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An Eels Journey: Source Point Analysis of the Tarawera River
Bay of Plenty, New Zealand

Introduction

The Tarawera River catchment encompasses an area of approximately 984 km^2 of the Bay of Pleny, New Zealand. The hydrological system of Lake Tarawera and its basin topography are primarily associated with the Taupo Volcanic Zone (TVZ), more specifically the Okataina Volcanic Center (OVC) region of the central North Island. The OVC has formed over the last 350 thousand years, but it is less understood than other areas in the TVZ. Past eruptions have isolated historic sediments, but the geology and structure of the basin is understood to be extremely active and dynamic. The region receives over 1.55 m of precipitation per year and the modern river and lake systems formed in response to the eruptive events at Kaharoa at ~AD1315 and Tarawera at AD1886 (Hodgson et al. 2004). This interplay of intensive hydrology and geothermal geomorphology creates a case study of source point analysis for naturally occurring and anthroprogenically induced aqueous containments.

Over its 65 km course to the Pacific Ocean, the Tarawera River drops 300 meters and variable levels of land-use conversion noticeably mark the river and lake system (EBOP, 1994). Environmental Bay of Plenty (EBOP) divides the river catchment into three sections; the Upper Lake, Upper Tarawera, and Lower Tarawera sections. The dynamic nature of the local geology and the eruption of Mt. Tarawera in 1886 physically created a new starting point for ecological redevelopment in the region and European development has since then heavily regulated the countryside. Each region is unique in its degree of anthropogenic modification and indigenous biota. The area has proven to have value for plantation forestry, dairying, fishing, farming, industrial pulp and paper milling, geothermal energy generation, urban development and tourism (EBOP 2004). The Tarawera River represents one of the major hydrological catchments of the region and Lake Tarawera has precious cultural and sustainable tourism value. Local lakes have experienced reduced water quality due to agricultural and urban runoff in the region threatens native wildlife and resource development.

Water sampling along the Tarawera River provides a perfect opportunity to study the flow of "pure" water across several diverse ecosystems of varying horticultural intensity. For this study, water samples were collected for chemical analysis in the laboratory at twenty points of interest along 65 km trek of the Tarawera River. These samples ranged from aquamarine lake water in the Upper Lakes and "pristine" artesian springs of Lower Tarawera to waste site sludge and a black-yellow river discharge into the Bay of Plenty. These waters further exist within the greater geothermal context of the TVZ (McKenzie et al, 2001). This contrast of water quality can be used to identify point sources of containments from agricultural, urban, or geothermal inputs. Small quantities of organic and inorganic contaminants can pose threats to human activities and wildlife and the region's combination of high rainfall and porous soils places human and ecological health at risk. It is necessary to understand what contaminants are in the local hydrological system because the region is an important agricultural center for New Zealand and cultural and historical sites represent potential development of sustainable tourism industries.

Past studies have indicated that the water quality along the Tarawera River is variable and this study aims to build from previous water analysis to better provide point source locations for anthropogenic, geothermal, and naturally aqueous ions. One of the goals of this study is build on these past surveys and further understand the transition of this landscape. By synthesizing Maori oral history and modern environmental surveys, this project aims to develop an understanding of the transition of this landscape.

Background

Upper Lake catchment

The Upper Lake catchment is comprised of seven small to medium sized lakes of variable water quality created through a combination of volcanic and hydrological process. Smaller eruptions and hydrothermal events created small craters that formed natural catchment basins and larger eruptions have produced silicic caldera volcanoes and rhyolite dome volcanoes. These volcanoes are prone to landslides and subsidence features and have dammed water in the river valleys, creating the modern day lake system. As seen in Figure A-1, Lake Rotokakahi (Green Lake), Lake Tikitapu (Blue Lake), Lake Okareka are connected by stream networks to Lake Tarawera. Lakes Okaro, Okataina and Rotomahana are believed to drain into Lake Tarawera through subsurface flow.

Since the 1960s, there has been extensive land modification of the forests surrounding the lakes. With the exceptions of Lake Tarawera and Lake Okataina, the land has been transformed from indigenous biota to pastoral land and exotic plantation forestry. There has been an observable decline in water quality in most lakes in the area determined by the Trophic Level Index, which measures phosphorous, nitrogen, chlorophyll *a*, and secchi depth (EBOP, 2004). Other testing parameters include dissolved oxygen and the presence of blue-green algal blooms. As seen in Table A-1, Lakes Okaro, Okareka, and Rotokakahi are currently rated below their targeted water quality. These lakes have experienced the largest development in urban and pastoral land use, while Lakes Tarawera and Okataina have remained more forested by both natural and exotic ecosystems. The pumiceous nature of the soils and the seven-lake system maintain the character steady-flow nature of the Tarawera River outlet.

Upper Tarawera catchment

Lake Tarawera drains into the river via the Tarawera Outlet and has a mean annual flow of 7.0 m^3/s. The Outlet extension of the river that grows through Maungawhakamana Bush Reserve and flows through Kawerau City is known as the Upper Tarawera catchment. As seen in Table A-2, the valley floor is covered with a pumiceous alluvium and debris layer from the Kaharoa Ash eruption approximately 700 years ago and the more recent Tarawera Lapilli deposition by the 1886 eruption. A major flood in 1904 and multiple faults throughout the region have further shaped the river valley (Hodgson, 2004). The majority of the Upper catchment is exotic plantation forest (~34 %), but eastern stretches of the river remain indigenous forests(~33%) (EBOP, 1994). This section of the river is fed by several smaller tributaries and 3.5 km downstream of Lake Tarawera, the river enters a subterranean channel, emerging farther downstream at the Tarawera Falls. This ecological region is diverse and beautiful and amazingly, eels are known to migrate up river and through gushing subterranean waterfalls. Invasive species, tourism, and forestry are currently the most controlling forces on this beautiful landscape.

Lower Tarawera catchment

The Lower Tarawera River catchment extends below Kawerau City to an estuary environment near the town of Matata. As seen inhe river discharges in the Pacific Ocean after passing through two major types of land use modification. This section of the river is greatly affected by industrial and urban discharge. Agriculture dominates this region and farming chemicals and dairying waste runoff have potentially added many contaminants into the river, reducing water quality. History of the region suggests that modern human influence has greatly impacted the plant and wildlife that has formerly lived within the river. During the 65 km journey of the Tarawera River, the water visibly changes from clear blue water at Lake Tarawera to a yellow-brown discharge into the Bay of Plenty. Figures A 3-5 provide satellite imagery of the three catchments.

Norske Skog Site Description and Inputs

Founded only in 1953, Kawerau is a rapidly growing city of 7,000 people and served as the plant site for Tasman Pulp and Paper Factory. Since then the plant has grown to be one of the largest consumers of energy in the country and it has recently developed its own geothermal wells on site to power its 24/7, year round production. The plant’s consumption is only matched by its output of waste material. The waste disposal site is located 3.0 kilometers west of the Tarawera River and has been used as the primary solids and water treatment ponds since 1971. Since then, sludge waste from saw milling, geothermal steam, industrial cleaning, pulp and paper milling has inundated the Te Wai U o Tuwharetoa spring and Lake Rotoitipaku, traditionally *tapu* (sacred) areas. Without Lake Rotoitipaku as the regional catchment of the spring fed stream valley, water has collected along a large conglomerate barrier built to mitigate containment flow through groundwater and into the Tarawera River. As seen in Figure A-6, the A8 pond that has formed has since been infilling with pulp material and there is fear for the health of this land and its wildlife. Norske Skog, a Norwegian company has purchased the plant and faces legal issues towards years of waste management. New efforts like wetlands development and water treatment have attempted to reduce the amount of pollutants that enter the river and ocean, but larger issues stand in the way of progress. The hydrology of the region needs to be further studied to restore the life quality of the land and prevent 50 years of toxic waste from entering an important region of New Zealand.

Owners of the land where the A8 pond has built up and residents fearful of the health of the Tarawera River have demanded that wells be drilled to monitor the movement of contaminants through the region and better predict the flow of groundwater. Water sampling at this site is very useful for revealing how many anthropogenic contaminants have infiltrated the A8 pond because the spring provides a representation of the background contaminants for comparison groundwater.

The stream travels through the native bush and meanders into a marshland rich in cattails and flax. Vegetation extends 45-50 meters across this marshland and then tree and shrub land climbs far up the valley slope. The stream braids and pools through the cattails and retains its clear, cold characteristics. The stream slows in this region, moving \ less than 0.2 m/s. The insect and bird life is almost deafening in this sunny, wide V-shaped river valley. There appears to be very well developed soils in this section of the stream, rich in organic material.

The marshland flows into the A8 pond and at this convergence zone, a thick, brown sludge covers the surface. In this area, particulate matter appears to contain wood waste plumes over one meter thick. Some tall grasses grow in this sludge, but there are extensive areas of dead vegetation. The southern side of the marsh is characterized by thick sludge and very little visible surface water, while the northern side has a shallow, but fairly strong flowing stream current.

The A8 pond has dimensions of approximately 225 meters long by 200 meters wide. With an average depth of 2 meters, the overall volume of the A8 pond is around 90,000 m^3. The water is dark brown/yellow and it is difficult to see the bottom, but lake weed appears to be growing around the entire shoreline. Many waterfowl inhabit the pond and there are insects hovering across its surface. The A8 pond discharges into a drainage canal that flows into an adjacent pond.

