachate from the primary solids waste disposal area. The mean concentrations of the selected inorganic contaminants are provided in Table 10 below. Only boron and zinc are reported at concentrations exceeding ANZECC guideline values for surface waters.

Parameter	Mean	ANZECC Guidelines
pH	7.5	-
Magnesium	22.8	-
Sodium	122	300
Ammonium	0.47	-
Boron	0.766	0.37
Arsenic	0.004	0.013
Cadmium	<0.00006	0.0002
Chromium	<0.0005	0.001
Mercury	0.00008	0.006
Lead	<0.0001	0.0034
Zinc	0.013	0.008

*Data is reported in mg/L

Table 10. Leachate Water Samples: Mean and ANZECC Guideline Concentrations (ppm) for Inorganic Constituents

Methods

Data Collection

For this study, we collected representative samples of the principal water bodies of interest, and also representative samples of pristine and geothermal waters. Table 11 below lists the sample name for each water body that was sampled, water type description and suspected contamination sources. The "pristine" water bodies were used to identify naturally occurring constituents in ground and spring waters while the geothermal waters were used to identify naturally occurring constituents in regional geothermal waters.

Sample Name	Description	Suspected Contamination Sources?
TWT	Cold spring that feeds A8 pond; Upgradient of waste disposal area	None
Tarawera	River that flows from Lake Tarawera, through the waste disposal area, and empties into the Bay of Plenty	Pulp and paper mill effluent, solid waste, and Leachate
Bremar	Cold spring located approximately 40 km offsite	None
A8 pond	Artificial pond fed by TWT Spring and dammed by the Upper Embankment	Pulp and paper mill leachate
Urupa Pond	Artificial pond fed by A8 pond and dammed by the Upper Embankment	Pulp and paper mill leachate; A8 pond
Savage Pools	Hot springs located approximately 30 km offsite	None
Rotooitipaku	Buried hot springs in the waste disposal site. Data presented in this paper for Rotooitipaku is from Bignall and Harvey (2005)	Pulp and paper mill solid waste and leachate

Table 11. Water Samples: Sample Name, Description, and Suspected Contamination Sources

The parameters measured in this study include oxygen and hydrogen isotopes, anions, trace metals, and cations. Also, the following parameters were measured in the field: depth (where possible), flow rate (where possible), pH, dissolved oxygen, temperature, conductivity, and turbidity. A GPS unit was used to record the exact location where the sample was extracted. The time of date, description of source (size, shape, depth, clarity, color, type of deposits, degree of ebullition) and outside conditions were also recorded.

New high-density polyethylene bottles were used to collect all samples. For trace metals and cations, the new bottles were acid washed prior to bringing them into the field. The acid washing procedure that was used is outlined in Table 12 below:

(1) Uncapped all bottles and soaked them in 5M HNO ₃ solution overnight (approx. 24 hours).
(2) Rinsed each bottle three times with ultra pure water and then filled each bottle with ultrapure water. The ultrapure water sat in the bottle for approximately 48 hours.
(3) Dumped the ultrapure water and then rinsed each bottle two times with more ultra pure water.
(4) Placed bottles and caps on trays and dried in a clean oven at 70° C for approximately 2 hours.

Table 12. Sample Preparation: Acid Washing Procedure

For trace metals, cations, and anions, samples were filtered before being placed into the sample bottle. Trace metal and cation samples were acidified (with ultra pure nitric acid) immediately after collection and filtration.

Samples were put on ice within one hour of collection until they were shipped. They were not kept cold during shipping, which took 3 days. They were then placed in a refrigerator upon arrival.

Data Analysis

Each collected sample was analyzed for major and minor ions and hydrogen and oxygen isotopes. Cation analyses were conducted in the or geochemistry laboratories within the Division of Earth and Ocean Sciences under the supervision of Gary Dwyer, Emily Klein, Paul Baker, and David Vinson.

Trace element concentrations (Li, Be, Mg, Ca, V, Cr, Mn, Co, Ni, Cu, Zn, As, Rb, Sr, Mo, Cd, Sb, Ba, Tl, Pb, Th, U) were determined by inductively coupled plasma mass spectrometry (ICP-MS) on a VG Plasmaquad 3 quadrupole ICP-MS calibrated using serial dilutions of certified water standard NIST1643e spiked with plasma-grade uranium and thorium (1643e has no U and Th to start with). Analytical precision for all cation analyses is typically better than $\sim\pm 2\%$ based on replicate analysis of samples and standards.

Ca, Mg, Na, Sr, Ba, Fe, and Mn were analyzed via direct current plasma optical emission spectrometer (DCP-OES) on a Fisons Spectraspan 7, and K was measured by atomic absorption spectrometry on a Perkin-Elmer AA. DCP-OES and AA analyses were calibrated using multi-element standards prepared from plasma-grade single-element solutions. Certified water standard NIST 1643e was analyzed as check standard.

Anion concentrations (chloride, bromide, nitrate, and sulfate) were measured using a Dionex DX-500 ion chromatograph with AS-4A analytical column and carbonate-bicarbonate eluent. Bicarbonate concentrations were measured using a standard titration technique.

Oxygen and hydrogen isotopes were analyzed at the University of Calgary's Isotope Science Laboratory. Deuterium/hydrogen was determined via chromium reduction and isotope ratio mass spectrometry and the $^{18}\text{O}/^{16}\text{O}$ ratio of natural waters was determined using the common $\text{CO}_2\text{-H}_2\text{O}$ equilibration technique. Accuracy and precision for $\delta^2\text{H}$ of natural waters are generally better than $\sim\pm 2.0$ per mil, which is (one standard deviation based on $n=10$ lab standards). Accuracy and precision for $\delta^{18}\text{O}$ are generally better than $\sim\pm 2.0$ (one standard deviation based on $n=50$ lab standards).

Calcium, magnesium, strontium, manganese, and barium concentrations were determined using both an ICP-MS and a DCP-MS. Concentrations for sodium and iron were only determined using the DCP-MS. All other ions concentrations were determined using only the ICP-MS. For each of these elements r^2 values are greater than 95% (Figure 4 below), indicating a strong correlation between ICP-MS and DCP-MS results. Because the results from both machines produced closely correlated results and because most of the ion concentrations were tested only on the ICP-MS, the reported concentrations (except sodium and iron) were measured on the ICP-MS.

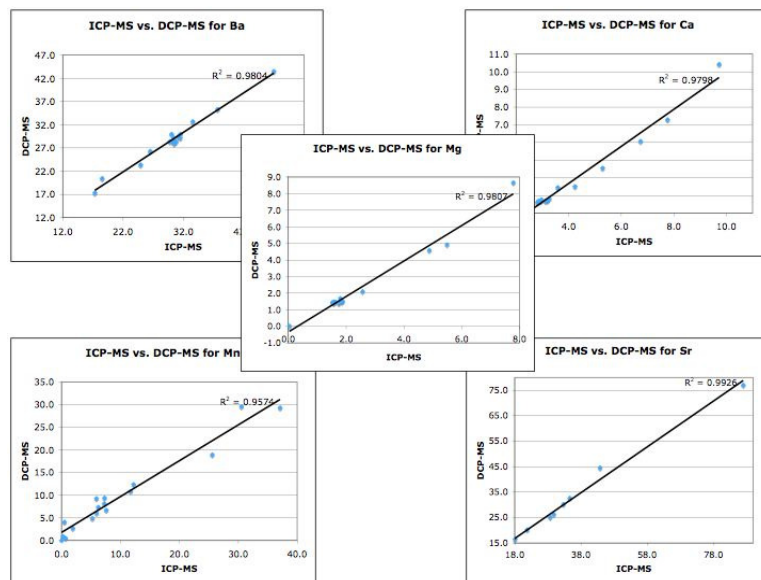


Figure 4. ICP-MS vs. DCP-MS and R-squared values

Charge Balance Errors

Calculations of ion balances, or charge balance errors, are a simple method to verify reliability of the lab results. Typically, an acceptable error is below 5%. Fritz (1994) reports that low ionic strength samples are prone to charge balance errors greater than 10%. Furthermore, high negative and positive errors might also be attributed to systematic laboratory errors involving salt standards and dilutions (Fritz, 1994). When alkalinity is not measured in the field, one is more likely to obtain inaccurate bicarbonate concentrations from lab tests. Unacidified samples that are supersaturated with calcite and/or dolomite likely precipitate carbonate minerals between the time the sample is collected in the field and alkalinity is measured in the lab, which leads to an underestimation of bicarbonate concentrations. If the cation samples are acidified, calcite or dolomite will not precipitate, and calcium and magnesium will be accurately reflected in ICP-MS and DCP-MS readings. With the milliequivalents for the anions being underestimated and the milliequivalents for cations being accurate, a positive charge balance error is likely to occur (Fritz, 1994). Alkalinity can also be a cause for a bias towards negative charge balance errors: if alkalinity is performed in the field but an unfiltered sample is titrated, then the bicarbonate will be overreported if there are suspended particles of calcite in the titration flask (Fritz, 1994).

The charge balance errors for this analysis are presented in Table 13. While most of the samples analyzed are within the acceptable range of 5%, the error for Savage pools, two TWT spring samples, and the sample for Tarawera River upstream exceed a value of 5%. The charge balance error for Savage pools is -38%, the error for TWT 1 springs is 18%, the error for TWT 2 is -17%, and the error for Tarawera river upstream is -6.9%. The high negative error for Savage pools is likely due to inaccurate bicarbonate measurements; if any carbon dioxide was converted to bicarbonate between the time the sample was collected in the field and the titration was performed in the lab, then the bicarbonate measurements could be overestimated. Savage Pools, which is a hot spring, was likely to have high levels of dissolved CO₂ due to elevated water temperatures. The charge balance errors associated with the TWT spring samples are likely due to the fact that the Spring's ionic strength is very low (TDS is 70 mg/L). The slightly high error for the Tarawera River could be do to a number of factors, as discussed above.

