Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

The Environmental Fate of Geothermal Arsenic in a Major River System, New Zealand

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Keywords: Arsenic, geothermal, environment

ABSTRACT

Arsenic is released from various geothermal fields in the central North Island of New Zealand, into the Waikato River. Arsenic concentrations in the river water typically range from 0.02 to 0.06 mg/L. A review of As behaviour in this large catchment system is presented, based on over 10 years of water quality monitoring data and the results of more detailed, specific studies of As speciation and toxicity, and uptake or release from plants and biota, suspended particulate material and lake bed sediments. The primarily conservative behaviour of dissolved As in this river and its estuary, has significantly reduced the likelihood of long term adverse effects from As discharge. However, a portion of the As is retained in the river system, principally due to two processes; adsorption onto suspended particulate matter in winter/early spring, followed by settlement of the particulates into the lakes dammed for hydroelectricity, and uptake by diatoms and aquatic plants. The environmental and health implications of As retention in the river system are examined, and placed in the context of changing local government policy on the development and discharge from geothermal fields in the Waikato region.

1. INTRODUCTION

The Waikato River is New Zealand's longest and most utilised river, and includes within its catchment a large area of natural geothermal activity and several geothermal power stations. Arsenic is commonly elevated in geothermal fluids, leading to natural and/or anthropogenic contamination of waterways in geothermally active catchments (Webster & Nordstrom, 2003). Arsenic in untreated Waikato River water typically ranges from 0.02 to 0.06 mg/L (e.g. McLaren and Kim, 1995). Undeveloped geothermal fields such as Orakeikorako and Wai-o-tapu drain to the Waikato, as do natural thermal springs on developed fields such as Ohaaki and Mokai (Fig 1). The largest single discharge of geothermal fluid is, however, separated bore water from the Wairakei Geothermal Power Station (Timperley and Huser, 1996) on the developed Wairakei/Tauhara geothermal field.

Reay (1972) cited earlier references to a combined Wairakei-Tauhara field output of 22 t/yr of As prior to the development of Waikarei Power Station in the late 1950's. Post development, an annual outflow of 145 t/yr As from the Wairakei Power Station alone was reported prior to 2000 (Aggett & Aspell, 1980). This was reduced to ~70 t/yr in 2000, due to increasing reinjection of separated bore water (Webster-Brown et al., 2000), but remains the largest single source of As to the river, contributing ~40% of the As in the Waikato River.

With a recent application for permission to continue separated bore water discharge into the Waikato River from Wairakei Power Station (Contact Energy, 2001), concerns have resurfaced concerning the effects of the relatively high As inputs to this river. Potential environmental problems associated with increasing the amount of As discharged to the Waikato River were identified many years ago as the accumulation of As in hydrolake sediments (Axtmann, 1975; Aggett & O'Brien, 1985) and in plants (Reay, 1972; Axtmann, 1975). Although the WHO (1993) recommended As guideline for drinking water of 0.01mg/L is exceeded, adequate treatment is available to remove As from domestic water supplies of the region.

The purpose of this review to use the now comprehensive monitoring database and research results to identify:

i) The most important mechanisms of As retention in the river system, and where these occur