Reeds, cattails and grasses similarly surround the Urupa pond. It is recharged from the outflow channel from the A8 drainage canal. The water is also brown/yellow in color and also contains some suspended sediments. The Urupa pond is approximate 190 meters long and 90 meters wide. With an average depth of 2 meters, the pond has a volume of 34,200 m^3.

Overall, the lake and valley down sloping stratigraphy suggests that water could potentially move through the ground and contaminated groundwater may be flowing towards the Tarawera River. As seen in Figure A-7, mitigate this flow of contaminants, two embankments were constructed on the eastern and western sides of the site to prevent water from inflowing into the river. The western embankment is approximately 20 meters high and forms the road to the dump site, There is a second, four meter wide road between the embankment and the A8 pond, which is also lined with several earth mover tires. The embankment is made up of earth, concrete materials, and a substantial amount of wood waste. The top of the embankment is covered with non-native grasses and trees and has an undulating topography, possibly due to underground subsidence. The eastern embankment is similar in composition, but shorter in height and longer in length. The entire embankment serves as the major road for the eastern side of the site. This road use has potential implications of weakening the integrity of the embankment and previous breaches may be the result of its constant use as a highway.

The waste material that fills the site is a light, gray material that is soft to the touch. It feels like a soft cardboard and contains visible paper, wood, and charcoal fragments. It is easily compacted and very absorbent. The material almost looks like dryer lint.

The Tarawera River pre-dump site is a clear, fast moving body of water. Rocks and sand cover the riverbed and some aquatic plants flourish. Mid-dump site, it retains its fast moving nature but is noticeably less clear. Post-dump site, the water has been turned brownish yellow and its flow drops slightly due to a widening of the river, Vegetation and wildlife still thrive despite the reduced water quality. Because the Tarawera River has steeply eroded banks and is known to migrate frequently, the eastern embankment and waste site are at great risk for breaching.

The waste site poses many problems from both an economic and environmental perspective. The cost of clean up will be expensive, but the potential hazard from ground water movement or Tarawera River migration will be worse as an environmental disaster. Various assessment firms have sampled the soil and water quality of the landfill and determined that the site exceeds ANZECC guidelines for drinking water. Time is running out over how to deal with this problem because the Norske Skog lease expires, the land will soon be returned to the local Maori Trust. Further study is necessary to fully understand the hydrology of the area, the chemicals that have been deposited there, and the long-term effects of this waste site.

Below Kawerau, the historic flood plains have marked the dynamic interplay between active coastal morphology and sea level change since the last glaciations of the Pleistocene epoch. Oral history of Maori communities in the Bay of Plenty and stratigraphic coring of the landscape confirm that the local topography is characterized by its ability to geologically reset itself and the Tarawera River has created and abandoned many former river channels and outlets along the coastline. The river has show to be extremely migratory across the plains and when coupled with the regions volcanic activity, it becomes apparent that the waste site is situated in an extremely poor and precarious location.

Geothermal Inputs

The area is geothermally active area and chloride springs have developed sinter terraces on the eastern shore of the Tarawera River. Many of the active geothermal features have been inundated with wood waste. This inundation is poorly understood and the natural response of the system can only be hypothesized, but attempts have been made to better recognize naturally occurring geothermal inputs in the system. Additionally, geothermal energy production discharges 0.193 m^3/s of effluent discharge into the river. Elevated chloride levels have been previously observed from the addition of geothermal effluent (Mroczek, 2005).

The nature of the geothermal contaminants depends on the influence of pressure, temperature, rock composition and regional hydrology. Calcium, lithium, mercury, potassium, sodium arsenites, bicarbonates, borates, carbonates, chlorides, silica, sulphates, sulphides, ammonia, carbon dioxide, hydrogen sulfide, and methane are commonly associated with geothermal contamination in the TVZ. Lower dissolved oxygen levels and the associated ground water contaminants can further be used to separate anthroprogenic inputs from the naturally occurring, background geothermal contaminants (McKenzie and al, 2001).

Agricultural Inputs

This Lower Catchment is well suited for agriculture. Approximately, 29% of the land area is used for mixed cropping and pastureland. Production of arable and herbage seed crops currently occupies a land area of about 225,000 ha throughout New Zealand. The Bay of Plenty region of the central North Island currently comprises about 35% of the total New Zealand area in crop production (EBOP, 2004).

Continuous arable cropping of land on the Bay of Plenty is not common as this results in a decline in soil fertility, a breakdown of soil structure, a decrease in crop yields and an increased risk of extensive loss of topsoil through wind erosion. Consequently, a mixed cropping system of farming is more common, in which arable crops are grown in rotation with ryegrass/white clover, either as grazed pastures or as seed crops. During this rotation, there are large fluctuations in soil properties, especially in nitrogen fertility (Schipper et al., 2008). Leaching losses of nitrate vary for the different crops in the rotation. These nutrient variations are related to a number of factors including the preceding crop management practices and current dairying, wool, and beef farming.

Methods

The sampling methodology conducted in February 2008 was based on Kristen Tull's June 2007 study on surface water features at the Norkse Skog waste sample site. Water quality analysis of both ground and surface water features is necessary to understand how contaminants travel through the local geology. Because surface water is directly connected to ground water recharge, it is necessary to understand aqueous inputs across the entire system before contaminant persistence can be further studied (Tull, 2008).

Eighteen sampling locations were selected 65 km stretch of the Tarawera River that represented contrasts in biodiversity, geography, geothermal influences and human land use. This contrast of sampling locations is used to identify naturally occurring constituents versus geothermal and/or anthropogenic introduced components in ground, surface, and spring waters. Testing parameters include oxygen and hydrogen isotopes anions, cations, and trace metals. GPS survey of each site was used to locate and understand source point contamination. A description of each site (size, shape, depth, local plant life, water clarity and color) and climatic conditions were also recorded in Appendix C (water collection logs).

To minimize sample contamination, samples were collected from those deemed less contaminated to most contaminated. In keeping with this logic, February samples were collected from the Te Wai U o Tuwharetoa through the Norske Skog waste site towards the Tarawera River. Samples were then collected from the Tarawera Outlet down to the Bay of Plenty. April sample collection was similar to those conducted in February, but samples were prepared using a procedure described later.

Sampling protocol is described as clean hands/dirty hands to ensure the quality of sample. The clean hands person essentially prepares and maintains collection equipment.

The dirty hands person essentially operates the equipment and prepares the sampling in a technique that follows.

All testing instruments were tested and cleaned with DI water to prevent cross-contamination. High-density polyethylene bottles were acid washed and labeled to ensure quality. During collected precautions were taken to limit sample exposure to atmospheric contamination. Preparation of bottles is described in the table below.

1. Uncapped all bottles and soaked them in 5M HNO_3 solution for 24 hours.
2. Rinsed each bottle three times with ultra pure water and then filled each bottle with ultra pure water. The ultra pure water sat in the bottle for approximately 48 hours.
3. Dumped the ultra pure water and then rinsed each bottle two times with more ultra pure water.
4. Placed bottles and caps on tray and dried in a clean oven at 70ºC for approximately 2 hours.

Blanks and Acidified Samples

February samples were prepared in the following manner. One field blank and two acidified samples were collected at each water body. The collection bottle was field rinsed 5 times. Blank 1 was not filtered and represented water directly from the source. Samples 2 and 3 were filtered and acidified with 0.06 mL of nitric acid. Sample 2 represents our anion sample and Sample 3 represents the cation sample. These samples were injected and filtered through a syringe. Samples were put on ice immediately after collection and refrigerated until further testing occurred. During April, a blank was filtered and stored and a second sample was filtered, acidified with nitric acid and stored (Tull, 2008).

Field Collection

The field collection procedure involved a 1.0 L bottle that was field rinsed at each site. The bottle was submerged in the water for five seconds and filled. The water was then dumped downstream of the collection site. This field rinse procedure is repeated five consecutive times and the water from sixth submersion is used.

Field measurements included pH, dissolved oxygen, temperature, Total dissolved solids, depth, and an estimation of flow rate. To conduct tests, each instrument was DI rinsed and when possible, measurements were taken at the water source. If the sample site was less accessible, measurements were taken from the collection bottle.

Ion Chromatography

Ion chromatography (IC) is extremely useful in assessing common inorganic anions in water and has been used to assess the water quality of wastewater, drinking, ground and surface water since the mid-1980s. Trace anion concentrations (NO_3, SO_4, HCO_3, Cl, Br) were determined by ionic chromatography (IC) on a Dionex ICS-2000 machine calibrated using self made standards and Milli-Q water. Anion exchange chromatography is used to measure concentrations in the parts-per-million (ppm) range. By inserting liquid standards of known concentrations, ion concentrations of collected unknowns can be determined. Ionic species are unique and behave differently when they interact with a resin. Ions are pressurized in a chromatographic column and are absorbed by the column constituents. Separation occurs in the column when the eluent ion extraction liquid runs through the column and the retention time of each species determines its concentration. Deionized water is then run through the system to purge the chamber of contaminants.

Ion chromatography (IC) is used worldwide and has proven to be an effective tool for measuring anion concentrations in water. While IC was the optimal choice for water quality analysis at the University of Auckland, NZ, there are other methods to test anion concentrations for water quality along the Tarawera River. The machine was effective in measuring concentrations in the ppm, but concentrations lower than this were not recorded.

Atomic Absorption Spectroscopy

Atomic Absorption Spectroscopy (AAS) determines cation concentrations by measuring the amount of energy in the form of photons that are absorbed by a sample. Variations in the photons and their concentrations change the wavelength of light passing through the sample. The change in wavelength is used by the AAS to create peak energy absorption readouts. Because each atom has distinct peak energy, the readouts can be compared and the types of cation present and its concentrations can be determined.

