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Investigation of seasonality effects on domestic wastewater quality

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EXECUTIVE SUMMARY

Background

Wastewater quality impacts on the lifetime of sewerage pipe assets, the operation of wastewater treatment plants, and the capacity for beneficial reuse of biosolids and effluent. A range of contaminants are expected to be present in wastewater including arsenic (As), antimony (Sb), boron (B), cadmium (Cd), copper (Cu), chromium (Cr), chloride (Cl), fluoride (F), iron (Fe), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), nitrogen (as TKN), phosphorus (as Total Phosphorus), selenium (Se), sodium (Na), tin (Sn), zinc (Zn), total dissolved solids (TDS) and colour.

These contaminants can impact the sewerage system, adversely impact sewage treatment, the environment and/or prevent the recycling of effluent and biosolids.

A desktop study of residential wastewater quality resulting from household product use estimated that households could be significant sources of Na and B and potential sources of As, Cd, Ni, Pb, Sn and Zn, but that many of these last elements would be either at or below the concentrations for analytical detection (Tjandraatmadja *et al.* 2008).

In a previous study, the concentration of such contaminants in wastewater in a residential neighbourhood in South-east Melbourne was evaluated during February to March 2008 (Tjandraatmadja *et al.* 2009). In that study, wastewater was monitored at three locations within the neighbourhood, each representing a wastewater catchment of a different size: 7, 163 and 697 properties.

That study determined that the summer concentration of a range of priority contaminants was not statistically different from the historical data for Melbourne wastewater. Concentrations of elements such as As, Cd, Co, Hg, Mo and Se were below the detection limit in summer as in earlier studies and TKN was similar. However, B, Na and P were lower in 2008 and Cr higher in concentration compared to earlier studies (Connor and Wilkie 1995).

Data had been gathered during summer, a season characterised by high temperatures (>23°C), low rainfall (i.e. less than 5 days with more than 1mm rainfall in a month), and, under 3a water restrictions at the time, which restricted garden watering with mains water to specific times and number of days in a week.

Under such conditions, it was expected that practices such as greywater diversion for garden irrigation would have been more commonly adopted by householders. This could have contributed to the lower concentrations observed for Na, B and P, which are major components of key ingredients found in laundry products.

To confirm if this was true and to better understand the characteristics of the wastewater generated in those catchments, it was also necessary to determine what impact seasonality would have on the wastewater. Hence, the quality of wastewater was also monitored during the winter period, when rainfall is more frequent.

This report is part of the Smart Water Fund project Round 3 – Project 5 *Household sources of priority contaminants in domestic wastewater.* The overall project aims to understand the origins of contaminants in domestic wastewater and to evaluate strategies for their reduction. Previous reports in the series have investigated the loads and sources of contaminants in households by characterising household products, wastewater discharge patterns and the operation of common household appliances.

The data collected in this report will be used for comparing the outputs from a desktop model simulation (base case) to an actual Melbourne residential development. The Base case model will serve as the basis for the evaluation of contaminant reduction strategies in a future report.

Major findings

The number of properties connected to sewer, can have a significant effect on the results of an assessment. Whilst the concentration of contaminants increased as the size of a catchment decreased, reproducibility in flow and concentrations tended to increase as larger size catchments were considered.

Seasonal differences were verified in the wastewater data collected. But changes we dependent on the element and parameters analysed.

Across seasons, reduction in volume of wastewater discharged in the catchment was minimal at 5% for the catchment of 697 households, which was within the normal variability range.

However, a shift of 1 hour was observed in the start of the diurnal water flow pattern, showing that the majority of residents rise later in the morning in winter compared to summer.

The frequency of detection and concentrations for the majority of elements were statistically significant given the standard deviation of the sample population.

From summer to winter the concentration of elements such as total phosphorus, sodium, sulphur, zinc, cobalt, calcium, magnesium and potassium, increased. Whilst a reduction in concentration was verified for other elements such as boron, copper, chromium, chloride, fluoride, nickel, electrical conductivity and TDS.

On the other hand, the concentration of nitrogen (as TKN), whose major source is human waste, and non-biodegradable colour did not change across the seasons.

Compared to earlier studies conducted in other parts of Melbourne, lower concentrations of boron, sodium and phosphorus and higher concentrations of chromium were verified in this study's wastewater.

Differences have been verified between the results from this study and from a 1995 study (Connor and Wilkie 1995) conducted before the introduction of water restrictions.