ii) Likely adverse environmental effects associated with As retention

iii) Whether the release of geothermal As should be reduced in this river system

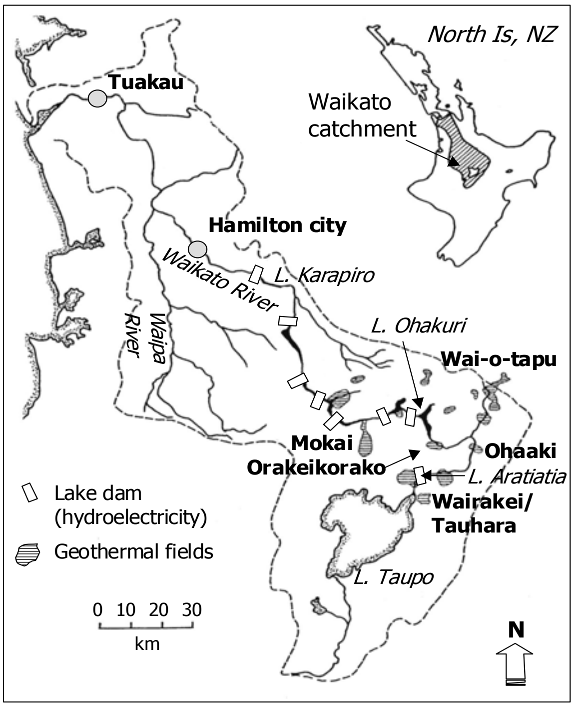

Figure 1. The Waikato River catchment, showing principal geothermal fields and hydroelectric lakes (after Webster-Brown & Lane, 2004). Between 12 and 15 monitoring sites at regular intervals along the river are routinely used by Environment Waikato.

2. STUDY AREA AND INFORMATION SOURCES

The locality of catchment features referred to in the text are shown in Figure 1. Water quality monthly monitoring data collected by Environment Waikato have been used, particular those data collected between 1995 – 2001, and methodology for sampling and analysis is outlined in the monitoring reports (Huser and Prowse, 1994; Huser & Wilson, 1995, 1996,1997; Wilson et al., 1998, Wilson, 1999, 2000; Wilson & Smith, 2001; Smith 2002). All results in Environment Waikato's reports are given as "total recoverable" As concentrations. In addition, other published results for the Waikato River have been used, including the authors' data collected for As in the water column, bed sediment and suspended particulate matter (SPM) over the 1998-2000 period (Webster-Brown et al., 2000; Webster-Brown & Lane 2004), using the same monitoring sites as Environment Waikato. In the latter studies, "dissolved" As is defined as that portion of the As which passes through a 0.45mm membrane filter, and "acid-soluble" As as the As analysed in an unfiltered water sample acidified to pH 2. Acid-soluble As concentrations include As bound to SPM in the water column, as well as "dissolved" As. Arsenic concentrations were measured using HGAAS, with a detection limit of between 0.3 and 0.5 μg/L. Concentrations of AsIII were measured by HGAAS, using a citrate buffer, as outlined by Aggett & Aspell (1976).

3. CHEMICAL FORM OF ARSENIC IN WATER COLUMN

In 1998/99 the concentration of acid-soluble As in the water column ranged from 0.006 – 0.039 mg/L (Webster-Brown et al., 2000), with the highest concentration immediately downstream of Wairakei Power Station. This range is typical of recent years, but lower than that observed prior to 1995 when a programme of bore water reinjection commenced at the power station. In 1993, for example a maximum of 0.06 mg/L As at Hamilton was reported (McLaren & Kim, 1995). Total As concentrations of up to 0.077 mg/L in the upper river are reported in Environment Waikato monitoring reports over the period during 1991-1993.

Dissolved and acid-soluble As concentrations have been measured at all monitoring sites in summer (November 1998) and winter (July 1999), and monthly at Tuakau Bridge in 1999 (Webster-Brown et al, 2000). Dissolved As predominates, constituting between 73% and 100% of the As carried in the water column, with a mean of 87% (n = 45).

Table 1. Previously reported instances of dissolved AsIII occurrence (mg/L), and as a percentage of total dissolved As, in the Waikato River reported by ^{1}Aggett & Aspell (1980) and ^{2} Polya et. al. (2003).