Sample	Charge Balance Error
Tarawera 1	-6.90
Tarawera 2	-2.52
Tarawera 3	-2.56
TWT 1	18.04
TWT 2	-17.49
TWT 3	-2.14
A81	-0.81
A82	-4.28
A83	0.62
A84	-1.76
A85	-0.93
A86	-0.61
A87	-2.84
Urupa 1	-1.12
Urupa 2	-2.00
Bremar	1.02
Savage	-38.03
Rotooitipaku	-4.10

Table 13. Charge Balance Errors

Results

The four different water types considered in this study include springs, ponds, geothermal waters, and a river. Water chemistry data, including field measurements, cation, anion, trace metal, and isotope data is documented in Table 14. For each water body, the relative compositions of the major water constituents are illustrated in Figures 5 and 6. Also X-Y plots were constructed to evaluate the influence of potential geothermal input in the sampled water bodies. They are shown in Figures 9-16 (Appendix A) and include the following: HCO_3 vs. Cl, Na vs. Cl, Br vs. Cl, Ca vs. Cl, K vs. Cl, Li vs. Cl, Mg vs. Ca, and SO_4 vs. Cl. Mixing calculations were performed for the conservative elements and also for hydrogen and oxygen isotopes. Additionally, chloride/lithium ratios for each water type were used to aid in identifying potential mixing patterns.

Parameter	Units	Tarawera 1	Tarawera 2	Tarawera 3	TWT 1	TWT 2	ANZECC Guidelines <i>Recreational Use</i>
		<i>River</i>	<i>River</i>	<i>River</i>	<i>Spring</i>	<i>Spring</i>	
Conductivity	uS	460.0	318.0	320.0	75.4	113.3	-
pH	pH units	7.9	7.3	7.3	6.1	5.5	6.5-8.5
Dissolved Oxygen	%	82.0	102.0	72.0	86.0	73.0	>80%
TDS	mg/L	n/a	10.5	7.4	n/a	n/a	>6.5
Turbidity	NTU	220.0	152.0	153.0	34.0	53.0	1000.0
Temp	°C	0.9	3.7	6.8	0.2	0.5	-
Depth		11.8	13.6	13.2	15.5	17.8	-
Flowrate	m/s	80 cm	-	-	9 cm	n/a	-
Ca	mg/L	0.4	-	-	0.4	-	-
Ca	meq	9.7	6.7	7.8	5.3	3.0	200.0
Mg	mg/L	0.5	0.3	0.4	0.3	0.1	-
Mg	meq	7.8	5.5	4.9	2.6	1.6	-
K	mg/L	0.6	0.5	0.4	0.2	0.1	-
K	meq	7.9	6.1	6.1	4.0	3.3	-
Na	mg/L	0.2	0.2	0.2	0.1	0.1	-
Na	meq	62.8	47.8	48.2	11.8	9.0	300.0
Cl	mg/L	2.7	2.1	2.1	0.5	0.4	-
Cl	meq	63.5	43.1	41.6	5.8	6.0	400.0
SO4	mg/L	1.8	1.2	1.2	0.2	0.2	-
SO4	meq	40.8	18.3	22.5	4.9	19.0	400.0
HCO3	mg/L	0.8	0.4	0.5	0.1	0.4	-
HCO3	meq	131.3	100.7	98.4	29.7	31.6	-
NO3	mg/L	2.2	1.6	1.6	0.5	0.5	-
NO3	meq	ND	1.4	2.2	1.5	0.7	10.0
Br	mg/L	ND	0.0	0.0	0.0	0.0	-
Br	meq	0.2	0.2	0.1	0.0	0.0	-
Li	µg/L	0.0	0.0	0.0	0.0	0.0	-
B	µg/L	401.7	286.1	244.7	16.4	12.2	-
Sr	µg/L	-	-	-	-	-	1000.0
Be	µg/L	43.8	32.7	34.6	29.8	17.9	-
V	µg/L	0.0	0.0	0.0	0.0	0.0	-
Cr	µg/L	1.0	1.4	1.6	1.2	1.3	-
Mn	µg/L	2.2	1.3	3.2	0.5	0.2	50.0
Co	µg/L	0.7	37.1	30.5	25.6	0.0	100.0
Ni	µg/L	0.1	0.2	0.2	0.2	0.0	-
Cu	µg/L	0.3	6.1	0.6	7.4	3.9	100.0
Zn	µg/L	0.0	0.0	54.3	0.0	10.8	1000.0
As	µg/L	12.0	11.8	17.0	14.3	11.4	5000.0
Rb	µg/L	29.1	33.2	28.1	3.3	4.3	50.0
Mo	µg/L	34.6	29.3	28.2	15.8	11.4	-
Cd	µg/L	3.4	1.5	1.5	0.2	0.5	-
Sb	µg/L	0.0	0.0	0.0	0.0	0.0	5.0
Ba	µg/L	0.2	1.9	1.7	0.1	0.2	-
Tl	µg/L	17.3	30.0	33.5	47.0	31.5	1000.0
Pb	µg/L	0.0	0.0	0.1	0.0	0.0	-
Th	µg/L	0.0	0.0	0.0	0.0	0.0	50.0
U	µg/L	0.0	0.0	0.0	0.0	0.0	-
Fe	µg/L	0.0	0.0	0.0	0.0	0.0	-
d ¹⁸ O _{water}	‰	11.1	126.0	180.8	32.2	3.9	300.0
d ² H _{water}	‰	-1.9	-4.1	-4.0	-	-	-
		-17.0	-26.0	-26.0	-	-	-

Table 14. Chemical and Isotopic Compositions of Water Samples from Tasman Pulp and Paper Waste Disposal Site in Kawerau, New Zealand

Parameter	TWT 3	A81	A82	A83	A84	A85	A86	A87	ANZECC Guidelines
	Spring	Pond	Pond	Pond	Pond	Pond	Pond	Pond	Recreational Use
Conductivity	78.9	79.5	77.7	76.3	75.7	76.5	76.2	75.1	-
pH	6.2	6.88	7.08	7.19	7.25	7.53	7.46	7.6	6.5-8.5
Dissolved Oxygen	33	105	120	116	106	122	120	117	>80%
TDS	n/a	11.5	13.03	12.22	11.75	13.56	13.36	12.81	>6.5
Turbidity	39	37	36	36	36	36	36	35	1000
Temp	0.29	9.9	3.38	2.73	1.85	2.21	2.47	3.83	-
Depth	16.6	11.1	10.7	10.8	10.5	10.4	10.6	11	-
Flowrate	6 cm	22 cm	1.5 m	2.9 m	1.6 m	> 3 m	-	-	-
Ca	0.61	0	0	0	0	0	0	0	-
Ca	3.6	3.2	3.3	3.2	2.8	2.9	3.1	2.8	200
Mg	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.1	-
Mg	1.8	1.9	1.9	1.9	1.6	1.6	1.8	1.6	-
K	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	-
K	3.6	3.4	3.3	3.2	3.2	3.2	3.3	3.3	-
Na	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-
Na	10.0	9.0	9.0	8.9	9.0	9.2	8.7	8.7	300
Na	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	-
Cl	5.9	5.8	5.9	5.9	5.8	5.8	5.8	5.8	400
Cl	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	-
SO4	10.6	6.8	7.0	6.7	7.0	7.0	7.0	7.2	400
SO4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	-
HCO3	30.9	30.9	34.3	29.2	28.9	29.1	28.9	29.0	-
HCO3	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.5	-
NO3	1.2	0.4	0.4	0.4	0.3	0.4	0.4	0.3	10
NO3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
Br	-	0.0	-	-	-	0.0	-	-	-
Br	-	0.0	-	-	-	0.0	-	-	-
Li	12.6	13.8	13.4	13.5	10.3	10.9	13.5	10.9	-
B	-	-	-	-	-	-	-	-	1000
Sr	21.8	17.7	18.1	17.6	16.9	17.6	17.8	17.4	-
Be	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
V	1.2	1.5	1.4	1.8	1.2	1.2	1.3	1.3	-
Cr	0.2	0.5	0.4	0.5	0.2	0.2	0.5	0.3	50
Mn	7.3	11.7	12.2	7.3	5.2	5.9	7.6	6.2	100
Co	0.1	0.5	0.2	0.2	0.2	0.5	0.5	0.1	-
Ni	2.1	7.7	7.5	8.6	2.2	3.4	7.3	6.5	100
Cu	20.4	0.0	0.0	0.0	12.3	11.7	0.0	17.2	1000
Zn	11.4	14.7	13.5	11.2	8.9	9.2	12.0	9.4	5000
As	3.8	4.5	4.2	4.2	4.0	4.0	4.3	4.2	50
Rb	12.5	12.0	12.1	11.9	11.0	11.2	11.6	11.3	-
Mo	0.5	0.3	0.3	0.3	0.6	0.6	0.4	0.5	-
Cd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5
Sb	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	-
Ba	37.7	31.1	31.5	30.4	29.8	30.5	30.1	30.5	1000
Tl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
Pb	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	50
Th	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
U	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
Fe	8.5	176.3	114.2	77.0	76.7	75.3	73.9	76.2	300
d ¹⁸ O _{water}	-4.9	-4.0	-	-	-	-	-	-3.9	-
d ² H _{water}	-30.0	-29.0	-	-	-	-	-	-29.0	-

Table 14 (continued)

