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Te Kuha Mine - Water Management Plan - Information Report

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Scope and Introduction

Stevenson Mining Ltd is currently seeking resource consents from the Buller District Council (BDC) and West Coast Regional Council (WCRC) associated with the development of Mining Permit (MP) 41289 – the Te Kuha Mine Project. CRL Energy Ltd (CRL) was contracted by to implement background research, sampling and analysis programmes and prepare a conceptual Water Management Plan for the Te Kuha Mine project.

This report includes:

- Climate data
- Stream flow data
- Stream quality data
- Groundwater levels in drill holes
- Groundwater quality in drill holes
- Geochemical analysis of waste rocks
    - Acid base accounting information
    - Leach test information
    - Comparison to geochemical data from similar sites
- Interpretation of these datasets

Integration of the data sets above with geological model (Dutton, 2012) and conceptual mine plans (Avery, 2014) to form a quantified site water volume and chemistry model for water management planning are contained 'Te Kuha – Water Management Plan – Integrated Report'.

Site Description

MP41289 covers an area of 884.4 hectares of the Te Kuha Sector of the Buller Coalfield, New Zealand (Figure 1). The Te Kuha deposit is located 10 km southeast of Westport on the northern side of the Buller River. The deposit is an erosional remnant of both Brunner and Paparoa Coal Measures which lie upon Hawks Crag Breccia.

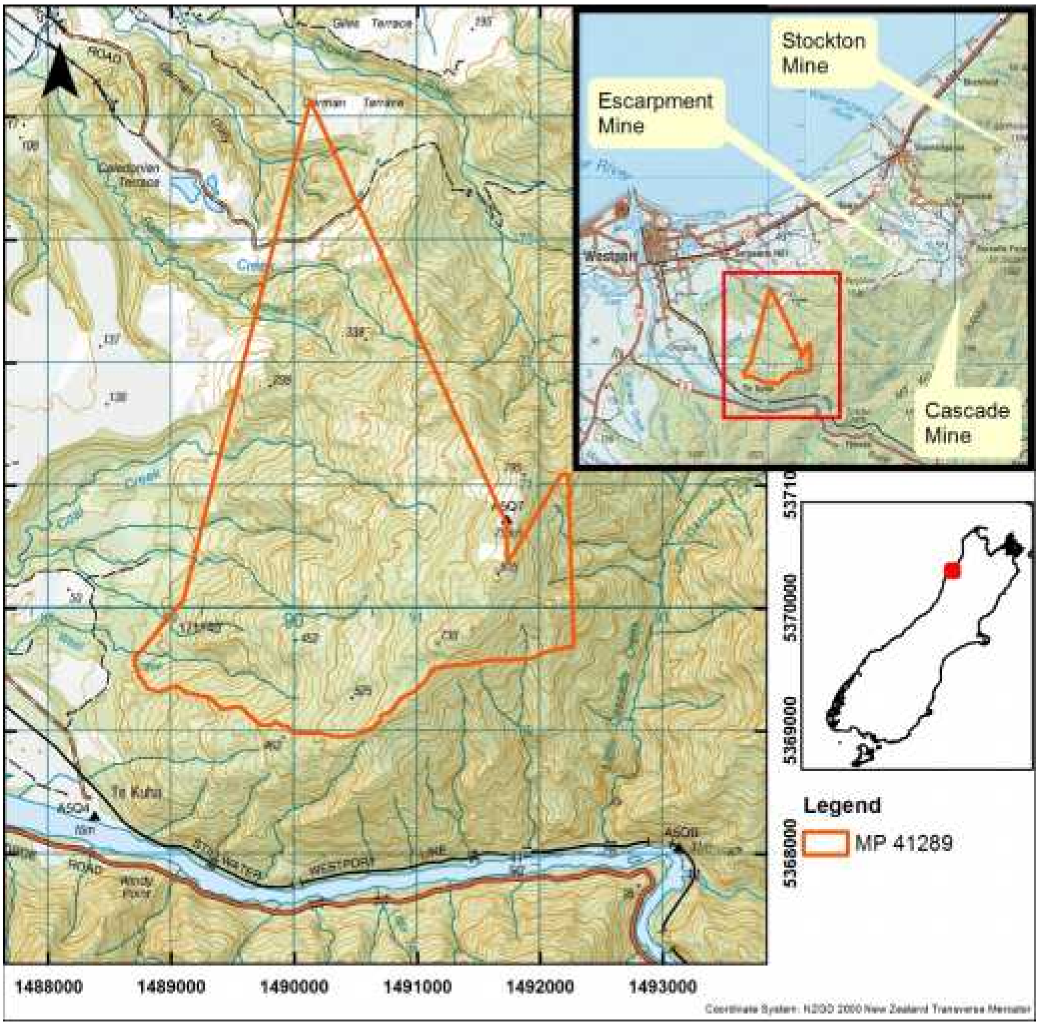

Figure 1: Location of mine permit and regional features including Westport, major roads, Buller River, Escarpment Mine, Cascade Mine, southern Stockton Mine.

The deposit is accessed by helicopter, occurs between 640 and 805 m elevation and lies under the ridge line of the western range front of the Mount William Range. Strata that host the coal dip at about 15° to the west. Most coal lies on the shallow sloped western flank of this range, with the remainder outcropping on the steep eastern flank between 30 and 70 m below the ridge line (Figure 2).

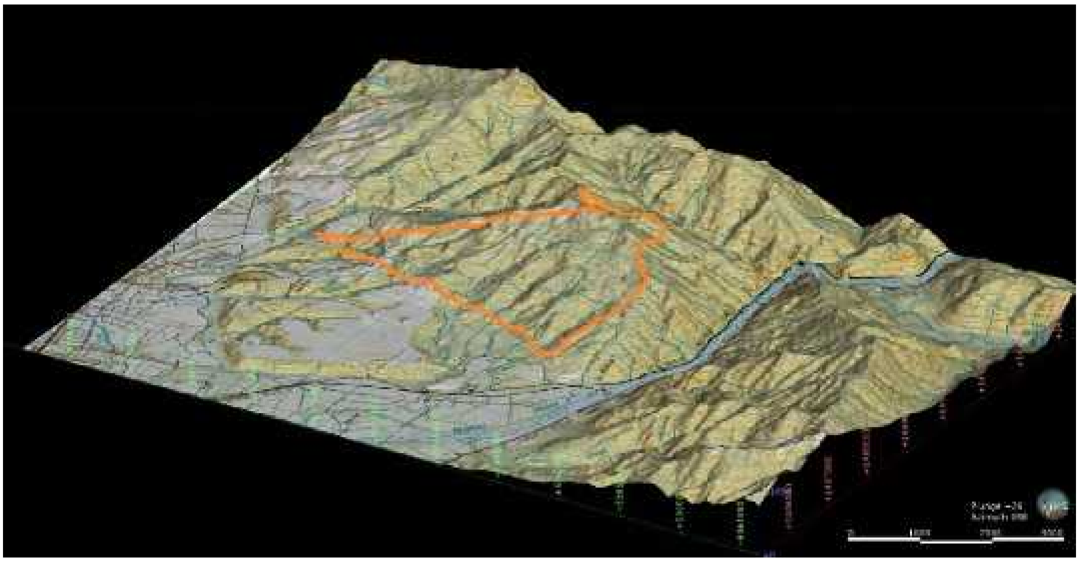

Figure 2: Oblique view of the deposit area and catchment (topographic data)

The Te Kuha deposit and area that will be disturbed by mine operations mostly lies under tributaries to West Creek and Coal Creek on the Western side of the ridge line. Upper parts of Little Cascade Creek and un-named tributaries to the Buller River also occur in the footprint of mine disturbance (Figure 3 and Figure 4).

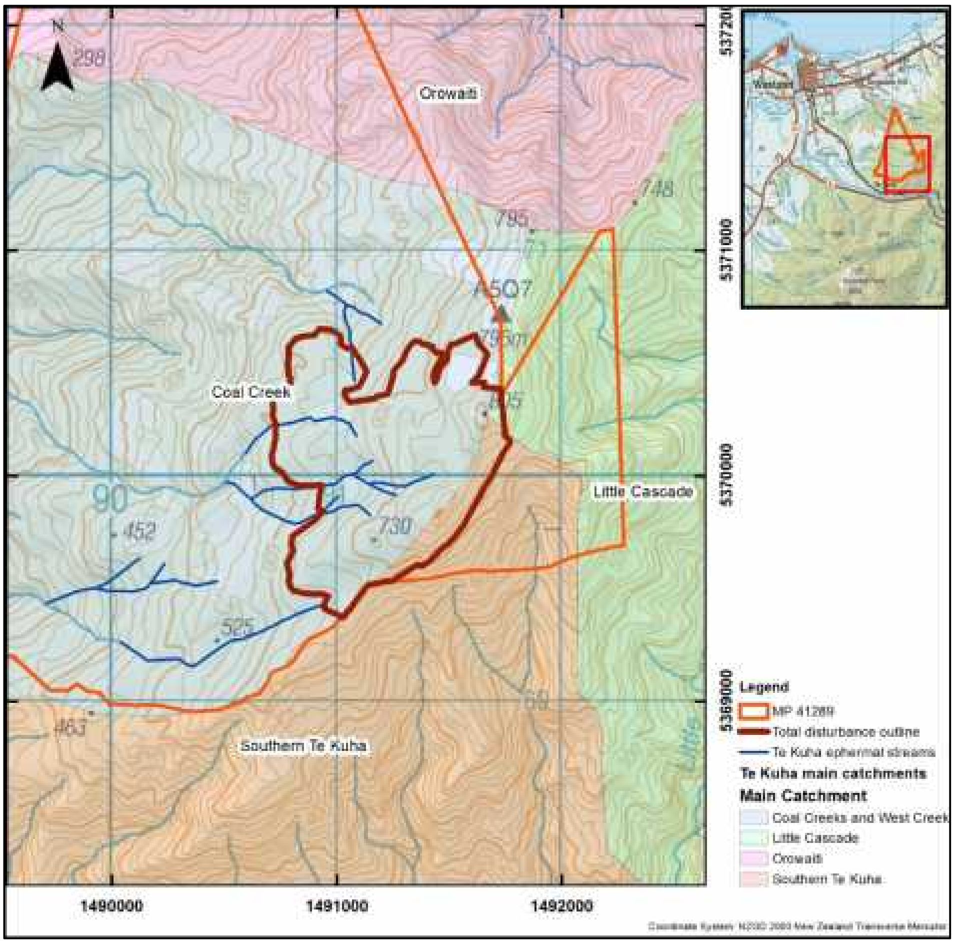

Figure 3: Te Kuha Deposit outline, mine disturbance outline (including waste rock dumps) and main catchment map.

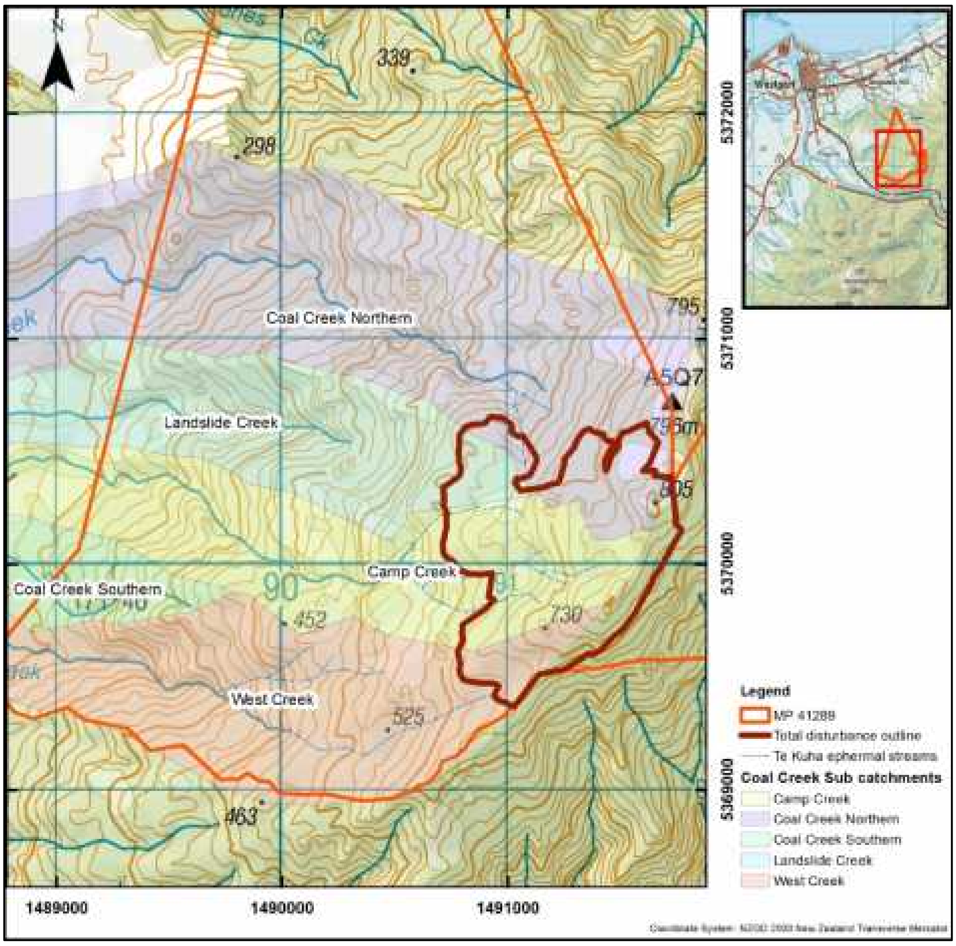

Figure 4: Te Kuha Deposit outline, mine disturbance outline (including waste rock dumps) and Coal Creek Sub-catchments map.

The mine plan is to operate two pits overlapping in time, one in the Brunner coal and one in the Paparoa coal (Avery, 2014) throughout a 20 year period. The ridgeline will be removed and restored during mine operations with final rehabilitation restoring the ridgeline to a position slightly west of its original location.

Impact of mine on catchments

During mining operations all site water will be directed to the west through water treatment and into tributaries of West and Coal Creeks. At maximum disturbance this causes a 1.1% increase in the size of the combined catchments of West and Coal Creeks (above stream monitoring sites) at the expense of Little Cascade Creek catchment and un-named Buller River tributaries. At site closure, catchment sizes will be restored as close to original as possible within the geotechnical constraints of landform engineering. This will permanently reduce the size of the combined West and Coal creek catchment by 0.2% (above stream monitoring sites) with slight increases to un-named Buller River tributaries and Little Cascade Creek (Figure 5).

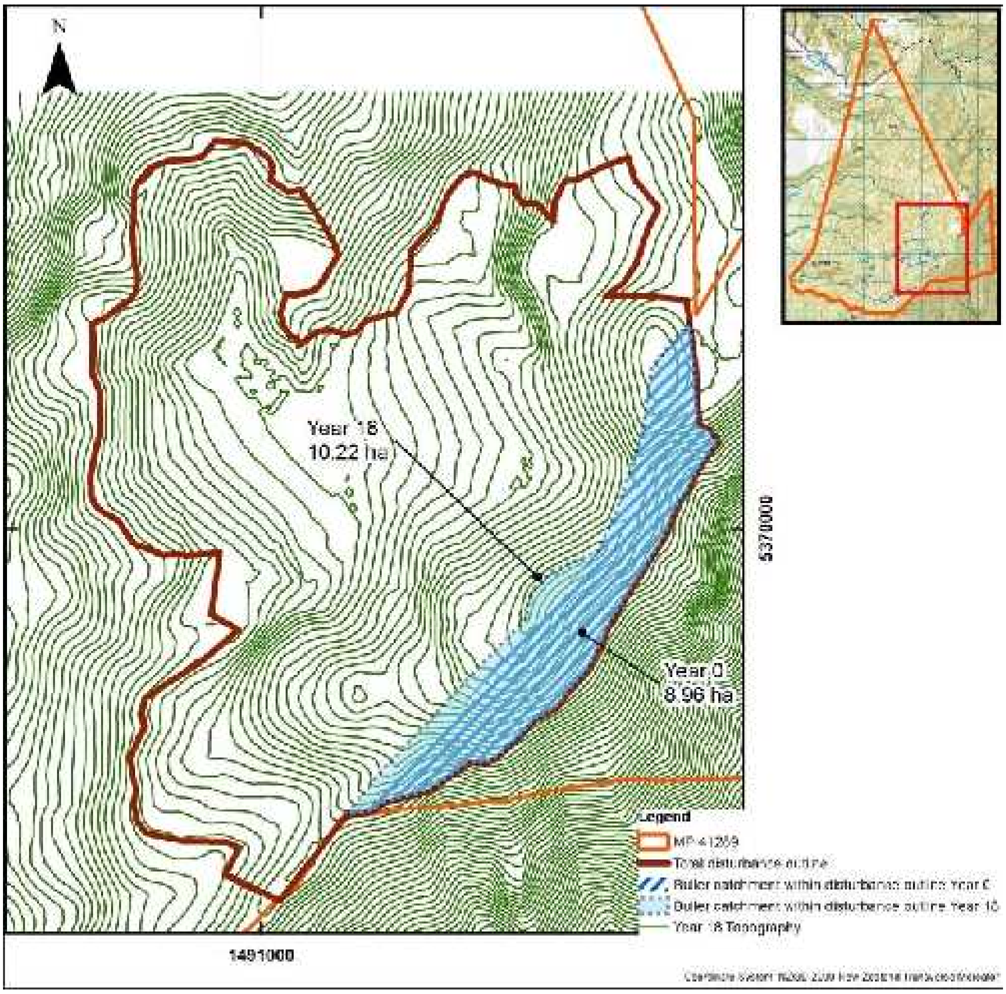

Figure 5: Permanent catchment change at the end of mine

During mine operations stream flows in the upper reaches of tributaries to Coal Creek and West Creek will be modified. However, site water will be managed to cause minimal disturbance to natural flows in these creeks. Flows in streams are highly variable to ephemeral and therefore modifications during mining will fall within natural variability for these headwater streams.

Methods

Climate data collection

Climate data was collected on the proposed Te Kuha Mine Site (1491092E, 5370118N) (Figure 6) with a Davis Vantage Pro 2 Plus weather station from October 2012 until present. The weather station is mounted >1.2 m above ground (Figure 7). Hourly readings of the following climate parameters have been made for this period:

- Temperature
- Humidity
- Dew point
- Solar radiation
- Rainfall
- Barometric pressure

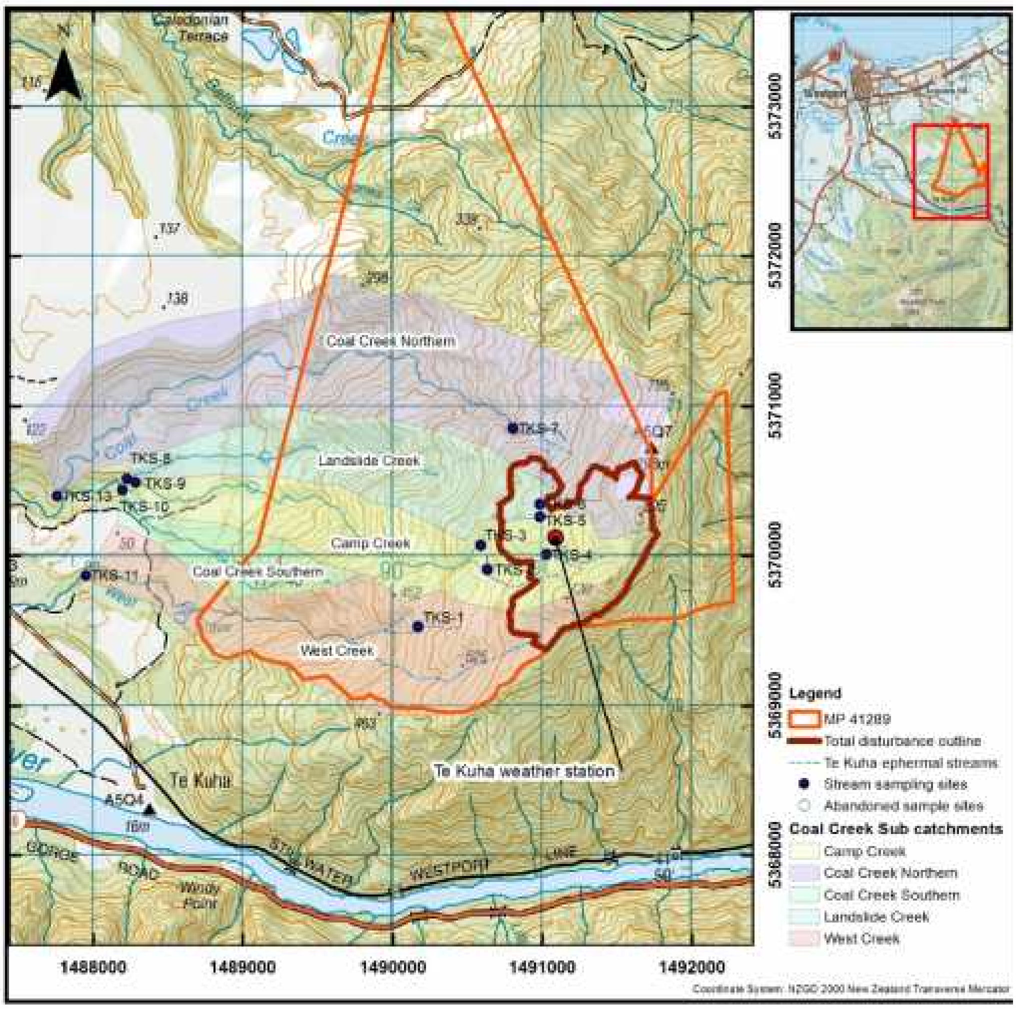

Figure 6: Collection sites for climate and stream flow data

Figure 7: Te Kuha weather station (on a fine day)

Historic climate data is also available from Te Kuha (21 January 1986 to 15 April 1988), collected from an old EDR (Environmental Data Recorder) type of station (Ota Tipping-Bucket Rain gauge and Li-Cor Silicon Cell Radiometer). The nearest weather station with current publicly available data is operated by NIWA at Westport Airport. Information recorded at the Westport weather station was manual via a Stevenson Screen station from 1 February 1944 to 31 October 1991 and is currently automatic. Data from the Westport Airport station provides the best direct comparison to the Te Kuha weather station because it overlaps both the short term data sets available from Te Kuha. Other public weather station data from Buller sites with long term records include Downertown (1945-1999) and Millerton (1914-1968) (Figure 8).