Site.	Sept, 1976^1	Oct, 1976^1	Feb, 1978^1	April, 1998^2
L. Taupo	0.012 (100%)	0.012 (80%)	-	-
L. Aratiatia	0.035 (97%)	0.008 (19%)	-	0.030 (79%)
L. Ohakuri	0.018 (42%)	0.010 (26%)	0.038 (76%)	-
Hamilton	0.013 (56%)	0.012 (44%)	-	-
Tuakau	0.003 (27%)	0.003 (20%)	-	

3.1 Oxidation State

Arsenic enters the Waikato River from the Wairakei borefield in the form of arsenate ion, with As in the AsV oxidation state (Finlayson and Webster, 1989; Polya et al, 1998). Arsenate is also the more stable form of As under the oxic conditions generally present in the Waikato River. However, between August and November of 1976 Aggett & Aspell (1980) found arsenite ion, with As in the AsIII oxidation state, to be periodically the predominant form of dissolved As in the upper river (Hamilton and upstream). In other sampling programmes, AsIII was again found to be predominant in the surface water of Lake Ohakuri in February (1978), and in Lake Aratiatia in April (1998) as shown in Table 1. However, in a recent monthly monitoring programme, undertaken in the lower river at Tuakau by the authors in 2003, AsV consistently predominated. ArsenicIII did not exceed 5% of the total dissolved As (Figure 2).

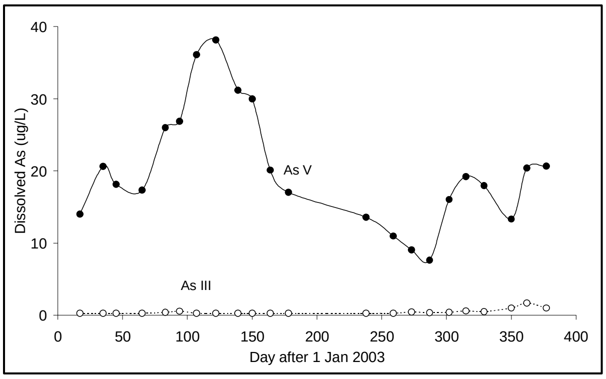

Figure 2. Dissolved arsenate (AsV) and arsenite (AsIII) concentrations in the lower Waikato River at Tuakau, in 2003. Arsenite concentrations were below the detection limit (0.3 μg/L) except in March-April 2003 (maximum = 0.54 μg/L) and September 2003-January 2004 (maximum = 1.7 μg/L).

Summary. Arsenic in the Waikato River is predominantly dissolved and in the form of AsV. Periodic conversion of AsV to AsIII occurs in the upper catchment over the summer months, but does not persist into the lower catchment. Summer production of AsIII has been attributed to the action of As-reducing bacteria, initially identified by Freeman (1985). Late summer/autumn overturn of the deep, stratified hydroelectric lakes is also likely to contribute by releasing AsIII from the base of the lake into the river water (Aggett & Aspell, 1980; Aggett & O'Brien, 1985; Aggett & Kreigman, 1988).

4. RETENTION IN THE RIVER SYSTEM

It has been estimated that in the order of 10% of the As transported by the Waikato River is retained in the river sediments and plants (e.g., Aggett & Aspell, 1980; Webster & Timperley, 1995). One of the most common methods of determining where in a catchment a dissolved element is being removed from the water column, is to use the ratio with an element from the same source, which is known to behave conservatively. For As, the ratio with lithium (Li) or boron (B), also derived solely from geothermal fluids, has proved useful.

4.1 Arsenic removal from the water column

The weight ratio of total As:Li immediately downstream of the largest geothermal fluid input (at Wairakei) is relatively constant at 0.29 ±.02 (average and standard deviation for combined monthly data for 1998, 1999 and 2000). As shown in Fig. 3, in summer this ratio persists into the lower reaches of the river (at Hamilton and Tuakau), with neither As nor Li being preferentially removed from the water column. Consequently, in summer and autumn the concentrations of As reflect mainly conservative behavior. The apparent addition of As in the upper river (Ohaaki and Lake Ohakuri) in March and April (autumn) may be due to the release of As from lake sediments during stratified lake turnover at this time.