Unlike the Ion Chromatography (IC) machine, the AAS machine focuses on one specific cation during a trial run. Light is transmitted through a cathode tube designed to receive a specific atom. This cation specific tube must heat up for 30 minutes before use. For this section of the project, eight cations were measured: Na, K, Zn, Mg, Cd, Ni, Ca, Pb. The AAS is first calibrated with standards of known cation concentrations. These standards were prepared in the same manner as the standards used for IC. Three working standards were used to produce a calibration curve. A record of the each atom's degree of absorbance is compared to the calibration curve and sample concentrations can be extrapolated.

Standards

Standards are water samples containing known concentrations of ions. Standards for each anion and cation were prepared from 1000 mg/L stock standards. Two composite working standards were prepared at lower analyte concentrations. These standards were measured by mass and their concentrations were calculated. In total, three standards were used. Specific standard values were not necessary because anion concentrations were estimated from the work of Kristen Tull (Tull, 2008).

Data Analysis

Each sample was analyzed for major and minor ions and hydrogen and oxygen isotopes. Cations and anions analyses were conducted in the water quality laboratories within the School of Geography, Geology, and Environmental Science at the University of Auckland under the supervision of Angela Slade.

Sample Location Notes

Samples were numbered 1 to 18 and represent a physical location between Lake Tarawera and the estuary discharge into the Bay of Plenty (Figure A 3-5). Sample 1 is the only sample taken from the Upper Lake Catchment. Samples 2 through 3 are from sites the between Tarawera Outlet and Kawerau City. Samples 4 through 14 represent collection sites sourced from Te Wai U o Tuwharetoa spring through the solid materials waste site. Samples 12 and 13 represent water collected directly from the Tarawera River upstream and downstream of the waste site. Site 14 is water collected from a geothermal spring along the banks of the Tarawera River (Figure A-7). Samples 15 through 18 represent water collected below the Tarawera River from treatment ponds to the Bay of Plenty.

pH

pH is a measurement of acidity or alkalinity of a solution determined by the concentration of dissolved hydrogen ions (H^+) relative to hydroxide ions (OH^-). The pH index scale ranges from numerical values -1 to 14. Solutions with pH values from -1 to 7 are acidic; a value of 7 is considered neutral; and values 7 to 14 are basic solutions (EBOP, 1994).

Local vegetation, surface runoff, geothermal inputs, and soil types influence the water quality and pH value at a survey. Ranges of pH values between 5 and 9 are generally accepted as levels that are suitable for most aquatic life. As seen figure B-1, February and April pH values were within this acceptable range. February pH values were higher at water collection sites 6 through 11, making these waters more basic than any other site in the Tarawera River cachment. Stank et al. (2006) suggests the increased alkalinity at these sites may be attributed to the mixing of pulp and paper waste. The most acidic values were found at sites 4 and 5 along the Te Wai U o Tuwharetoa spring. Discharged sulphide and ammonia from geothermal springs has the potential to lower the pH of groundwater, and these sites may naturally be more acidic than the Tarawera River (Stanko and Angus, 2006).

As seen in Figure B-2, some seasonal variation was observed. These varying pH values for each month may be due to natural processes like the torrential rainstorm that occurred during field collection in April of 2008. On this day, surface run off was observed and the Tarawera River was visibly closer to peak flow than in February. February samples were collected on a hot sunny day, during a summer period of little precipitation. Despite these different collection environments, there are still some observable trends in pH variation along the Tarawera River. Further study is recommended to better understand these trends in order to improve water quality for aquatic life.

Dissolved Oxygen

Because the Tarawera River has long been recognized for its viable food stocks, low dissolved oxygen (DO) concentrations are of great concern to Environmental Bay of Plenty. DO levels below 5.0 g/m^3 (50% DO) are considered too low to support aquatic life (Dell, 1993). For this study, dissolved oxygen is measured as %DO; the dissolved oxygen per saturation potential of a liquid. As seen in appendix B, figure 3, measurements between February and April greatly varied in their dissolved oxygen contents. February DO concentrations were highest from sites around the A8 and Urupa ponds and along the Upper Tarawera River. This suggests that water survey sites from still water bodies were more saturated with oxygen than faster moving water sites along the lower Tarawera River. The lowest DO concentrations were recorded along the Lower Tarawera River, however, these levels are still high enough to support aquatic life. April DO concentrations were on average lower than February levels, but as seen in Figure B-2, similar trends are apparent. Higher DO levels are fond around the A8 Pond and Urupa ponds and waters closer to source the river's source. Lower DO levels are again observed at sites along the Lower Tarawera catchment.

Though nitrates were not recorded in high concentrations, lower DO levels of the waters of the Lower Tarawera could be attributed to some algal growth and eutrophication of the water around the Rangitiki Plains (EBOP, 1994). Lower observed April DO concentrations may be attributed to newly input surface water runoff from the torrential rain showers that occurred that day.

Total Dissolved Solids

Total dissolved solids (TDS) measurements provide the relative abundance of organic and inorganic substances that are suspended in a water body. While TDS is used to suggest fresh water quality, it is not a specific determinant of pollutants. Sources for TDS include waste treatment, agricultural runoff, salt water mixing, storm water runoff, and soil leaching.

Previous studies by Chandra et. Al (2006) suggest that TDS levels are elevated by pulp and paper waste mixing. As seen in figure B-5, there was a large variation in TDS measurements between February and April (Stanko and Angus, 2006). None of the February sites exceeded the 1000 mg/L TDS drinking water standard (Ministry of Health, 2005). It is noted that geothermal spring survey site 14 had the highest recorded TDS for the month of February. April TDS measurements were up to eight times higher than those in February and this may be attributed to surface runoff from that day's rainfall.

As seen in Figure B-6, despite the large differences between each month's TDS measurements, several trends are apparent. Site 14 again has the highest concentration of total dissolved solids, likely attributed to the geothermal influences of the site. For both months, the Tarawera River survey sites had higher than average TDS measurements. This is likely due to the volume of particles that flow into the river from the entire river catchment. The waste site survey points revealed lower than average TDS measurements for both months despite the visible sludge contained in the water bodies. These lower TDS values for waste site waters may be attributed to the original purity of water from the Te Wai U o Tuwharetoa spring. For each month, the Te Wai U o Tuwharetoa spring at site 4 had the lowest TDS measurements.

Chloride

Chloride (Cl^-) ions are input into the Tarawera River environment from several natural and anthropogenic sources. Chloride naturally occurs as salt minerals and may be the result of salt-water intrusion or surface runoff from chlorine rich minerals. Soil chemistry of the TVZ suggests that chloride is associated with the local soil and groundwater chemistry (McKenzie and al, 2001). Chloride is also associated with geothermal effluent from power generation and previous surveys have determined that is found in waters around the waste site (Mroczek, 2005). The Pulp and Paper Mill uses chlorinated compounds to bleach paper products and waste from this process is disposed of in the waste site. ANZECC guidelines suggest a concentration of 400 ppm dissolved chloride in a water body is acceptable for recreational use (PIMC).

As seen in Figure B-7, in the month of February, none of the 18 sites recorded chloride concentrations that exceeded ANZECC guidelines. During the April survey, sites 14 and 15 exceeded the 400 ppm recreational use standard. This may suggest that water associated with geothermal springs may be the largest point source of chloride input into the Tarawera River.

Sulfate

Sulfate ions are inorganic molecules that acidify their environments and are the result of the dissolution of salt into sulfuric acid. At the Norske Skoge plant, sulfuric acid is used in the pulping process and creates a dry material that ends up in the waste site. Sulfuric acid is also associated with geothermal activity (McKenzie and al, 2001). Surveys by Sinclair Knight Merz (SKM) have previously found elevated sulfate levels in the ground water around the waste site.

None of the 18 water sites exceeded ANZECC guidelines for sulfate concentrations for both February and April (PIMC, 2000). As seen in Figure B-8, February and April concentrations were similar at most survey sites. Waste site sulfate concentrations were lower than sites along the Tarawera River. Sites related to geothermal springs saw elevated sulfate levels, however, these levels are still well within the acceptable range of dissolved sulfate.

Calcium

Calcium is an essential component for life and is commonly found in groundwater associated with geothermal activity of the Taupo Volcanic Zone and dissolved in seawater (McKenzie and al, 2001). Dissolved calcium (Ca^{2+}) cannot exceed 200 ppm in drinking water according to ANZECC guidelines (PIMC, 2000).

As seen in Figure B-9, similar concentration variations were observed in February and April water samples, however concentrations did not exceed ANZECC guidelines. Calcium levels were highest in survey sites along the Tarawera River and this is likely due to mineral leaching from soil around the 984 km^2 catchment. Water from site 15 below the water treatment ponds contained highest concentration for both February and April.

Potassium

Potassium is an alkali-Earth metal commonly associated with seawater, fertilizers, and igneous soils (McKenzie and al, 2001). Potassium also provides an important biological role in cation exchange and is an essential element in plant growth. Currently, there are no ANZECC guidelines for dissolved potassium (K^+) in water for recreational use. As seen in Figure B-10, potassium concentrations were similar in the February and April water samples. Waste site concentrations were slightly lower than the Tarawera River concentrations. The observed dissolved potassium concentrations are considered to pose no threat to human life.