Although this study has attempted to ensure that the overall catchment selected was as homogeneous and controlled as possible, the data does not allow the determination of the causes for the changes observed, nor was it possible to attribute the changes to the implementation of water restrictions. Other contributing factors such as changes in product formulations or use in the last 13 years may also have been contributing factors.

To further understand the causes of the changes in wastewater it would be necessary to gain access to more information of household practices and habits within the catchment which was not within the initial scope of this study.

Detailed findings

Wastewater volumetric flow was lower in winter by 5% for the catchment of 697 households and by 33% for the catchment of 163 households. However, in both catchments this was within the normal data variability.

The frequency of detection of heavy metals such as Pb, was generally higher in summer.

Analysis of the summer and winter data has shown that for many contaminants concentrations were within similar range of values recorded in earlier Melbourne studies (Connor and Wilkie 1995, CWW 2007):

- Arsenic, cadmium, mercury, selenium and tin were below the limits of detection (μg/L) in both seasons, in agreement with results reported in the literature for earlier Melbourne studies.
- Lead and nickel were the heavy metals most commonly detected, but at concentrations close to the detection limit in μg/L and respectively at 60% and 54% more often in summer than in winter.
- Antimony, cobalt, tin and molybdenum were seldom detected in wastewater, but more often detected in winter than in summer in the μg/L range.
- The mean concentration of boron was at least 44.8% and 33% lower in the catchment of 697 properties in summer and winter than in the literature (Connor and Wilkie 1995 and CWW 2007). Hence, historically the concentration of boron discharged in 2008 is lower than in 1995.
- The mean concentration of sodium was at least 7%, 64% and 14.5% lower in the catchment of 697 properties when compared to earlier values in the literature for Melbourne 1995 (Connor and Wilkie 1995) and for summer and winter 2006-7 in the west of Melbourne (CWW 2007).
- The mean concentration of phosphorus was at least 32.5%, 14.4% and 9.2% lower in the catchment of 697 properties compared to earlier studies conducted in 1995, summer and winter 2007 (Connor and Wilkie 1995 and CWW 2007). This may indicate a reduction in phosphorus content in household products since 1995.
- However, earlier studies had a larger standard deviation than this study. For instance, in the case of phosphorus the standard deviations were ±11.3mg/L in 1995 compared to ±1.3 mg/L in 2008. Likewise for boron ± 0.206mg/L in 1995 compared to ± 0.031 mg/L in this study. Hence, the results from this study are within the 95% confidence limit range of the earlier study for boron and phosphorus across the seasons, but the lower concentration of sodium verified in summer signals a statistically significant reduction in wastewater.
- The concentration of sodium and phosphorus was higher in winter than in summer at 65.5mg/L and 15.1mg/L, the opposite was observed for boron with a 37.5% lower concentration in winter at 0.06mg/L than in summer for the catchment of 697 households.
- Chromium, nickel and fluoride concentrations were detected at higher concentrations, than those reported in the literature (Connor and Wilkie 1995 and CWW 2007). In summer these were 0.024mg/L, 0.022mg/L and 1.1mg/L, respectively, but concentrations were lower in winter than in summer for the catchment of 697 properties.
- Total dissolved solids in this catchment was 12% higher compared to studies conducted in 1995, but lower by 30% compared to a 2006-2007 study conducted in the west of Melbourne (CWW 2007).
- Concentrations of individual elements in wastewater were subject to significant variability, changing from one day to another and from week to week.
- No concentration trends were verified over a week as reported in earlier literature (Pantsar-Kalio *et al.* 1999).
- True Colour ranged from 60 to 140 Pt-Co units during the sampling period, with mean values of 71± 9 Pt-Co units in summer and 85 ± 17 Pt-Co units in winter. The mean non-biodegradable colour was 51 Pt-Co units across both seasons.
- Electrical conductivity was lower in winter at 617μS/cm compared to summer at 870 μS/cm.