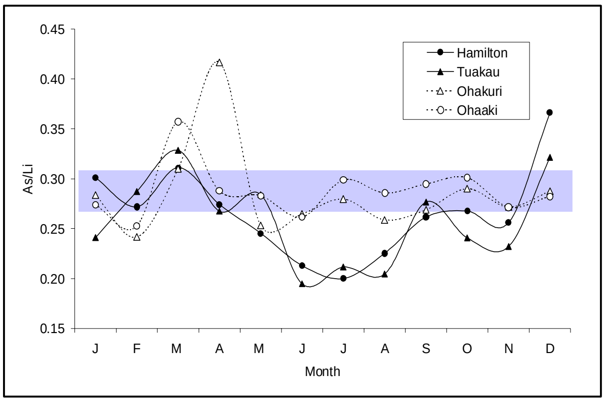

Figure 3. The weight ratio of total As:Li in the lower Waikato River at Ohaaki, Ohakuri, Hamilton and Tuakau, in 1998 (from the data of Wilson, 1999). The shaded area shows the ratio (± SD) present in the upper Waikato River immediately below Wairakei Power Station but upstream of the hydroelectric lakes.

In winter (June-August), however, the As:Li ratio decreases between Lake Ohakuri and Hamilton city, indicating a removal of As from the water column. This is occurring predominantly in the upper river, as there is little difference between the As:Li ratio at Hamilton and Tuakau.

4.2 Mechanisms of As removal

Chemical conditions in the river do not favour precipitation of As-bearing minerals, so the most likely mechanisms for As removal are uptake by biota or adsorption onto particulate material. Arsenic accumulation by aquatic plants has been reported from this river (Reay, 1972; Robinson et al., 2003). However, the maximum growth period for plants, when they can remove dissolved As most effectively, is in spring and summer, rather than in winter. Arsenic uptake by phytoplankton is also a recognized phenomenon (e.g., Faye and Diamond, 1996), but once again diatom growth occurs predominantly in summer and autumn, rather than in winter.

Therefore As removal by adsorption onto abiotic particles, particularly adsorption onto the reactive SPM in the water column, appears to be the most viable option. The partitioning of As between the dissolved state, and the SPM, can be assessed using a partitioning coefficient K_D. This is usually expressed as log K_D, where $K_D = [As_{SPM}]/[As_{DISS}]$. K_D values calculated for monthly sampling at Tuakau throughout 1999 fell within the range of log $K_D = 3.8 – 4.2$, but showed a broad minimum over the summer/late autumn period (Webster-Brown et al, 2000). Experimental adsorption studies confirmed the ability of winter SPM to adsorb As to a greater degree, and ultimately attributed this to a higher concentration of Fe–oxide (an effective adsorbent for As) in this SPM (Webster-Brown & Lane, 2004). The SPM settles from the water column in the hydrolelectric lakes, leading to the significant loss of As in that stretch of the river which has most of the lakes between Ohakuri and Hamilton.

This is consistent with the high concentrtaion of As in the deep sediments of hydroelectric lakes. While As concentrations of 13 – 82 mg/kg have been reported from the main channels of the Waikato (Webster-Brown et al, 2000), levels of 1000mg/kg (up to 6000mg/kg) have been reported in the lake sediments (Aggett & O'Brien, 1985; Hickey & Martin, 1996). It has estimated that approximately 7% of the As transported by the Waikato River is ultimately retained in the sediments (Aggett & Aspell, 1980).

4.3 Seasonal variation in As concentrations

The preferential removal of As from the water column in winter contributes to the highly seasonal behaviour of As, which was evident in Fig 2. Maxima during summer and minima during winter have been apparent in Environment Waikato water quality monitoring data since monitoring began in 1991. Although partially due to geothermal fluid dilution in the higher river flows over winter, the trend is exacerbated by As adsorption onto SPM in winter (Webster-Brown & Lane, 2004).