Magnesium

Magnesium is an alkaline-Earth metal commonly found in seawater and igneous minerals. Magnesium is an essential component of nucleic acid and is fundamental to the DNA of all life. Currently, there are no ANZECC guidelines for dissolved magnesium (Mg^{2+}) in water for recreational use. As seen in Figure B-11, there were some similarities between February and April concentrations. River sites contained more dissolved magnesium than waste sites around the A8 and Urupa ponds. Lower Tarawera catchment sites contained the highest concentrations of magnesium.

Sodium

Sodium is most commonly associated with sodium chloride (NaCl) and is found in large quantities in the Earth’s oceans and igneous rocks. Sodium plays an important biological role in fluid transport and is a necessary dietary requirement. Sodium hydroxide is used during the pulping stage of paper production, ANZECC guidelines for dissolved sodium (Na^+) suggest 300 ppm is an acceptable concentration for recreational freshwater (PIMC, 2000).

As seen in figure B-12, February and April concentrations were very similar. Only site 15 of the April samples exceeds ANZECC guidelines. This site is directly below the water treatment ponds and may be the result of some sodium based industrial solvent used in the treatment of wastewater (Bruere, 2003).

Cadmium

Cadmium is a transition-Earth metal that is found in zinc ores and is known to cause cancer. Cadmium is commonly found as a component of industrial dyeing and is most frequently is absorbed by humans through cigarette smoking. Past surveys have indicated that pulp and paper mill discharge may be releasing cadmium into the groundwater around the waste treatment sites (SKM, 2005). ANZECC guidelines limit cadmium concentrations to 0.002 ppm for drinking water.

As seen in figure B-13, cadmium concentrations exceeded ANZECC guidelines at several sites around the Tarawera River. During February collection, four sites exceeded the 0.002 ppm ANZECC guideline (PIMC, 2001). Sites 1 and 18 had highest cadmium levels during February and waste sites around the Urupa pond and below the water treatment ponds recorded the greatest April cadmium concentrations. There are some similarities between February and April samples, but trends are difficult to observe. Groundwater may be picking up cadmium as it moves through the waste material, but further study is necessary to better understand point sources of cadmium leaching.

Zinc

Zinc is a necessary component of many biological functions and ion exchange processes. While zinc is essential for human life, higher concentrations can disrupt ion exchange in living organisms and lead to zinc toxicity. Zinc is used as during the pulping process at the Norske Skog mill. Barrels containing large quantities of zinc sulphide are believed to be buried somewhere in the waste site, creating a point source for high levels of zinc (SKM, 2005).

As seen in Figure B-14, zinc concentration at some sites exceeded ANZECC standards. February river samples and Te Wai U o Tuwharetoa spring water contained elevated zinc levels. For both February and April, Sites downstream of the waste and water treatment sites had zinc concentrations that suggest an anthropogenic input of dissolved zinc (Zn+). Wastewater effluent may contain higher concentrations of zinc and be the greatest source of zinc the local environment. Elevated zinc concentrations were not observed in the waste site or near the embankment.

Lead

Lead is a valuable heavy metal that is used in many types of industries at the Norske Pulp and Paper Mill. It is a primary component of the pulping process of to refine wood and can accumulate in the wood waste that ends up in the dry materials landfill. Lead is resistant to corrosion and it may be found in the metal barrels that contain zinc sulfide buried in the eastern embankment (GES, 2004). High dissolved lead (Pb^{2+}) concentrations have also been observed in the pulp and paper mill effluent wastewater. Lead leaching into drinking into the Tarawera River greatly threatens water quality and high concentrations can be toxic to humans and other wildlife. ANZECC guidelines limit 0.0034 ppm dissolved lead in drinking water.

As seen in Figure B-15, every site exceeded ANZECC guidelines for drinking water. Lead concentrations were observed to increase from source waters of the Upper Lakes through the plantation forests. In February, site 4 Te Wai U o Tuwharetoa spring water contained 1.162 ppm lead, the highest recorded lead level of the study, however the April sample contained lower than average lead. As seen in Figure B-16, waste site water samples were observed to have lower than average lead concentrations. Water samples from the Lower Tarawera River contained higher than average lead concentrations. These trends are generalized and vary by month and further study is needed to observe dissolved lead concentrations.

Conclusion and Future Work

This study was successful in that it provided an opportunity to develop my own water quality study along the Tarawera River. Valuable gains were made in my understanding of water chemistry and project procedure. Additional successes were made in building upon previous site assessments of the Norkse Skog waste site. It is the author's hope that this research will be useful and supply the local iwi with information about ground water quality.

Many contaminants are water-soluble and can easily move through pumicious soils as ground water, making point source location extremely difficult. Procedures and experiments were conducted to try to assign numerical values to many anions and cations that can reduce water quality. During this process, some trends became apparent that suggest the current state of the Tarawera River and more specifically, points sources for contaminant inputs. New information about seasonal variations in water chemistry has been collected and more data provides a better understanding of the extent of contamination in water bodies in and around the Tarawera River.

Though this study has proven that some contaminants exceed ANZECC guidelines, others were found to be well within the acceptable range for recreational water quality standards. Because of the toxic nature of these higher concentrations, further cleanup and chemical leaching mitigation is necessary to ensure the safety of those living around the Tarawera River.

Future study of the waste site's drainage canal through the A8 toe drain may provide the best evidence of what is migrating through the ground water. Concentrations of each cation were higher at the toe drain than any other site. The toe drain sample, however, was not included in this study because water collection only occurred during February. This sample had concentrations an order of magnitude higher than at any other site, suggesting that the A8 toe drain is effective at collecting and transferring contaminated water to the water treatment ponds. These high concentrations may be the result of many volumes of runoff and ground water building up around the drain. Further water sampling around this site would better confirm this and determine if contaminated water may be escaping somewhere near the drain.

While this survey's results add to past assessments of the land, it is clear that further observation is necessary to monitor the elevated concentrations of potentially harmful contaminants contained in the water around the Tarawera River. It is clear that recognition needs to be given to the dynamic nature of hydrology, geology and related geothermal influences on the entire river catchment and more sample sites are needed to better refine the distinction between anthropogenic and geothermal contaminants.

Bibliography

Bruere, A. 2003. Pulp and Paper Mills in the Bay of Plenty, Bay of Plenty Regional Council, Whakatane. 23

Dell, P.M. 1993. Tarawera River: Dissolved Oxygen Levels, A report to the Chairman and members of the Environmental Monitoring Committee meeting of 16 March 1993, Environment BOP. Bay of Plenty Regional Council, Whakatane

Environment BOP 1994 (1 February 2004) Regional Plan for the Tarawera CatchmentL :and Use Capability Classification, Bay of Plenty Regional Council, Whakatane, 131-150.

Environment BOP 1994 (February); Oxygen summary for Tarawera River Produced by Environment BOP for the Tarawera River. Bay of Plenty Regional Council, Whakatane

Environment BOP 1994 (September) Draft Tarawera River Regional Plan: Water Quality Factors. Bay of Plenty Regional Council, Whakatane, 174-194.

Environment BOP 2004 Bay Trends 2004: Report on the state of the Bay of Plenty environment. Bay of Plenty Regional Council, Whakatane, 1-90.

Gwilym Environmental Services (GES). March 2004. Investigation of Subsurface Conditions at the Upper Embankment Within the Tasman Primary Solids Waste Disposal Area. Consulting report). KT 6.

Hodgson, K. A., and I.A. Nairn. 2004. The Sedimetnation and Drainage History of Haroharo Caldera and the Tarawera River System, Taupo Volcanic Zone, New Zealand. Environment BOP. Bay of Plenty Regional Council, Whakatane. 1-16.

McIntosh, J 1994 (July) Tarawera River Regional Plan Technical Investigations – Water Quality Component, Environment BOP. Bay of Plenty Regional Council, Whakatane

McKenzie, E. J., K.L. Brown, et al. 2001. Trace metal chemistry and silicification of microorganisms in geothermal sinter, Taupo Volcanic Zone, New Zealand. *Geothermics* **30**: 483-502.

Ministry of Health 2005 (August) Drinking-water Standards for New Zealand, Ministry of Health, Wellington. 131.

Mroczek, E.K. 2005. Contributions of arsenic and chloride from the Kawerau geothermal field to the Tarawera River, New Zealand. *Geothermics* **34**: 223-238.

Primary Industries Ministerial Council (PIMC) and Natural Resource Management Ministerial Council. 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality: Chapter 5 Guidelines for Recreational Water Quality and Aesthetic.

Schipper, L.A., and A. McGill. 2008. Nitrogen transformation in a denitrification layer irrigated with dairy factory effluent. *Water Research*. 1-7.

Sinclair Knight Merz (SKM. 2004. Primary Solids Waste Landfill: Assessment of Geothermal Risks. (Consulting report)

Stanko, J.P., and R.A. Angus. 2006. Paper Manufacture and Its Impact on the Aquatic Environment, *Review of Environmental Contamination and Toxicology* **185**:67-92.

Tull, K., and A. Vengosh. 2008. “Mini-superfund” Site in Kawerau, New Zealand: A Closer Look at Water Quality. (Masters project for the Mast of Environmental Management degree in the Nicholas School of the Environment and Earth Sciences of Duke University), 1-53.