Parameter	Urupa 1	Urupa 2	Bremar	Savage	Roto 1	ANZECC Guidelines <i>Recreational Use</i>
	<i>Pond</i>	<i>Pond</i>	<i>Spring</i>	<i>Geothermal</i>	<i>Geothermal</i>	
Conductivity	75.4	75.3	92.9	2.9 mS	-	-
pH	8.01	8.4	6.4	8.89	5.9	6.5-8.5
Dissolved Oxygen	148	124.0	-	97	-	>80%
TDS	15.3	13.7	63.3	-	-	>6.5
Turbidity		35.0	44.0	1450	-	1000
Temp	2.59	-	0.5	2.26	-	-
Depth	11.3	10.9	16.8	49.6	86	-
Flowrate	-	-	60 cm	40 cm	-	-
Ca	0	0.0	0.6	0.02	-	-
Ca	2.8	3.0	4.2	2.2	8.6	200
Mg	0.1	0.1	0.2	0.1	0.4	-
Mg	1.5	1.6	1.8	0.0	1.0	-
K	0.1	0.1	0.1	0.0	0.1	-
K	3.2	3.1	3.4	89.0	59	-
Na	0.1	0.1	0.1	2.3	1.5	-
Na	9.2	8.8	11.1	116.0	385	300
Cl	0.4	0.4	0.5	5.0	16.7	-
Cl	5.8	5.7	8.3	399.1	536	400
SO4	0.2	0.2	0.2	11.3	15.1	-
SO4	6.9	6.8	8.1	10.1	158.0	400
HCO3	0.1	0.1	0.2	0.2	3.3	-
HCO3	28.9	29.1	29.2	372.2	117	-
NO3	0.5	0.5	0.5	6.1	1.9	-
NO3	-	0.4	2.8	-	-	10
Br	-	0.0	0.0	-	-	-
Br	0.0	-	0.0	1.5	-	-
Li	0.0	-	0.0	0.0	-	-
B	10.7	10.0	25.1	4027.9	3300	-
Sr	-	-	-	-	0.021	1000
Be	17.2	16.6	28.7	87.1	-	-
V	0.0	0.0	0.1	0.5	-	-
Cr	1.3	1.2	0.6	6.0	-	-
Mn	0.8	0.1	0.5	14.8	-	50
Co	6.0	0.5	0.2	1.9	-	100
Ni	0.2	0.0	0.2	0.7	-	-
Cu	1.8	2.7	7.9	9.3	-	100
Zn	27.2	13.0	0.0	0.0	-	1000
As	11.1	11.7	11.1	11.7	-	5000
Rb	4.0	3.7	18.5	1324.1	-	50
Mo	11.0	10.6	13.3	586.2	-	-
Cd	0.8	0.5	0.4	0.8	-	-
Sb	0.0	0.0	0.0	0.0	-	5
Ba	0.3	0.2	2.4	154.5	-	-
Tl	30.8	26.5	24.9	18.5	-	1000
Pb	0.0	0.0	0.0	4.7	-	-
Th	0.1	0.0	0.0	0.0	-	50
U	0.0	0.0	0.0	0.0	-	-
Fe	0.1	0.0	0.0	0.0	-	-
d ¹⁸ O _{water}	75.5	57.1	6.9	20.9	-	300
d ² H _{water}	-	-4.7	-4.6	-0.3	-	-
	-	-26.0	-28.0	-23.0	-	-

Table 14 (continued)

Parameter	Roto 2	Roto 3	Roto 4	Roto 5	Roto 6	ANZECC Guidelines
	<i>Geothermal</i>	<i>Geothermal</i>	<i>Geothermal</i>	<i>Geothermal</i>	<i>Geothermal</i>	<i>Recreational Use</i>
Conductivity	-	-	-	-	-	-
pH	6.2	6.3	7.7	-	6.8	6.5-8.5
Dissolved Oxygen	-	-	-	-	-	>80%
TDS	-	-	-	-	-	>6.5
Turbidity	-	-	-	-	-	1000
Temp	72	90	-	68	94	-
Depth	-	-	-	-	-	-
Flowrate	-	-	-	-	-	-
Ca	-	-	8	-	-	200
Ca	-	-	0.4	-	-	-
Mg	-	-	-	-	-	-
Mg	-	-	-	-	-	-
K	49	-	52	49	53	-
K	1.3	-	1.3	1.3	1.4	-
Na	330	-	360	240	356	300
Na	14.4	n/a	15.7	10.4	15.5	-
Cl	445	480	521	304	481	400
Cl	12.6	13.5	14.7	8.6	13.6	-
SO4	-	90.0	-	-	107	400
SO4	-	1.9	-	-	2.2	-
HCO3	-	158	-	-	118	-
HCO3	-	2.6	-	-	1.9	-
NO3	-	-	-	-	-	10
NO3	-	-	-	-	-	-
Br	-	-	-	-	-	-
Br	-	-	-	-	-	-
Li	2700	-	4600	1900	2900	-
B	-	0.025	-	-	0.023	1000
Sr	-	-	-	-	-	-
Be	-	-	-	-	-	-
V	-	-	-	-	-	-
Cr	-	-	-	-	-	50
Mn	-	-	-	-	-	100
Co	-	-	-	-	-	-
Ni	-	-	-	-	-	100
Cu	-	-	-	-	-	1000
Zn	-	-	-	-	-	5000
As	-	-	-	-	-	50
Rb	-	-	-	-	-	-
Mo	-	-	-	-	-	-
Cd	-	-	-	-	-	5
Sb	-	-	-	-	-	-
Ba	-	-	-	-	-	1000
Tl	-	-	-	-	-	-
Pb	-	-	-	-	-	50
Th	-	-	-	-	-	-
U	-	-	-	-	-	-
Fe	-	-	-	-	-	300
d ¹⁸ O _{water}	-	-	-	-	-	-
d ² H _{water}	-	-	-	-	-	-

Table 14 (continued)

Parameter	Roto 7	Roto 8	Roto 9	Roto 10	ANZECC Guidelines
	<i>Geothermal</i>	<i>Geothermal</i>	<i>Geothermal</i>	<i>Geothermal</i>	<i>Recreational Use</i>
Conductivity	-	-	-	-	-
pH	7.6	2.2	7.1	2.2	6.5-8.5
Dissolved Oxygen	-	-	-	-	>80%
TDS	-	-	-	-	>6.5
Turbidity	-	-	-	-	1000
Temp	100	63	82	86	-
Depth	-	-	-	-	-
Flowrate	-	-	-	-	-
Ca	-	-	-	-	200
Ca	-	-	-	-	-
Mg	-	-	-	-	-
Mg	-	-	-	-	-
K	53	50	59	46	-
K	1.4	1.3	1.5	1.2	-
Na	398	315	400	310	300
Na	17.3	13.7	17.4	13.5	-
Cl	544	410	537	396	400
Cl	15.3	11.6	15.1	11.2	-
SO4	96	630	133	980	400
SO4	2.0	13.1	2.8	20.4	-
HCO3	153	42	56		-
HCO3	2.5	0.7	0.9		-
NO3	-	-	-	-	10
NO3	-	-	-	-	-
Br	-	-	-	-	-
Br	-	-	-	-	-
Li	3300	2500	3100	2600	-
B	0.025	0.019	0.025	0.019	1000
Sr	-	-	-	-	-
Be	-	-	-	-	-
V	-	-	-	-	-
Cr	-	-	-	-	50
Mn	-	-	-	-	100
Co	-	-	-	-	-
Ni	-	-	-	-	100
Cu	-	-	-	-	1000
Zn	-	-	-	-	5000
As	-	-	-	-	50
Rb	-	-	-	-	-
Mo	-	-	-	-	-
Cd	-	-	-	-	5
Sb	-	-	-	-	-
Ba	-	-	-	-	1000
Tl	-	-	-	-	-
Pb	-	-	-	-	50
Th	-	-	-	-	-
U	-	-	-	-	-
Fe	-	-	-	-	300
d ¹⁸ O _{water}	-	-	-	-	-
d ² H _{water}	-	-	-	-	-

Table 14 (continued)

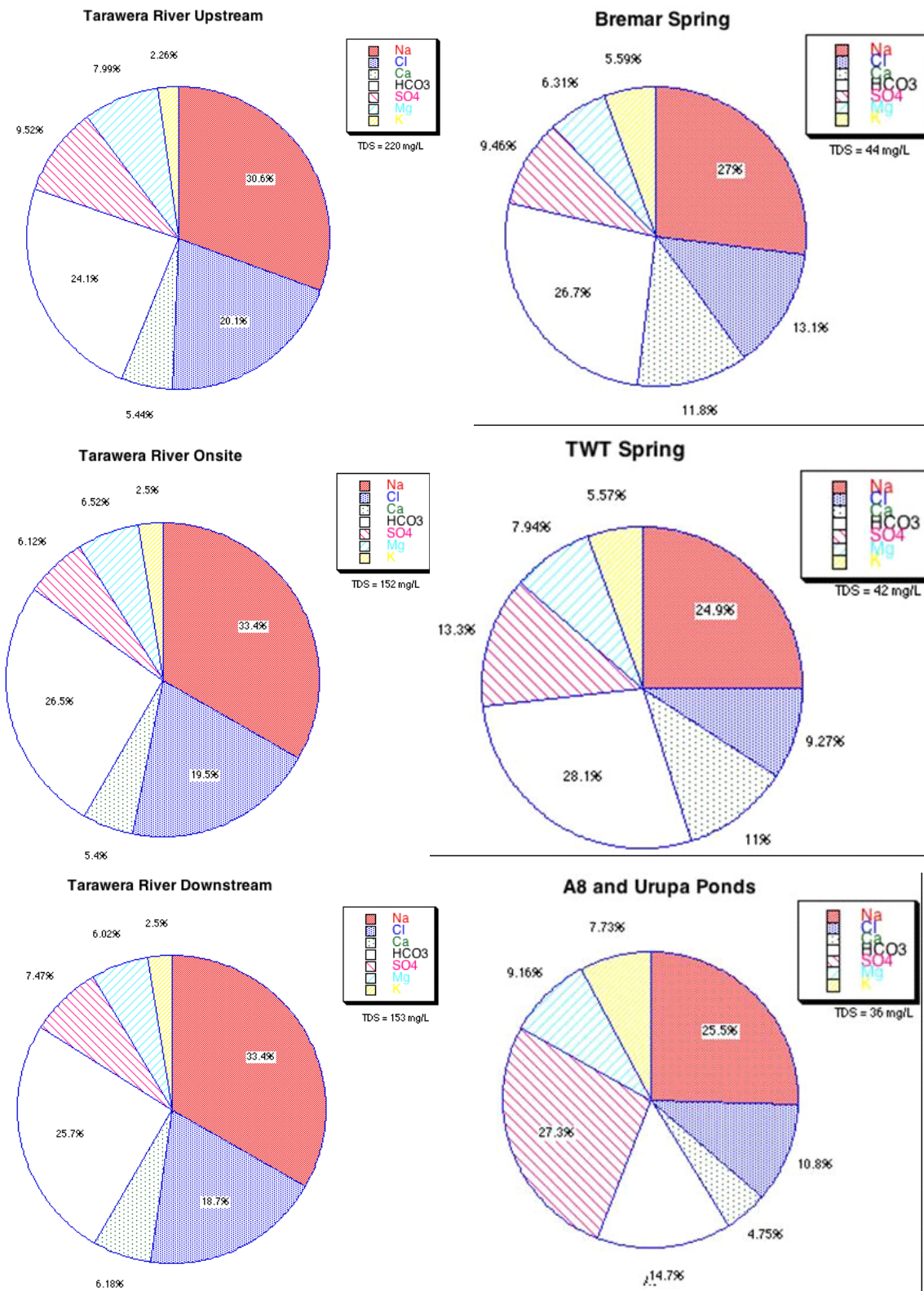


Figure 5. Pie Charts for Tarawera River Upstream, Oniste, and Downstream, Bremar Sprng, TWT Spring, and A8 and Urupa Ponds