Other explanations for the broad seasonal trend have been offered. Most of these have been based on the apparent release of As from sediments during summer, rather than a greater degree of As removal over winter. McLaren and Kim (1995), for example, suggested that the seasonal trend identified in 1993/94 was due to desorption of As from sediments during summer months, either as a direct effect of temperature on the adsorption process, or as an indirect effect of temperature influencing physiochemical or biological conditions. Aggett & O'Brien (1985) suggested the release as AsIII from shallow (oxic) lake sediments, when As-reducing bacteria are active in the summer months. AsIII is less readily adsorbed than AsV onto Fe-oxide (Swedlund & Webster, 1999), which is considered to be the principal binding surface for As in the sediment (Aggett & Roberts, 1986; Webster-Brown & Lane, 2004). However, in the Environment Waikato monitoring database and results presented here, there is little evidence for protracted release of As from sediments over summer, or for the persistence of AsIII into the lower river, where the seasonal variations in As concentrations are still very obvious.

There *is* evidence for the short-term release of As derived from sediments in the base of hydroelectric lakes, during lake turn-over as reported by Agget & Kriegman (1988). This is apparent in Figure 3, for example, and also in the fact that the 2-week maximum of >0.06 mg/L As reported by McLaren & Kim (1995) at Hamilton in 1993 was not picked up in the EW monitoring data covering the same period. Neither the magnitude or the exact timing of these short-term, high dissolved As concentrations generated by lake turnover can be predicted. We can not be sure that the true magnitude of any of the As maximums occurring as a result of lake overturn have been measured, and it is very likely that they have not.

4.4 Microalgae and plant uptake

Many plants (including microalgae) accumulate As because the arsenate ion has very similar chemical properties to phosphate ion, which is an essential plant nutrient. Some species are capable of distinguishing between the two ions and will not build up high As levels (eg., Morris et al., 1984) while other plants are "hyperacumulators" building up to levels of 20,000 mg/kg dry weight (e.g., Ma et al, 2001) when grown on contaminated soils or sediments.

The abundance of microalgae, or diatoms in the Waikato River can be estimated from chlorophyll-a concentrations in the water column, and from electron microscopy of air-dried SPM. Diatom abundance is also indicated by the TOC (total organic carbon) content of the SPM. The Waikato River has relatively high concentration of diatoms, due to the abundance of nutrients (including geothermal silica which is used in the skeleton) in this river. In 1999, for example, diatom blooms of *Asterionella spp*. in summer, and *Melosira spp*. in autumn were evident, corresponding to chlorophyll-a concentrations of ~ 0.035 mg/L (compared with the winter chlorophyll-a concentrations of ~0.008 mg/L). In winter SPM is predominantly comprised of inorganic particulate material, with few diatoms in evidence (Webster-Brown et al., 2000).

A positive correlation was evident between the As and TOC content of SPM collected monthly at Tuakau in 1999, suggesting diatoms are taking up or adsorbing As (Figure 4). However, this does not appear to be occurring at a sufficient rate to significantly affect the As:Li ratio during summer and autumn (Fig 3).

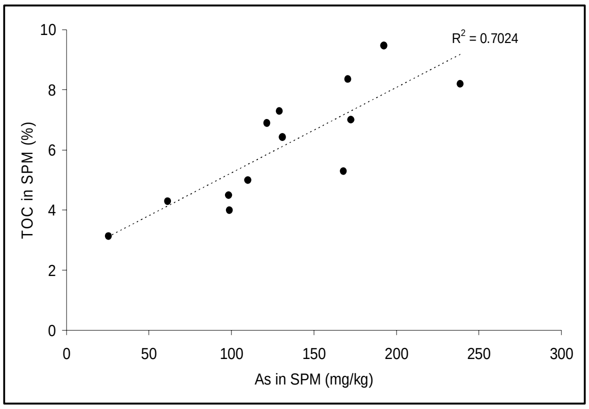

Figure 4. The correlation of As and TOC in air-dried SPM collected at Tuakau throughout 1999 (refer Webster-Brown et al., 2000, for methodology).