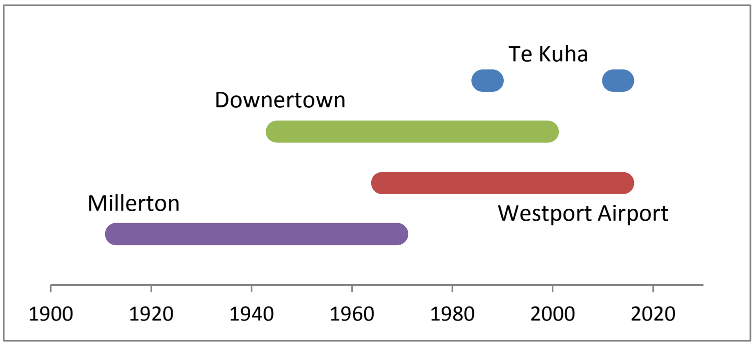

Figure 8: Long term rainfall datasets for the Buller region

Stream flow data collection

Stream flow was measured in tributaries to West Creek and Coal Creek at seven sites in the upland reaches of the catchment (TKS1 to TKS7) on three occasions and at five sites in the lowland reaches of the catchment (TKS8 to TKS11 and TSK13) monthly. Stream flows are measured by different methods in different parts of the catchment. In the upland reaches, flows are low and creek beds rocky so a bucket and stopwatch approach is used for flow measurement. In the lowland sites creek beds are larger and a hand held meter (SonTek Flow Tracker Acoustic Doppler Velocimeter – ADV) is used for stream flow data collection. The flow tracker uses USGS “6 tenths method” of calculation (Turnipseed, 2010).

Stream quality data collection

Water quality samples were collected concurrently with stream flow measurements. In the field, pH, temperature (T), electrical conductivity (EC), and dissolved oxygen (DO) was measured with a YSI multi probe. This probe is calibrated regularly for pH, T and EC, however DO readings are indicative.

Field filtered acidified samples were collected for dissolved metal analysis, unfiltered acidified samples were collected for total metals and unfiltered non-acidified samples were collected for other analyses. All samples were submitted to Hills Laboratories for analyses and the analyses were completed to recognised standard analytical procedures.

Slightly downstream from sampling point TKS-13 (1487794E, 5370362N at confluence of Coal and Landslide, Camp and Southern Coal Creeks) a continuous monitoring station was set up to measure pH and EC variability in the lower reaches of the catchment.

Groundwater data collection

There is the potential for mining activities to affect groundwater in the area. It is also possible that groundwater will contribute to water inflow into open pits during mining operations. To determine pre-mining groundwater conditions, including location of potentiometric surface, aquifer hydraulic conductivity, groundwater flow rates and response of groundwater to precipitation events, data were collected from drill holes at the site by Aqualinc (Figure 9).

Drillholes TK-1 to TK-16 are completed with one-inch PVC casing and are not screened or capped on the bottom. Boreholes TK-17 to TK-28 are completed with 65 mm PCV casing and capped at the end. These caps were dislodged by punching with a steel rod to allow water levels to equilibrate with formation water levels. Water level data loggers were installed in five boreholes to record water levels over time. Water levels were measured in 17 boreholes using a water level sounder on two occasions. Recovery rate tests were performed on one borehole (TK-28) on one occasion to estimate aquifer hydraulic conductivity.

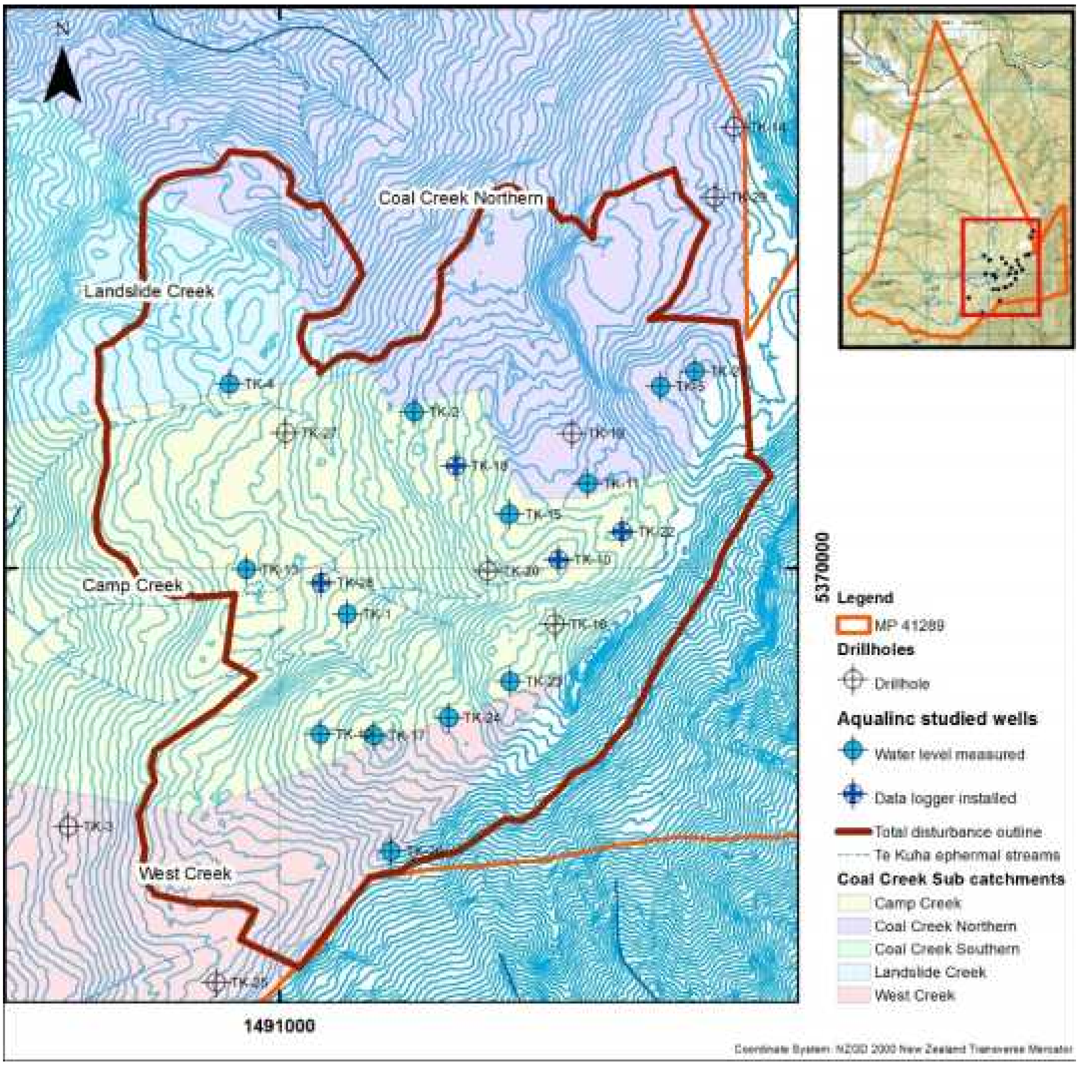

Figure 9 Drill hole plan and groundwater data collection wells

Rock geochemistry samples

Acid base accounting testing was completed by standard methods (Smart et al., 2002). The total number of samples analysed for acid base accounting to date is 46. The size of samples collected for acid base accounting is 2-5 kg of HQ drill core. Core preservation was variable with occasional sulphate salts noted on the surface of the core. Sulphur speciation analysis was not completed, therefore the dataset is conservative because total sulphur is used to calculate potential acidity and non-pyritic sulphur has been documented in previous studies of the Brunner Coal Measures. Samples were collected to obtain representative samples of lithology and where sulphides or carbonates could be identified in core to provide information on highly acid neutralising or highly acid producing samples.

Leachate column procedure

Field columns were used for collection of leachate chemistry to predict leachate chemistry at the Te Kuha deposit during mining operations. This method is preferred over laboratory leach column testing. There is a large database of laboratory column data (Pope and Weber, 2013), therefore, rather than duplicate laboratory tests that have been conducted and published previously for BCM, field based analysis were selected to add more value and include variability that is likely under field conditions.

Five field columns were set up at the foot of the hill slopes to Te Kuha (Figure 10). Each column included a 50 L bucket connected to a 200 L collection drum with a tap for sampling. In the base of each bucket a geotextile liner was placed over the outlet to prevent loss of solid material with leachate. Over this a thin ~2 cm layer of cleaned washed quartz gravel was placed with the rock material to be leached placed above. Each column contained 23 kg of drill core crushed to <10 mm. Samples were collected monthly and analysed for a suite of cations, anions and physiochemical parameters.

The columns were set up at the base of the hills between the Te Kuha deposit and Westport and therefore are expected to receive less rainfall than the Te Kuha mine site but have similar environmental variability. The columns were moved once after initial setup after suspected vandalism prevented sample collection from some columns.

Figure 10: Field leach columns for Te Kuha rocks

Samples for column leaching were selected from different rock types and stratigraphic horizons within the deposit. Two samples were selected from Brunner Coal Measures above the coal seam, a sandstone (Column 1) and a mudstone (Column 2). One sample was selected from the Brunner Coal Measures below the coal seam, a mudstone (Column 3). One sample was selected from the Paparoa Coal Measures above the seam and included mostly fine grained rock (Column 4) and one sample was selected from the Paparoa Coal Measures below the seam and included mostly coarse grained rock (Column 5).

Results

Climate

Climate data (Table 1, Appendix 1) from current the Te Kuha weather station indicate the temperate is between -1° and 30°C with an average temperature of 9.5°C (2013 calendar year). Annual (2013 calendar year) rainfall measured at Te Kuha is 2834mm. Prevailing wind and strongest gusts come from the E or S at the Te Kuha while sustained windiest periods are commonly NW winds.

Table 1: Climate data summary from Te Kuha weather station - 2013 calendar year

Parameter	Units	Maximum	Minimum	Average	Total
Temperature	°C	29.9	-0.7	9.3	-
Humidity	%	100	28	89	-
Dew point	°C	18.4	-8.5	7.5	-
Average wind speed (1 hr)	km/h	29.7	0	3.4	-
Max wind speed (1 hr)	km/h	99.8	0	12.8	-
Rain (1 hr)	mm	32	0	0.32	2834
Hourly data rain event*	mm	138	0.6	13.5	2626

* A hourly data rain event is defined as any rainfall that occurs for a 3hr or more duration with up to a 2hr of break in the rain between hours where rain is recorded.

Rainfall at the Te Kuha site is typical for the West Coast, where short duration heavy rainfall accounts for most precipitation. The heaviest rainfall events during the 2013 calendar year deposited 138 mm, 119.4 mm and 119 mm and all took place over 30-45 hr. For the 2013 calendar year, over half the rainfall occurs in the 23 heaviest rainfall events with the remainder spread out over about 200 rainfall events.

Comparison of rainfall at Te Kuha to other local sites

Rainfall patterns recorded at other local weather stations over longer periods provide context for the data measured at Te Kuha over shorter periods during 1986-1988 and from 2012 until present (Figure 11). In general, the weather systems delivering rainfall to Te Kuha also deliver rain to Westport and clearly the rainfall at Te Kuha is substantially higher than at Westport. Analysis of the difference between Westport rainfall and Te Kuha rainfall for periods where there is overlapping data provides an indication of what Te Kuha rainfall would look like over a longer period.

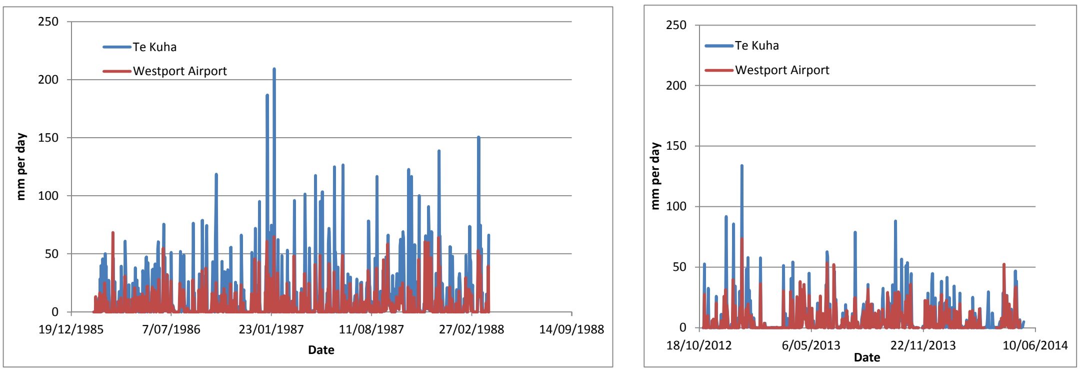

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Figure 11: Comparison of daily rainfall data at Te Kuha to Westport a) 1986-1988, b) 2012-2014.

The 1986-88 data indicates that Te Kuha rainfall is relatively heavier than the data collected from 2012 to present compared to Westport. The reason for this difference is uncertain. The data collected during 1987 and 1988 comes from relatively heavy rainfall years for Westport whereas data collected from 2012 and 2013 comes from years where Westport rainfall is slightly below average (Figure 12). It is possible that during relatively wet years, Te Kuha receives increased rainfall over Westport compared to relatively dry years.

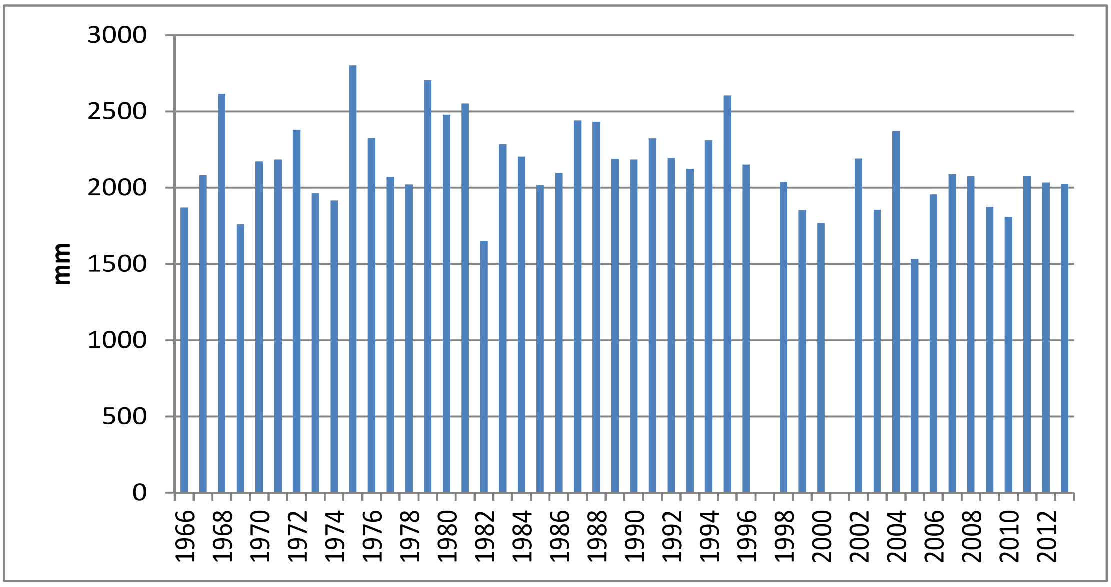

Figure 12: Westport annual rainfall data 1966 – 2012. 1997 and 2001 are excluded because there is substantial missing data.

The rainfall patterns for these measuring stations are clearly linked (Figure 11) but there is not a strong linear relationship between the amount of extra rain recorded at Te Kuha compared to Westport on a daily basis. This is because the rainfall patterns vary on an hourly basis within a weather system that delivers the rain and the measurement period in some of the older data is variable. Therefore in order to use the Westport data to predict what Te Kuha rainfall might look like over a longer period, the weather systems that deliver rain must be compared rather than rain that occurs within a 24 hour period.

The total amount of rain delivered by the 20 largest rainfall events at Te Kuha compared to the same event at Westport provides a strong linear relationship (Figure 13).

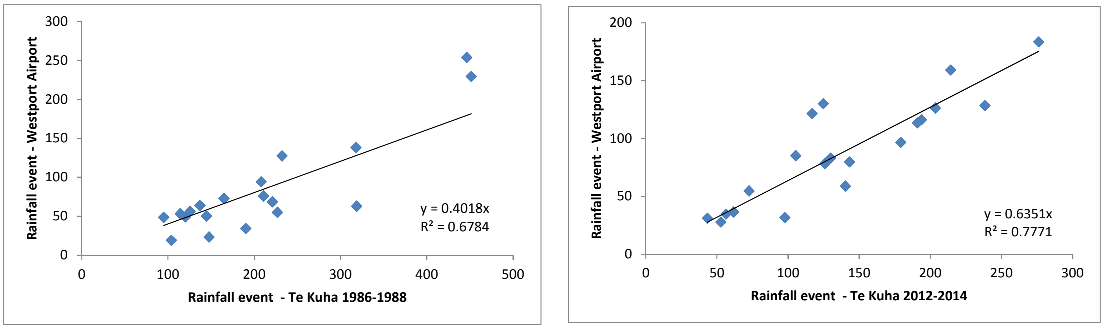

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Figure 13: Regression of the total rainfall in the 20 largest events at Te Kuha to same days in Westport a) 1986-1988, b) 2012-2014. Rainfall events were selected by identification of the heaviest rainfall days calculating the total amount of rainfall for all consecutive days when rain fell – within these datasets rainfall events between 1 and 15 days are included.

Based on the 1986 to 1988 data heavy Te Kuha rainfall events are 2.4 times as heavy as Westport rainfall events and based on the 2012 to present data Te Kuha rainfall events are 1.7 times as heavy as Westport rainfall events. These relationships provide predictive value for what a long term rainfall pattern might look like for Te Kuha and are factors by which Te Kuha data can be scaled for further comparison to Westport data.

The maximum rainfall for a 24hr period for different flood events can be derived from the Westport data by resampling. For example, a one in 10 year flood event can be estimated by taking random 10 year data intervals and analysing the characteristics of the rainfall events. Using 20 random 10 year intervals for Westport, a one in 10 year flood event has a maximum daily rainfall of 128 mm. Comparison of this approach to the NIWA High Intensity Rainfall Design System (Thompson, 2011) which uses regionalised data sets, and statistical distributions to extrapolate from median annual maximum rainfall to events for different time periods yields good results. A one in 10 year rainfall event for Westport based on HIRDS is also 128 mm. HIRDS cannot be used to calculate a rainfall events at Te Kuha. If this is attempted, it produces similar predictions to those for Westport and this does not match rainfall data collected at Te Kuha. There are insufficient weather stations close to Westport with records that can be incorporated into HIRDS to predict changes in rainfall that occur between Westport and Te Kuha.

Based on rainfall events at Westport from either HIRDS or resampling methodologies a corresponding maximum daily rainfall event at Te Kuha would be about 2.4 times as much Westport rain. So the size of a 2 yearly event in Westport is 92mm and at Te Kuha, 221mm and the size of a 1:10 year event at Te Kuha is 306mm. There are several assumptions in these calculations:

- A linear relationship (Figure 13) is assumed between size of rainfall events measured at Te Kuha to date, and larger events that would be expected over a longer period.
- The scale factor calculated from rainfall events at Westport compared to Te Kuha is directly related to the maximum daily rainfall.

- The data collected at Westport over a 48 year period from 1966 until 2014 are accurate and adequately reflect the climate variability for both Westport and Te Kuha.

There is some conservatism built into the calculations and assumptions above because only the rainfall data from the relatively wet years has been used to calculate the size of a corresponding maximum daily rainfall events at Te Kuha. However, the 48 year dataset might also be missing some large rainfall events if it samples an unusually dry climatic period for the Westport region. The accuracy of high intensity rainfall predictions is difficult to assess, and uncertainty must be accepted in the figures adopted.

Stream flow

Stream flow data from the upland sites demonstrate variable and ephemeral flow, which is common in headwater regions (Table 2) (Appendix2).

Table 2: Stream flow upland sites

Site	TKS1	TKS2	TKS3	TKS4	TKS5	TKS6	TKS7
Catchment	West Ck	Camp Ck	Camp Ck	Camp Ck	Camp Ck	Landslide Ck	Coal Ck Northern
Date	Flow L/s						
21/03/2013	1.0	9.0	0.1	1.6	0.4	ponded	50
30/05/2013	1.0	9.1	0.25	7.9	5.3	ponded	2
5/07/2013	1.0	10.4	0.18	5.6	0.5	ponded	35.6

TKS1, 2 and 3 are sited in or beneath steep topography and have relatively stable flow where as TKS4, 5 and 7 have variable flow and TKS 6 is ponded. Stream flow data from the lowland sites demonstrate continuous relatively stable flow variable through about an order of magnitude at each site on the days when samples have been collected (Table 3).

Table 3: Stream flow lowland sites (na – not analysed)

Site	**TKS8**	**TKS9**	**TKS10**	**TKS11**	**TKS13**
Catchment	Landslide Ck	Camp Ck	Coal Ck Southern	West Creek	Coal Ck Northern
Area (ha)	118	146	47	174	354
Date	Flow L/s				
21/03/2013	60	20	1	40	na
30/05/2013	35	45	5.3	90	88
5/07/2013	45	53	4.4	74	102
20/08/2013	26	37	5.5	58	62
31/08/2013	23	35	2.8	45	73
10/10/2013	74	76	9.6	145	172
12/11/2013	15	24	1.6	34	43
16/12/2013	29	67	3.8	55	72
14/01/2014	61	60	5	66	130
13/02/2014	23	19	4	41	57
11/03/2014	13	13	0.6	22	34
10/04/2014	15	11	0.07	16	25
8/05/2014	150	180	18	280	476

In general, the flow volumes match up with the catchment areas, highest flows occur in the largest catchments (Figure 14). Although changes in flow within sub-catchments can occur that are not represented in adjacent sub-catchments. This reflects changes in the intensity of rainfall patterns between the sub-catchments or variability of the timing of flow measurement compared to the response of sub catchments to rainfall.