- pH ranged from 5.9 to 9.3 across the seasons, with the winter range slightly narrower by + 0.4 pH units.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

Al	Aluminium
As	Arsenic
B	Boron
Ca	Calcium
Cd	Cadmium
Cl	Chloride
Cr	Chromium
Co	Cobalt
Cu	Copper
df	Degrees of freedom
DI	Ductile iron
DN	Nominal diameter
EC	Electrical conductivity
F	Fluoride
Fe	Iron
hh	Households
Hg	Mercury
ICP-AES	Inductively coupled plasma atomic emission spectroscopy
ICP-MS	Inductively coupled plasma mass spectroscopy
K	Potassium
LOD	Limit of detection
μ	Mean
Mo	Molybdenum
Mn	Manganese
Na	Sodium
Ni	Nickel
P	Phosphorus
PE	Polyethylene
PVC	Poly (vinyl chloride)
Q	Volumetric flow rate
S	Sulphur
Sb	Antimony
SD	Standard deviation
Se	Selenium

Sn	Tin
TDS	Total dissolved solids
TKN	Total Kjeldahl nitrogen
TP	Total phosphorus
uPVC	Unplasticised poly(vinyl chloride)
VC	Vitrified clay
Z	Z-score
Zn	Zinc

1. INTRODUCTION

Wastewater quality impacts the lifetime of sewerage assets, the operation of wastewater treatment plants, and the beneficial reuse of biosolids and effluent. Among the major quality parameters in wastewater, water authorities in Victoria have a particular interest in: arsenic (As), antimony (Sb), boron (B), cadmium (Cd), copper (Cu), chromium (Cr), chloride (Cl), fluoride (F), iron (Fe), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), nitrogen (as TKN), phosphorus (as Total Phosphorus), selenium (Se), sodium (Na), tin (Sn), zinc (Zn), total dissolved solids (TDS) and colour.

In countries such as the UK, the Netherlands and Sweden, control of emissions to air and trade waste discharges in the last 2 decades has resulted in significant reduction of heavy metals from industrial sources (Icon 2001). In many instances, this is increasing the importance of stormwater run-off and domestic sewage as major sources for metals such as copper, lead and zinc in wastewater reaching treatment plants (Icon 2001, Gray and Becker 2002).

Domestic wastewater is the main source of the nitrogen load reaching wastewater treatment plants (Metcalf and Eddy 2003), yet the contribution of domestic wastewater to other contaminant loads at treatment plants is still under investigation worldwide (Eriksson *et al.*, 2002, Comber and Gunn 1996, Palmquist and Hanæus 2005, Rule *et al.* 2006, Sörme and Lagerkvist 2002, Wilkie *et al.* 1996).

Background levels and the characterisation of critical contaminants in domestic sewage are difficult to estimate and costly to monitor as sources are diffuse, concentrations low and subject to high variability and are often impacted by stormwater run-off, exfiltration and infiltration.

A number of studies have been investigated the quality of wastewater collected in domestic catchments in Australia (Connor and Wilkie 1995, Lock 1994, City West Water 2007, Pantsar-Kallio, *et al.* 1999) and overseas (Palmquist and Hanæus 2005, Rule *et al.* 2006).

Earlier studies (1994) in Adelaide identified domestic sewage as a significant contributor to the load of copper and zinc reaching the treatment plant (Lock 1994), whilst concentrations of cadmium, mercury, arsenic and boron verified in domestic wastewater were not considered significant (Lock 1994).

Recent desktop assessments by Melbourne's water utilities suggest that domestic sewage contributes to a significant proportion of copper, zinc, cadmium, mercury and TDS loads arriving at the two major Melbourne sewage treatment plants, and to the loads of arsenic, boron and lead at the Western Treatment Plant (TWRG 2005, CWW 2007). However, significant uncertainty exists in the assessment of the loads and the contribution from unaccounted sources to wastewater treatment plants (TWRG 2005).

Using Melbourne data collected in 1994 by Connor and Wilkie for a range of mixed catchments, Pantsar-Kallio *et al.* confirmed the sensitivity of wastewater quality to sampling location, lifestyle of residents, days of the week and sampling time. Significant differences had been observed with higher concentrations of phosphorus and nitrogen observed during weekends and higher metal concentrations during weekdays (Pantsar-Kallio, *et al.* 1999).

Wilkie *et al.* (1996) had verified a peak in contaminant load and activity on Sunday morning for Melbourne catchments (Wilkie *et al.* 1996), whilst in a UK study, the concentration of metals was consistent throughout the week, with high readings of Pb, Ni and Cr observed on the Friday, which was attributed to the more frequent use of appliances such as washing machines and dishwashers at that time (Rule *et al.* 2006). Hence, in residential catchments, the lifestyle of the residents plays a significant role on the concentration of pollutants found in wastewater. Yet, in a recent assessment conducted in Melbourne in 2008, no specific distribution patterns corresponding with the days of the week had been observed (Tjandraatmadja *et al.* 2009).