Although aquatic plants were not a dominant feature of the Waikato River prior to the formation of hydroelectric lakes, they have been introduced since and now thrive in the lake environments. So much so that they have to be regularly removed to prevent clogging of the turbine intakes in the hydroelectric power stations. Arsenic levels of 100-1000 mg/kg dry weight have been reported in the lake weeds including dominant species *Lagarosiphon major*, *Egeria densa* and *Ceratophyllum demersum*, with concentrations typically at a maximum in spring (Reay, 1972; Aggett & Aspell, 1980). The bulk of the As in these plants is in the liquid phase, and is predominantly in the form of AsIII, the most toxic form of arsenic (Aggett & Aspell, 1980). In a more recent study of watercress (*Lepidium sativum*) in the Waikato River, Robinson et al. (2003) observed that As uptake was likely to be related to sediment As content, as well as to the concentration of dissolved As in the water column. Mean leaf (dry weight) concentrations of 500 mg/kg and a maximum of 1766 mg/kg were observed, consistent with the previous observations.

Waikato River plants have been estimated to take up ~3% of the available As (Reay, 1972; Aggett & Aspell, 1980). However, once again this does not appear to influence As:Li concentrations and the seasonal behaviour of As in the river.

4.5 As removal in the estuary

Major chemical, physical and biological changes occur within a freshwater/seawater mixing zone of an estuary. One of the most important of these, from a metal transport perspective, is the flocculation and settlement of fine colloidal SPM under conditions of increasing salinity. Metals with a strong affinity for SPM tend to accumulate in estuarine sediments as a result of this process. Previous studies of As behaviour in overseas estuaries mainly support conservative behaviour, i.e. little or no change in the dissolved As load during estuarine mixing (e.g. Andreae et al.,1983). However, increased adsorption of arsenic onto hydrous iron oxide or organic particulate matter in the low salinity estuarine zone has also been proposed (Van der Shoot et al., 1985).

Dissolved As concentrations in the Waikato River estuary are very similar to those expected for conservative mixing of the As-bearing river water and seawater (Webster-Brown et al., 2000). This suggests that As is not being adsorbed or otherwise removed from solution in the estuary. Estuarine log K_D values remained within the range of values (3.8 – 4.2) calculated for the freshwaters upstream.

Summary. Arsenic behaves predominantly conservatively in the Waikato River, but it is estimated that ~10% is retained in sediments and plants. The principal mechanism of removal is adsorption onto SPM during winter and settlement of the SPM in the hydroelectric lakes. This results in relatively high concentrations of As in lake sediments, and ultimately to the release of As back into the water column during lake turnover in autumn. However the uptake of As by diatoms in SPM is also likely to remove As (again due to settlement of SPM in lakes) during period of diatom growth.

5. ENVIRONMENTAL EFFECTS OF ARSENIC

5.1 Bioaccumulation in aquatic plants

High concentrations of As in aquatic plants pose a direct health risk to humans, wildlife and farm animals. The NZ limit for As in food is 1-2 mg/kg fresh weight (FSANZ, 2003), which is equivalent to ~10 - 20 mg/kg dry weight. This is significantly exceeded by edible plants such as watercress in the Waikato River. Robinson et al (2003) recommended that watercress should not be not collected from the river for human consumption.

The level of As present in these plants, combined with the highly toxic form of As present (AsIII), suggest that chronic or even acute As poisoning of animals grazing on aquatic weeds could occur. While this would be hard to detect for macro-invertebrates and other grazers in the river, there is anecdotal evidence of cattle poisoning through eating weeds extracted from a hydroelectric lake on the Waikato River. Aquatic weeds are extracted from the hydrolakes to prevent turbine damage and to improve the recreational and/or aesthetic value of the lakes. The disposal of this As-rich weed material, after its removal from the lake water, is therefore of concern. Leaving the weed to dry out on the banks of the lake is not recommended, but burial in a landfill would lead to re-release of As into leachate, under the anoxic conditions.