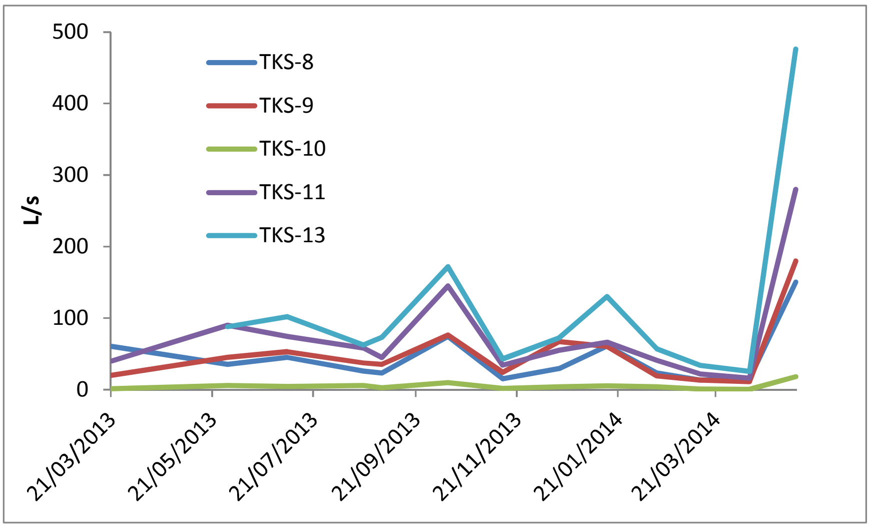


Figure 14: Stream flows at lowland sites

Stream water Quality

Results of stream water quality analysis (Appendix 2) are different in upland parts of the catchment (TKS 1-7) compared to the lowland sites (TKS 8-11 & 13).

Upland Sites - Major Components

Water quality results from the upland sites (Table 4) have a pH range from 4.1 to 6.5 with more than 80% of analyses between pH 4.5 and 5.2 (Appendix 2). Acidity at these sites is in the range 0 to 111 mg/L ($CaCO_3$) and is similarly variable between the different sites and between different samples at the same site through time. However, the laboratory reported acidity values do not always match well with acidity calculated from pH, Fe and Al concentrations. The maximum acidity by calculation is 8.4 mg/L (H_2SO_4). Calculated acidity values are likely to be most accurate and will be used in interpretations. Alkalinity at the upland sites is low, from below detection to about 2.7 mg/L ($CaCO_3$) and electrical conductivity is low, up to a maximum of 5.8 mS/m. Suspended sediment at the upland sites is below detection in all samples and low concentrations of phosphate (<0.012 mg/L), nitrate and/or nitrite (<0.11 mg/L) are present in most samples. Anions are mostly chloride (commonly 4–5 mg/L) with less bicarbonate (1–3 mg/L) and less sulphate (commonly 1-2 mg/L). Cation concentrations are mostly Na (3-3.5 mg/L), with less Mg (0.3–0.5 mg/L) and lower concentrations of K and Ca (0.1–0.3 mg/L). In general the total and dissolved concentrations of these components are similar, and these values relate well to low TSS values.

Lowland Sites – Major Components

Water quality results from the lowland sites (Table 5) have a pH range from 6.0 to 7.6 (Appendix 2). Acidity at these sites is in the range 1.8 to 8 mg/L ($CaCO_3$) and is variable between the different sites and between different samples at the same site with time. Alkalinity at the lowland sites ranges from 3.4 to 18.8 mg/L ($CaCO_3$) and electrical conductivity is low, up to a maximum of 6.8 mS/m. Suspended sediment at the lowland sites ranges from 0 to 10 mg/L in all samples and low concentrations of phosphate (<0.013 mg/L), nitrate and/or nitrite (<0.07 mg/L) are present in most samples. The most abundant anions are variable between the sampling sites, however in general the concentrations are low: sulphate (1–30 mg/L), bicarbonate (4.3–19.9 mg/L) and chloride (5.2–10.7 mg/L). Cation concentrations are mostly Na (4.1–6.4 mg/L), with less Ca (0.59-4.2 mg/L), lower concentrations of Mg (0.72–1.86 mg/L) and K (0.31–0.56 mg/L). In general the total and dissolved concentrations of these components are within analytical uncertainty and this matches up with low TSS values.

Trace Elements

A suite of 31 metals were analysed (Table 6 & 7) by ICPMS for both dissolved concentrations (aq) and total concentrations including suspended particulate matter (t). Of these, 20 were above detection in dissolved samples, Cd and Cs were detected rarely in suspended particulate matter but not in filtered samples and Sb, Bi, Mo, Se, Ag, Tl, Ti and V were below detection in all analyses completed. Concentrations of trace elements were low and relatively uniform. The highest concentrations were measured for Fe, up to about 1.5 mg/L though most commonly below 0.5 mg/L, and for Al, up to 0.47 mg/L but most commonly <0.3 mg/L. Almost all other measured trace element concentrations were below 0.01 mg/L (10 ppb) with the exception of Mn and Sr which have values up to 0.045 mg/L at lowland sites.

Continuous monitoring data

Continuous monitoring data of pH from site TKS13 indicate variability in pH of about 2 units (5-7). Changes in pH are usually relatively sharp decreases and rises that can sometimes be correlated with rainfall events. Continuous monitoring data of EC shows variation of about 40 µS/cm (20 -60 µS/cm), generally with gradual increases and sharp decreases. The gradual increases occur during dry periods and sharp decreases sometimes relate to rainfall events. Temperature at this site shows seasonal variation from winter temperatures as low as about 5°C and summer maximums of about 20°C.

		TKS 1			TKS2			TKS 3			TKS 4			TKS 5			TKS 6			TKS 7		
Analyte	units	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min
pH			4.8	4.5		5.4	5.1		4.6	4.1		5	4.9		4.6	4.4		4.7	4.5		6.5	5.2
Acidity	mg/L ($CaCO_3$)	40	111	0	92	92	92	46	100	19	42.6667	96	16	43.3333	92	19	22.5	48	10	9.575	11	7.3
Alkalinity	mg/L ($CaCO_3$)	1.3	1.8	1	2.175	2.4	2.1	1.4	1.4	1.4	1.825	2.7	1.5		0	0	1.4	1.5	1.3	2.525	2.6	2.5
HCO_3^-	mg/L	1.56667	2.2	1.2	2.675	2.9	2.6	1.7	1.7	1.7	2.225	3.3	1.8	1.1	1.1	1.1	1.7	1.8	1.6	3.05	3.2	3
Hardness	mg/L ($CaCO_3$)	2.06667	2.2	1.9	3.05	4	2.7	2.225	2.5	2	2.725	3	2.5	2	2.1	1.9	2.3	2.5	1.9	2.875	3.2	2.5
EC	mS/m	3.33333	3.6	3.1	2.525	2.6	2.5	4	5.8	3.2	2.85	3.1	2.7	3.35	3.6	3.2	3.1	3.3	2.8	2.475	2.5	2.4
TSS	mg/L		0	0		0	0		0	0		0	0		0	0		0	0		0	0
Cl	mg/L	5.4	5.5	5.3	4.95	5.2	4.8	5.4	5.4	5.4	5.4	5.8	5.2	5.125	5.2	5.1	4.825	5.1	4.1	5.25	5.4	5
NO_2^-	mg/L	0.004	0.004	0.004		0	0	0.003	0.003	0.003		0	0	0.0025	0.003	0.002	0.00333	0.004	0.003		0	0
NO_3^-	mg/L	0.103	0.103	0.103	0.01175	0.014	0.008	0.378	0.75	0.006	0.0315	0.034	0.028	0.041	0.041	0.041	0.011	0.011	0.011	0.012	0.03	0.002
$NO_2^- + NO_3^-$	mg/L	0.0555	0.107	0.004	0.01275	0.015	0.01	0.3795	0.75	0.009	0.03275	0.035	0.029	0.0225	0.043	0.002	0.015	0.015	0.015	0.01375	0.031	0.004
Reactive P	mg/L		0	0		0	0	0.005	0.005	0.005		0	0		0	0		0	0		0	0
Total P	mg/L	0.008	0.008	0.008	0.006	0.006	0.006		0	0	0.005	0.005	0.005	0.009	0.009	0.009	0.012	0.012	0.012	0.011	0.011	0.011
SO_4^{2-}	mg/L	4.96667	12	1.2	1.4	1.4	1.4	1.55	1.8	1.3	1.5	1.5	1.5	1.45	1.8	1.1	1.2	1.4	1	1.35	1.5	1.2
Ca (aq)	mg/L	0.16	0.16	0.16	0.28	0.28	0.28	0.15	0.15	0.15	0.23	0.23	0.23	0.15	0.15	0.15	0.2175	0.29	0.18	0.27	0.28	0.25
Mg (aq)	mg/L	0.41333	0.45	0.37	0.4775	0.5	0.47	0.4425	0.48	0.39	0.50333	0.52	0.47	0.35333	0.36	0.34	0.4225	0.46	0.34	0.525	0.56	0.46
K (aq)	mg/L	0.14	0.14	0.14	0.22667	0.24	0.22	0.14667	0.16	0.14		0	0	0.12333	0.13	0.12	0.19	0.19	0.19	0.29	0.29	0.29
Na (aq)	mg/L	3.25	3.3	3.2	3	3	3	3.36667	3.4	3.3	3.1	3.1	3.1	3.06667	3.1	3	3.2	3.2	3.2		0	0
Ca (t)	mg/L	0.28	0.28	0.28	0.31	0.31	0.31	0.182	0.182	0.182	0.24	0.24	0.24	0.157	0.157	0.157	0.26675	0.3	0.187	0.30667	0.31	0.3
Mg (t)	mg/L	0.42333	0.45	0.39	0.5025	0.51	0.49	0.465	0.48	0.44	0.53667	0.55	0.51	0.39333	0.4	0.38	0.4575	0.51	0.36	0.57	0.6	0.5
K (t)	mg/L	0.14	0.14	0.14	0.27667	0.39	0.22	0.16867	0.184	0.161		0	0	0.12067	0.132	0.115	0.23	0.23	0.23	0.3	0.3	0.3
Na (t)	mg/L	3.25	3.3	3.2	3.03333	3.1	3	3.36667	3.4	3.3	3.1	3.1	3.1	3.13333	3.2	3	3.2	3.2	3.2		0	0

Table 4: Chemistry of upland stream catchment

		TKS 8			TKS 9			TKS 10			TKS 11			TKS 13		
Analyte	units	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min
pH			7.6	6		7.4	6.1		6.4	6		7.5	6.4		7.2	6.3
Acidity	mg/L ($CaCO_3$)	3.06429	7.7	1.4	3.22857	7.4	1.9	4.57143	8	2.9	2.73571	4.6	1.8	2.92857	5.8	1.8
Alkalinity	mg/L ($CaCO_3$)	5.70714	10.5	3.8	6.65714	10.8	4	4.54286	12.3	3.4	7.09286	10.1	4.6	11.3286	18.8	4.4
HCO_3^-	mg/L	8.25714	12.7	6.2	8.88571	13.1	7.3	6.3	15	4.3	9.87143	12.3	6.9	14.1	19.9	5.8
Hardness	mg/L ($CaCO_3$)	13.0286	15.8	11.1	13.2571	18.2	10.4	5.61429	10	4.7	6.61429	7.3	6	11.7857	16.2	5.8
EC	mS/m	5.02143	6	3.8	5.14286	6.7	3.8	4.14286	6.2	3.5	3.62857	4.1	3.1	4.93571	6.7	3.4
TSS	mg/L	7	10	4		0	0	5.66667	9	4		0	0		0	0
Cl	mg/L	6.42857	6.9	5.5	6.61429	6.9	5.7	9.11429	10.7	7.7	6.55714	6.9	5.8	6.68571	8.8	5.2
NO_2^-	mg/L		0	0		0	0		0	0		0	0		0	0
NO_3^-	mg/L		0	0		0	0	0.0045	0.006	0.003	0.003	0.003	0.003	0.003	0.004	0.002
$NO_2^- + NO_3^-$	mg/L		0	0		0	0	0.00467	0.007	0.003	0.00425	0.005	0.004	0.004	0.005	0.003
Reactive P	mg/L		0	0		0	0		0	0	0.00543	0.011	0.004	0.006	0.006	0.006
Total P	mg/L	0.0086	0.013	0.004	0.00667	0.008	0.004	0.01025	0.012	0.006	0.011	0.013	0.006	0.0094	0.014	0.006
SO_4^{2-}	mg/L	8.20714	11.2	4.5	7.46429	12	4.1	1.63333	2.4	1	1.48333	1.9	1	5.64167	30	2.3
Ca (aq)	mg/L	2.65	3	2.4	2.71667	3.5	2.3	0.65667	0.79	0.59	1.32	1.52	1.17	3.23333	4.2	2.8
Mg (aq)	mg/L	1.50571	1.86	1.26	1.37667	1.84	1.14	0.85571	1.33	0.72	0.80857	0.86	0.74	1.13667	1.43	1
K (aq)	mg/L	0.49	0.56	0.45	0.37	0.41	0.33	0.3375	0.43	0.28	0.44333	0.5	0.39	0.40667	0.49	0.31
Na (aq)	mg/L	4.225	4.4	4.1	4.55	4.8	4.2	5.8	6.3	5.5	4.75	5.1	4.5	4.76667	5.3	4.1
Ca (t)	mg/L	2.66667	3	2.4	2.86667	3.6	2.5	0.67333	0.7	0.66	1.47	1.99	1.19	3.36667	4.4	2.6
Mg (t)	mg/L	1.54429	1.87	1.38	1.51833	1.95	1.21	0.89571	1.34	0.75	0.84429	0.92	0.76	1.21167	1.53	0.93
K (t)	mg/L	0.52	0.56	0.48	0.39	0.45	0.33	0.3425	0.44	0.29	0.45	0.51	0.37	0.43	0.55	0.32
Na (t)	mg/L	4.325	4.7	4.1	4.675	5.2	4.3	5.8	6.4	5.4	4.875	5.3	4.5	5.03333	5.8	4.3

Table 5: Chemistry of lowland stream catchment

		TKS 1			TKS2			TKS 3			TKS 4			TKS 5			TKS 6			TKS 7		
Analyte	units	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min
Al (aq)	mg/L	0.235	0.29	0.165	0.12367	0.148	0.09	0.34	0.38	0.26	0.166	0.2	0.107	0.22033	0.28	0.151	0.184	0.25	0.092	0.13267	0.174	0.085
As (aq)	mg/L		0	0		0	0		0	0		0	0		0	0		0	0		0	0
Ba (aq)	mg/L	0.00108	0.00108	0.00108	0.00233	0.0024	0.0023	0.0009	0.00097	0.00075	0.00238	0.0026	0.0021	0.00075	0.00078	0.00072	0.0009	0.00141	0.00064	0.004	0.0041	0.0039
B (aq)	mg/L		0	0		0	0		0	0		0	0		0	0		0	0		0	0
Cr (aq)	mg/L		0	0	0.0008	0.0008	0.0008	0.0006	0.0006	0.0006	0.001	0.001	0.001		0	0		0	0		0	0
Co (aq)	mg/L		0	0		0	0		0	0		0	0		0	0		0	0		0	0
Cu (aq)	mg/L		0	0		0	0		0	0	0.0007	0.0007	0.0007	0.0005	0.0005	0.0005		0	0		0	0
Fe (aq)	mg/L	0.43	0.54	0.34	0.21333	0.25	0.16	0.20667	0.24	0.17	0.17	0.23	0.09	0.19667	0.23	0.14	0.06	0.08	0.03	0.30667	0.35	0.25
La (aq)	mg/L		0	0		0	0		0	0		0	0		0	0		0	0		0	0
Pb (aq)	mg/L	0.00018	0.00018	0.00018	0.00015	0.00016	0.00014	0.00024	0.00026	0.0002	0.00018	0.00018	0.00018	0.00021	0.00023	0.00019	0.00015	0.00016	0.00014	0.00017	0.00019	0.00012
Li (aq)	mg/L	0.00033	0.0004	0.0003	0.0008	0.0008	0.0008	0.00045	0.0005	0.0004	0.0008	0.0008	0.0008	0.00023	0.0003	0.0002		0	0	0.0011	0.0014	0.001
Mn (aq)	mg/L	0.0012	0.0014	0.0011	0.00373	0.0049	0.0031	0.00063	0.0009	0.0005	0.00353	0.0044	0.0029	0.0006	0.0006	0.0006	0.0036	0.0058	0.0024	0.01107	0.0131	0.0093
Ni (aq)	mg/L		0	0		0	0		0	0	0.0005	0.0005	0.0005		0	0		0	0		0	0
Rb (aq)	mg/L	0.00045	0.00045	0.00045	0.00089	0.00098	0.00084	0.00039	0.00043	0.00037	0.00102	0.00105	0.001	0.00027	0.00031	0.00025	0.00054	0.00079	0.00041	0.00068	0.00077	0.00064
Sr (aq)	mg/L	0.00285	0.0029	0.0028	0.0027	0.0027	0.0027	0.00287	0.003	0.0026	0.00283	0.0031	0.0027	0.00263	0.0028	0.0025	0.00313	0.0038	0.0028	0.00307	0.0031	0.003
U (aq)	mg/L		0	0		0	0		0	0		0	0		0	0		0	0		0	0
Zn (aq)	mg/L	0.0023	0.0023	0.0023	0.00337	0.0039	0.0024	0.00163	0.0026	0.0011	0.0041	0.0047	0.0037	0.0018	0.0018	0.0018	0.003	0.0036	0.0024	0.0039	0.0077	0.0011
Al (t)	mg/L	0.24567	0.29	0.187	0.137	0.168	0.111	0.39	0.47	0.3	0.18667	0.22	0.13	0.24833	0.31	0.185	0.21333	0.28	0.11	0.14967	0.2	0.099
As (t)	mg/L		0	0		0	0		0	0		0	0		0	0		0	0		0	0
Ba (t)	mg/L	0.00145	0.00145	0.00145	0.00243	0.0025	0.0024	0.00105	0.00106	0.00103	0.0024	0.0026	0.0022	0.0009	0.00096	0.00086	0.00145	0.00189	0.00123	0.00413	0.0042	0.0041
B (t)	mg/L		0	0		0	0		0	0		0	0		0	0		0	0		0	0
Cr (t)	mg/L		0	0	0.0009	0.0009	0.0009	0.00093	0.00093	0.00093	0.00091	0.00101	0.0007		0	0	0.00145	0.00145	0.00145		0	0
Co (t)	mg/L		0	0		0	0		0	0		0	0		0	0		0	0	0.00024	0.00024	0.00024
Cu (t)	mg/L		0	0	0.0008	0.0008	0.0008	0.00098	0.00098	0.00098		0	0	0.00074	0.00074	0.00074	0.00168	0.00168	0.00168	0.00084	0.00084	0.00084
Fe (t)	mg/L	0.46667	0.58	0.37	0.25333	0.28	0.22	0.26333	0.31	0.22	0.18033	0.24	0.112	0.21833	0.28	0.135	0.08167	0.113	0.044	0.40333	0.43	0.37
La (t)	mg/L		0	0		0	0		0	0		0	0		0	0		0	0		0	0
Pb (t)	mg/L	0.00023	0.00027	0.00016	0.00061	0.0015	0.00013	0.00035	0.0004	0.00027	0.00019	0.0002	0.00018	0.00028	0.00029	0.00028	0.00044	0.0007	0.00018	0.00024	0.00027	0.00021
Li (t)	mg/L	0.00037	0.0004	0.00035	0.00085	0.00085	0.00085	0.00051	0.00053	0.00048	0.00089	0.0009	0.00088	0.00027	0.00034	0.00021	0.00028	0.00028	0.00028	0.0011	0.00117	0.00105
Mn (t)	mg/L	0.00125	0.00136	0.00114	0.00427	0.0047	0.0035	0.00123	0.00178	0.00069	0.00353	0.0043	0.0029	0.0006	0.00064	0.00055	0.00387	0.0059	0.0022	0.01197	0.0138	0.01
Ni (t)	mg/L		0	0	0.0032	0.0032	0.0032		0	0		0	0		0	0		0	0		0	0
Ru (t)	mg/L	0.00047	0.00047	0.00047	0.00101	0.00117	0.00093	0.00047	0.0005	0.00043	0.00103	0.0011	0.001	0.0003	0.00036	0.00027	0.00067	0.00093	0.00054	0.00075	0.00087	0.00069
Sr (t)	mg/L	0.00285	0.0029	0.0028	0.0027	0.0027	0.0027	0.00293	0.003	0.0028	0.00283	0.0031	0.0027	0.00273	0.0029	0.0026	0.0033	0.0039	0.003	0.00327	0.0033	0.0032
U (t)	mg/L		0	0		0	0		0	0		0	0		0	0		0	0		0	0
Zn (t)	mg/L	0.00305	0.0037	0.0024	0.0035	0.0062	0.0021	0.0048	0.0048	0.0048	0.00263	0.003	0.002	0.00205	0.0027	0.0014	0.00355	0.0044	0.0027	0.00375	0.0048	0.0027