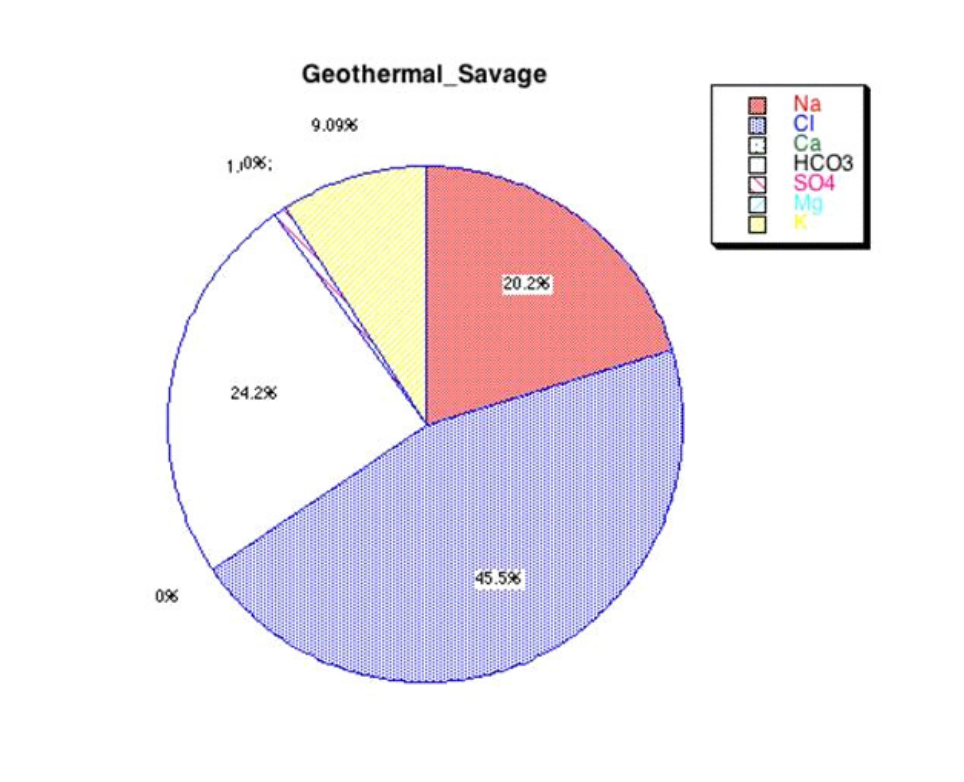
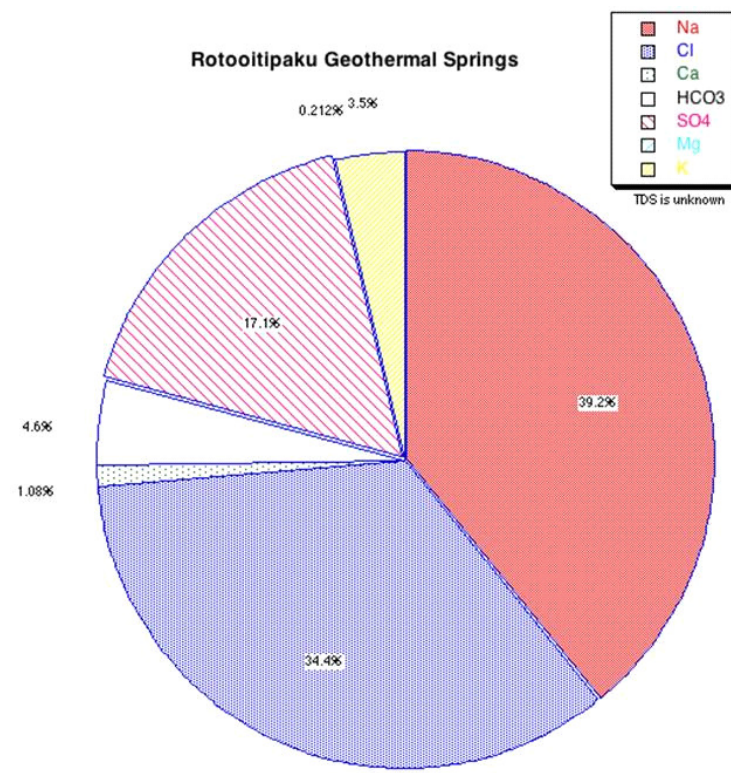


Figure 6. Pie Charts for Rotooitipaku Hot Springs and Savage Pools

Geothermal Mixing

Mixing models used in this study refer to several end-member components including geothermal waters (Rotootipaku and Savage Pools), A8 or Urupa ponds, TWT or Bremar Springs, and/or the Tarawera River. A number of techniques are used to identify mixing including hydrogen and oxygen isotopic fingerprinting and mixing calculations for conservative elements (*i.e.* do not interact with the aquifer matrix or sediments). If the concentrations of the two end members are known, mixing calculation can model their relative relationships. The mixing equations used in this analysis assume conservative mixing; the conservative elements considered in this analysis include bromide, chloride, lithium, sodium, and potassium. Data was not available for boron, which is also a conservative element, and therefore was not considered. If elements were acting conservatively, then we would expect the percent mixing calculations for each element and individual sample to be similar.

Lithium/Chloride Ratios

SKM (2007) calculated lithium/chloride ratios for a number of onsite groundwater bores and also for the buried hot springs (SKM, 2007). The bores and hot springs are all located on the perimeter or within the primary solids waste disposal area. The lithium/chloride ratios range from 0.0003 to 0.0139 with an average value of 0.0056. The buried hot springs have some of the highest lithium/chloride ratios (~0.008). The Li/Cl ratios from our samples range from 0.00175 to 0.01 with an average value of 0.0044. A histogram of the lithium/chloride ratios for groundwater bores, buried hot springs, and our water samples is shown in Figure 7 below.

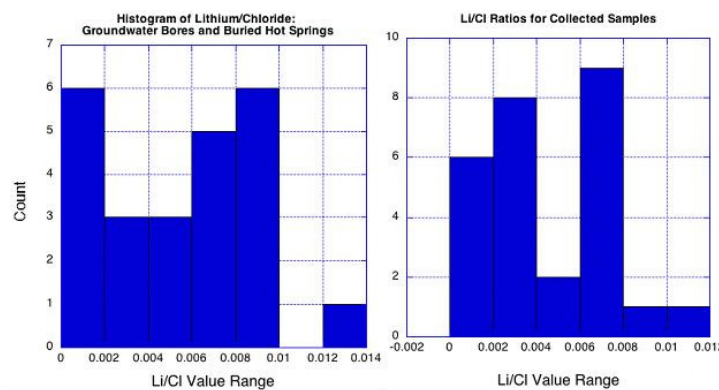


Figure 7a. Histogram of Lithium/Chloride Values for Groundwater Boes and Buried Hot Springs. Figure 7b. Histogram of Lithium/Chloride Values for Collected Samples

Hydrogen and Oxygen Isotopes

Hydrogen and oxygen isotopic fingerprinting is a useful way to identify mixing and evaporation. The hydrogen and oxygen isotope fingerprints for the relevant water samples are illustrated in Figure 8. The Global Meteoric Water Line (GMWL), which is the line connecting by the yellow dots in Figure 8, approximates compositions of hydrogen and oxygen for rain/snow on earth and is defined by the following equation: $\delta D = 8(\delta^{18}O) + 10$. The Local Meteoric Water Line (LMWL) for New Zealand is $\delta D = 8\delta^{18}O + 13.6$ (Steward & Taylor 1981; Stewart & Williams 1981) and is illustrated in Figure 8 via the line connecting the pink dots.. By plotting the GMWL, the LMWL, and $\delta^{18}O$ and δD values for each sample, one can clearly identify deviations from the GMWL and LMWL.

Deviations from the GMWL and LMWL could be due to extensive water-rock interaction, evaporation/precipitation, or mixing. Extensive water-rock interaction causes waters to be more enriched $\delta^{18}O$. This happens under hot temperature as the water exchanges oxygen with the host rock, which has relatively heavy oxygen isotope ratios. Hydrogen is not affected much by this process, because there is negligible hydrogen in rocks. On an X-Y plot with $\delta^{18}O$ on the X-axis and δD on the Y-axis, waters that are heavily influenced by water rock interaction will shift to the right of the global and local meteoric water lines, such that $\delta^{18}O$ values are greater but there is little change in δD . Because geothermal waters are heavily influenced by water rock interaction, one would expect the relationship between $\delta^{18}O$ and δD to deviate from the linear relationship (between $\delta^{18}O$ and δD) representative of local and global meteoric waters.