Indirect environmental effects include the potential for re-release As into the water column during seasonal die-back and decomposition of plant matter. This will contribute, at least locally, to unpredictable dissolved As concentrations.

5.2 Reduced biodiversity of algae species

Because As concentrations are typically well above those recommended for aquatic life protection (e.g., 0.013 mg/L AsV, ANZECC 2000), it seems likely that As-sensitive algal species are not present in the Waikato River. One could speculate that the more frequent occurrence of toxic algae blooms in the Waikato River noted in recent summers may be related to the reduced algal biodiversity.

A mean As concentration of 0.010 – 0.015 mg/L As can be predicted for the upper Waikato River in the absence of the current discharge for Wairakei Power Station. This is considerably closer to the ANZECC guideline for aquatic life protection that the current mean As concentrations of 0.023 – 0.027 mg/L.

5.3 Increased exposure of benthic organisms to As

ANZECC (2000) interim sediment quality guidelines for aquatic life protection specify a trigger level of 20 mg/kg As, and a higher level of 70 mg/kg As, above which severe effects on aquatic life might be expected. Clearly very severe effects on benthic organisms might be expected in Waikato River sediments, particularly in the hydroelectric lakes. The ANZECC guidelines are in line with other sediment quality guidelines; for example, the Ontario freshwater low and severe effects guidelines (Persaud et al., 1993) are 6 mg/kg and 33 mg/kg As respectively, and Canadian interim quality guidelines of 7.2 and 42.5 mg/kg As for freshwater sediments are currently being proposed (ANZECC 2000).

The only reported impact on benthic organisms is the significant accumulation of As in freshwater mussels from Lake Ohakuri and other sites on the Waikato River (Hickey et al.,1995). The levels of As (up to 153 mg/kg dry weight) exceeded recommended food standards for As (FSANZ, 2002) at all sites upstream of the Waipapa dam. Although not commonly collected for food, such significant accumulation of As in any animal species increases the risk of adverse effects on that species, and on others higher in the food chain. Notably, there appear to be no evidence of As accumulation in other fauna, such as trout (Robinson et al., 1995).

Arsenic-sensitive benthic invertebrate species, which are currently unable to survive in the river, may be able to tolerate lower As concentrations, increasing the biodiversity of the upper Waikato which is generally considered to be very low.

5.4 Drinking water

The Waikato River water is used as a raw drinking water supply for many small towns and communities, as well as farms, Hamilton city and, more recently, Auckland city further to the north. All domestic water supply is treated. However, the standard alum-based drinking water treatment processes commonly used in the catchment do not effectively remove AsIII (Hering et al., 1997; McNeill & Edwards, 1995, Gregor, 2001). It has also been noted that there is a tendency for proportionally less As removal when there are higher raw water As concentrations (McLaren & Kim, 1995; Gregor, 2001).

Given the likely co-incidence of summer As maxima and a high proportion of AsIII, there is a potential risk to human health. On 3 out of the 5 sampling dates shown in Table 1, As III concentrations in Lakes Aratiatia and Ohakuri were well above (3.5 – 4.5x) the NZMoH (2000) drinking water standard of 0.01 mg/L As. In summer, when As behaves conservatively, high AsIII concentration in the lakes are likely to persist through the treatment process and into reticulated drinking water. As noted above, neither the magnitude or the exact timing of these high dissolved As concentrations can be reliably predicted; particularly the short-term fluctuations generated by hydrolake overturn. It is likely that the true magnitude of any of the As maximums occurring as a result of lake overturn has not been measured. Consequently, this risk is currently unquantified, and is of concern.