Table 6: Trace elements in upland stream catchment

		TKS 8			TKS 9			TKS 10			TKS 11			TKS 13		
Analyte	units	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min
Al (aq)	mg/L	0.079786	0.182	0.027	0.082429	0.174	0.023	0.192643	0.31	0.081	0.082643	0.174	0.027	0.091429	0.21	0.012
As (aq)	mg/L	0.0034	0.0034	0.0034		0	0		0	0		0	0		0	0
Ba (aq)	mg/L	0.023	0.024	0.022	0.01054	0.0122	0.0096	0.0057	0.0058	0.0054	0.010175	0.0106	0.0091	0.005725	0.0062	0.0048
B (aq)	mg/L	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006		0	0	0.0065	0.007	0.006
Cr (aq)	mg/L	0.000625	0.0009	0.0005		0	0	0.001033	0.0011	0.0009	0.0008	0.0008	0.0008	0.0006	0.0008	0.0005
Co (aq)	mg/L	0.000733	0.0008	0.0006		0	0		0	0		0	0		0	0
Cu (aq)	mg/L	0.000857	0.0012	0.0006	0.000575	0.0007	0.0005		0	0	0.0012	0.0017	0.0006	0.0005	0.0005	0.0005
Fe (aq)	mg/L	0.213571	1.07	0.04	0.135714	0.2	0.07	0.162857	0.2	0.06	0.091538	0.16	0.04	0.197857	0.28	0.09
La (aq)	mg/L		0	0		0	0	0.00014	0.00019	0.00011	0.000207	0.00029	0.00012	0.00021	0.00021	0.00021
Pb (aq)	mg/L	0.000144	0.0002	0.00011	0.00013	0.00013	0.00013	0.00011	0.00012	0.0001	0.00013	0.00016	0.0001	0.00019	0.00019	0.00019
Li (aq)	mg/L	0.002433	0.0029	0.0022	0.001714	0.0021	0.0014	0.000743	0.001	0.0007	0.0007	0.0008	0.0006	0.001743	0.0025	0.0007
Mn (aq)	mg/L	0.057243	0.35	0.0109	0.004207	0.0064	0.0032	0.006021	0.01	0.0016	0.002414	0.0038	0.0015	0.007014	0.0093	0.0043
Ni (aq)	mg/L	0.002093	0.0025	0.0012	0.000936	0.0011	0.0007		0	0		0	0	0.0005	0.0005	0.0005
Rb (aq)	mg/L	0.00116	0.00142	0.00101	0.000816	0.00106	0.00061	0.001039	0.00138	0.00082	0.000991	0.00119	0.00087	0.001044	0.00145	0.00073
Sr (aq)	mg/L	0.0246	0.028	0.022	0.0295	0.045	0.024	0.0093	0.0094	0.0091	0.0164	0.0192	0.0144	0.0241	0.034	0.0147
U (aq)	mg/L	2.25E-05	0.00003	0.00002		0	0		0	0	0.00002	0.00002	0.00002		0	0
Zn (aq)	mg/L	0.004356	0.0055	0.0035	0.001843	0.0025	0.0013	0.001363	0.0022	0.0011	0.001633	0.0023	0.0011	0.00165	0.0028	0.001
Al (t)	mg/L	0.131714	0.26	0.093	0.104	0.138	0.059	0.260857	0.34	0.106	0.107	0.139	0.069	0.123143	0.184	0.04
As (t)	mg/L	0.0022	0.0042	0.0012		0	0		0	0		0	0		0	0
Ba (t)	mg/L	0.024667	0.025	0.024	0.01104	0.0126	0.0102	0.00604	0.0062	0.0059	0.010475	0.011	0.0095	0.0061	0.0067	0.0052
B (t)	mg/L	0.006367	0.007	0.0055	0.00625	0.0064	0.0061	0.006	0.0067	0.0053		0	0	0.00675	0.0071	0.0064
Cr (t)	mg/L	0.000658	0.0007	0.00063		0	0	0.000915	0.00113	0.00058	0.000797	0.00115	0.00062	0.00077	0.00098	0.00056
Co (t)	mg/L	0.000827	0.00089	0.0007		0	0	0.00068	0.00068	0.00068		0	0		0	0
Cu (t)	mg/L	0.001087	0.00152	0.00082	0.000728	0.00086	0.00066		0	0	0.000863	0.00122	0.00061		0	0
Fe (t)	mg/L	0.591429	1.64	0.23	0.21	0.25	0.145	0.273	0.45	0.081	0.180333	0.39	0.083	0.313571	0.39	0.135
La (t)	mg/L		0	0		0	0	0.000177	0.00022	0.00014	0.000243	0.00032	0.00016	0.00025	0.00025	0.00025
Pb (t)	mg/L	0.000219	0.00039	0.00015	0.000138	0.00022	0.00011	0.00019	0.00033	0.00011	0.000215	0.00023	0.0002	0.00033	0.00033	0.00033
Li (t)	mg/L	0.0026	0.0031	0.0022	0.001901	0.0023	0.00158	0.000854	0.00124	0.00072	0.000792	0.00083	0.00073	0.001876	0.0027	0.00083
Mn (t)	mg/L	0.101714	0.35	0.023	0.004886	0.0058	0.0039	0.011129	0.038	0.002	0.003756	0.0108	0.00175	0.0076	0.0105	0.0053
Ni (t)	mg/L	0.002257	0.0027	0.0013	0.001073	0.00118	0.00081		0	0		0	0		0	0
Ru (t)	mg/L	0.001346	0.00181	0.00111	0.000869	0.00108	0.00069	0.00114	0.00158	0.00087	0.001057	0.00137	0.00087	0.001074	0.00145	0.00074
Sr (t)	mg/L	0.0256	0.028	0.024	0.030833	0.045	0.025	0.0094	0.0098	0.009	0.01684	0.0198	0.015	0.024671	0.036	0.0147
U (t)	mg/L	2.51E-05	0.000037	0.000022		0	0		0	0	2.64E-05	0.000037	0.000021	0.000022	0.000022	0.000022
Zn (t)	mg/L	0.00435	0.0048	0.0039		0	0	0.0013	0.0013	0.0013	0.0023	0.0024	0.0022		0	0

Table 7: Trace elements in lowland stream catchment

Groundwater

A groundwater study (Appendix 3) was completed by Aqualinc during 2013 (Flintoft, 2013). This study indicates that interpretations are limited because the drill holes were designed to provide geological information rather than hydrogeological information and that piezometer completion is not optimal. Despite some limitations and caveats, a clear conceptual understanding of the ground water system at Te Kuha is provided, which builds on previous interpretations and includes several data sources:

- review of previous information collected at the Te Kuha site
- two site visits and field observations
- measurement of drill hole depth and groundwater level in 17 drill holes
- installation of groundwater depth loggers for several weeks in 4 drill holes
- measurement of hydraulic conductivity from a recovery rate test

The groundwater study (Flintoft, 2013) identifies two groundwater systems at Te Kuha, one shallow and one deep. The shallow groundwater system is rainfall driven, discontinuous (time and space), perched and feeds the highest levels in stream beds and the tarn (TKS6). The unsaturated zone around the perched shallow groundwater contains large open fractures, voids and slump features that provide relatively direct communication between surface water that is not perched and the deeper groundwater system.

The deeper groundwater system is extensive throughout the field area, occurs 30 to 80 m below topographic surface and sits below coal in all drill holes where data is available except two, TK5 and TK10 (Figure 9). The deeper groundwater shows some seasonal variation and responds rapidly to rainfall based on groundwater information logged in TK28. A piezometric surface generated on the available data intersects topography roughly at the 600 m contour corresponding to the origin of most streams on contour maps

Groundwater chemistry was analysed from 6 drill holes (Table 8 & 9) and has neutral pH (5.4-7.2). Bicarbonate as the most abundant anion with concentrations between 3.9-59mg/L and chloride next most abundant with 4.5-7.6mg/L. Calcium and Sodium are the most abundant cations. In general trace element concentrations are low, except Fe (up to 0.49mg/L) and Zn (0.051-0.69mg/L). Rarely other trace elements have higher than expected concentrations in these ground waters, V, Sn and Fe are all enriched in TKS4 total concentrations indicating suspended particulates are present in this drill hole.

Analyte	units	TK4	TK17	TK18	TK22	TK26	TK28
pH		5.4	7.1	7.2	6.4	7.3	7.1
Acidity	mg/L ($CaCO_3$)	28	7.8	5.1	9.4	3.4	4.5
Alkalinity	mg/L ($CaCO_3$)	3.2	49	32	10.2	30	26
HCO_3^-	mg/L	3.9	59	39	12.5	37	31
Hardness	mg/L ($CaCO_3$)	2.7	54	30	9.8	32	26
EC	mS/m	3	12.2	7.7	3.7	7.6	6.8
TSS	mg/L	3,800	49	44	20	19	41
Cl	mg/L	4.5	7.6	6.5	4.6	6.1	6.7
NO_2^-	mg/L	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.008
NO_3^-	mg/L	0.74	< 0.002	< 0.002	0.166	< 0.002	0.019
$NO_2^- + NO_3^-$	mg/L	0.74	< 0.002	< 0.002	0.167	< 0.002	0.027
Reactive P	mg/L	0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Total P	mg/L	na	na	na	na	na	na
SO_4^{2-}	mg/L	1.1	1	0.7	1.2	0.8	1.2
Ca (aq)	mg/L	0.66	18.9	11	2.8	12	9.4
Mg (aq)	mg/L	0.26	1.62	0.56	0.66	0.62	0.57
K (aq)	mg/L	0.64	0.56	0.32	0.59	0.32	0.48
Na (aq)	mg/L	2.4	4	4.1	3.2	3.2	3.7
Ca (t)	mg/L	1.02	18.7	11	2.9	11.9	9.5
Mg (t)	mg/L	0.42	1.69	0.59	0.7	0.66	0.67
K (t)	mg/L	2.4	0.63	0.33	0.59	0.34	0.61
Na (t)	mg/L	2.6	4.1	3.9	3.2	3.1	3.7

Table 8: Major components in groundwater

Analyte	units	TK4	TK17	TK18	TK22	TK26	TK28
Al (aq)	mg/L	0.028	0.069	0.096	0.016	0.061	0.148
As (aq)	mg/L	< 0.0010	0.0012	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Ba (aq)	mg/L	0.002	0.0134	0.0029	0.0059	0.0042	0.0054
B (aq)	mg/L	< 0.005	0.012	0.006	< 0.005	0.007	0.006
Cr (aq)	mg/L	0.0006	0.0008	< 0.0005	0.0007	0.0007	0.0011
Co (aq)	mg/L	< 0.0002	0.0002	0.0002	< 0.0002	< 0.0002	0.0004
Cu (aq)	mg/L	0.0027	0.0024	0.0011	0.0076	0.0007	0.0033
Fe (aq)	mg/L	0.49	0.37	0.46	< 0.02	0.23	0.35
La (aq)	mg/L	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010	< 0.00010
Pb (aq)	mg/L	0.00145	0.19	0.0037	0.00029	0.0005	0.0064
Li (aq)	mg/L	0.0002	0.0012	0.001	0.0011	0.0009	0.001
Mn (aq)	mg/L	0.009	0.031	0.0098	0.0163	0.0131	0.024
Ni (aq)	mg/L	0.0012	0.0009	0.0008	0.0047	0.0006	0.0031
Rb (aq)	mg/L	0.00079	0.00142	0.00102	0.0027	0.00084	0.00097
Sr (aq)	mg/L	0.0029	0.018	0.0124	0.0048	0.0132	0.0117
U (aq)	mg/L	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002	< 0.00002
Zn (aq)	mg/L	0.15	0.157	0.051	0.22	0.086	0.69
Al (t)	mg/L	2.8	0.2	0.159	0.176	0.175	0.46
As (t)	mg/L	0.025	0.0014	< 0.0011	< 0.0011	< 0.0011	< 0.0011
Ba (t)	mg/L	0.0139	0.0173	0.0038	0.0086	0.0049	0.0082
B (t)	mg/L	0.0055	0.0115	0.0057	< 0.0053	0.0069	0.0062
Cr (t)	mg/L	0.0091	0.00148	0.00114	0.0022	0.00163	0.0053
Co (t)	mg/L	0.00037	0.00031	0.00028	0.00092	0.00029	0.00064
Cu (t)	mg/L	0.023	0.0042	0.0034	0.032	0.00195	0.0102
Fe (t)	mg/L	14.9	0.71	0.55	0.53	0.45	1.51
La (t)	mg/L	0.00123	0.00013	< 0.00011	0.00012	0.00011	0.00027
Pb (t)	mg/L	0.053	0.39	0.0064	0.0038	0.0038	0.026
Li (t)	mg/L	0.00117	0.00135	0.00107	0.0012	0.00103	0.00129
Mn (t)	mg/L	0.02	0.034	0.011	0.06	0.0153	0.033
Ni (t)	mg/L	0.0037	0.00145	0.00117	0.0053	0.00102	0.0054
Ru (t)	mg/L	0.0166	0.00186	0.00118	0.0032	0.00114	0.00182
Sr (t)	mg/L	0.0057	0.02	0.0133	0.0054	0.014	0.0136
U (t)	mg/L	0.00072	0.000035	< 0.000021	0.000035	< 0.000021	0.000034
Zn (t)	mg/L	0.23	0.33	0.171	0.28	0.26	1.06

Table 9: Trace elements in groundwater

Rock Geochemistry

The main trend in rock geochemistry (Appendix4) is that Paparoa Coal Measures are mostly NAF and Brunner Coal Measures are mostly PAF (Table 10, Figure 15). Paparoa Coal Measures have ANC between 0 and 92kg(H_2SO_4)/t with an average of 14 and have an average MPA of 3kg(H_2SO_4)/t. Whereas Brunner Coal Measures have an average ANC of 2 and MPA of 4kg(H_2SO_4)/t. Negative ANC values are present in the laboratory report from Brunner Coal Measures samples perhaps indicating that there are secondary acidic salts present in sample. However, paste pH values remain high all samples. At Te Kuha trends that relate acid base accounting data to lithology/rock type, depth, proximity to coal rock type are not strong.

Table 10: Acid Base Accounting data for Te Kuha

Lithology	Hole	Depth from (m)	NAG (kg H SO /t)	Total S (%)	Paste pH	NAG pH	ANC (kg H SO /t)	MPA (kg H SO /t)	NAPP (kg H_2SO_4/t)
Paparoa GRCG 2	TK-19	69.35	4	0.11	6.44	4.8	5	3	-2
Paparoa GRCG 3	TK-20	70.00	0	0.01	7.86	7.5	13	0	-13
Paparoa GRCG 4	TK-25	38.72	0	0.01	8.40	8.0	92	0	-92
Paparoa SST 1	TK-22	81.81	0	<0.01	8.10	7.3	12	0	-12
Paparoa SST 2	TK-23	32.37	3	<0.01	7.32	6.1	6	0	-6
Paparoa SST 3	TK-17	38.67	4	<0.01	6.80	5.8	6	0	-6
Paparoa SST 4	TK-25	21.40	4	0.05	7.30	5.3	13	2	-11
Paparoa MST/CY 1	TK-23	43.54	4	0.02	7.16	5.7	9	1	-8
Paparoa MST/CY 2	TK-24	36.05	37	0.23	7.26	2.9	11	7	-4
Paparoa MST/CY 3	TK-19	118.94	36	0.12	7.62	3.0	0	4	4
Paparoa MST/CY 4	TK-26	49.60	60	0.45	6.58	2.6	2	14	12
Paparoa ZZS/VFSS 1	TK-28	81.21	5	0.02	7.64	6.3	14	1	-13
Paparoa ZZS/VFSS 2	TK-21	84.25	16	0.40	6.94	3.2	4	12	8
Paparoa ZZS/VFSS 3	TK-26	50.45	2	0.04	7.22	6.5	8	1	-7
Paparoa ZZS/VFSS 4	TK-18	94.16	7	0.02	7.79	6.0	12	1	-11
Brunner GRCG 1	TK-22	13.07	1	0.01	7.34	6.0	0	0	0
Brunner GRCG 2	TK-23	16.41	2	0.01	7.00	5.9	0	0	0
Brunner GRCG 3	TK-24	12.63	10	0.01	7.36	5.9	0	0	2
Brunner GRCG 4	TK-19	40.72	9	0.01	7.38	5.9	0	0	0
Brunner GRCG 5	TK-24	24.26	0	0.03	8.0	7.4	22	1	-21
Brunner SST 1	TK-21	66.23	2	<0.01	7.1	5.9	0	0	0
Brunner SST 2	TK-27	16.90	5	0.01	6.4	5.0	0	0	3
Brunner SST 3	TK-18	26.27	5	0.01	7.5	5.8	0	0	2
Brunner SST 4	TK-28	28.93	6	0.19	6.5	3.7	0	6	6
Brunner MST/CY 1	TK-21	23.92	10	0.02	6.7	3.9	0	1	1
Brunner MST/CY 2	TK-20	31.00	14	0.02	6.3	3.4	0	1	7
Brunner MST/CY 3	TK-27	31.38	64	0.09	6.1	2.6	0	3	3
Brunner MST/CY 4	TK-18	21.92	83	0.23	6.1	2.6	0	7	7
Brunner ZSS/VFSS 1	TK-20	16.30	34	0.05	6.3	2.7	0	2	5
Brunner ZSS/VFSS 2	TK-27	26.68	27	0.02	6.3	3.0	0	1	1
Brunner ZSS/VFSS 3	TK-28	24.73	8	0.01	6.4	5.2	0	0	0
Brunner ZSS/VFSS 4	TK-18	86.02	4	0.02	7.5	4.9	11	1	-10
Sulphide 1	TK-19	81.90	34	0.22	7.4	3.2	14	7	-7
Sulphide 2	TK-22	103.74	0	0.02	8.0	7.5	46	1	-45
Sulphide 3	TK-24	17.35	48	1.90	6.5	2.5	0	58	58
Sulphide 4	TK-26	45.60	20	0.36	7.0	3.0	14	11	-3
Sulphide 5	TK-24	101.79	20	0.40	7.4	3.1	7	12	5
Shallow weathered zone 1	TK-28	12.20	17	0.01	6.2	4.0	0	0	0
Shallow weathered zone 2	TK-21	9.30	23	0.03	6.0	3.6	0	1	1
Shallow weathered zone 3	TK-22	20.45	6	<0.01	6.5	5.4	0	0	0
Shallow weathered zone 4	TK-23	17.48	7	<0.01	6.4	5.4	0	0	0

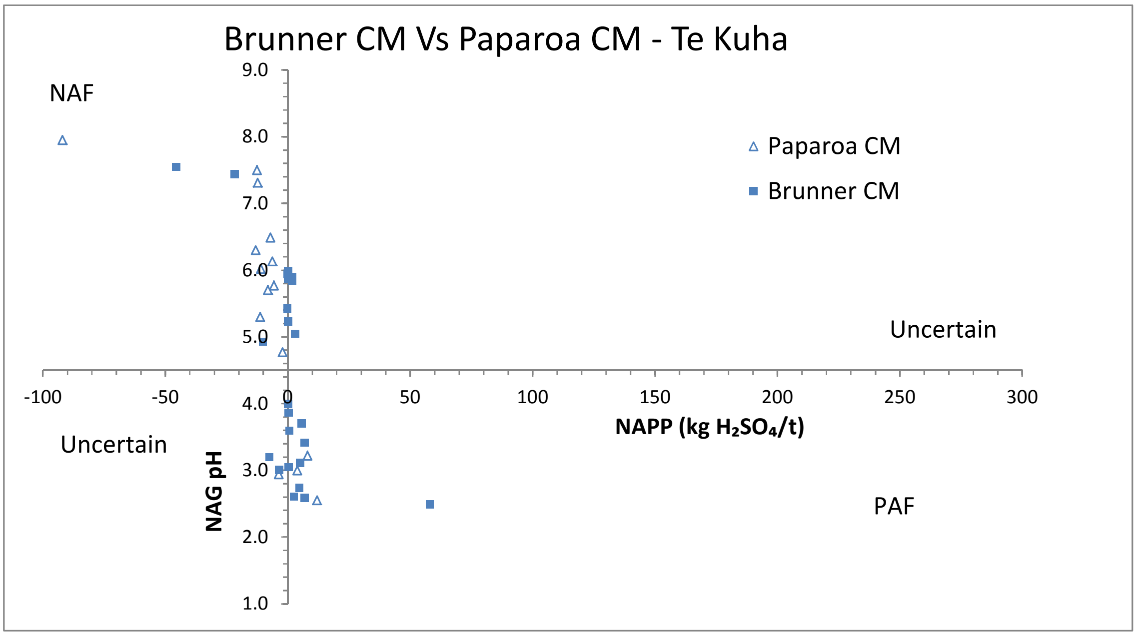


Figure 155: Acid base accounting for Te Kuha rocks showing Paparoa and Brunner Coal Measures (same scale as figure 21)

Field Column Leach Tests

Column leach testing (Appendix5) is conducted on 23kg drill core samples that are characterised with geochemical analysis. Acid base accounting analysis of representative samples from the columns is used to characterise the rocks used for column leach testing (Table 11).

Table 11: Acid base accounting data from samples in field leach trials (*units kg(H2SO4)/t)

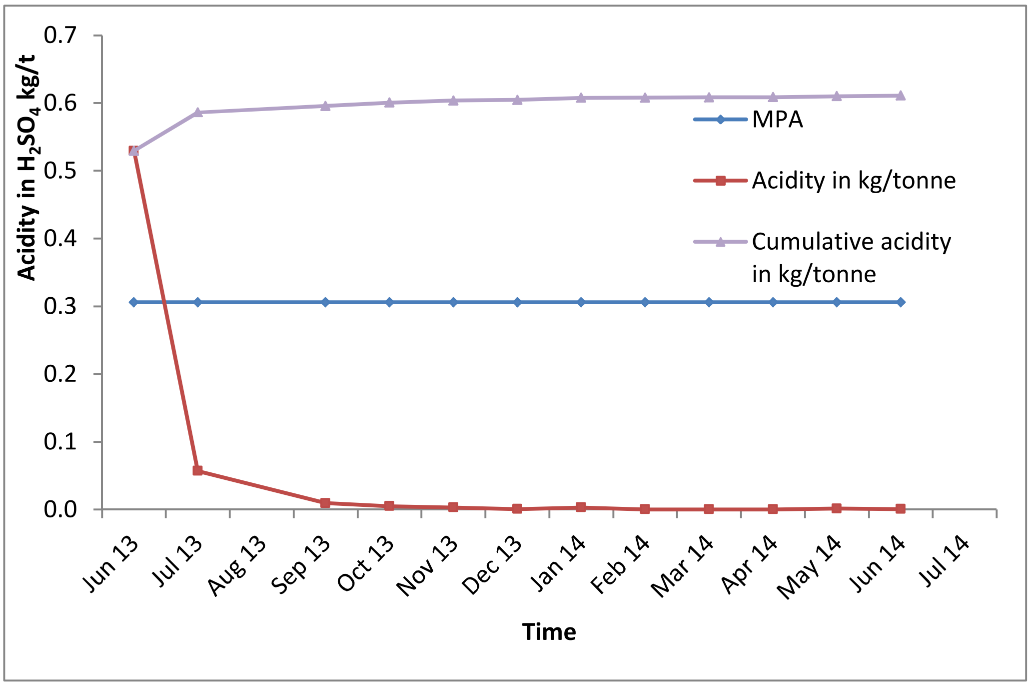
Column	Description	MPA*	ANC*	NAG*	NAG pH	Paste pH
1	Sandstone BCM	0.3	0	11.8	4.8	7.1
2	Mudstone BCM	1.5	0	5.5	5.5	5.6
3	Mudstone BCM	4.9	0	47	2.9	5.1
4	Fine grained PCM	6.1	18.2	0	7.1	6.4
5	Coarse grained PCM	3.7	15.5	0	8.0	7.4

The Brunner Coal Measures rocks (Columns 1-3) have low acid forming potential (MPA) and no neutralising capacity (ANC). Net acid generation values (NAG) are higher than might be expected by comparison with the MPA values, however, NAG values can overestimate total available acidity at low values (Pope et al., 2010b). NAG pH values indicate that only Column 3 contains rocks that would be classified as PAF whereas Columns 1 and 2 contain rocks that are 'uncertain'. Circum-neutral paste pH values indicate that these rocks are unlikely to contain acidic salts that that could cause rapid acidification.