Appendix A:
Table A-1 Lake Quality as determined by the Trophic Level Index (TLI)

	TLI	State
Lake Rotokakahi (Green Lake)	**3.2**	**M**
Lake Tikitapu (Blue Lake)	**3.2**	**O**
Lake Okareka	**3.3**	**M**
Lake Okaro	**5.4**	**ST**
Lake Okataina	**3.0**	**O**
Lake Rotomahana	**3.8**	**M**
Lake Tarawera	**2.9**	**O**

Mesotrophic Lake Traits
- **Clear water**
- **Intermediate algal production.**
- **Medium nutrient levels**

Oligotriphic Lake Traits
- **Clear and drinkable water.**
- **Low algal production.**
- **Low nutrient levels.**

Supertrophic Lake Traits
- **Reduced water quality.**
- **Nitrogen and phosphorous saturation.**
- **High algal growth.**
- **High nutrient levels.**

Table A-2

Soil Types	Area in Soil Coverage (ha)	% Coverage
Tarawer Ash and Lapili	44,280	45
Rotomahana Mud	12,800	13
Kaharoa Ash	22,800	12
Alluvial Soils	14,760	15
Other Soil Tpyes	14,760	15
Total	98,400	100

Appendix B:

Figure B-1. pH values at 18 survey sites.

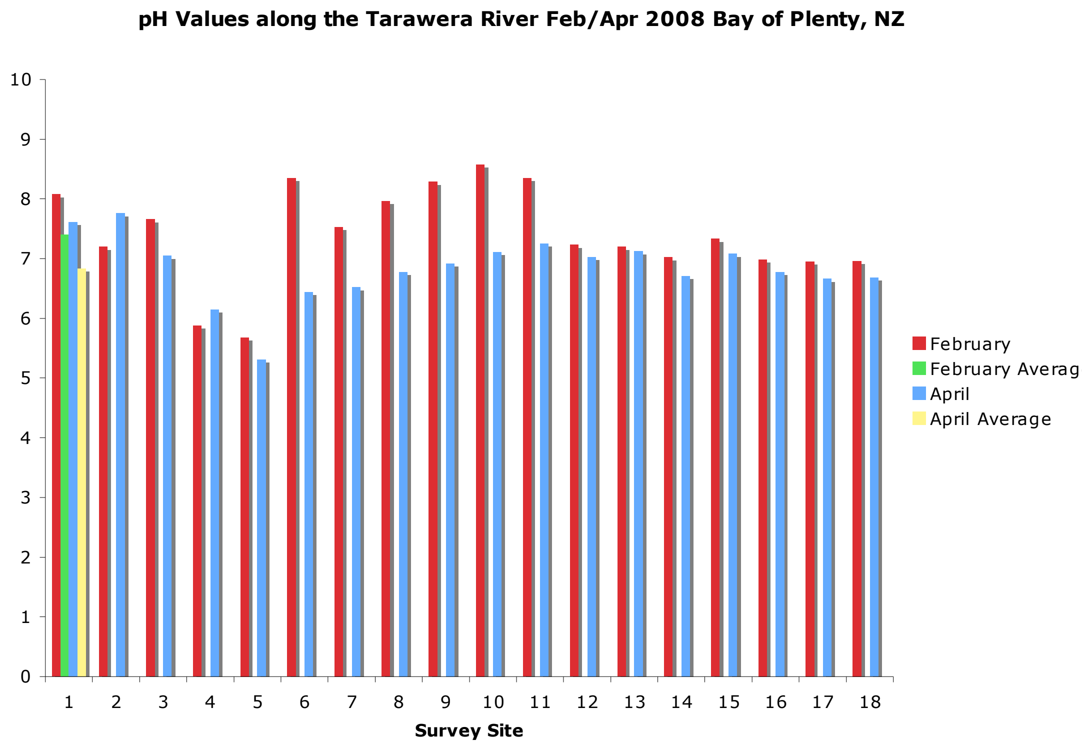

Figure B-2. pH Variances at 18 survey sites.

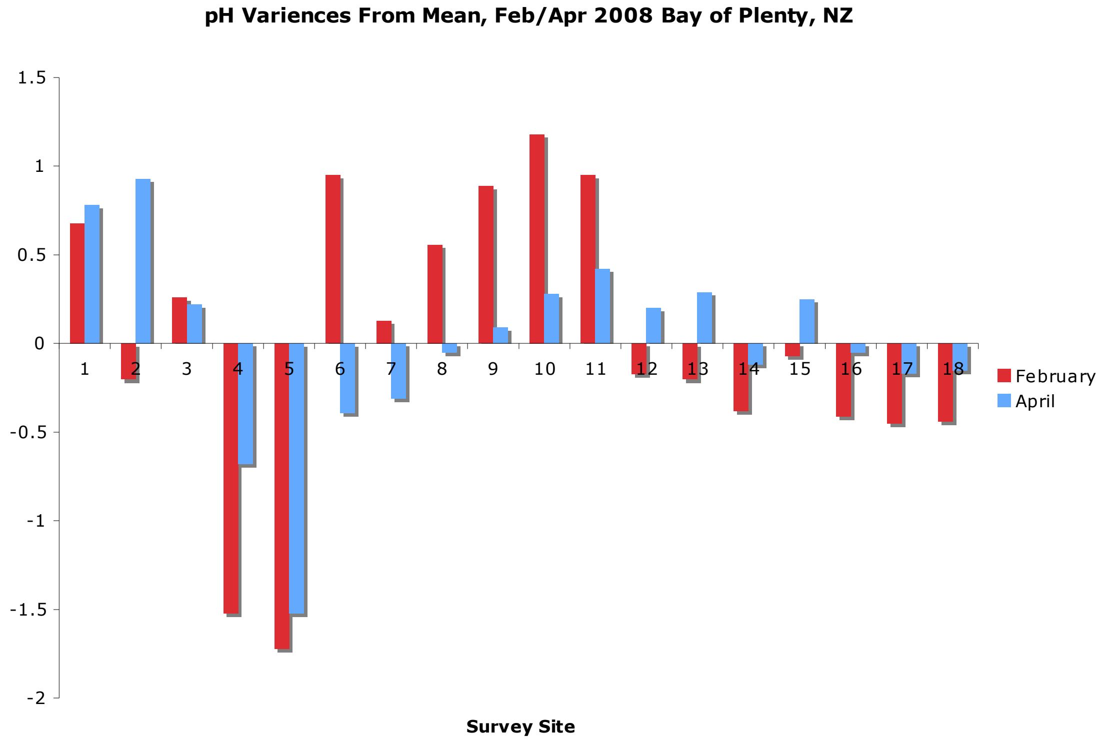

Figure B-3. Dissolved oxygen values at 18 survey sites.

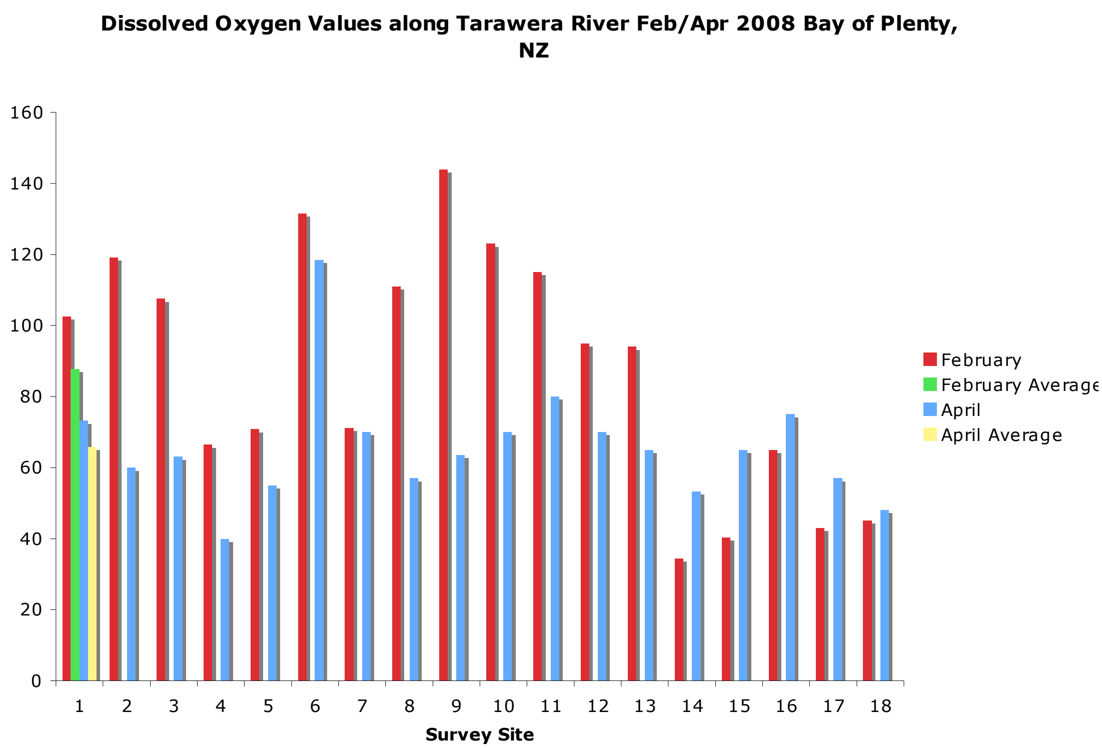

Figure B-4. Dissolved oxygen variances from 18 survey sites.