We know that the magnitude of the AsIII concentration is likely to be related to the concentration of total As in the water column *and* the activity of As-reducing bacteria (in spring and summer) or to the As content of the deep hydrolake sediments *and* degree of lake stratification (in autumn). At least two of these factors can be reduced by decreasing the amount of As discharged into the Waikato River. Reducing the As content of the sediments in particular would lead to a progressive decrease in the magnitude of the autumn release of AsIII.

Summary. The environmental impacts of geothermal As retention in the Waikato River system include the accumulation of As in benthic organisms and aquatic plants. Human health risks include those posed by the release of AsIII from lake sediments during autumn (which is unlikely to be removed by standard drinking water treatment methods), and by consuming edible aquatic flora or fauna.

6.0 ARSENIC REDUCTION IN THIS RIVER SYSTEM

It is clear that this river system has elevated As concentrations, and that these are giving rise to adverse affects on the aquatic environment and potentially on human health. However, the environmental management of As inputs to this river is not straight forward. The Waikato River had elevated As concentrations prior to development of the first geothermal fields in the catchment in the late 1950s, due to natural geothermal activity and fluid discharge. Quantification of As concentrations, fluxes and effects prior to field development was not undertaken rigorously. Consequently it is not possible to accurately define “background” conditions, or the degree of change.

This has complicated recent attempts to compile a plan for the management of geothermal fields and their discharges in the catchment (Environment Waikato, 2004), and to process an application for the consent to discharge geothermal fluid from Wairakei Power Station to be renewed (Contact Energy, 2001).

6.1 Regional legislation

In the proposed regional plan (Environmental Waikato, 2004), which has yet to be finalised, the number of geothermal fields which can be developed has been limited to those with little aesthetic, cultural or ecological value in their natural state. Discharge to surface water will still be considered under some circumstances for field development, though only for larger developments. Permission to discharge greater than 15,000 tonnes/day (which is commensurate with natural discharge from larger fields such as Wai-o-tapu and Wairakei-Tauhara) is likely to be very difficult to obtain under the terms specified. A further improvement to this approach would be to consider the natural discharge rate to surface water as an upper limit for such discharge from any developed field.

6.2 Individual case management

In the case of separated bore water discharge from Wairakei Power Station and the renewal of this consent (Contact Energy, 2001), the concept of "baseline" conditions, and whether these should pertain to pre-development discharge from the field, or the natural discharge that would occur from the depleted field if the power station was removed (or something in between these extremes) became a relatively contentious issue. Both conditions were difficult to define, based on estimated chloride flux from the pre-development field, and to justify. Even if Wairakei Power Station was to reduce its discharge to that of a "baseline" limit, should the ongoing release of As from sediments and plants be taken into consideration? This relates to previous discharge from the station, removing the opportunity to consider future discharge in isolation.

However, there is little doubt that the development of Wairakei Power Station more than doubled the influx of As to the Waikato River for river for over 30 yrs. The Station still contributes 40% of the As input, and a proportionate amount of As in the sediment and plants of the Waikato River. Total reinjection of geothermal fluid at Wairakei Power Station, would allow recognised water quality guidelines to be approached in the Waikato River environment. It would also reduce, over time, As content of plants and sediments. Difficulty in quantifying the degree of change, rate of recovery or baseline conditions should not be used to support ongoing discharge which significantly increase As concentrations over the natural levels.

Summary. The levels of As in the Waikato River system need to be reduced to avoid the environmental impacts which are currently occurring. It is difficult to argue that these levels should be less than would have occurred naturally if none of the geothermal fields had been developed. However, even reduction to this level is likely to have significant positive effects on the biodiversity and health of aquatic life, and reduce accumulation in sediments and periodic re-release of AsIII into the water column.

7.0 ACKNOWLEDGEMENTS

The author acknowledges the support and help of Environment Waikato staff and Watercare Services Ltd., in the compilation of this review. Data collection by the authors has been funded by the University of Auckland.

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