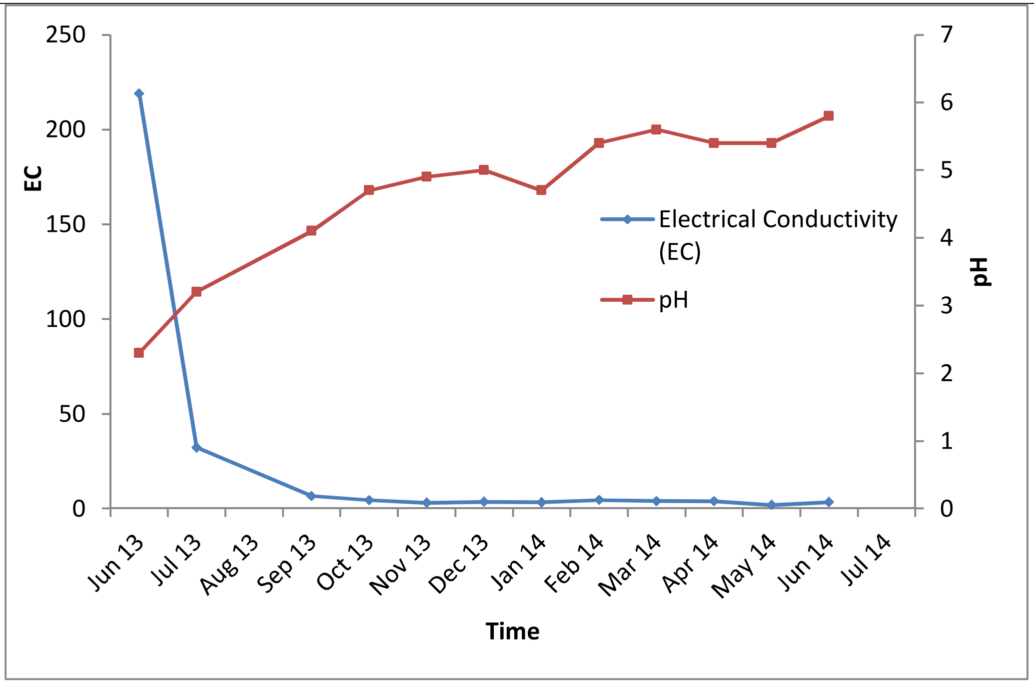
Two trends are present within the column leach data, an initial acidic two samples followed by mostly stable leachate chemistry or concentrations in leachate that decrease with time. The early acidic samples occur because the equipment was acid washed prior to use and some acidic wash solution was not removed (probably from the 200L drum) by rinsing after the columns were set up and the rocks were in place (see interpretation).

Column 1

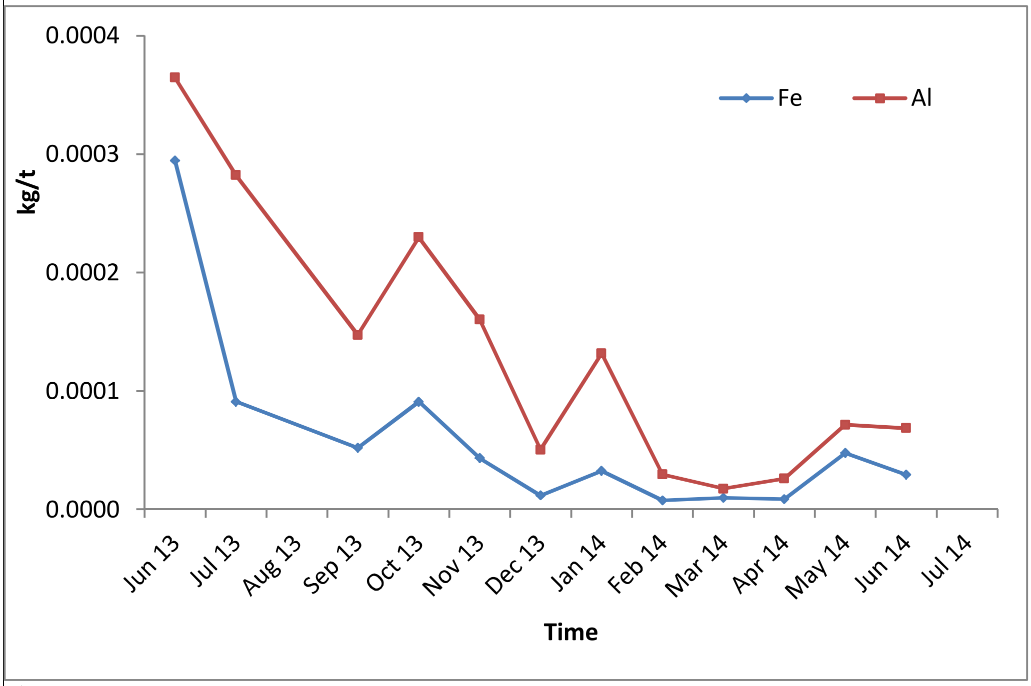
The first two samples from column 1 are acidic with a pH below 4 (2.3 and 3.1), but subsequent samples are less acidic and pH of the leachate derived from column 1 is between 4.1 and 5.8 generally increasing. Acidity released from column 1 (Figure 16a) mostly controlled by pH (Figure 16b) because Al and Fe concentrations are low (Figure 16c) and therefore acidity release decreases as pH increases. Alkalinity release from this sample is below detection or low (<3 mg/L), major anions are Cl in the first two samples (187 & 32 mg/L), then SO_4^{2-} (Figure 16e) and Cl range between 2 & 10 mg/L in subsequent samples from Column 1. The major cation released is Na between 2 & 5 mg/L with Ca, Mg & K all between 0.2 and 1.4 mg/L. Zn is released at relatively high concentrations (Figure 16 e) compared to other trace (Figure 16f) elements, between 0.049 and 0.56 mg/L. All other trace elements are released at low concentrations (almost always less than 0.005 mg/L) in the leachate and usually with a stable trend through time. The only exception is Cu which decreases from a high of 0.01 mg/L in the first sample to ~0.002 mg/L after the first two samples.



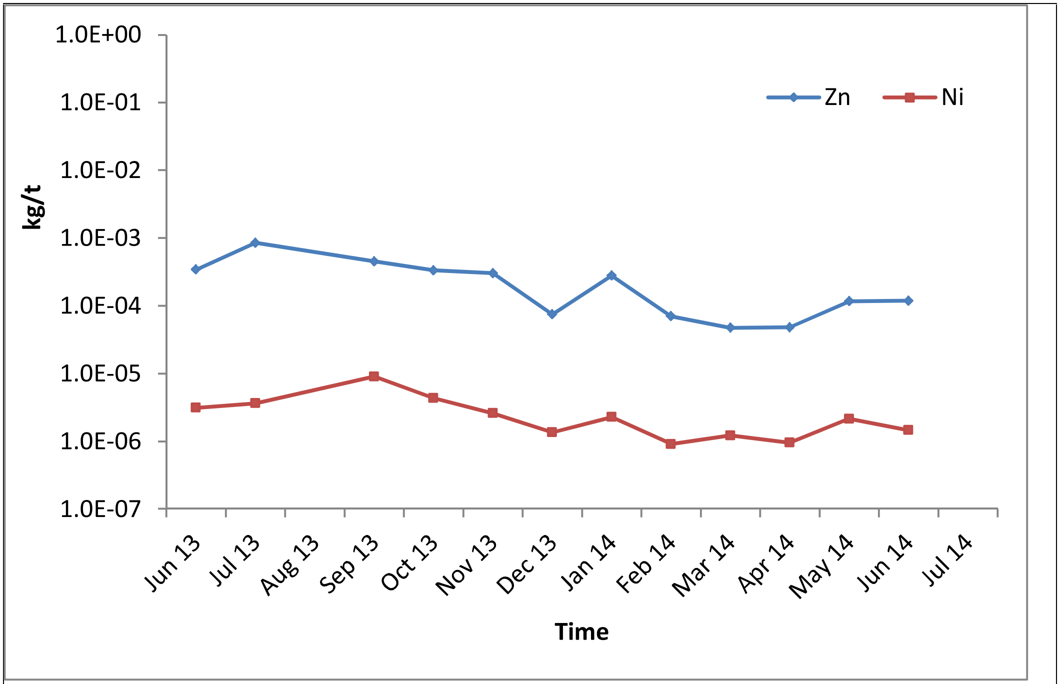
a)


250
200
150
100
50
0
EC
7
6
5
4
3
2
1
0
pH
Electrical Conductivity (EC)
pH
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time

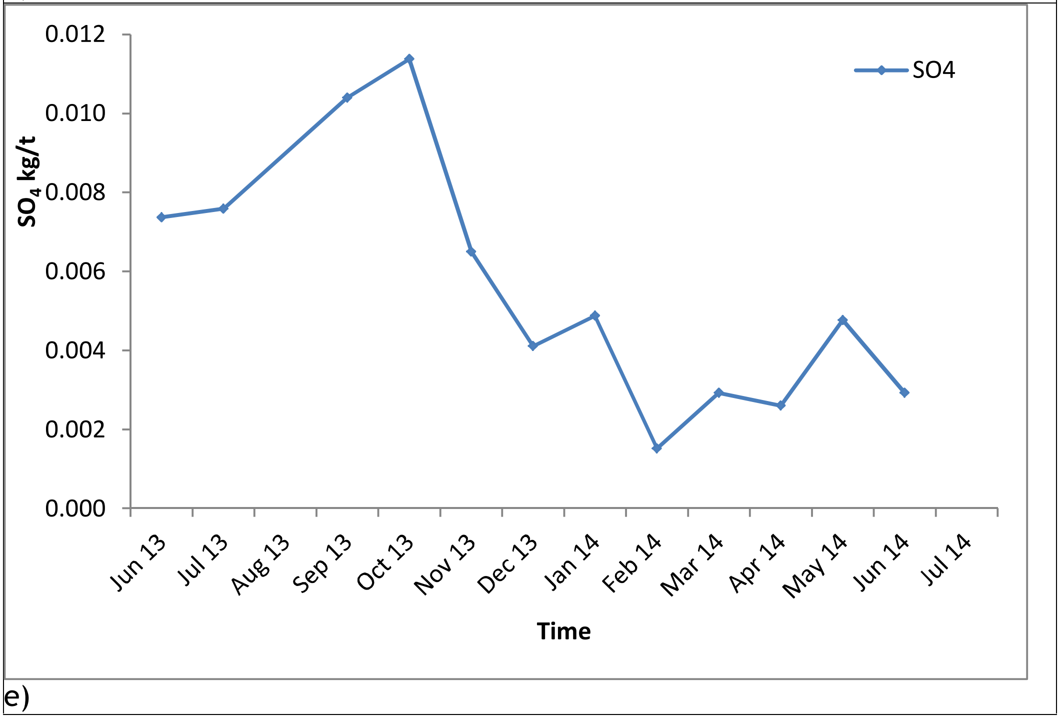
b)


0.0004
0.0003
0.0002
0.0001
0.0000
kg/t
Fe
Al
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time

c)


1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
kg/t
Zn
Ni
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time

d)


0.012
0.010
0.008
0.006
0.004
0.002
0.000
SO4 kg/t
SO4
Jun 13
Jul 13
Aug 13
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Oct 13
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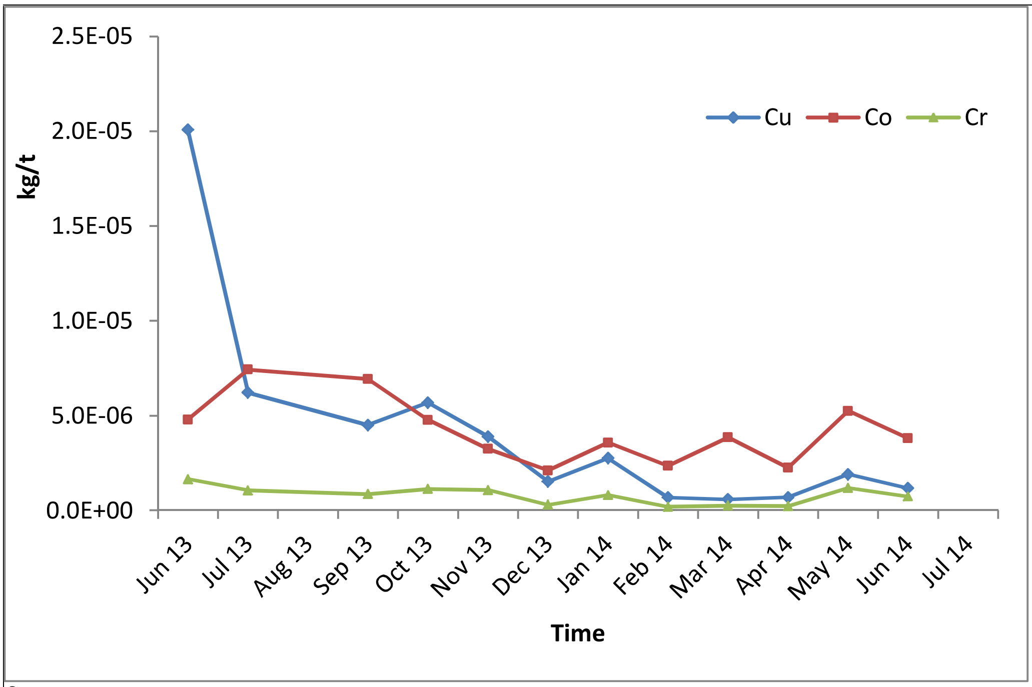
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time

e)

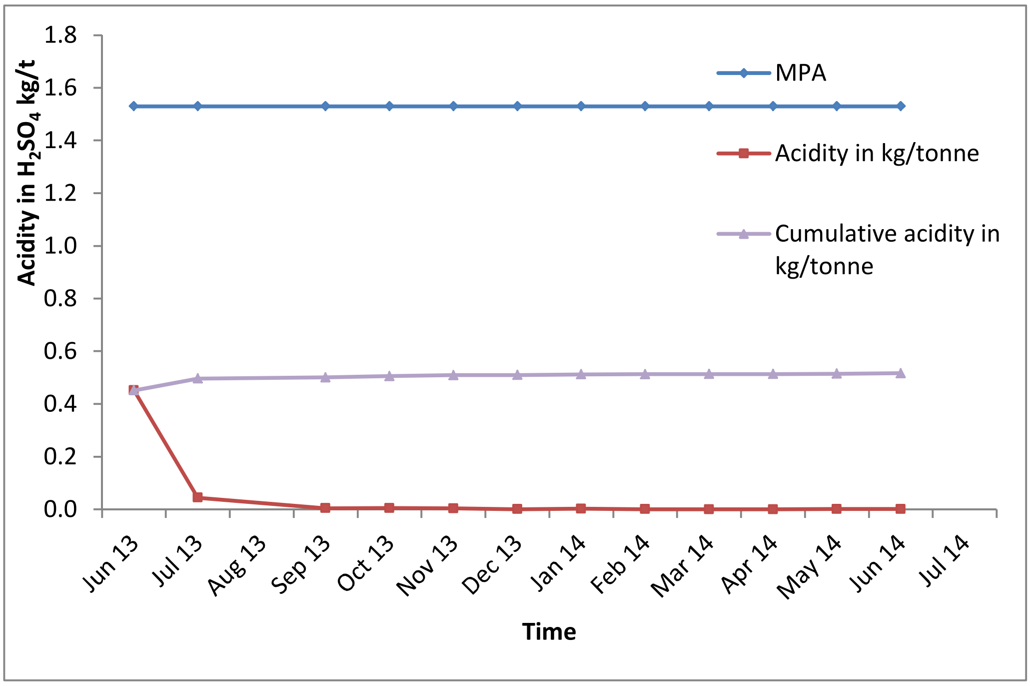


f)

Figure 166: Column 1 Summary figures

Column 2

The first two samples from column 2 are acidic with a pH below 4 (2.4 and 3.3), but subsequent samples release little acid and pH of the leachate derived from column 2 is between 4.3 and 5.4 generally increasing. Acidity released from column 2 (Figure 17a) is controlled by pH (figure 17b) as well Al and Fe concentrations because the concentrations of these ions decrease sharply after the first flush (figure 17c). Alkalinity release is below detection or low (<3 mg/L), major anions are Cl in the first two samples (113 & 23 mg/L), then SO_4^{2-} (figure 17d) and Cl range between 3 & 8 mg/L in subsequent samples from Column 2. The major cation released is Na between 2 & 4 mg/L with Ca released at between 0.45 & 2 mg/L and low concentrations of Mg & K all between 0.4 and 1.0 mg/L. Zn is released at relatively high concentrations between 0.01 and 0.4 mg/L (Figure 17e). All other trace elements are released at low concentrations (almost always less than 0.005mg/L) in the leachate and usually with a stable trend through time. The only exceptions are Cu and Co concentrations which decrease from a high of 0.014 and 0.008 mg/L respectively in the first sample (Figure 17f). Cu concentrations decrease quickly, whereas Co concentrations decrease gradually over several samples.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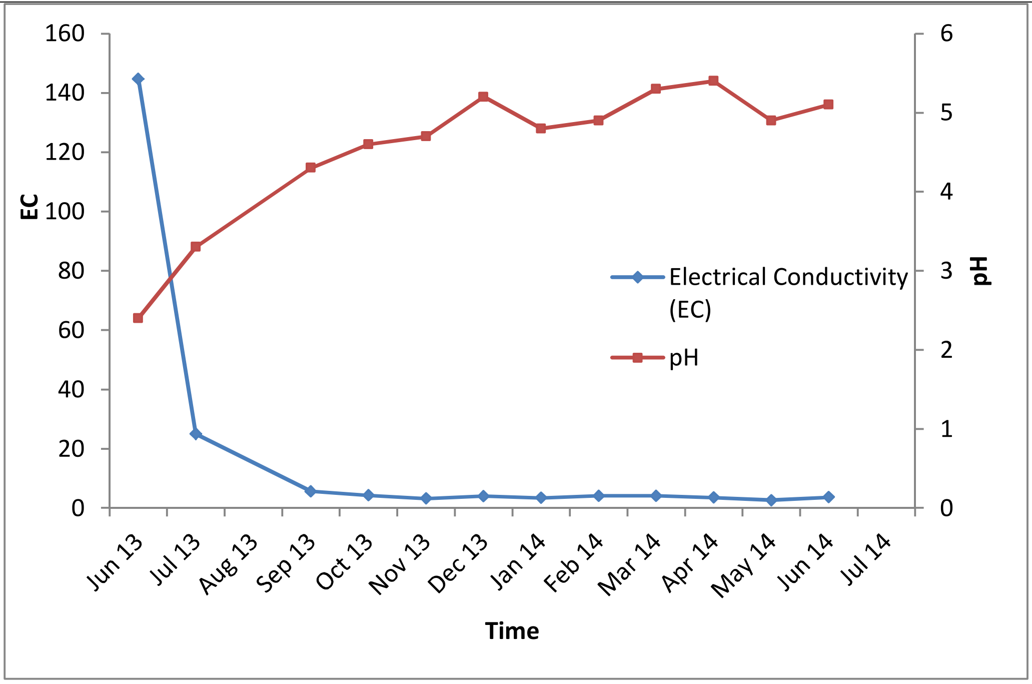
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
MPA
Acidity in kg/tonne
Cumulative acidity in kg/tonne
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time

a)


160
140
120
100
80
60
40
20
0
EC
6
5
4
3
2
1
0
pH
Electrical Conductivity (EC)
pH
Jun 13
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Dec 13
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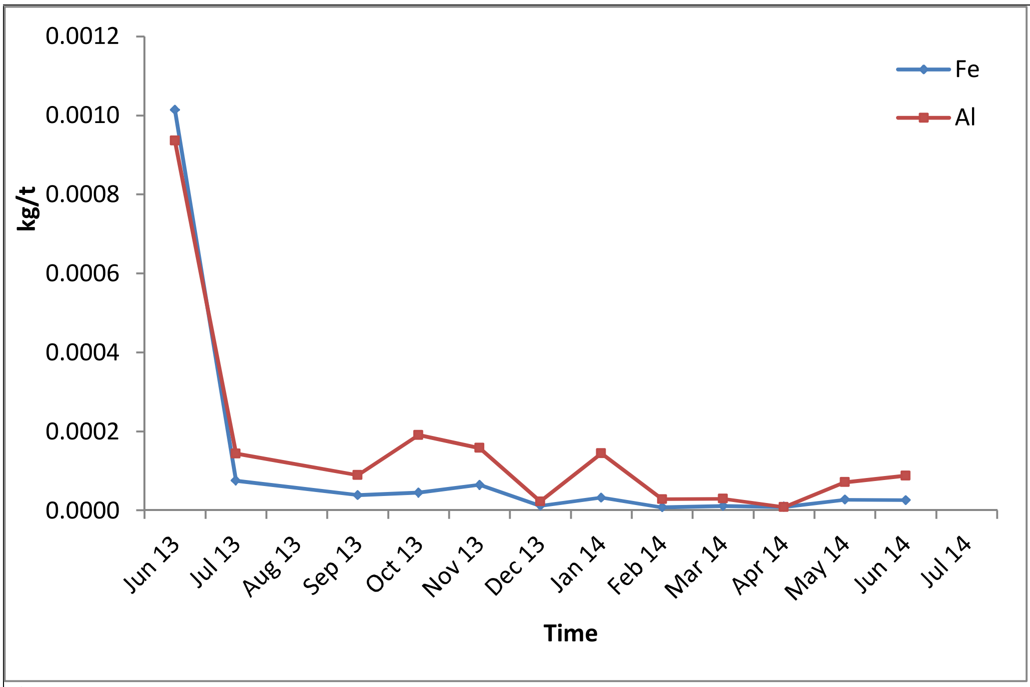
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time

b)