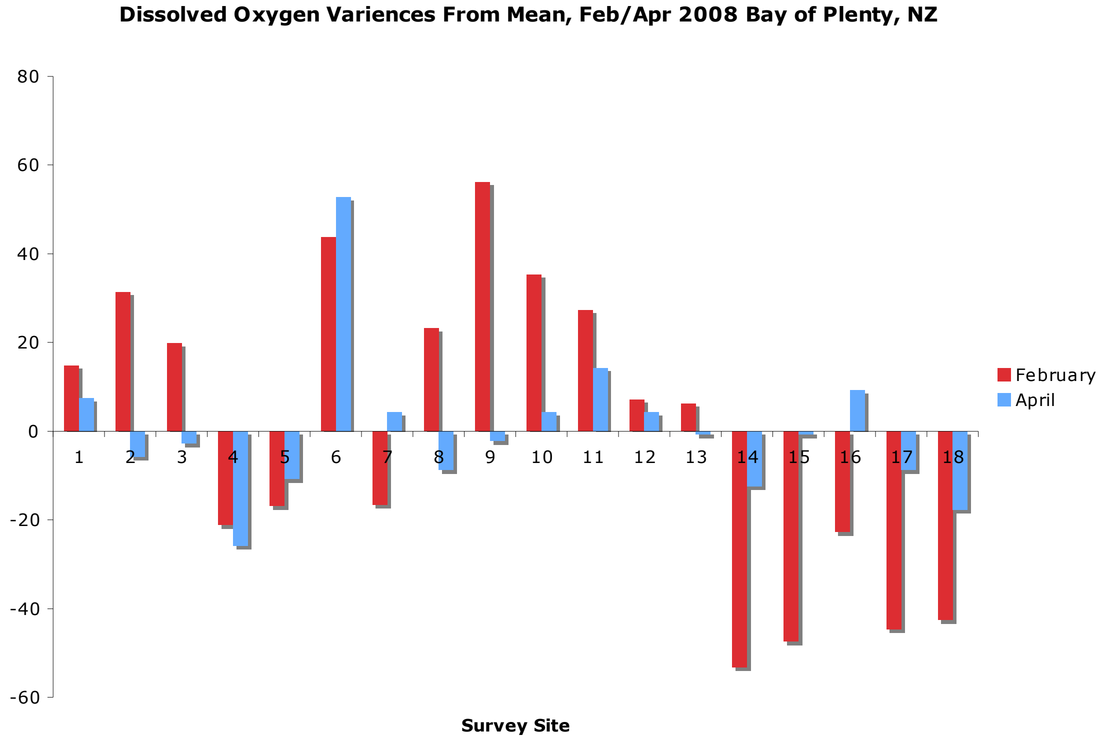

Figure B-5. Total dissolved solids at 18 survey sites.

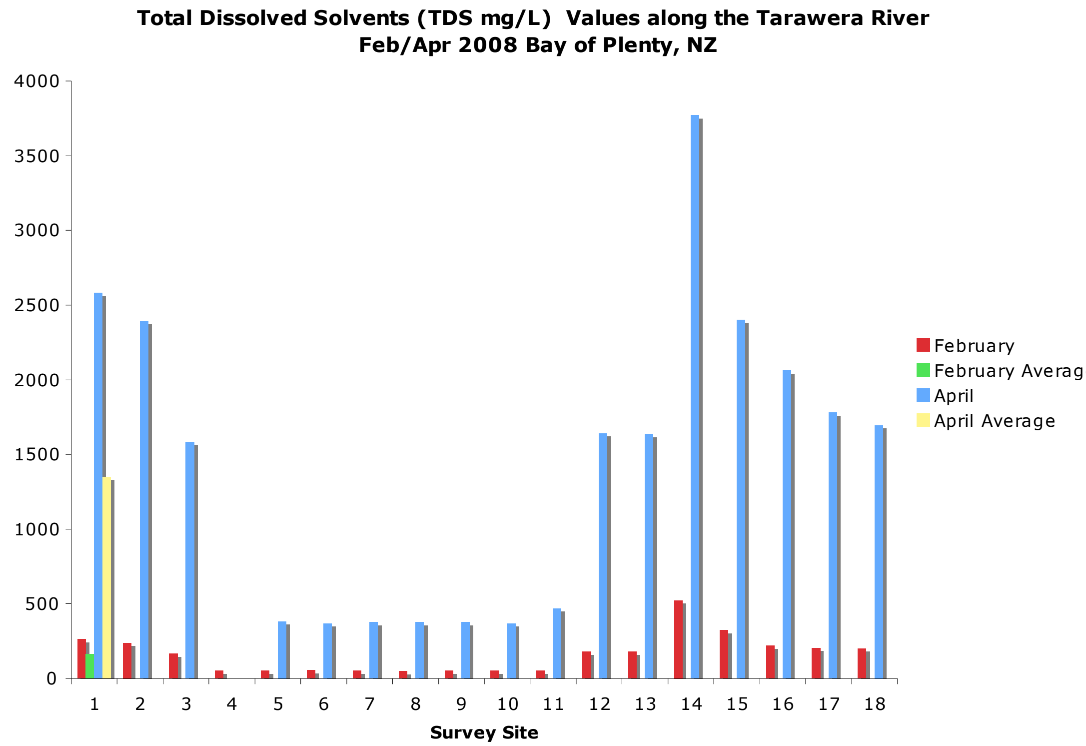

Figure B-6. TDS variances at 18 survey sites.

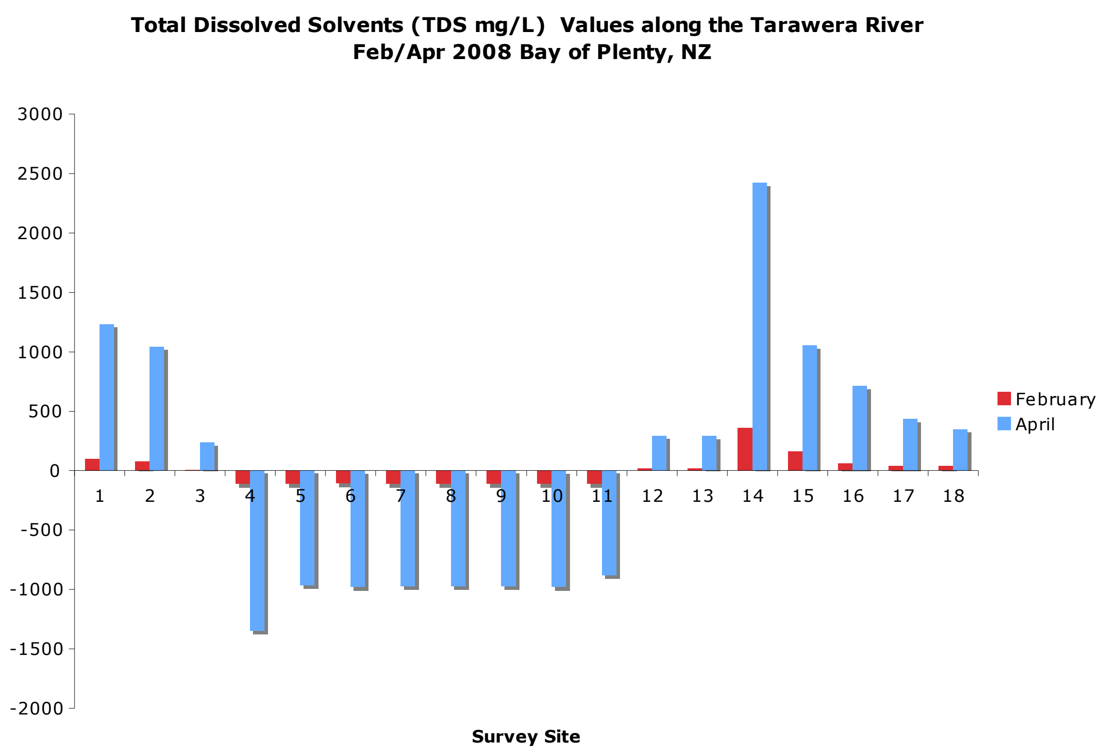

Figure B-7. Chloride concentrations at 18 survey sites.

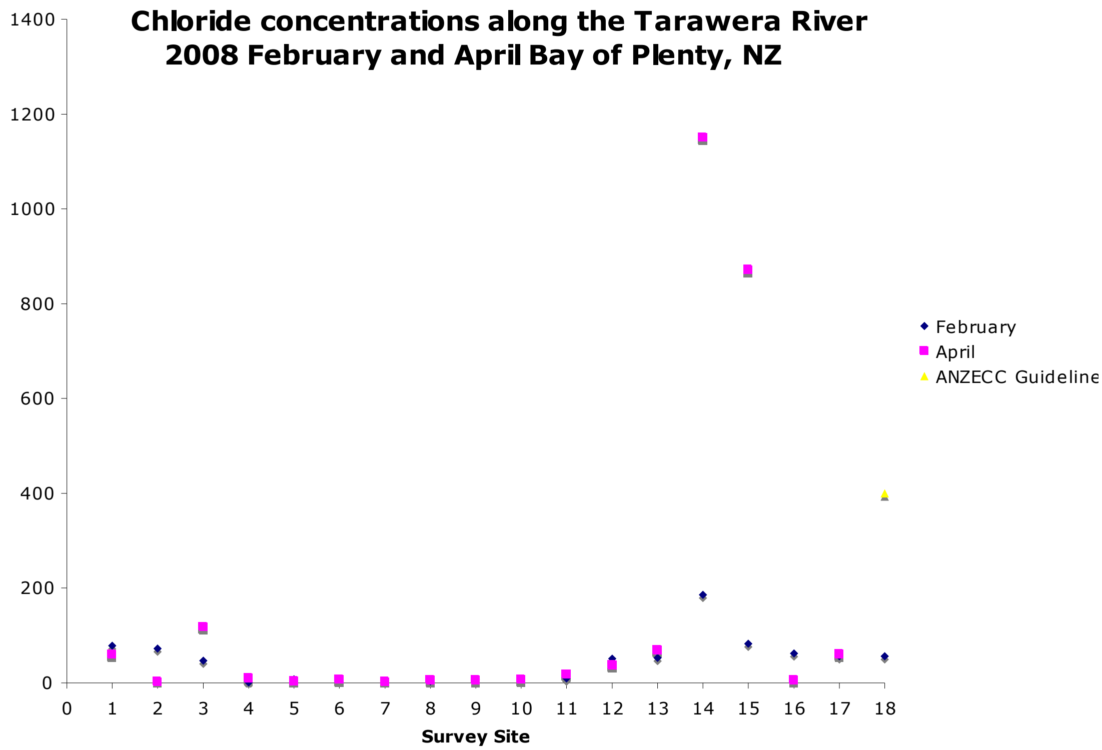

Figure B-8. Sulfate concentrations at 18 survey sites.