Between the 2008 study and the data reported by Connor and Wilkie (1995), thirteen years had elapsed. In that period water management in Melbourne has undergone some significant changes. Reduced rainfall at catchments has increased the need for water conservation and demand reduction, since 1st April 2007 Melbourne has been under level 3a water restrictions. Under such conditions, outdoor watering with potable water is limited to specific times of the day and the week, and alternative water sources, such as greywater and rainwater, are encouraged for non-potable uses.

The 2008 study verified that the summer concentration of priority contaminants did not differ significantly from majority of the historical data for Melbourne wastewater as reported in Connor and Wilkie (1995) for elements such as As, Cd, Co, Hg, Mo and Se that were either at or below the detection limit as in earlier studies and TKN at an average concentration of 68mg/L was similar to earlier studies.

However, among the deviations from historical results reported by Connor & Wilkie (1995) it was verified that for 2008 concentrations:

- Boron was 10 times lower;
- Pb was 60% lower;
- Phosphorus was 48% lower;
- Sodium was 30% lower, but TDS was 12% higher;
- Nickel was similar to tap water in the catchment but 300% higher than Connor and Wilkie (1995) literature;
- Colour was on average 77 Pt-Co units.

The data had been gathered during summer, a season characterised by low rainfall, and subject to 3a water restrictions limiting garden irrigation with mains water. It was expected that practices such as greywater diversion for garden irrigation would have been more commonly practiced by householders. This could have contributed to the lower concentrations observed for Na, B and P, which are major components of key ingredients found in laundry products.

This research aims to address some of the uncertainties from the previous studies and subject to gain a better understanding of the current wastewater quality and flow patterns generated in a given domestic catchment in Melbourne.

For such purpose, a domestic catchment of 697 properties was monitored over a period of up to 3 weeks during the winter of 2008 and the data collected compared to data obtained for the same catchment during the summer of 2008. The data generated will be used in a future study for calibration of models and scenarios regarding wastewater generation.

This report is part of the Smart Water fund project “Sources of contaminants in domestic wastewater”, which aims to gain a better understanding of the sources and evolution of contaminants in domestic wastewater.

This report is part of the Smart Water fund project “Sources of contaminants in domestic wastewater”, which aims to gain a better understanding of the sources of contaminants in domestic wastewater and of the impact of contaminant reduction strategies. Figure 1 shows a summary of the overall project structure.

This report is part of stage (7) Verification. The data collected in this report will be used to evaluate the Base case model that will be adopted in the scenario assessment stage against actual domestic wastewater discharged by a residential development in Melbourne.

Other published reports from this project include:

- Sources of Critical contaminants in domestic wastewater: a literature review (Tjandraatmadja and Diaper 2006);
- Sources of priority contaminants in domestic wastewater: contaminant loads from household products (Tjandraatmadja et al 2008); and
- Sources of contaminants in domestic wastewater: contaminant loads from household appliances (Diaper et al 2008).
- Characterisation of priority contaminants in residential wastewater (Tjandraatmadja et al 2009)