0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
kg/t
Jun 13
Jul 13
Aug 13
Sep 13
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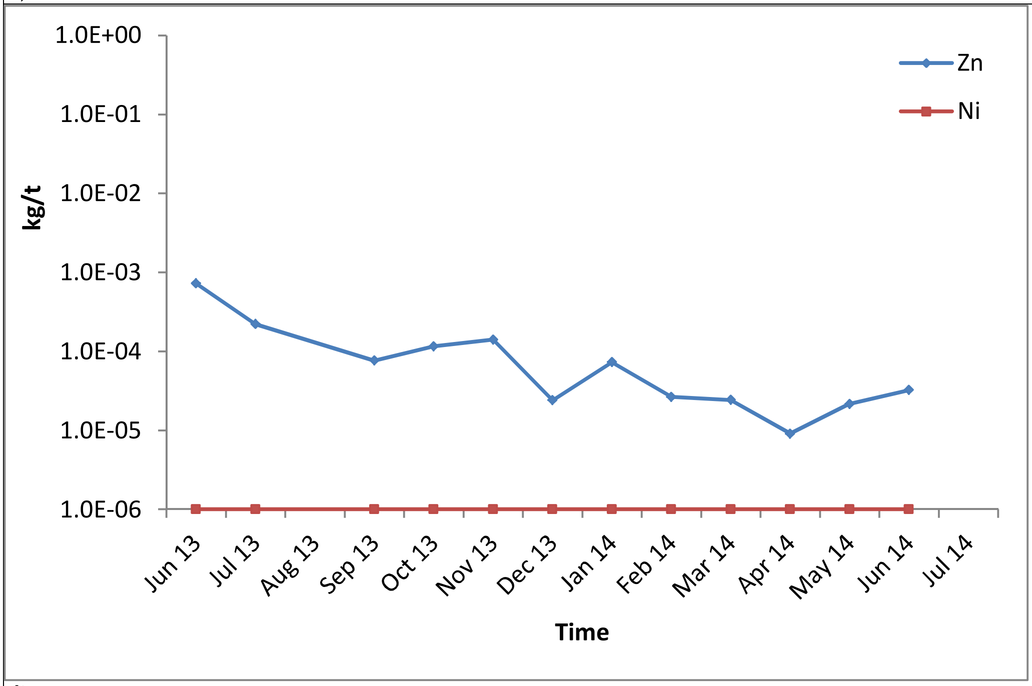
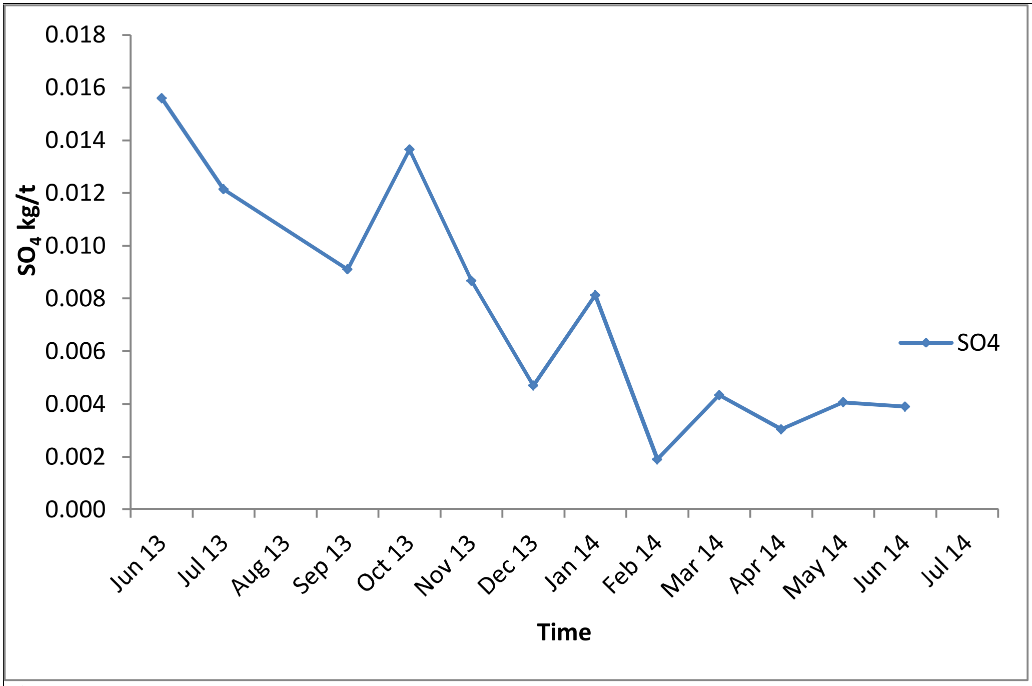
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time
Fe
Al

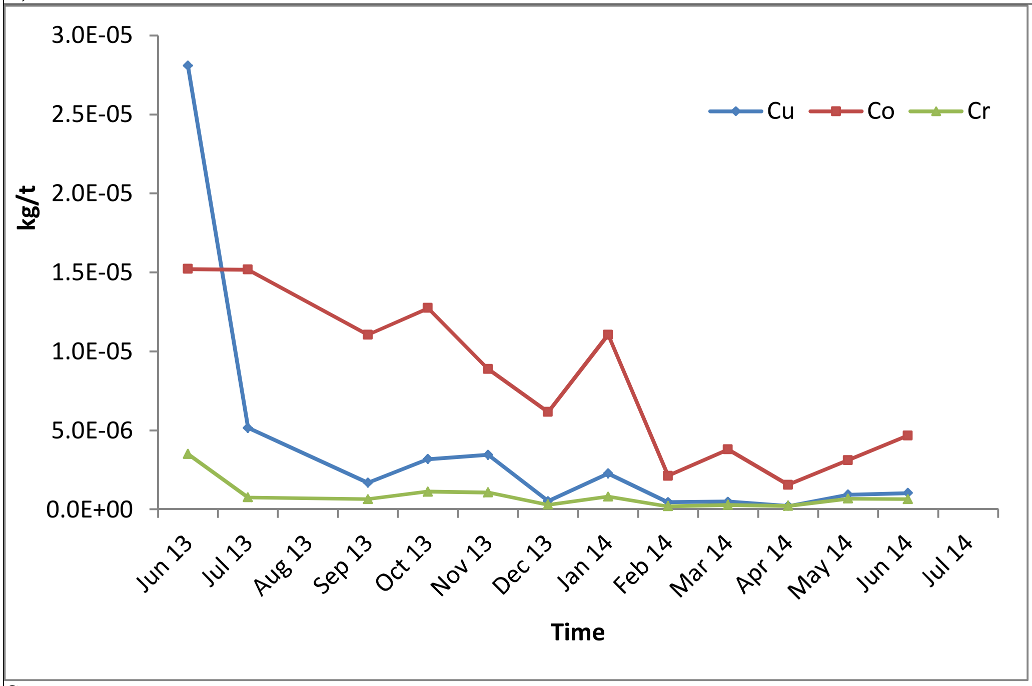
c)


1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
kg/t
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time
Zn
Ni

d)



e)



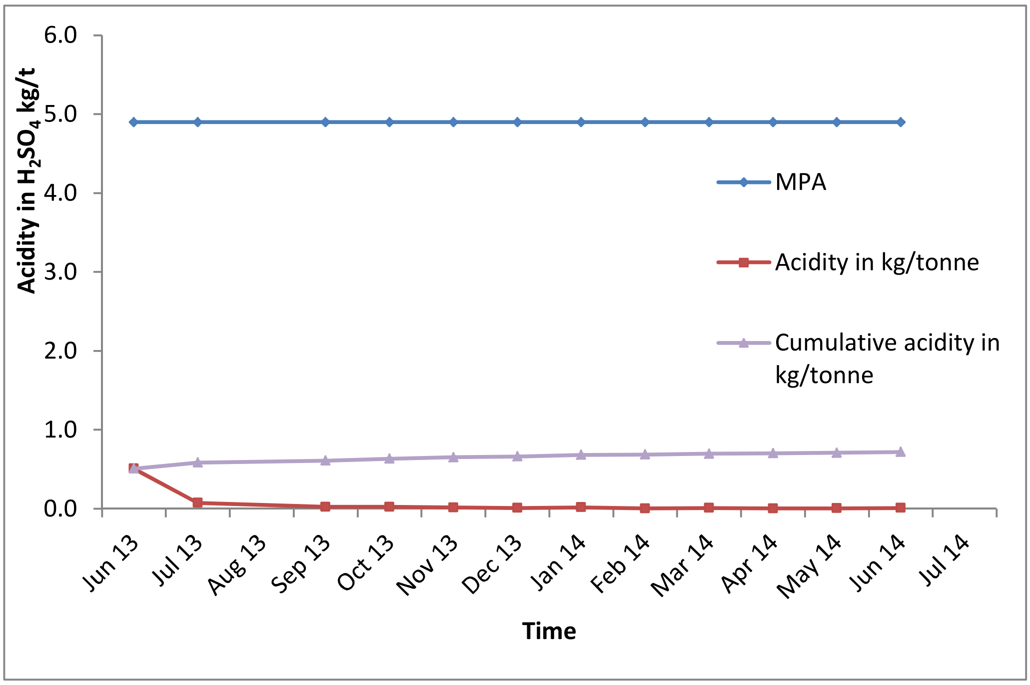
f)

Figure 177: Column 2 Summary figures

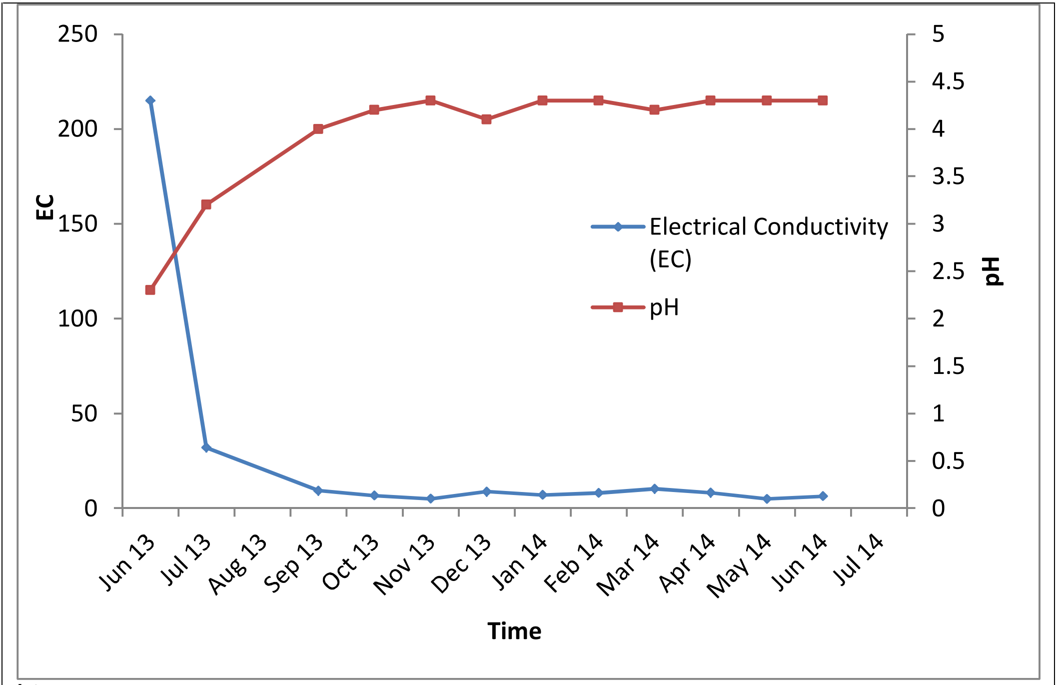
Column 3

The two first samples from column 3 are acidic with a pH below 4 (2.3 and 3.2), but subsequent samples release little acid and pH of the leachate derived from column 3 is between 4.0 and 4.3 generally increasing. Acidity released from Column 3 (Figure 18a) is controlled by pH (Figure 18b) as well as Al without substantial contribution from Fe (Figure 18c). Alkalinity release is below detection. Major anions are Cl in the first two samples (186 & 25 mg/L) and then occurs at lower concentrations between 3 & 8 mg/L. The next most abundant anion then

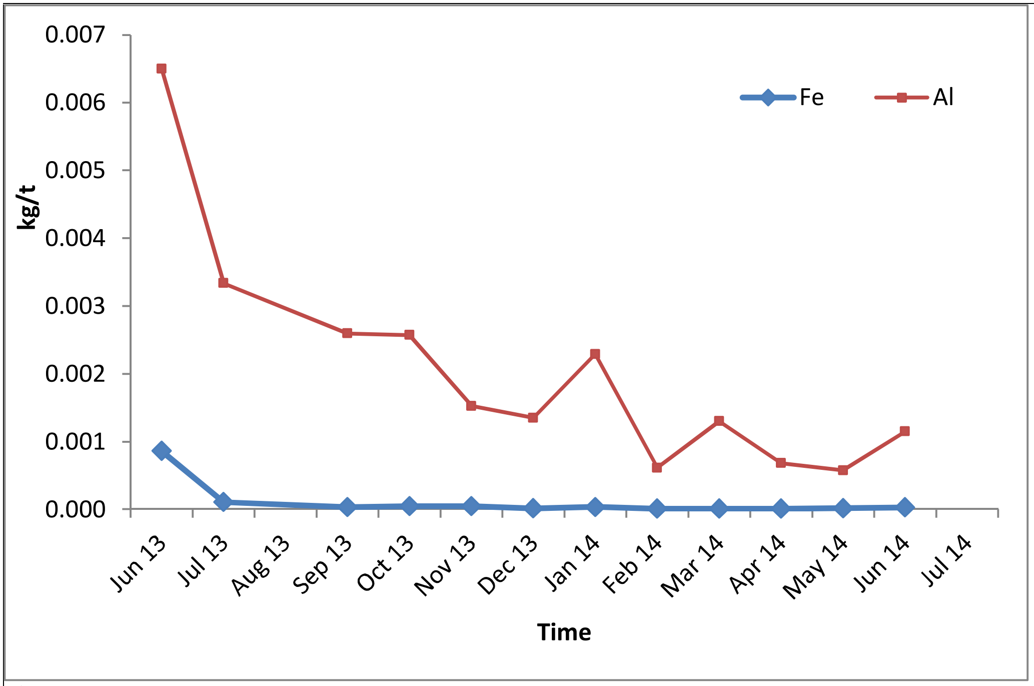
SO_4^{2-} (Figure 18d) which decreases from 54 to 10 mg/L throughout the sampling period. The major cation released is Na between 2 & 4.1 mg/L . The other major cations K, Mg and Ca are all released in decreasing concentrations with time between 0.2 and 3.2 mg/L. Zn is released at relatively high concentrations compared to other trace elements between 0.15 & 1.33 mg/L (Figure 18e). Of the other trace elements (Figure 18f), Cu, Co, Pb, Ni, B and Ba all have concentrations over 0.01 mg/L generally decreasing with time, except Cu which has elevated concentrations in occasional samples.



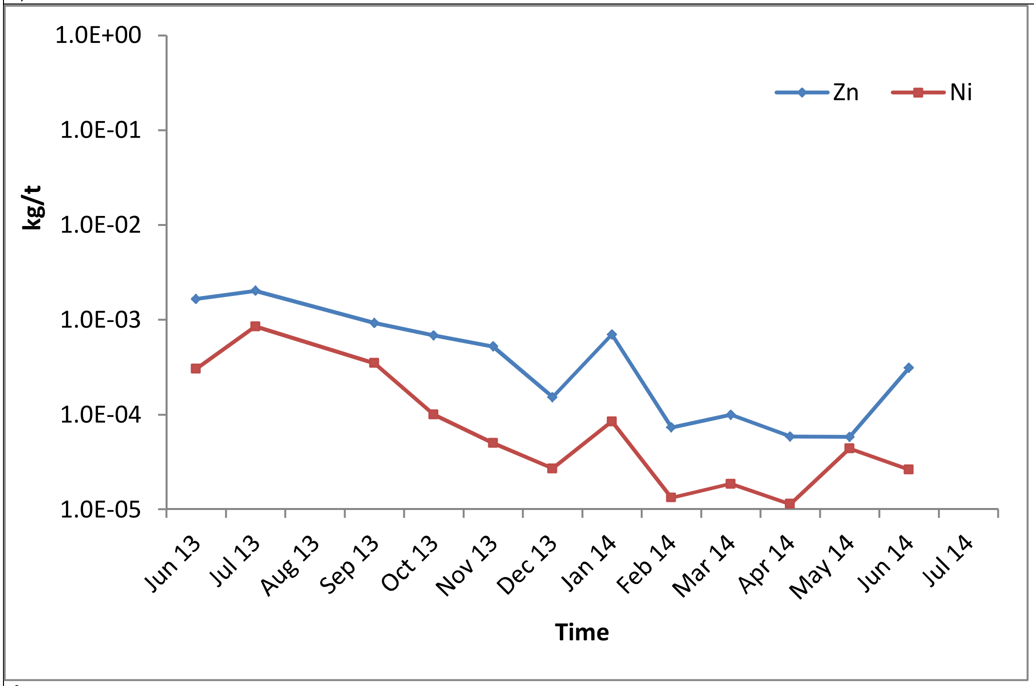
a)



b)


0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
kg/t
Fe
Al
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time

c)


1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
kg/t
Zn
Ni
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time

d)

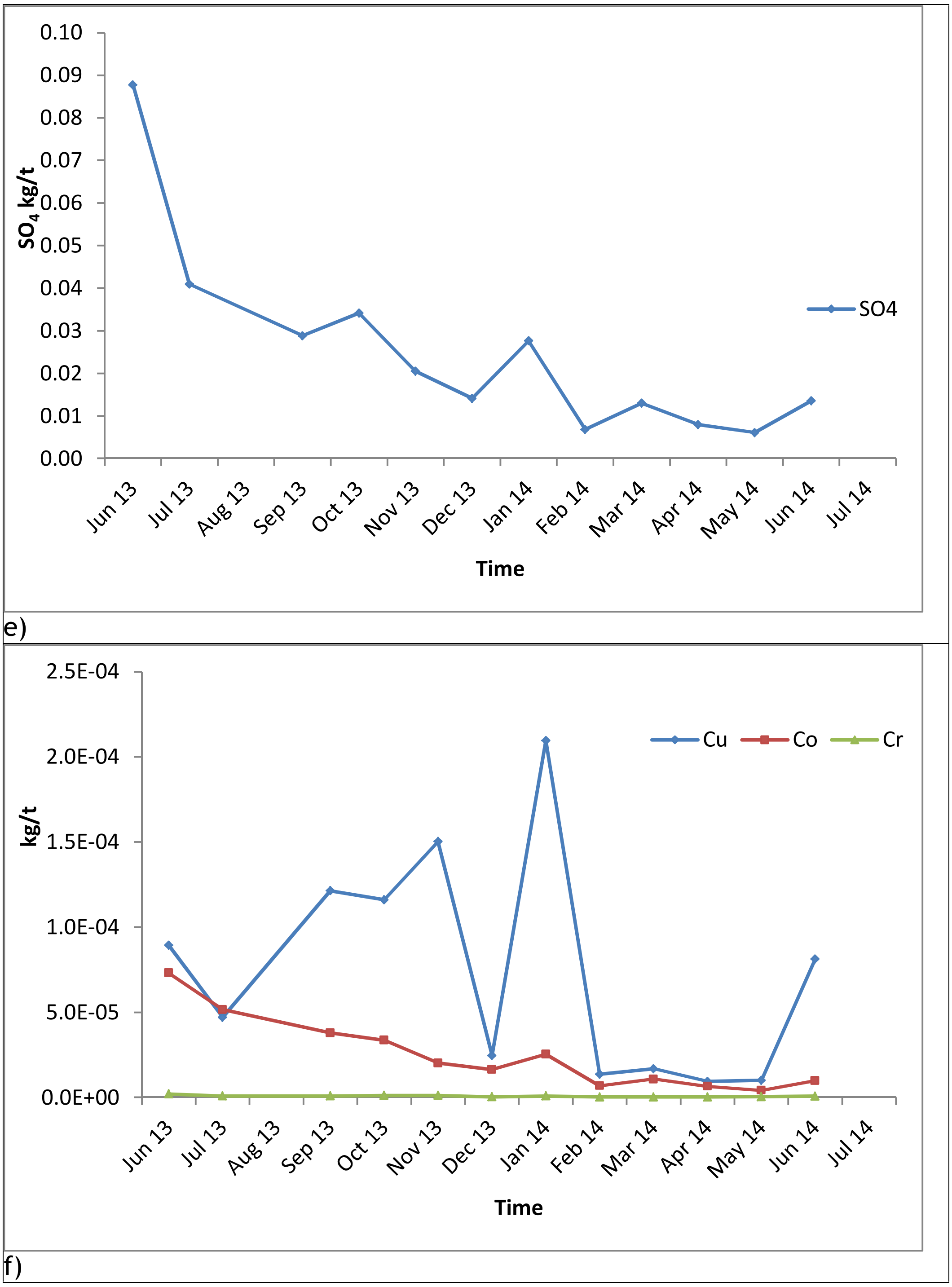
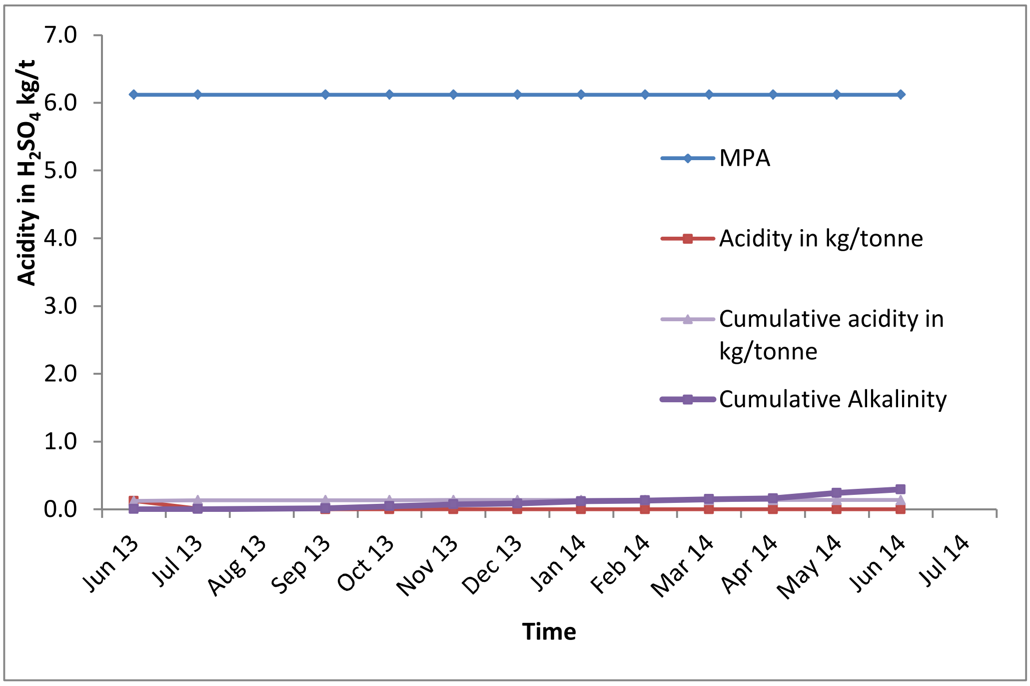