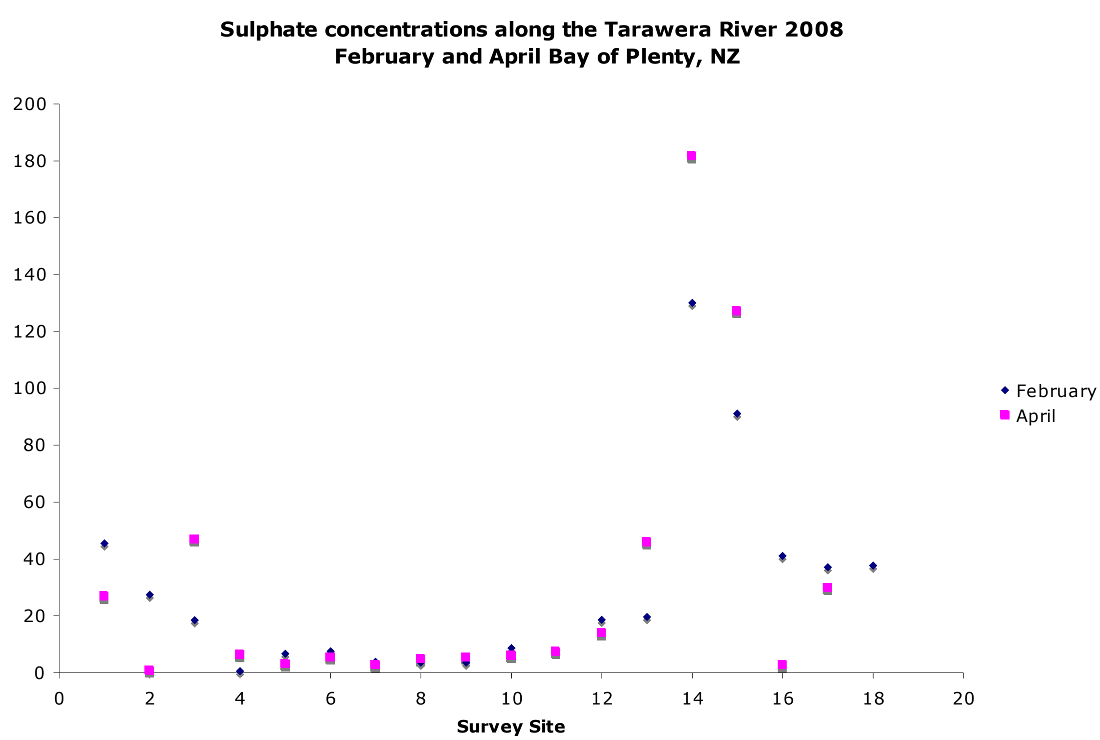

Figure B-9. Calcium concentrations at 18 survey sites.

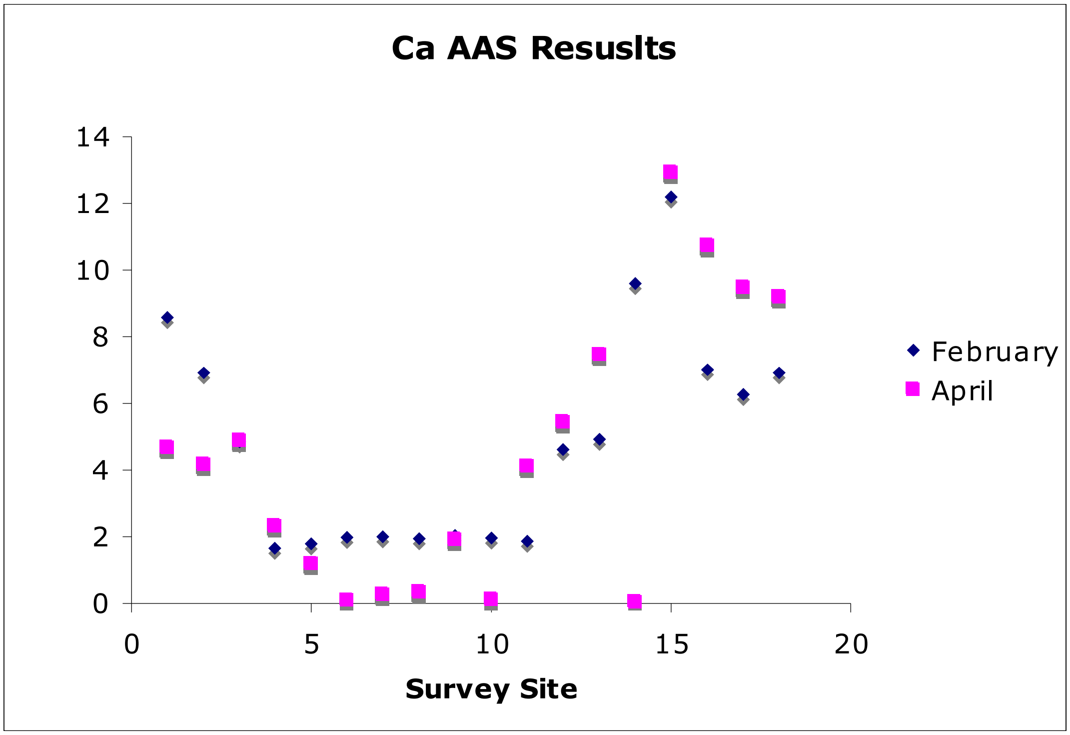

Figure B-10. Potassium concentrations at 18 survey sites.

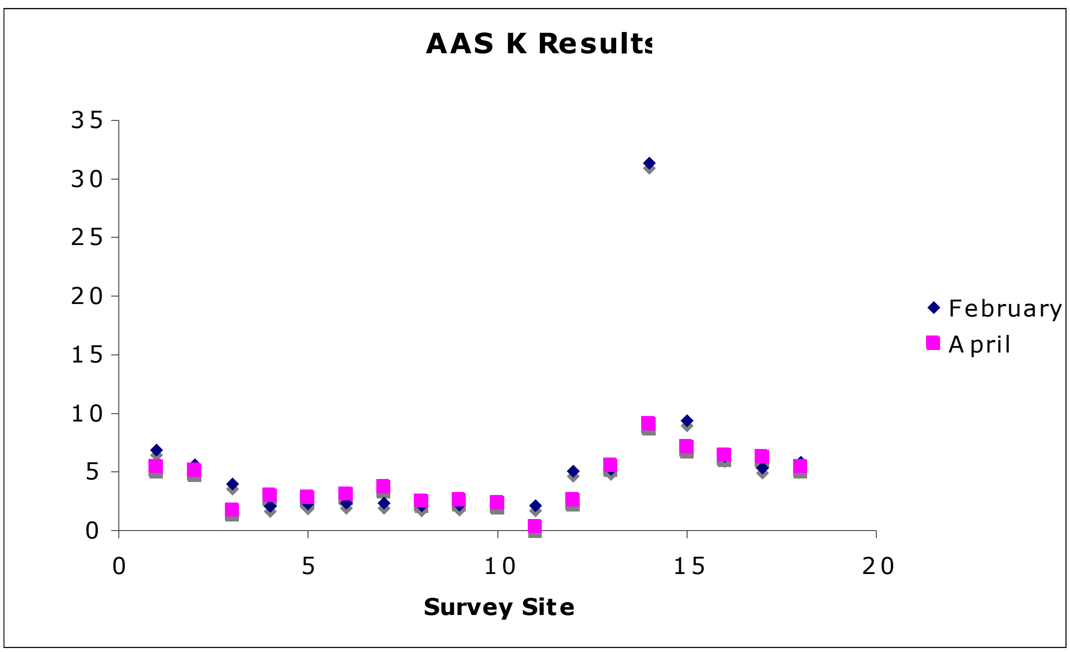

Figure B-11. Magnesium concentrations at 18 survey sites.