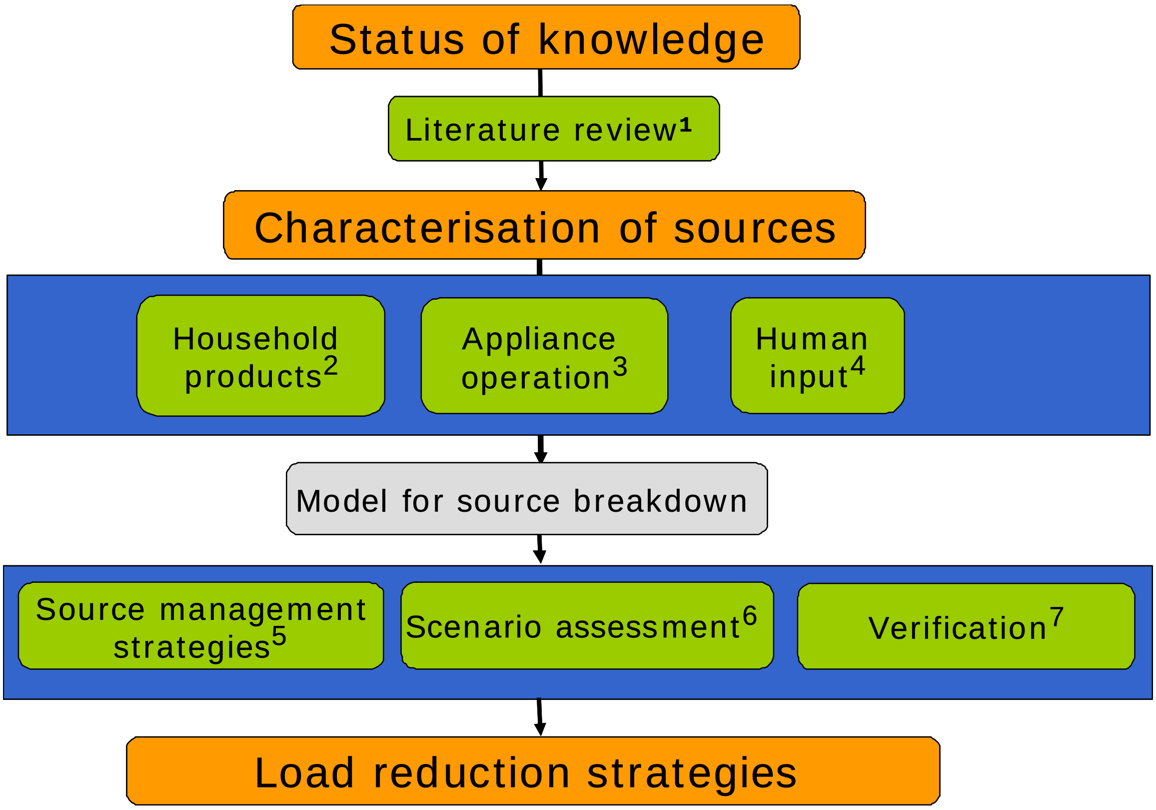


Figure 1: Summary of "Sources of contaminants in domestic wastewater" project

2. IMPACT OF SEASONALITY

Diurnal, weekly and seasonal differences in the pattern of contaminants released in sewage have been reported in the literature.

These have been attributed to infrastructure (Taylor *et al.* 2998) and domestic activities, e.g. phosphate discharge (Pantsar-Kallio *et al.* 1999).

Contamination attributed to infrastructure include studies reporting higher concentrations of metals in wastewater following periods of water stagnation or inactivity in pipes, such is the case for Cu (O'Halloran *et al.* 2001 and 2002, Rule *et al.* 2006) in residential and mixed estates; and for Cd, Cr, Cu, Pb and Zn in commercial estates after inactivity during the weekend (Rule *et al.* 2006).

Differences in element concentrations attributed to the lifestyle of residents have also been reported. For instance, studies conducted in 1995 in Melbourne by Wilkie *et al.* verified a peak in contaminant loads and activity on Sunday mornings (Wilkie *et al.* 1996), whilst in the UK higher readings of Pb, Ni and Cr had been observed in older housing estates on Fridays, and were hypothesised to be caused by greater use on household appliances such as washing machines and dishwashers on those days (Rule *et al.* 2006).

Pantsar-Kallio *et al* had reported increased concentrations of BOD, COD, TSS, TOC, P, N, ammonia, K, Ca, Co, Sn and Mn and lower concentrations of B, Cr, Pb and Sn in wastewater collected in Melbourne during warmer weather compared to wastewater collected in cool and rainy weather (Pantsar-Kallio *et al.* 1999).

Families with active lifestyles, e.g. with children and who undertook sports, are likely to use laundry and washing machines more frequently and also to have more particulate matter in the washing wastewater. Likewise during warmer weather, there is greater potential for participation in outdoor activities, e.g. sports and/or gardening, compared to cooler months.

On the other hand, activities as greywater diversion for use in the garden are also more likely during warmer months, when there is low rainfall compared to cooler periods. This could have been a potential cause for the lower concentration of Na, B and P detected in a study in Frankston 2008 (Tjandraatmadja *et al.* 2009).

3. METHODOLOGY

Wastewater flow and quality from a residential catchment located in Frankston North were monitored during the period of February to March 2008 and June to July 2008. Details of catchment selection are outlined in a previous report (Tjandraatmadja *et al.* 2009).

This section outlines the details of the monitored catchment, the equipment and methodology adopted.

3.1. Catchment characteristics

Wastewater was monitored in a residential catchment located north of Skye Rd in Frankston North along the Mornington coastline (Figure 2). The Frankston area is characterized by households with an average income range of $1200 to $1399 per week (ABS 2006). Households in the area are typically comprised of couples (39.3%), couples with children (36.5%), one parent families (22.4%) and other families (1.7%) (ABS 2006).