As water evaporates, the residual water is more enriched with heavy isotopes. Thus, water bodies that have experienced evaporation are likely to have higher values of $\delta^{18}O$ and δD and shift to the right and upwards on a δD versus $\delta^{18}O$ plot. The degree to which evaporation shifts $\delta^{18}O$ and δD concentrations right-ward and upward depends on the humidity. Because A8 and Urupa ponds are surface water bodies with zero flow, we would expect evaporation to occur, causing the water in the ponds to be enriched with $\delta^{18}O$ and δD and deviate from the GMWL and LMWL. However, deviation from the global and local meteoric water lines could also result from mixing with geothermal waters with high $d^{18}O$ and d^2H values.

The theoretical mixing line is illustrated in Figure 8 and is a line extending from a point on the global meteoric water line to for the value of Savage pools (blue triangle). If samples fall

along or close to this theoretical mixing line, one might suggest mixing with geothermal waters. If appropriate, mixing calculations can be performed to determine percent mixing .

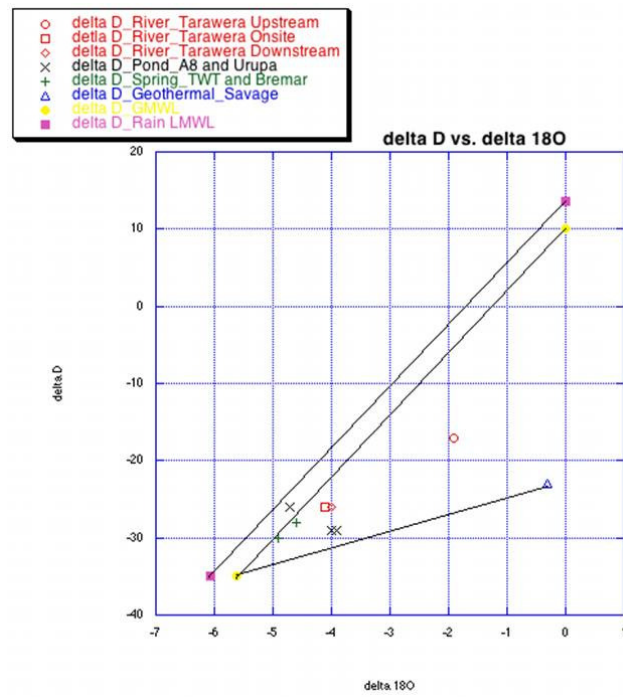


Figure 8. δD versus $\delta 18O$

Percent Mixing Calculations

Table 15 below shows the results from the percent mixing calculations for lithium, bromide, and chloride for the Tarawera River and A8 and Urupa ponds.

Sampling Location	Lithium	Bromine	Chloride
Tarawera Upstream	8.40%	11%	11%
Tarawera Onsite	6%	8%	7%
Tarawera Downstream	5%	6%	7%
A8 and Urupa Ponds	0%	0%	0%

Table 15. Percent Mixing Calculations for Tarawera River, A8 Pond, and Urupa Pond

Hydrochemical Facies: X-Y plots

For this analysis, standard hydrochemical constituents are presented graphically in X-Y plots (Appendix A: Figures 9-16). Most of the plots are normalized to Cl (presented on the X axis) because Cl⁻ is a conservative constituent and therefore its concentration will not be influenced by water rock interaction.

ANZECC Guidelines for Recreational Use

In Table 14, the measured concentrations of all samples are compared to the ANZECC guidelines for recreational use (PIMC and NRMCC, 2000). ANZECC guidelines do not exist for all of the measured inorganic constituents. The absence of an ANZECC guideline is denoted by a hash mark in the appropriate cell.

Discussion

Various techniques have been used to assess geothermal sources of contamination in selected water bodies. Analysis of inorganic constituents on the mass spectrometer provides concentrations of the various constituents in each water body. Because the charge balance errors for most of the samples were below 5%, the data is considered reliable and can be used for further assessment. The high reaction error for Savage pools and the fact that this sample may not be entirely representative of onsite geothermal waters because it is located approximately 40 km offsite, leads us to rely on hydrochemical data from Rotootipaku springs, which we did not collect (Bignall and Harvey, 2005). Even though data was not available for strontium and nitrate, the charge balance error for Rotootipaku springs is below 5%, therefore suggesting that concentration measurements are accurate.

Isotopic Fingerprinting

The isotopic data suggests that mixing with geothermal waters has occurred in the Tarawera River and has not occurred in A8 and Urupa ponds. Figure 8 illustrates hydrogen ($\delta^2\text{H}$) and oxygen ($\delta^{18}\text{O}$) isotope data for Savage Pools, Tarawera River, A8 pond, Urupa Pond, TWT spring, and Bremar spring. Hydrogen and oxygen isotope data was not available for Lake Rotootipaku. Therefore, values for hydrogen and oxygen isotopes from Savage Pools were used.

Figure 12 shows that two samples from A8 and Urupa ponds and upstream, downstream and onsite samples collected from the Tarawera River do not lie on either the GMWL or the LMWL. TWT and Bremar springs fall very close or on the global and local meteoric water lines, which is a strong indication that they are pristine meteoric waters. As expected, the data shows that Savage pool (geothermal water) is more enriched with $\delta^{18}\text{O}$ relative to both the GMWL and the LMWL. Deviations from the global and local meteoric water lines could either be an indication of mixing or evaporation. If spring, river, and pond samples deviate from the global meteoric water line and the local meteoric water line because of mixing (and not evaporation), we would expect that approximately 13% of geothermal waters have mixed with the spring, river, and pond waters. This quantity was derived from the theoretical mixing line shown in Figure 12 using a simple mixing calculation. While this analysis of hydrogen and oxygen isotopes may indicate mixing between meteoric and geothermal waters, the deviations could also be due to evaporation. Therefore, we use the other mixing calculations of conservative constituents in order to assess whether the deviation from the GMWL and LMWL is due to mixing or evaporation.

Geothermal Contribution

Mixing calculations (Table 15 above) for lithium, bromide, and chlorine suggests mixing of geothermal waters with the Tarawera River. Based on the same conservative mixing relationships, there is no possible mixing between A8 and Urupa ponds and geothermal waters. Furthermore, the geochemical data suggests between 5% and 11% mixing of geothermal waters with the Tarawera River at various locations. This is consistent with the isotopic offsets of $\delta^{18}\text{O}$ and $\delta^2\text{H}$ of the Tarawera River samples from the LMWL and contribution of enriched $\delta^{18}\text{O}$ and $\delta^2\text{H}$ from the geothermal source.

Lithium/Chloride Ratios

SKM's results (2007) show that the ratios from the bores are highly variable and range from 0.0003 to 0.0139 with an average value of 0.0056. The buried hot springs have some of the highest lithium-chloride ratios (~0.008). The lithium-chloride ratios for Rotootipaku Springs range from 0.006 to 0.008 and therefore closely resemble the SKM measurements. Such results are not surprising because the samples should be from the same buried hot springs. Furthermore, the lithium-chloride ratios for Savage Pools, the geothermal water source that is located offsite is

greater than the values measured in the Rotooitipaku Springs (0.01 versus 0.008) but are still considered representative of geothermal waters in the area.

The Li/Cl ratios from our samples range from 0.00175 to 0.01 with an average value of 0.0044. The Li/Cl ratios for A8 and Urupa ponds are approximately 0.002 and closely resemble the ratios for Bremar and TWT Springs (0.003 and 0.002, respectively), which do not have any expected contamination sources. The close resemblance between the pond and spring waters and also the discrepancy between pond and geothermal waters may be an indication that mixing of geothermal waters has not occurred between A8 and Urupa ponds.

The lithium-chloride ratios for the Tarawera River are approximately 0.006 and therefore more closely resemble the ratios for Rotooitipaku springs (*i.e.* 0.008). Because lithium and chloride are conservative constituents, the relatively high lithium chloride ratios in the Tarawera River, compared to background ratios, suggest that geothermal waters have mixed with Tarawera River waters.

Anthropogenic Contamination

Manganese, iron, and copper concentrations are greater in A8 pond, Urupa pond, and Tarawera River than the concentrations observed in geothermal and background waters. Table 16 below shows the average concentrations of manganese, iron, and copper in A8 pond, Urupa pond, Tarawera River, Savage Pools (geothermal waters), TWT Spring (background waters), and Bremar Spring (background waters). All other inorganic constituent concentrations in A8 and Urupa ponds are similar to the concentrations measured in TWT Spring and Bremar Spring, *i.e.* background waters.

	A8 <i>pond</i>	Urupa <i>pond</i>	Tarawera <i>river</i>	Bremar <i>spring</i>	Savage <i>geothermal</i>
Manganese (µg/L)	8	7	23	0	2
Copper (µg/L)	6	20	18.1	0	0
Iron (µg/L)	96	133	106	7	21

Table 16. Average Manganese, Copper and Iron Concentrations in A8 pond, Urupa Pond, Tarawera River, Bremar Springs, and Savage Pools

The high concentrations of iron, copper, and manganese present in the surface water bodies relative to background concentrations is evidence that manganese does not occur naturally oxic water in New Zealand. However, it is unlikely that the relatively high concentrations of

manganese, copper and iron are anthropogenically derived. Rather, it is likely that the relatively high manganese and iron concentrations reflect reducing conditions attributable to organic contamination in the surface waters. Organic contamination would trigger oxidation and eventually create reducing conditions. Under reducing conditions, Fe^{2+} and Mn^{2+} are leached from iron and manganese oxides present in sediments. Once Fe^{2+} and Mn^{2+} are leached from the oxides, they dissolve in the water, increasing the dissolved concentrations of these constituents.

The values of iron and manganese that are reported are typical to reduced waters and therefore it is likely that organic contaminants are present in these waters. Thus, we recommend analysis be done to determine the presence and concentrations of organic constituents in these waters. The results will not only serve to further explain the relatively high concentrations of manganese, iron and copper but also provide information about the potential for anthropogenic organic contamination in these waters.