Figure 188: Column 3 Summary figures

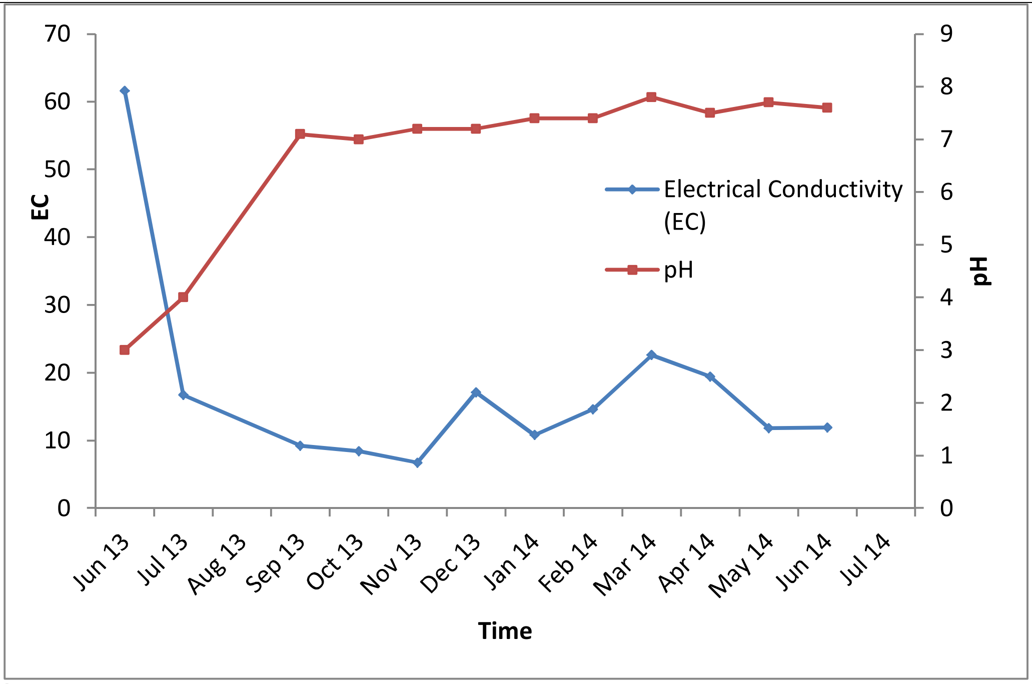
Column 4

The two first samples from column 4 are acidic with a pH between 3.0 and 4.0. Subsequent samples release little or no acid. Acidity released from Column 4 in less than alkalinity release after one year (Figure 19a) and pH of the leachate derived from column 4 is between 4.0 and 7.8 generally increasing (Figure 19b). Little Fe or Al are released from these columns except in the first two samples (Figure 19c). The most abundant anion is SO_4^{2-} (Figure 19d) which decreases from 54 to 10mg/L throughout the sampling period. Other major anions are Cl in the first two flushes

(37 & 11mg/L) then at lower concentrations between 2.4 to 7.6 mg/L. The major cations released are Ca and Mg between 3.62 & 15mg/L. The other major cations K, and Na are released in concentrations between 1 and 4.1mg/L. Zn is released at relatively high concentrations compared to other trace elements between 0.006 & 0.25mg/L (Figure 19e). Of the other trace elements (Figure 19f), Cu, Co, Li, Se, Sr, Ni, and Ba all have concentrations over 0.01mg/L generally decreasing with time.



a)



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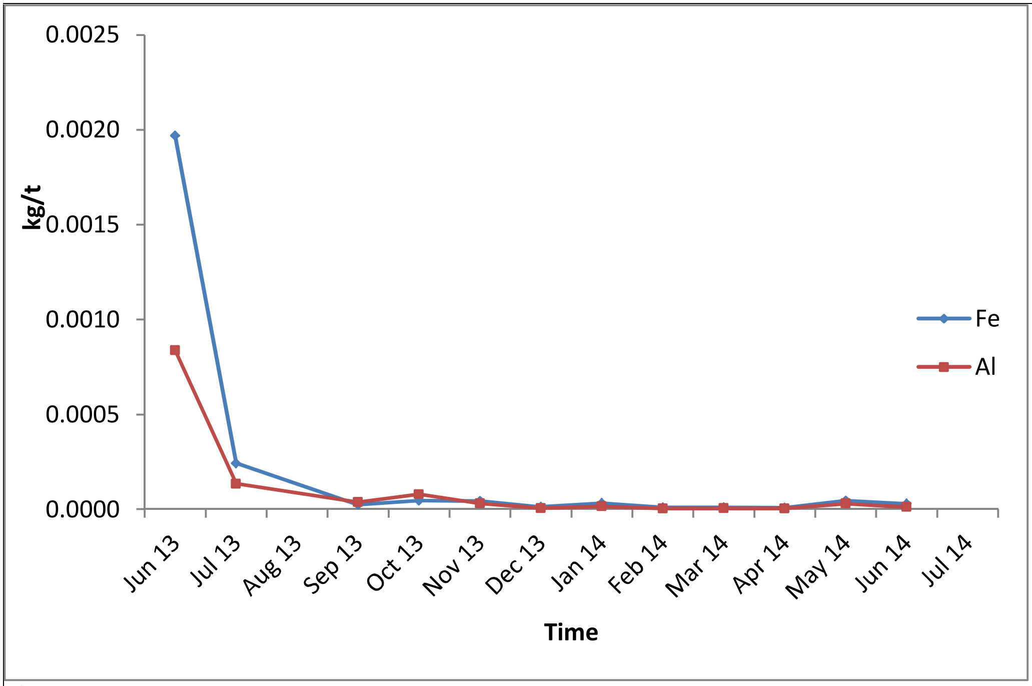
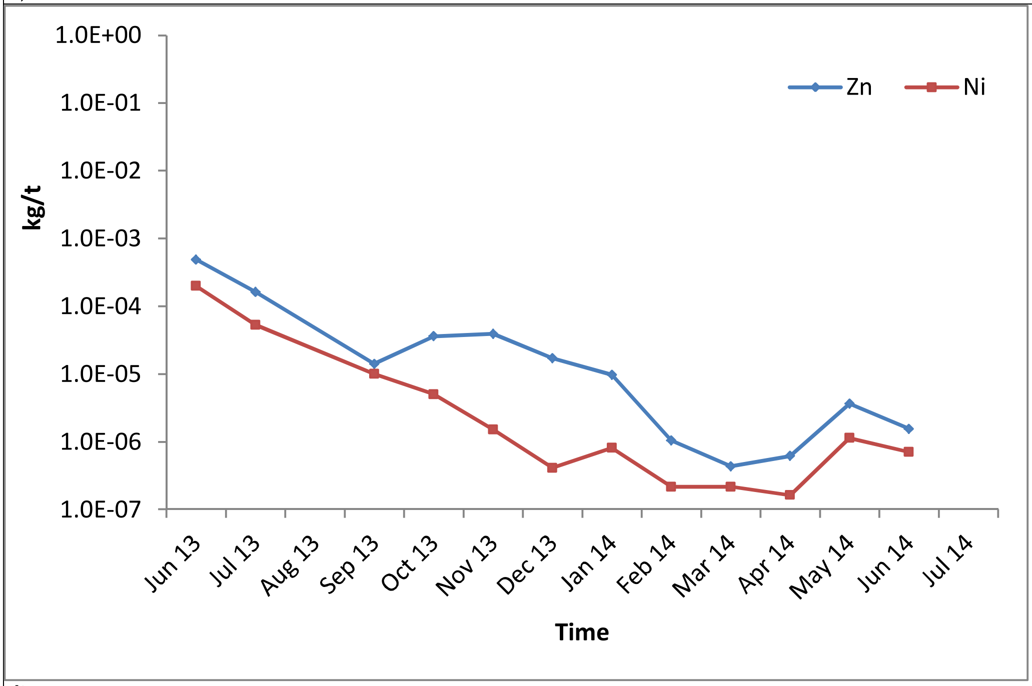

0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
kg/t
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time
Fe
Al

c)


1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
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kg/t
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time
Zn
Ni

d)

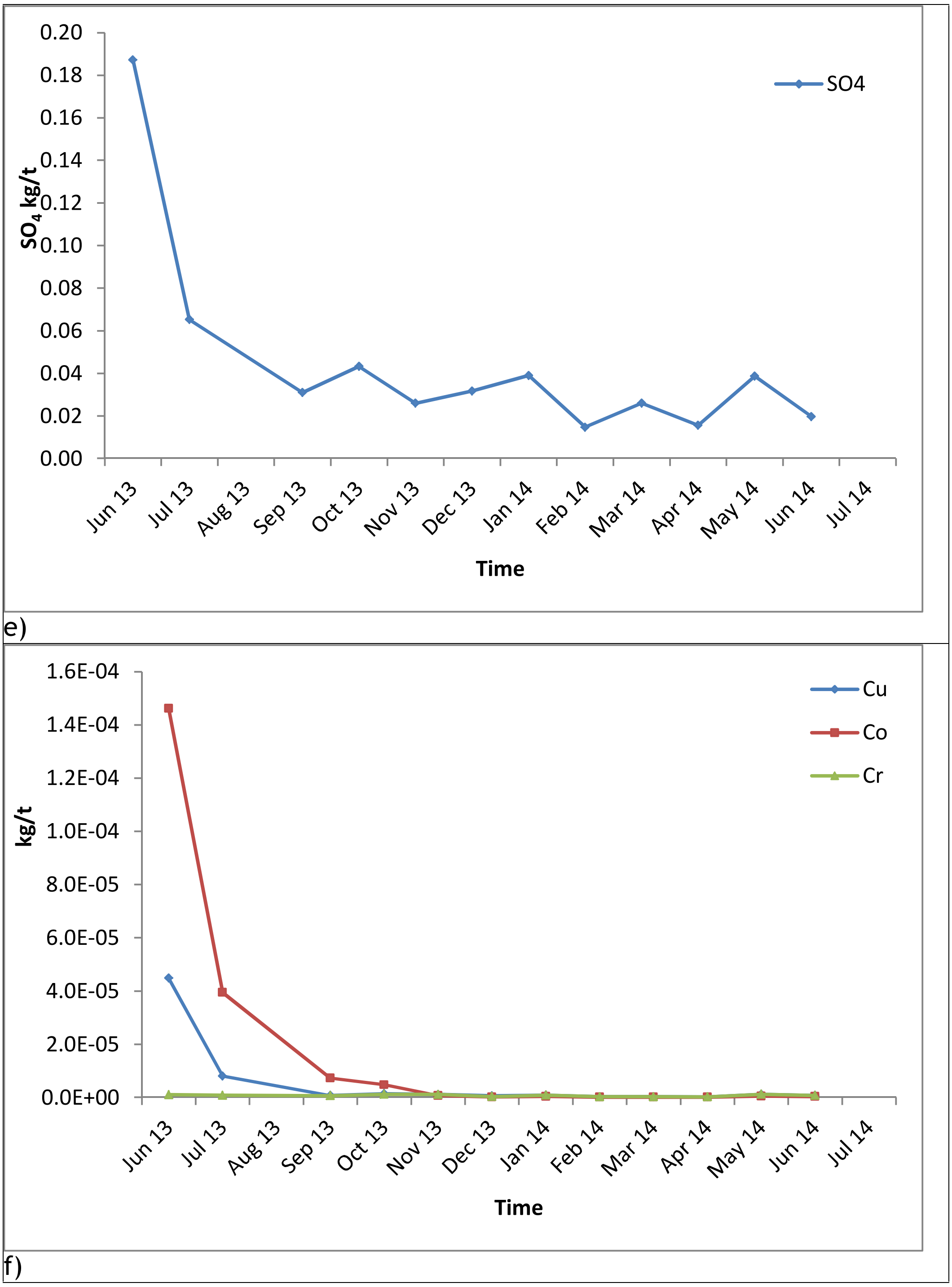
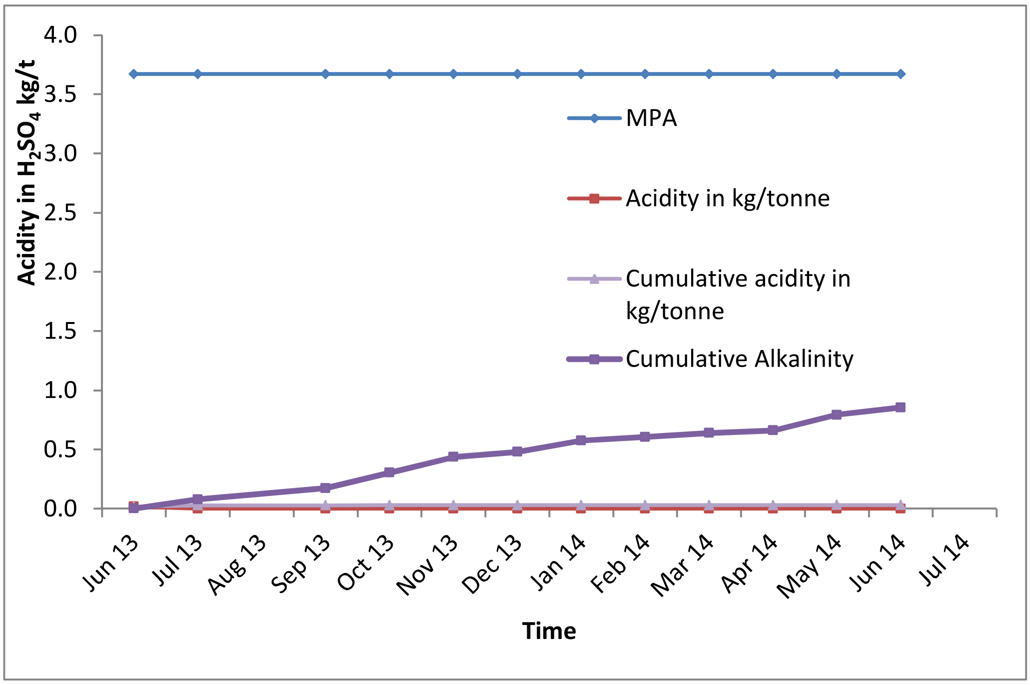


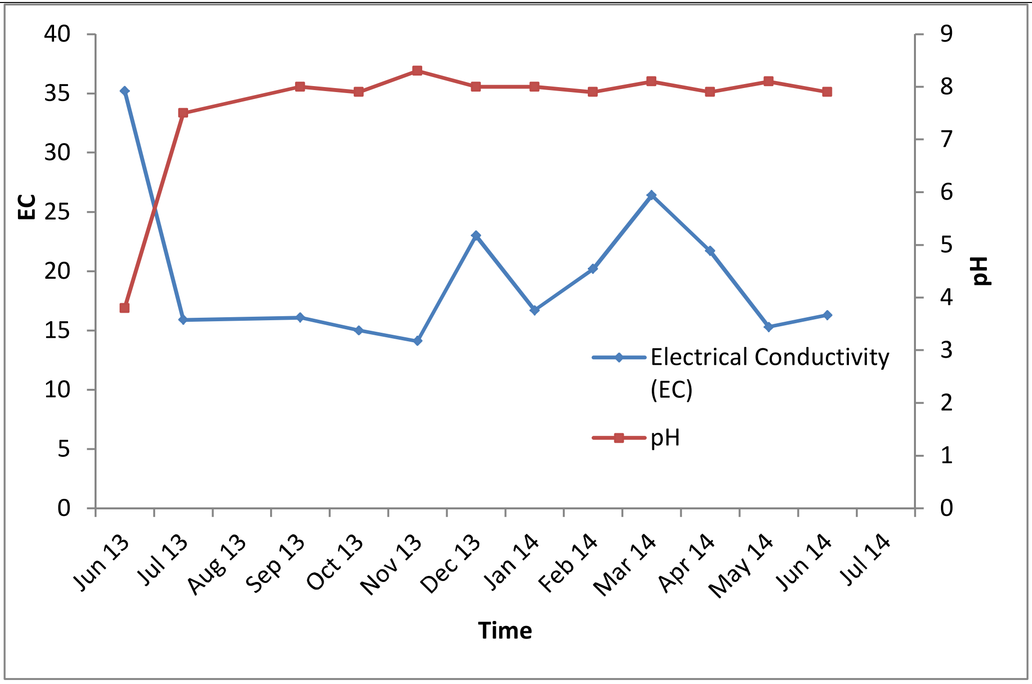
Figure 199: Column 4 Summary figures

Column 5

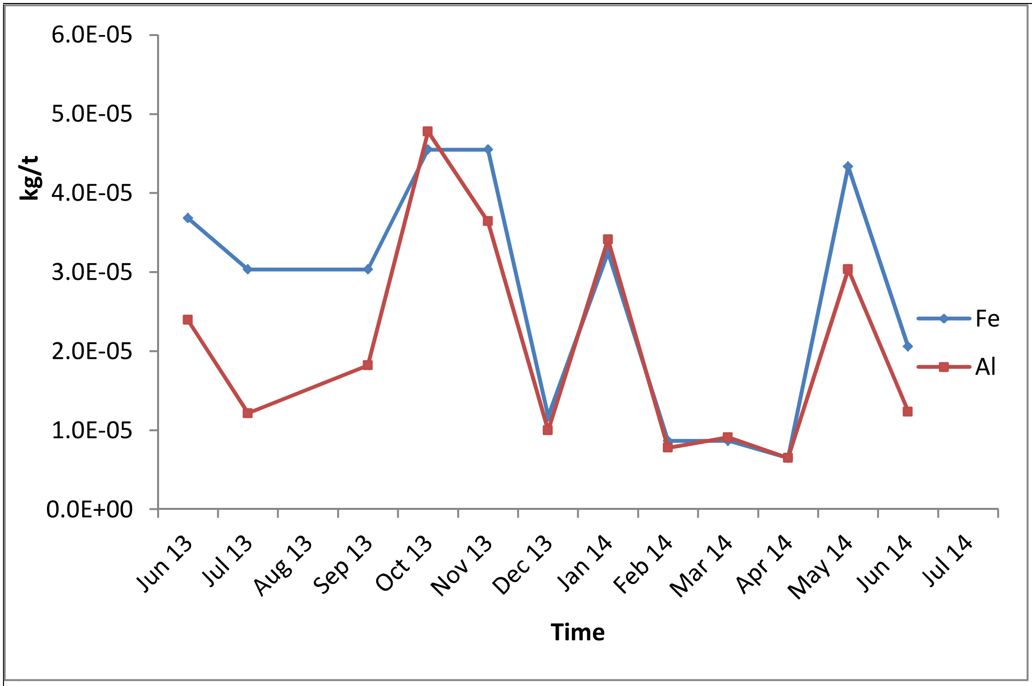
The two first samples from column 5 release acid with a pH at or below 4 (3.0 and 4.0), but subsequent samples release little or no acid. Acidity released from column 5 in substantially less than alkalinity release after one year (Figure 20a) and pH of the leachate derived from column 5 is between 4.0 and 7.8 generally increasing (Figure 20b). Little Fe or Al are released from these columns (Figure 20c). Major anion are Cl in the first sample (56mg/L) and then occurs at lower concentrations between 4 & 8 mg/L. The most abundant anion is SO_4^{2-} (Figure 20d) which has an irregular release pattern in the samples collected. The major cations released are Ca and Mg between 6 & 24 mg/L. The other major cations Na and K are released at concentrations between 0.8 and 4.0 mg/L. Zn is released at relatively high concentrations compared to other trace elements between 0.05 & 0.55 mg/L (Figure 20e). Of the other trace elements (Figure 20f), Cu, Co, Pb, Ni, B and Ba all have concentrations over 0.01mg/L generally decreasing with time.