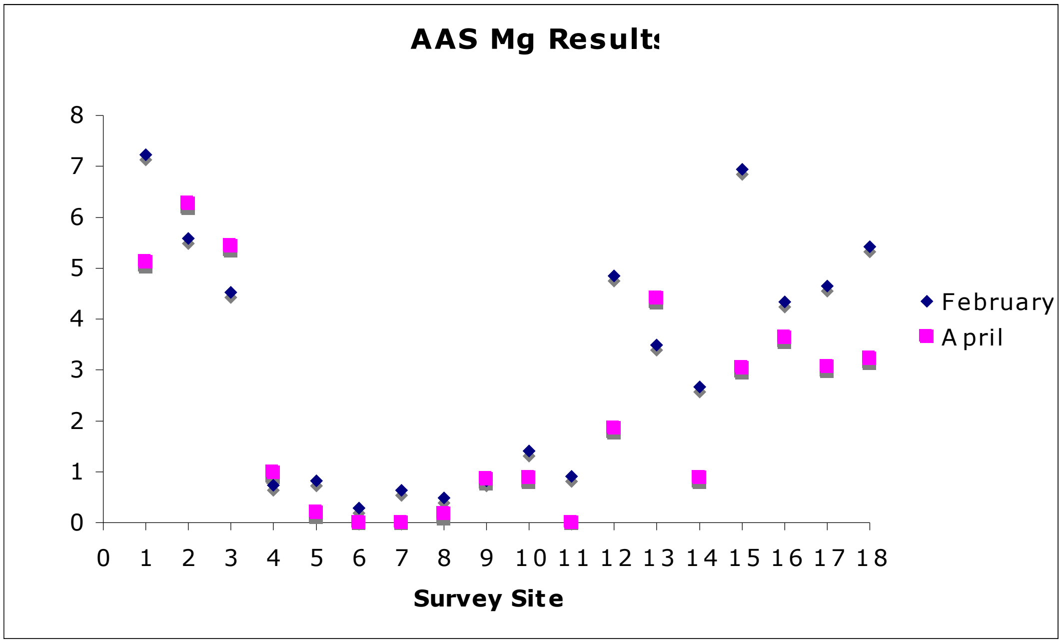

Figure B-12. Sodium concentrations at 18 survey sites.

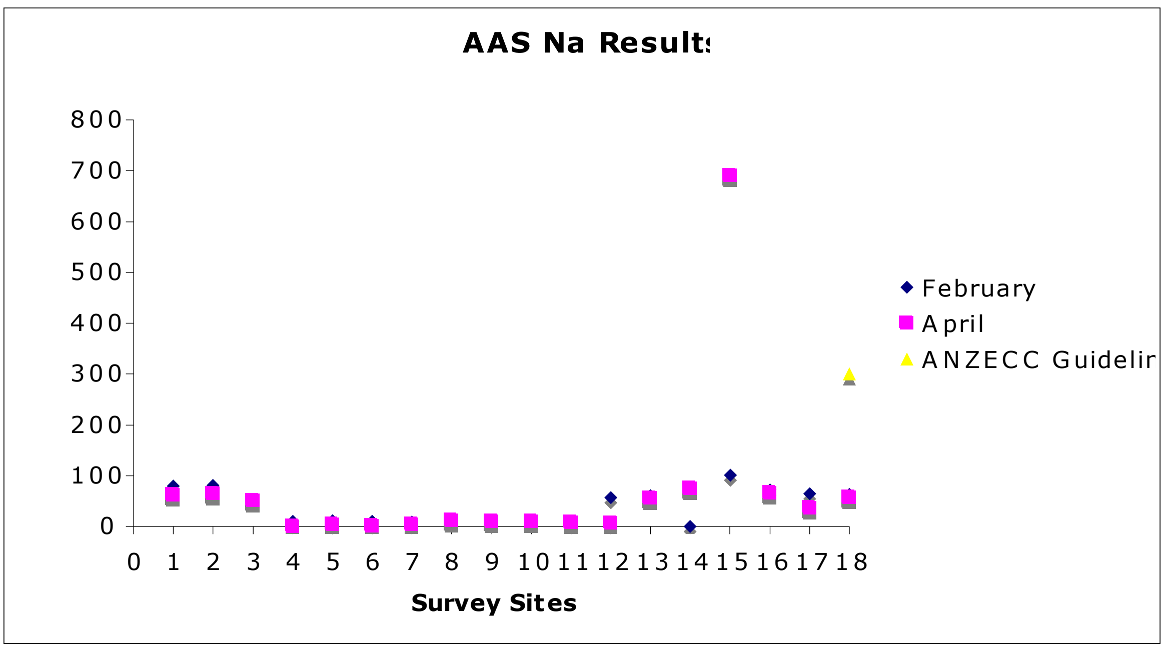

Figure B-13. Cadmium concentrations at 18 survey sites.

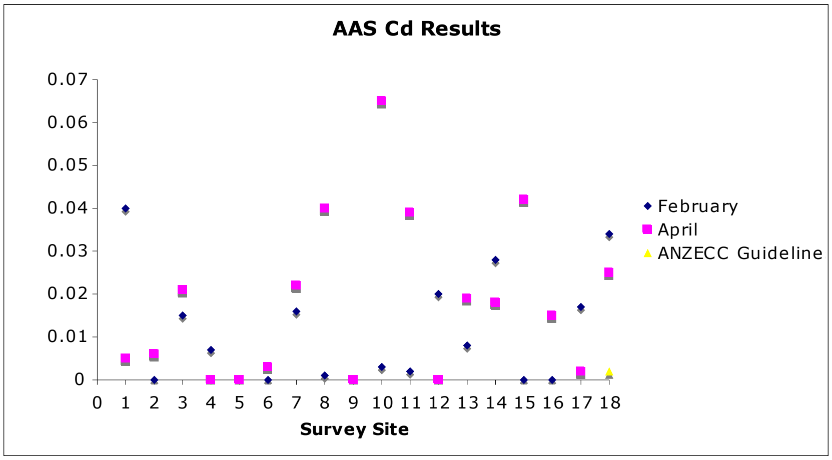

Figure B-14. Zinc concentrations at 18 survey sites.

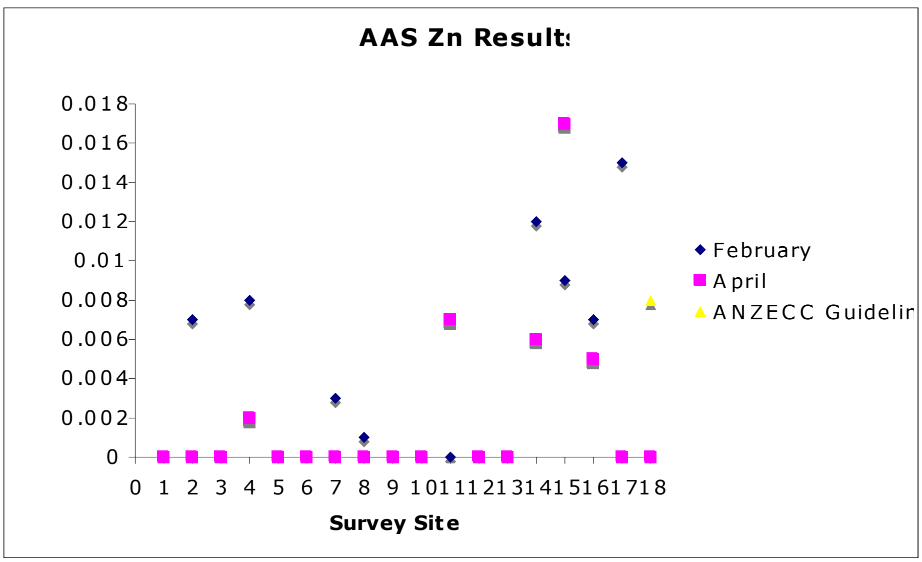

Figure B-15. Lead concentrations at 18 survey sites.

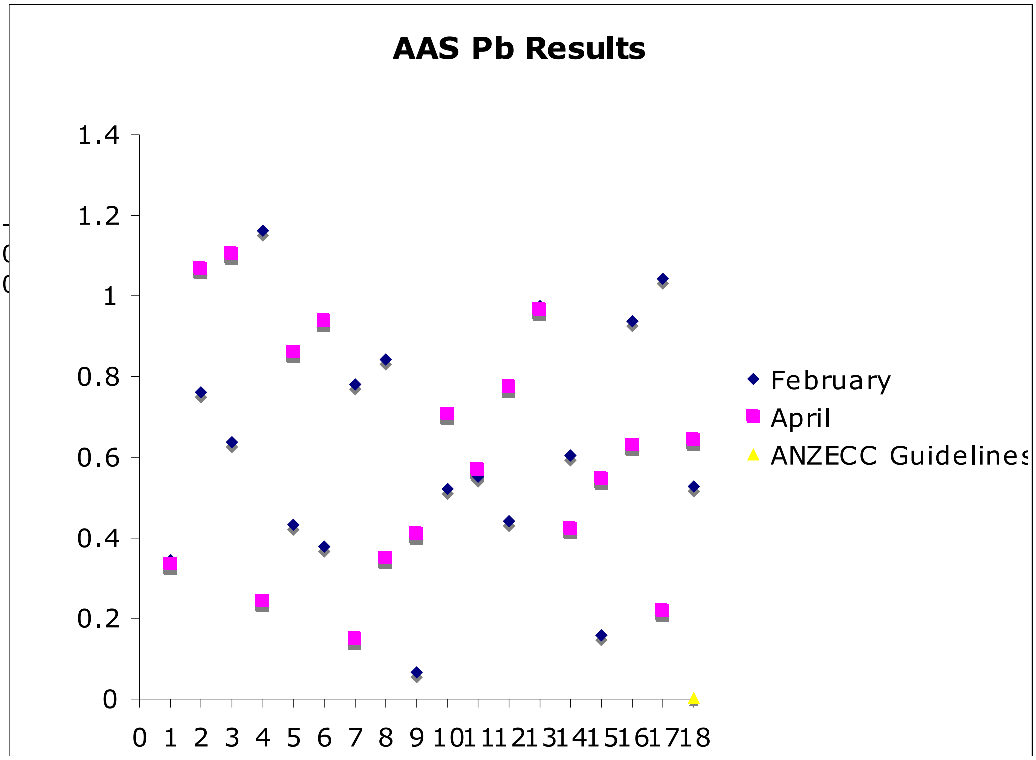

Figure B-16. Lead concentration variances from mean.