If A8 pond, Urupa pond, and the Tarawera River were receiving inputs from pulp and paper mill waste and effluent, then we would expect to find all or most of the same contaminants that were found in the groundwaters and sediments located in the waste disposal area. Furthermore, we would expect to find the constituents present at concentrations greater than background concentrations. The contaminants we would expect to find are listed and discussed in both the survey of pulp and paper mill contaminants section and the previous site assessments section and include elevated concentrations, relative to ANZECC guidelines, of sodium, sulfate, ammoniacal-nitrogen, phosphorus, sulfide, mercury, manganese, arsenic, boron, lithium, barium, cadmium, chromium, copper, nickel, lead, and zinc. The only contaminant that is found in both groundwater and surface waters is manganese. Thus, we do not find evidence which suggests anthropogenic sources of contamination in A8 pond, Urupa Pond, or Tarawera River.

Water Quality

None of the inorganic constituents measured in A8 pond, Urupa pond, or Tarawera River exceed the ANZECC guideline values for recreational water use. These results can be observed in Table 14. Therefore we conclude that the water quality is acceptable, with regard to inorganic contamination, for recreational purposes. However, the concentrations of inorganic constituents in these same water bodies are unknown. ANZECC guidelines values also exist for organic

constituents and therefore it is important to determine concentrations of organic constituents in these water bodies before determining whether the water bodies are safe for recreational use.

Summary and Conclusions

This paper provides an overview of the results of previous site assessments and the nature and extent of contamination in soils and groundwater. The new information gleaned from this project includes the nature and extent of contamination in the surface water bodies neighboring the Lake Rotootipaku waste disposal site. Analysis of XY plots, hydrogen and oxygen isotope data, mixing calculations, and mixing ratio calculations have been particularly useful in assessing geothermal and anthropogenic sources of contamination in the selected water bodies. The evidence suggests that geothermal waters have not mixed with A8 and Urupa ponds. However, evidence does suggest that geothermal waters have mixed with the Tarawera River. The evidence suggests that manganese, copper and iron are the principal inorganic contaminants that are anthropogenically derived.

Recommended Future Work

We recommend that further research focus on determining the nature and extent of organic contamination in onsite and nearby surface water bodies. Such an assessment would allow for a more complete assessment of the nature and extent of contamination in the selected surface water bodies.

Acknowledgements

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Appendix A: X-Y Plots for Conservative Constituents

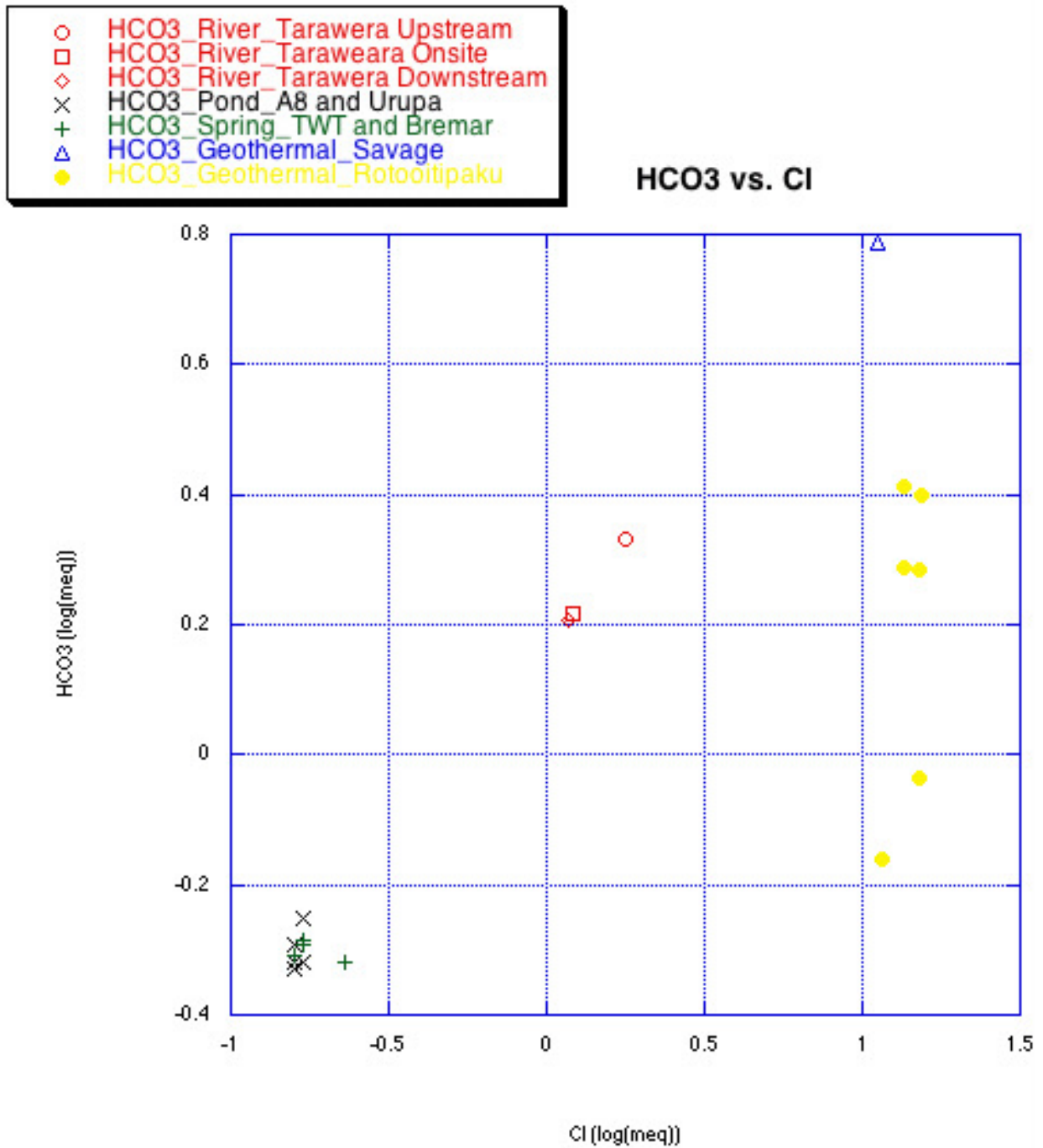


Figure 9. HCO3 (log(meq)) vs. Cl (log(meq))



Na vs. Cl

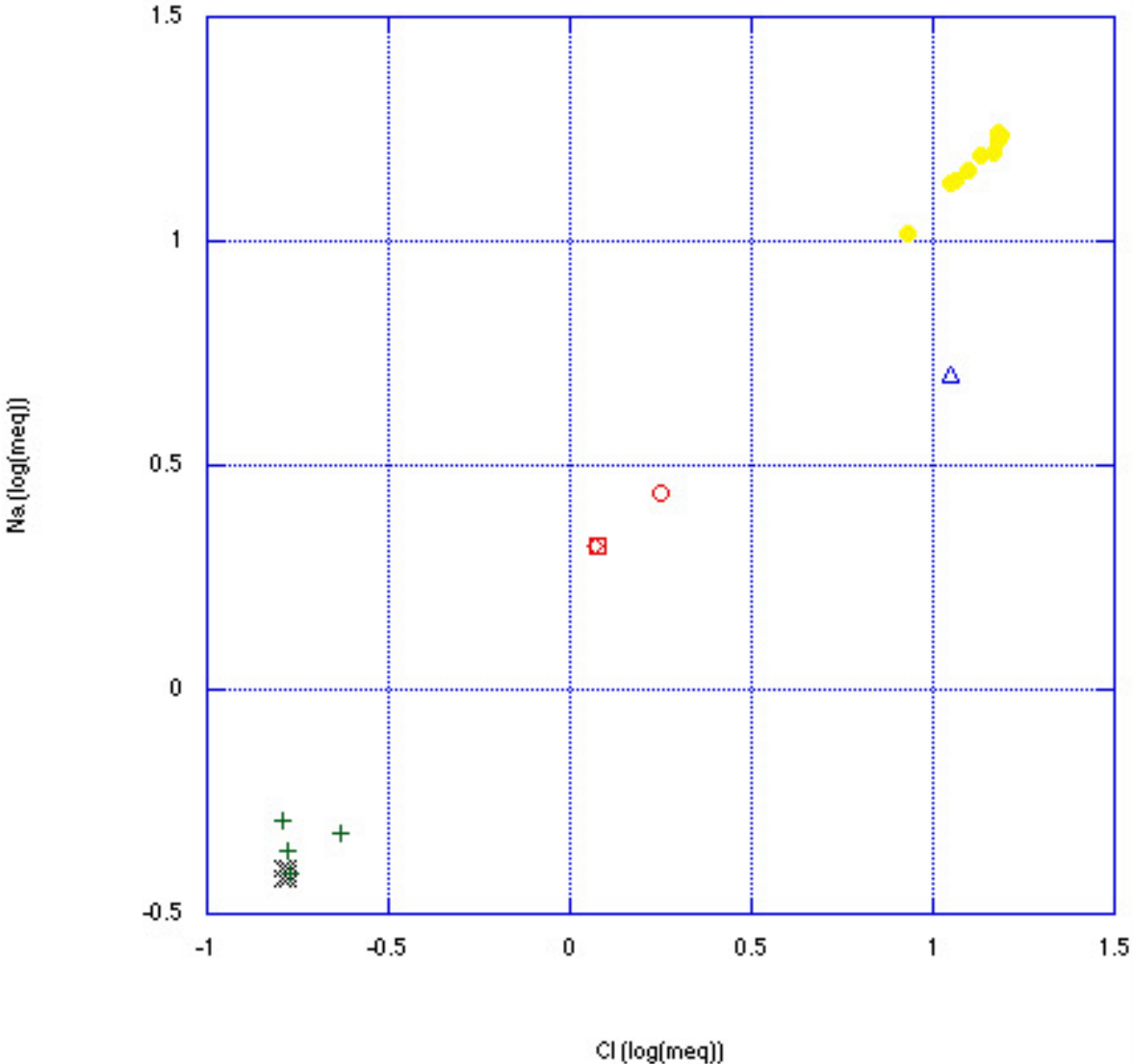


Figure 10. Na (log(meq)) versus Cl (log(meq))