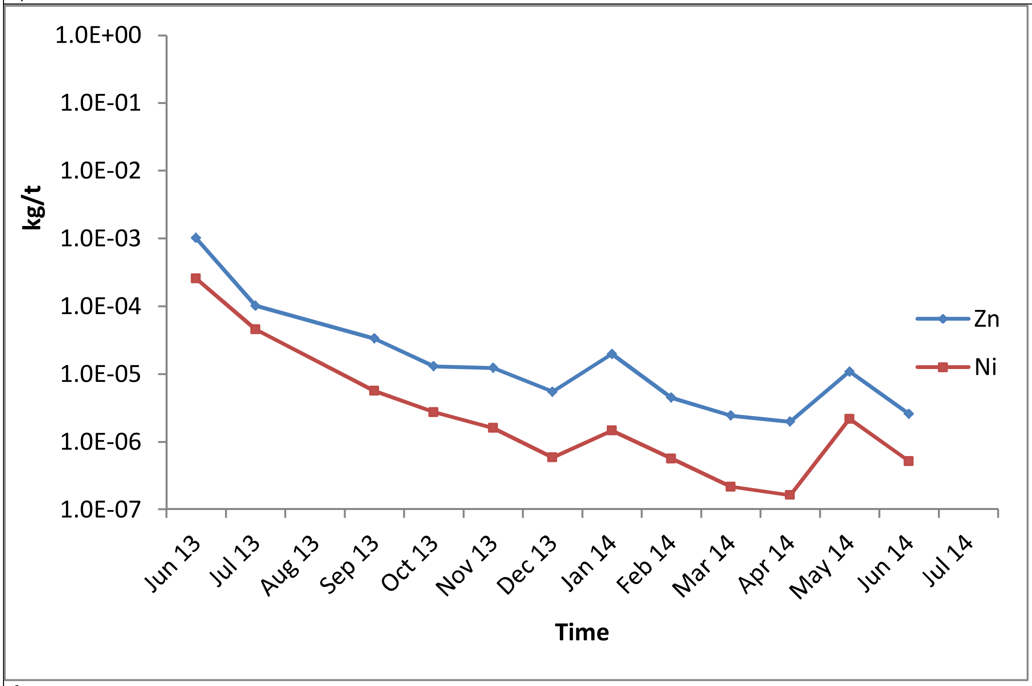
a)



b)


kg/t
6.0E-05
5.0E-05
4.0E-05
3.0E-05
2.0E-05
1.0E-05
0.0E+00
Jun 13
Jul 13
Aug 13
Sep 13
Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time
Fe
Al

c)


kg/t
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
Jun 13
Jul 13
Aug 13
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Dec 13
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Feb 14
Mar 14
Apr 14
May 14
Jun 14
Jul 14
Time
Zn
Ni

d)

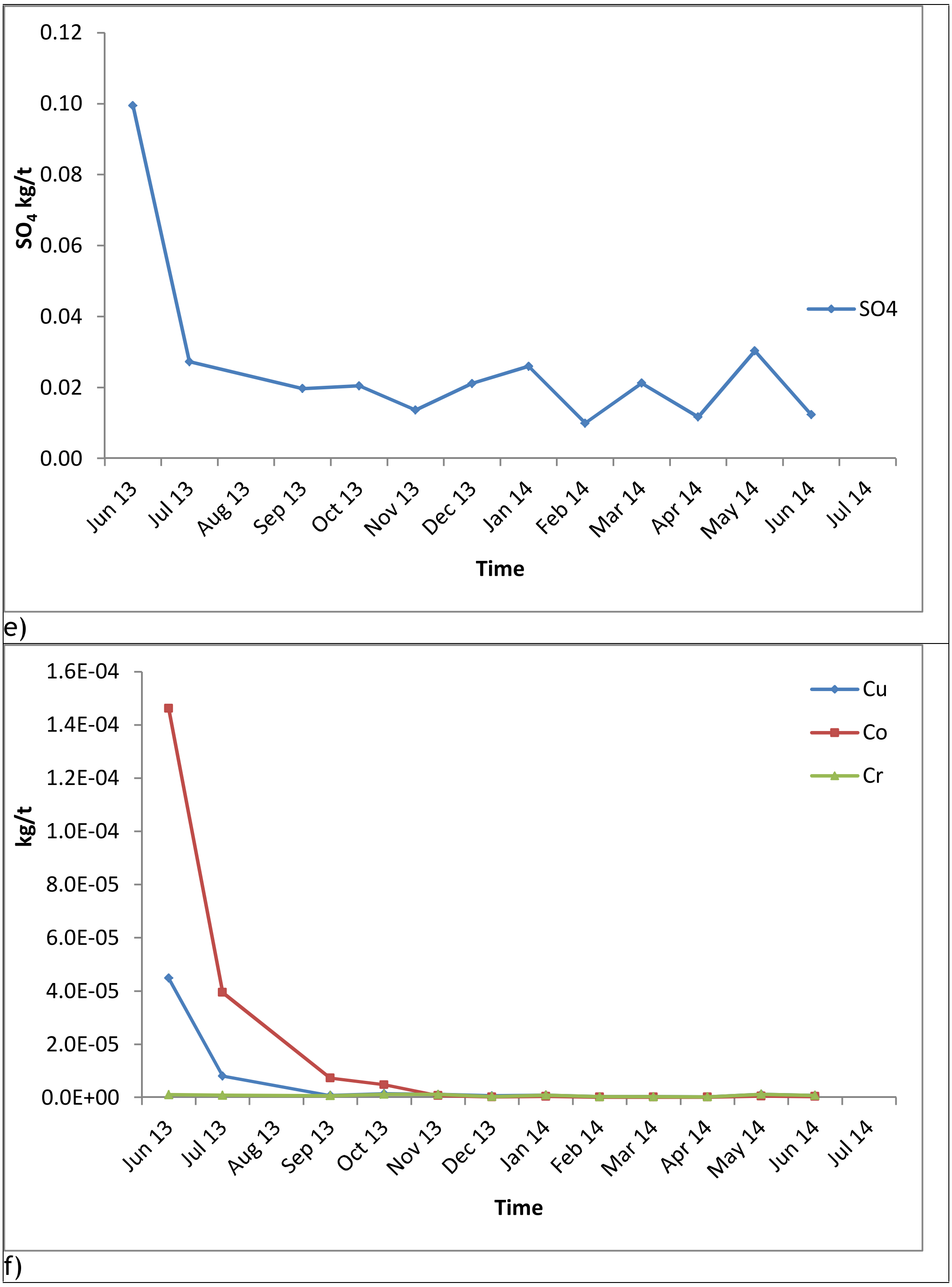

Figure 20: Column 4 Summary figures

Interpretation

Stream flow and groundwater

The conceptual groundwater model (Flintoft, 2013) matches well with observed stream flows in the upland field area. Stable flow at stream sites TKS1, 2 and 3 are all below the 600m contour line where a projected piezometric surface intersects topography and therefore these sites are likely to be fed by deep groundwater controlled springs. This contrasts with TKS4, and 5 where flows are highly variable or TKS 6 where water is either ponded but sometimes dry with rapid response to rainfall. TKS4 and 5 are likely to occur in an unsaturated aquifer recharge zone and TKS 6 relates to the shallow perched ground water system. Flow measurements at TKS 7 do not fit the same pattern because there is variable flow but this site occurs below the 600m contour. Further work is required to understand flow data from this site.

Groundwater depths measured to date are all beneath coal except in TK5 and TK10 which are close to the ridge line toward the north of the deposit. Therefore mining operations are unlikely to intersect significant permanent groundwater flows.

The groundwater model and data indicate that surface water is likely to be the largest contributor to flows within the operational zone of the Te Kuha site. During dry periods many of the upland catchment streams area are likely to have very low flows or remain dry. Therefore high intensity rainfall events are the main water management challenges at Te Kuha.

Hydraulic conductivity of the Brunner Coal Measures rocks has been measured and is typical of Brunner Coal Measures elsewhere (Flintoft, 2013). The rapid response of ground water levels to rainfall (hours) indicates that the groundwater system will store and release high intensity rainfall relatively quickly. Therefore the hydraulic conductivity of the coal measures is only responsible for a small fraction of the groundwater that is transmitted with secondary permeability related to fractures and voids responsible for most groundwater flow (Flintoft, 2013).

With these results and interpretations, water management planning will assume that ground water flows into the operational area are negligible compared to surface water discharges and planning will completed to cater to high intensity rainfall events using a water flow model with the following characteristics.

1. No infiltration of rainfall
2. No evapotranspiration of water by plants
3. No groundwater inflow

1) The assumption of no infiltration is conservative because groundwater response to rainfall is rapid at Te Kuha. It is equivalent to assuming that a rainfall event which is used to plan water management occurs immediately after an prior rainfall event large enough to saturate the recharge zone.

2) The assumption of no evapotranspiration is conservative because vegetation can transfer substantial volumes of water into the atmosphere. However, the mined area will be disturbed and while vegetation will be re-established it is unlikely to be a factor that will significantly influence the site surface water flows.

3) The assumption that there will be no groundwater inflow is not conservative. However, the absence of water above coal in the drill holes for which hydrogeological data has been collected indicates that groundwater discharge is likely to be minimal for Te Kuha operation.

Recommendations

1) Prior to mining or early during operations, groundwater monitoring wells should be installed at least in the ridge line area near TK5 and TK10 with completion methods designed by a hydro geologist. Data from these wells can be used to validate the conceptual model and ensure that the groundwater component of mine discharge will not cause problems as the ridgeline area is mined.

2) A programme to test the flow response of the upland streams to rainfall events should be completed to validate the hydrogeological model on which additional Te Kuha water management planning is based.

Stream chemistry and groundwater chemistry

Water quality in the upland rivers is similar to water quality that drains Brunner Coal Measures in other places (Davies, 2009; Davies et al., 2011; Pope et al., 2010a). In these catchments, pH is commonly low (~4 - 5.5) and the concentrations of dissolved metals including Fe and Al is commonly higher (0.1 – 0.5 mg/L) than catchments that drain other rock types on the West Coast. Typically these streams contain little or no alkalinity and can have slightly enriched trace element concentrations (particularly Zn, Ni and Mn) compared to streams that drain other rock types.

Lowland river sites indicate natural neutralisation of the mildly acidic upland river sites, with lower acidity, higher pH and increased alkalinity compared to the upland sites. Neutralising capacity for the lowland river sites comes either from Paparoa Coal Measures or underlying breccia units. The Paparoa Coal Measures are commonly acid neutralising and the underlying breccia contains clasts of Greenland group rocks that typically have carbonate minerals.

Groundwater chemistry data from the samples collected to date mostly falls within with the variability of surface water chemistry. This indicates that groundwater processes are the dominant control on water chemistry at Te Kuha at base flow conditions. In general, the surface water and groundwater system has relatively stable, and therefore predictable, chemistry.

Should other sites or analytes apart from those examined to date require investigation, one or two samples taken at average flow will provide a good indication chemistry and large variations are unlikely to occur naturally.

Recommendations

1) The response of upland stream physio-chemistry through a flow event would be useful information. It is possible that there are flushing events from the unsaturated zone that have elevated concentrations of dissolved components or lower pH that discharge as groundwater flushes through the aquifer. Using the conceptual hydrogeological model presented above, variations in the local flow

conditions should be well characterised to ensure the most appropriate consent conditions are in place.

2) It is also possible that surface water flushing events cause elevated TSS therefore short term temporal changes in TSS load in the upland streams should be investigated during early operations. Information collected to date indicates that the catchments have low levels of suspended sediment. TSS load will be one of the critical water management issues for the site.

Waste Rock Geochemistry

The Te Kuha deposit is a unique opportunity to opencast both Brunner and Paparoa Coal at the same mine in roughly equal quantities. The Te Kuha deposit is also unique because Brunner Coal Measures rocks at this site are the less acid forming than Brunner Coal Measures from all other sites for which data are available (Figure 15 & 20). The reason for this is unclear, it is possible that the BCM deposited at Te Kuha did not have as much sulphide as other areas or it is possible that the low groundwater table has allowed the Te Kuha deposit to oxidise gradually.

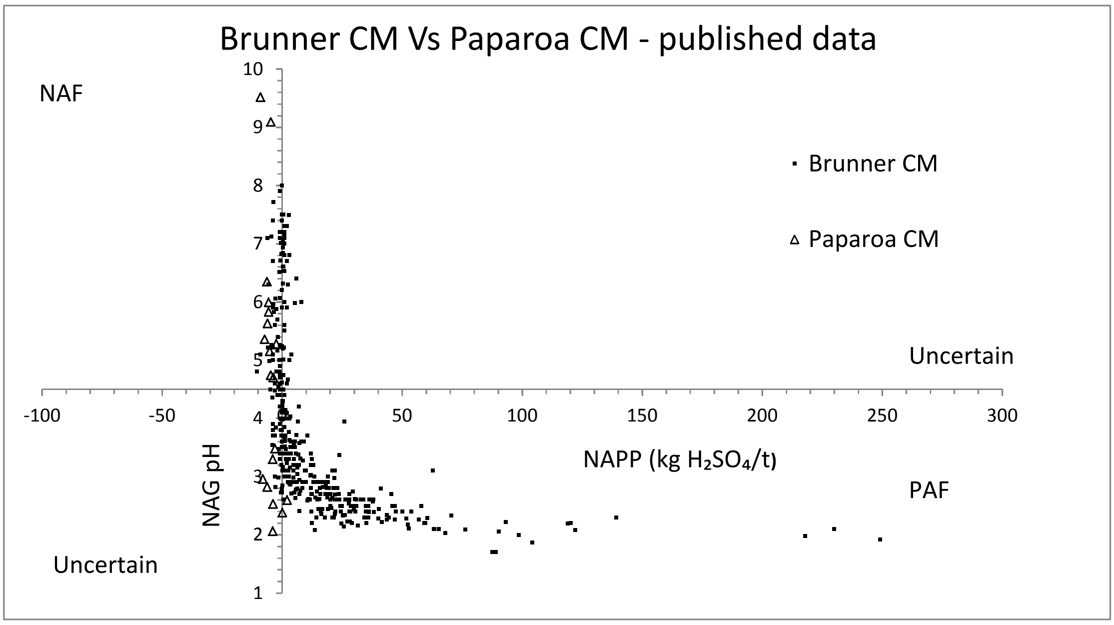

Figure 21: Typical distribution of Acid Base Accounting for Brunner and Paparoa Coal Measures Rocks. (Scale is the same Figure 15)

Mines within Brunner Coal Measures commonly produce acid rapidly and release Fe, Al, Zn, Ni, Mn and other trace elements as acid mine drainage (Davies et al., 2011; Pope et al., 2010a; Pope et al., 2010b). However, less commonly Brunner Coal Measures do not produce acid quickly and instead remain neutral either for a lag period (Pope and Weber, 2013; Weber et al., 2013) or perhaps continue to weather without producing acid.

Samples collected to date are well enough distributed throughout the deposit to give confidence that the balance of acid to non-acid forming rocks has been identified and that the stratigraphic nature of the distribution of Brunner and Paparoa Coal Measures allows predictive ability for which rocks are NAF and which ones could be acid forming. It is possible that additional more acid forming Brunner rocks will be identified as mining progresses. However, any departures from the trends identified so far can likely be managed during operations.

Re-handling of waste rock during final rehabilitation at the Te Kuha deposit could cause release of acid that is otherwise stabilised within the temporary waste rock dump. The acid could be stable in the temporary waste rock dumps either as unreacted sulphide minerals or as partially oxidised secondary minerals. Either way re-handling of waste rock poses a different risk with respect to acid mine drainage than placement of this rock in temporary waste rock dumps during mining.

Recommendations

1) The non-acid forming Paparoa Coal Measures can be used to minimise the oxidation and acid formation from Brunner Coal Measures by selective placement. Paparoa Coal Measures should be used as a capping material over Brunner Coal Measures. The cap thickness should be a minimum of the total root penetration depth for plant species proposed for final rehabilitation. This is likely to be 3-5m minimum depending on plant species. This strategy should apply to both temporary and final landforms. This strategy works by neutralisation of any acid generated with the excess alkalinity contained in the Paparoa Coal Measures and does not require compaction or low permeability zones. However, compaction to encourage runoff rather than infiltration be an advantage.

2) Dumps should be constructed in lifts ~5m to prevent grain-size segregation and chimney effects that encourage oxygen ingress.

3) An as-built model or plan of temporary waste rock dumps should be completed so that the relative volumes of and locations of Paparoa and Brunner Coal Measures can be predicted during construction of the final landform and Paparoa Rocks can be arranged as cap rocks.

4) A geochemical study should be completed prior to re-handling the large volumes of waste rock required to construct the final landform in the final years of this operation. This study will focus identification of any risks of acid or trace element release through secondary salts that were not previously present in the rock. If this study identifies pyrite the risk is the same as the risk for primary mining and the recommendations above apply. However if there is risk associated with secondary minerals then new management techniques might be required such as blending Paparoa and Brunner rock types or limestone addition to prevent rapid flushes of acid.

Mine Impacted Water Chemistry

In general the chemistry from leachate testing and the Brunner Coal Measures rocks is similar to the natural drainages from the upland stream sites. There is a very similar pH range between the leachate and the upland stream water and the suite of enriched cations, anions and trace elements are similar in both sets of samples. Dissolved components are higher in the leachate compared to the stream water especially during the early period of leaching. The only exception to this pattern is the acidic samples collected in the first one or two leachate samples from each column.

The most acidic analyses in early samples from the columns all have elevated Cl concentrations. Prior to set up of the columns all equipment was acid washed with dilute hydrochloric acid (~5%), this is standard practice to remove residual trace elements from experimental equipment and prevent contamination. This procedure should be followed by rinse with distilled water to remove any residual acid however, the rinse was not completed properly and some residual acid remained in the columns apparatus. This interpretation of the acid release for the first two samples from the columns can be confirmed by back calculation. For example, if 180 of the 187mg/L Cl in the first sample from Column 1 is assumed to be HCl then the pH would be 2.3, which matches the measured value. Therefore the apparent early acid release from all five field columns relates to inadequate rinsing of dilute HCl used to clean the equipment rather than a release of acid from the rocks. The concentrations of other components in the first two samples does not seem to be elevated so it is most likely that the residual HCl occurs in the large 200L sample collection drums rather than in contact with the rocks. For interpretation of water chemistry the pH, acidity & EC and Cl concentrations of the first two samples are not used further.

Comparison of upland stream chemistry compared to field column leach data (Table 12) indicates that leachate produced by mining at Te Kuha would be enriched in many dissolved components compared to surrounding surface water.

The main differences in leachate compared to upland stream surface waters are:

- Leachate commonly has a higher pH than stream waters.
- Leachate has a higher acidity but on average is within the range of values measured in streams.
- Leachate has a substantially higher alkalinity than upland streams
- The concentration of sulphate and major cations is higher in leachate.
- The concentration of trace elements is generally higher in leachate
    - Al, Zn, Ni, Mn, Fe all have average concentrations greater than 0.02mg/L and all have average concentrations in leachate that are outside the measured range in stream water.

The data presented in Table 12 represents the extremes and average concentration in leachate from Te Kuha rocks over a one year period. Concentrations that are this high are unlikely at the Te Kuha Mine discharge points because, they will be diluted by surface waters that have had little or no interaction with rocks.

Recommendations

1) In general, with the exception of elevated Al and Zn concentrations the water quality in the leachate is likely to cause only minor environmental impact if it was directly discharged compared to all other mines in the Brunner Coal Measures. However the chemistry in this table should be assessed by ecologists to identify the major components that can cause impact.

2) If there are concentrations of components in leachate that will cause substantial environmental impact, then alternative waste rock handling processes might be considered to improve leachate quality.

		Upland sites		Lysimeter Data		
Analyte	units	Max	Min	Max	Min	Average
pH		6.5	4.1	8.3	4	
Acidity	mg/L ($CaCO_3$)	8.4	0	25	1	4.7
Alkalinity	mg/L ($CaCO_3$)	2.7	0	79	1	17
HCO_3^-	mg/L	3.3	1.1	95	1	20
EC	mS/m	5.8	2.4	26.4	1.8	9.3
Cl	mg/L	5.8	4.1	9.2	2.3	4.8
NO_2^-	mg/L	0.004	0	0.02	0.002	0.0029
NO_3^-	mg/L	0.75	0.002	0.54	0.002	0.054
$NO_2^- + NO_3^-$	mg/L	0.75	0.002	0.55	0.002	0.055
Reactive P	mg/L	0.005	0	0.24	0.004	0.0085
$SO4_2^-$	mg/L	12	1	96	2	18.5
Ca (aq)	mg/L	0.81	0.15	27	0.26	6.01
Mg (aq)	mg/L	0.56	0.34	15.6	0.27	4.04
K (aq)	mg/L	0.29	0	2.9	0.3	1.01
Na (aq)	mg/L	3.7	0	4.5	1.77	3.13
Al (aq)	mg/L	0.38	0.085	4	0.008	0.409
As (aq)	mg/L	0	0	0.002	0.001	0.00101
Ba (aq)	mg/L	0.0041	0.00064	0.055	0.005	0.0194
B (aq)	mg/L	0	0	0.048	0.005	0.0074
Cr (aq)	mg/L	0.001	0	0.0029	0.0005	0.000585
Co (aq)	mg/L	0	0	0.075	0.0002	0.00838
Cu (aq)	mg/L	0.0007	0	0.129	0.0005	0.012
Fe (aq)	mg/L	0.54	0.03	1.01	0.02	0.0608
La (aq)	mg/L	0	0	0.0032	0.0001	0.000418
Pb (aq)	mg/L	0.00026	0.00012	0.041	0.0001	0.003
Li (aq)	mg/L	0.0014	0	0.0135	0.0003	0.00232
Mn (aq)	mg/L	0.0131	0.0005	0.4	0.0005	0.0524
Ni (aq)	mg/L	0.0005	0	0.56	0.0005	0.0287
Rb (aq)	mg/L	0.00105	0.00025	0.0197	0.00091	0.00461
Sr (aq)	mg/L	0.0038	0.0025	0.044	0.004	0.0157
Zn (aq)	mg/L	0.0077	0.0011	1.33	0.001	0.154

Table 12 Variation in upland stream chemistry compared to field column data

Summary and Conclusion

Datasets on, climate, stream flow, stream chemistry, groundwater level, groundwater chemistry, rock geochemistry and leachate formation for the Te Kuha site have been collected. These datasets provides information on the environment in which mining is planned to operate and the receiving environment downstream of operations.

Te Kuha receives substantially more rain than Westport although the number and frequency of weather systems is clearly related. About 50% of the rainfall is contributed by the 10% of the rainfall events.

A conceptual hydrogeological model for the deposit area has been developed by integrating stream flow data and groundwater information. Permanent groundwater levels are deep in the Te Kuha area, beneath coal in all but two of the seventeen drill holes that could be measured. Therefore, most of the deposit area represents a groundwater recharge zone. In this zone secondary porosity controls groundwater flow and the deep aquifer responds relatively quickly to rainfall. Streams in this recharge area have variable flow. Below about 600 m the pizometric surface of the deep aquifer intersects topography and streams below this elevation relatively stable flow. Groundwater is unlikely to contribute substantial flow to the Te Kuha site through in pit seepage.

Stream chemistry is variable between the upland and lowland sites. The upland sites have chemistry that is typical of Brunner Coal Measures hosted streams, low pH, no alkalinity, elevated dissolved metals. Whereas the lowland sites have moderate pH, excess dissolved alkalinity, higher dissolved cations and variable trace element concentrations.

The most important feature of the rock geochemistry at the Te Kuha deposit is that both NAF Paparoa Coal Measures and PAF Brunner Coal Measures are present. This means that there is an opportunity to use waste rock management techniques to prevent acid formation. In addition at the Te Kuha site the Brunner Coal Measures rocks contain substantially less acid forming potential than has been previously documented.

Leachate from Brunner Coal Measures columns has a pH range that is similar to the upland stream sites, but with elevated concentrations of dissolved metals compared to upland streams. Leachate from the Paparoa columns has excess alkalinity and some elevated dissolved metals.

Integration of the leachate chemistry with the mine plan at Te Kuha using the conceptual models developed in this report is in progress.

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