Br vs. Cl

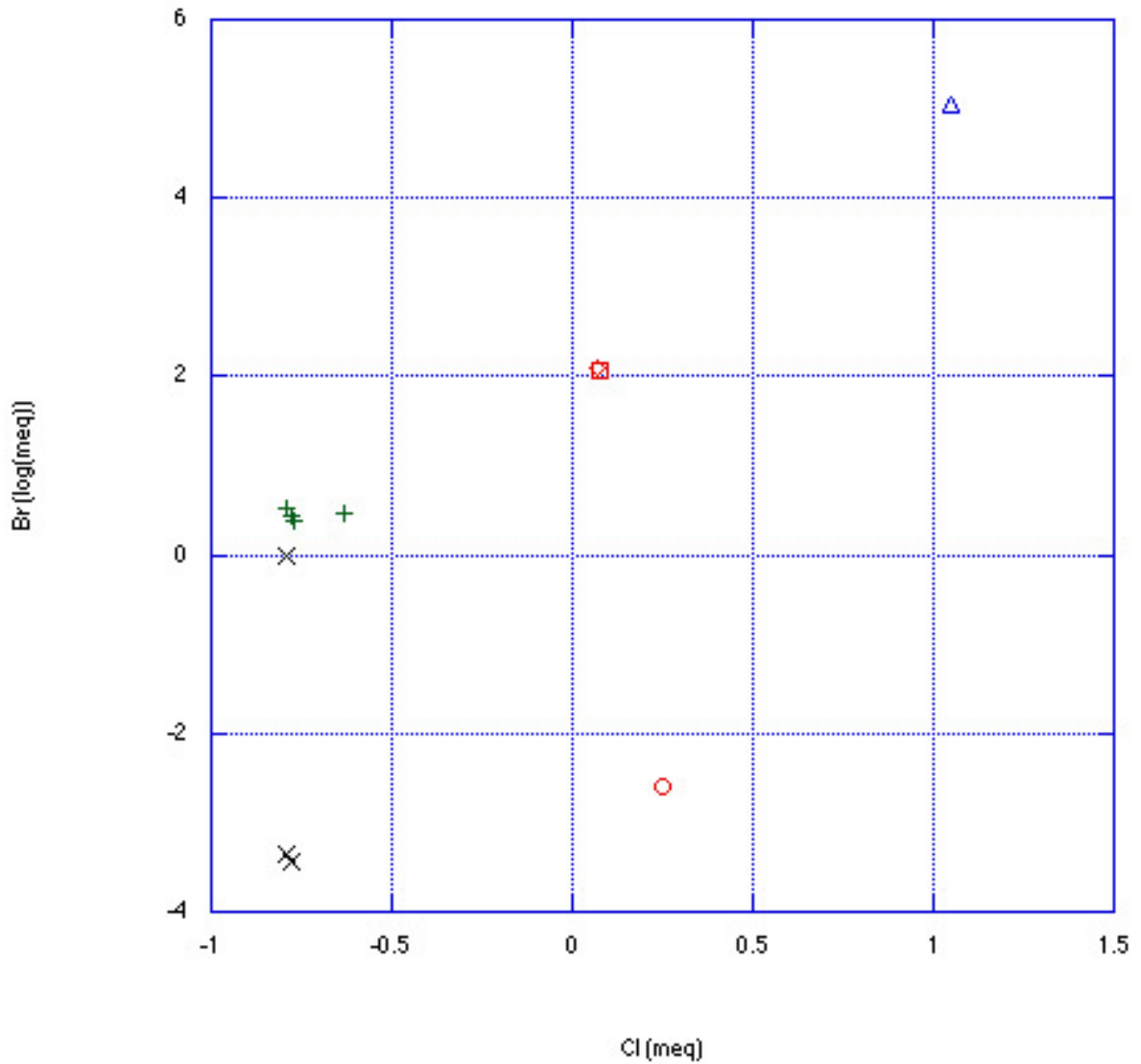


Figure 11. Br (log(meq) vs. Cl (log(meq))

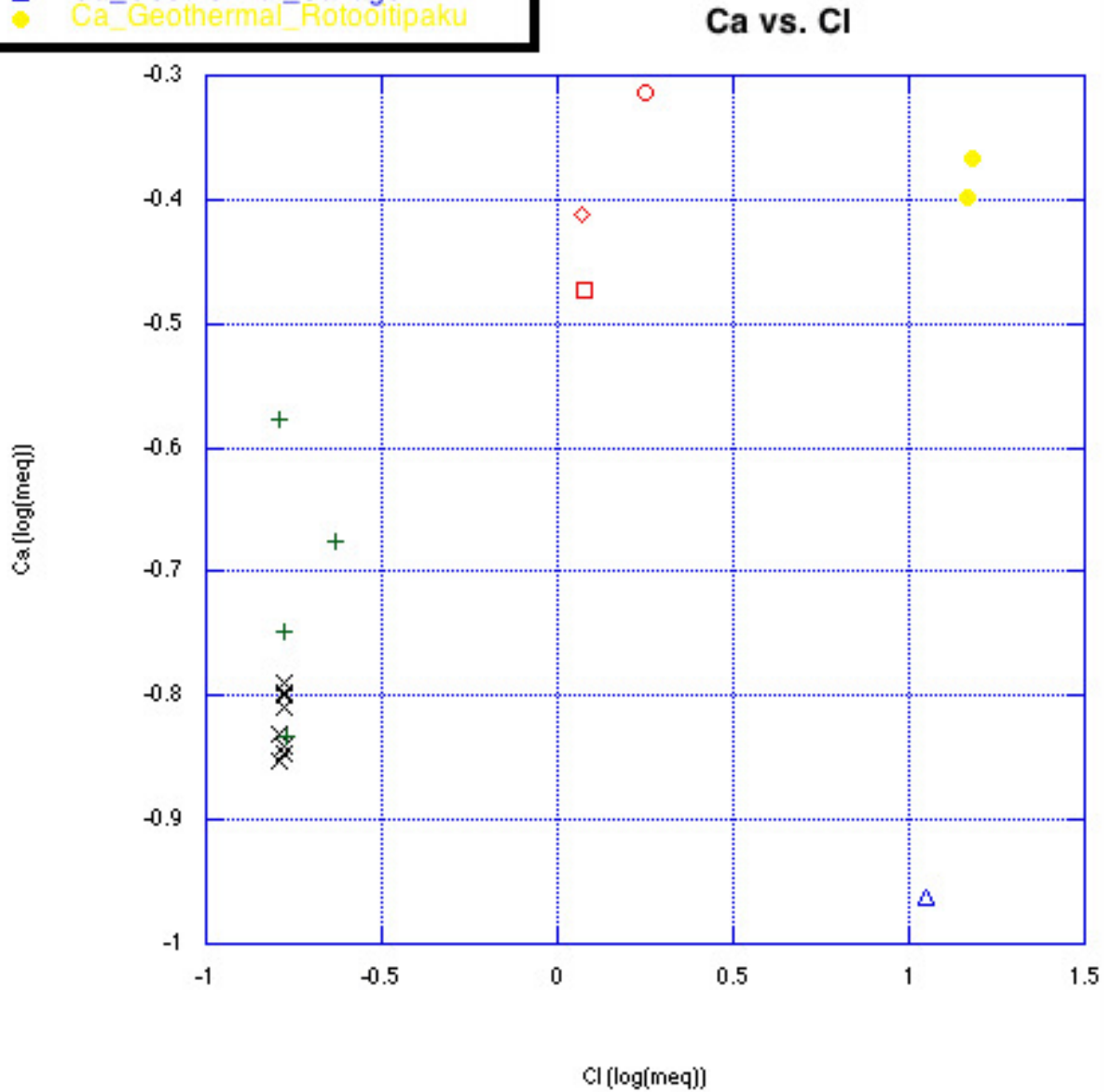


Figure 12. Ca (log(meq)) vs. Cl (log(meq))



K vs. Cl

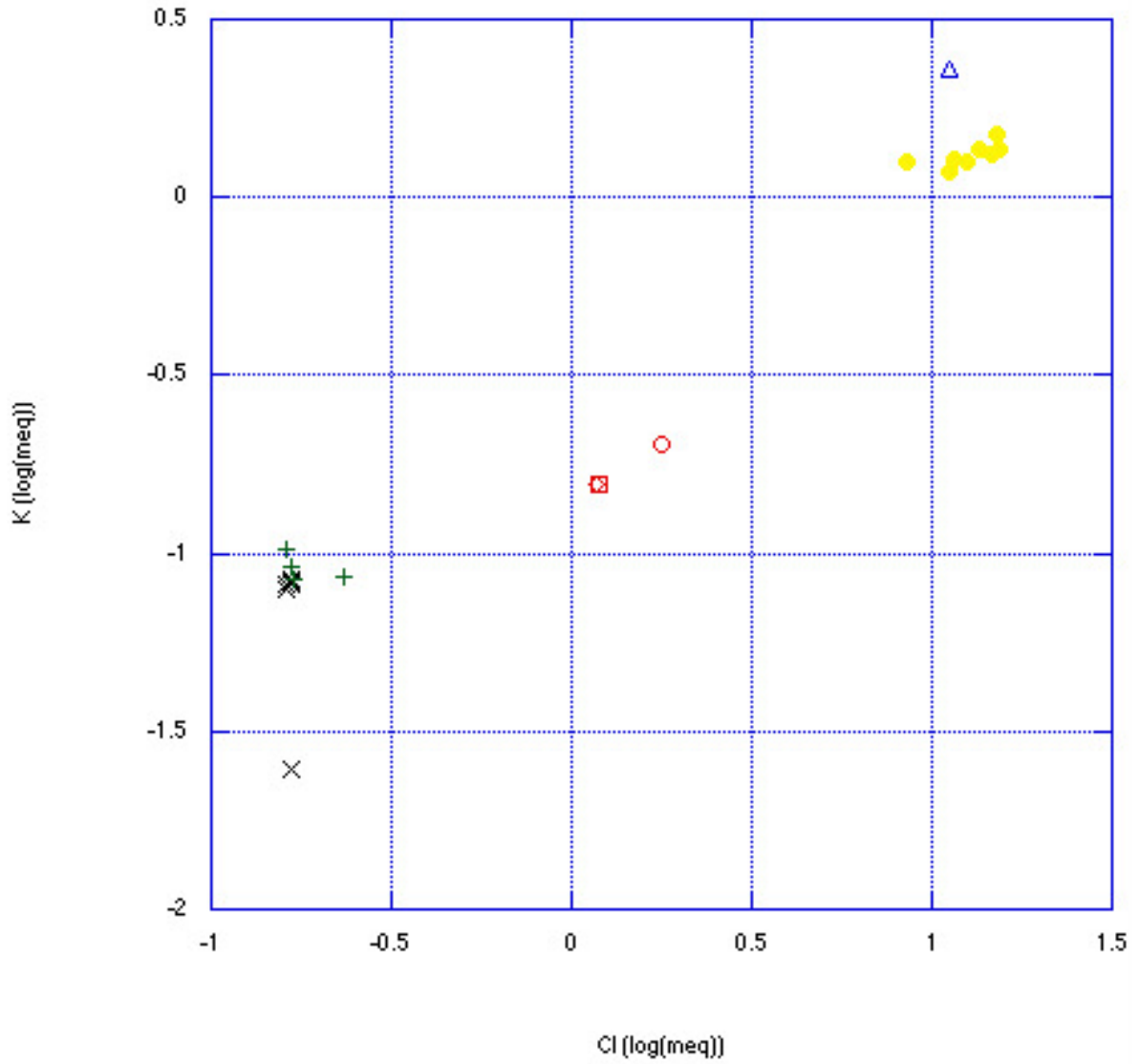


Figure 13. K (log(meq)) vs. Cl (log(meq))

- Mg_River_Tarawera Upstream
- Mg_River_Tarawera Onsite
- ◇ Mg_River_Tarawera Downstream
- × Mg_Pond_A8 and Urupa
- + Mg_Spring_TWT and Bremar
- △ Mg_Geothermal_Savage
- Mg_Geothermal_Rotooitipaku

Mg vs. Ca

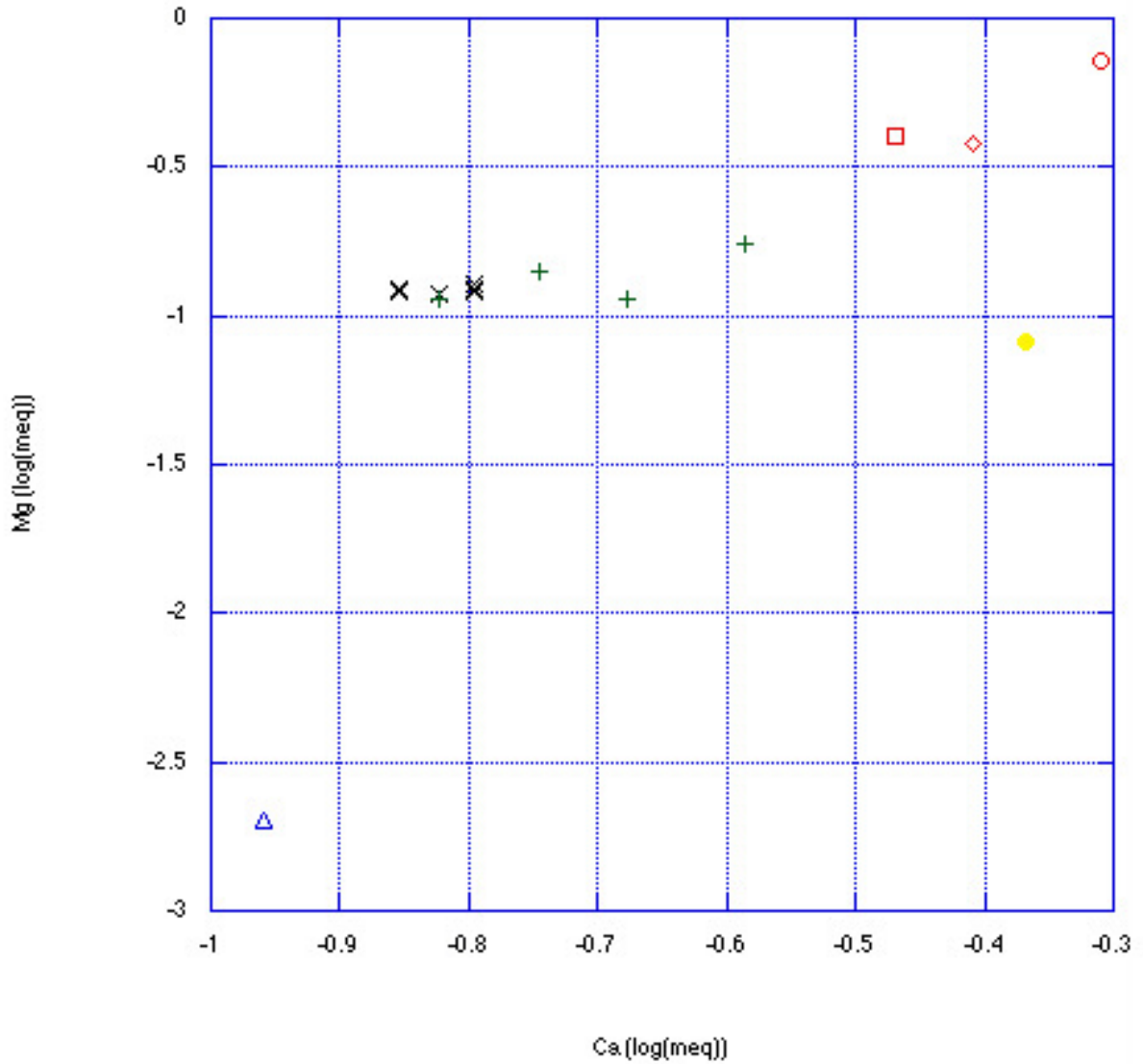


Figure 15. Mg (log(meq)) vs. Ca (log(meq))



SO4 vs. Cl

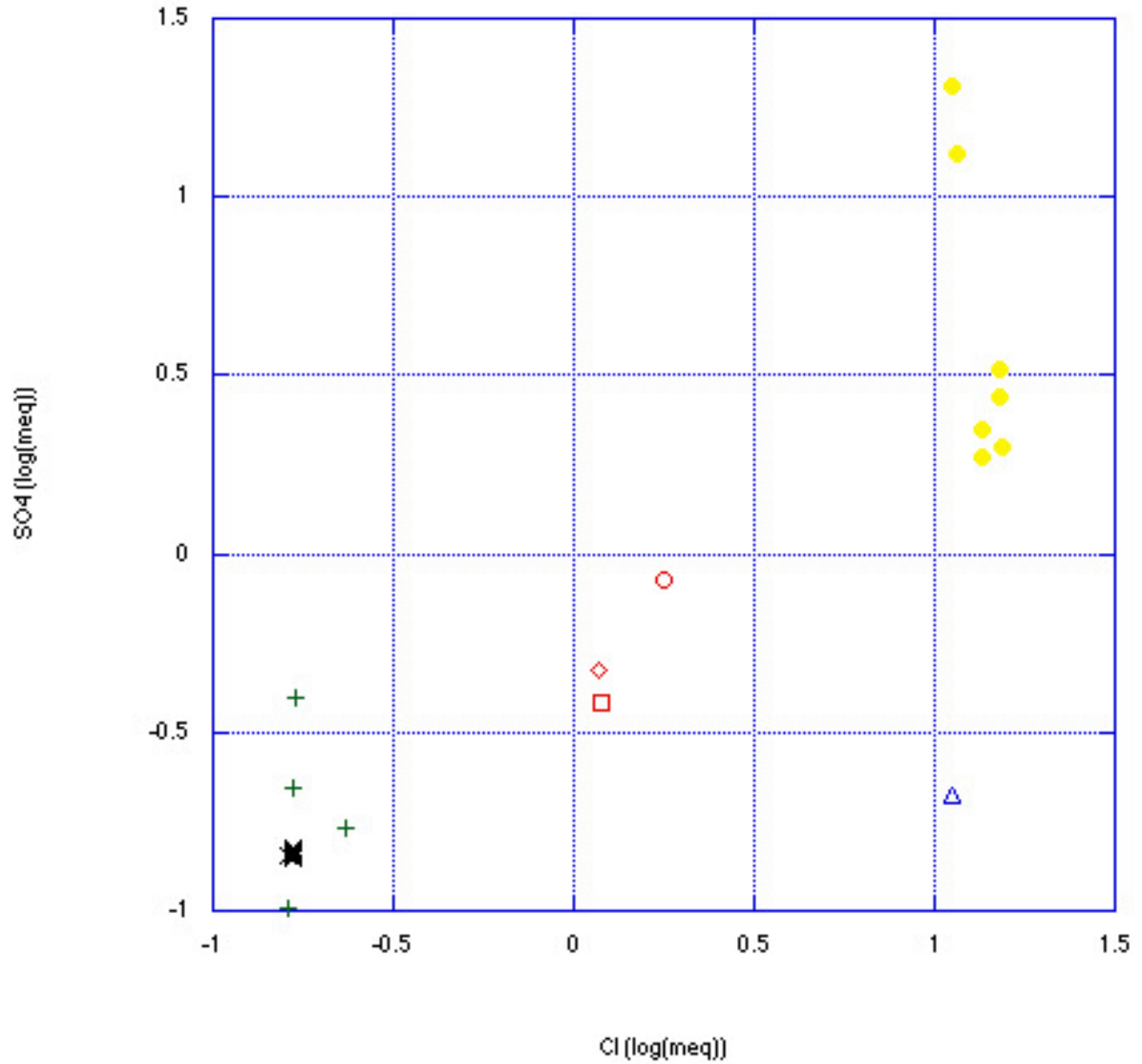


Figure 16. SO4 (log(meq)) vs. Cl (log(meq))