The selected catchment was classified as a residential zone 1 and 2. Properties in the area were stand alone houses, with no flats, hence each sewer connection was representative of one household.

The major characteristics of the wastewater infrastructure in the catchment are outlined in Table 1. The sewerage was a gravity collection system comprised mainly of vitrified clay pipes, with small sections of polymer and iron pipe following a rising main. Pipe nominal sizes were DN 100-150, DN 150-375 for major sewers and DN 600 to 750 after the pump station. The assets range in age from 19 to 38 years, have a condition grading 1 (good) and are within the lowest permanent infiltration band 0-5L/m/day (SEWL 2006). The sewerage was laid in soil characterised as free draining sandy soil, not prone to water logging.

Table 1: Characteristics of selected network (SEWL 2006)

Properties	*Details*
Catchment type	Mainly gravity sewer, with the exception of 1 rising main.
Land use	Residential (R1Z and R2Z)
Pipe installation	1970 to 1970 and 1980-1989
Material	VC, CI and DI after pump station and small section of PE, PVC and uPVC.
Pipe sizes (mm)	100 -150 600-750 after pump station 150-375 major sewers
Pipe condition grading	1
Permanent infiltration (L/m/d)	0-5
Inflow/Infiltration for recorded events (PWWF:ADWF)	2-4

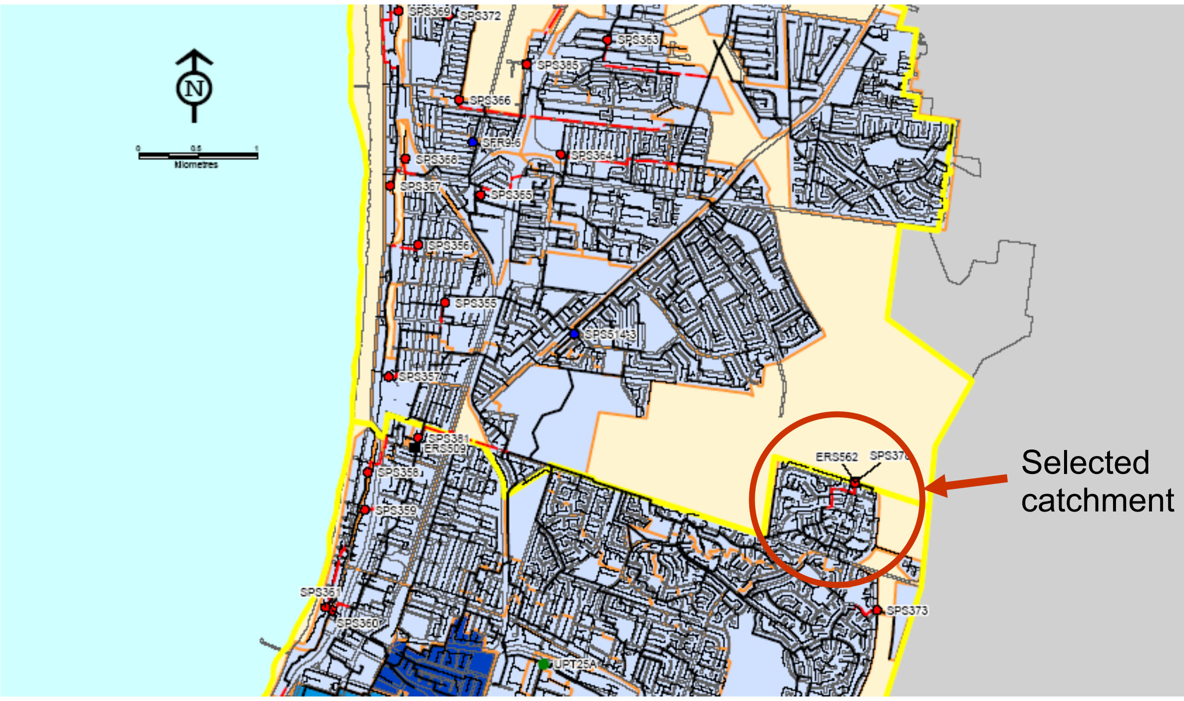


Figure 2 : Selected Catchment (SEWL 2006)

3.2. Sampling sites

Three manholes within the catchment were selected as sampling points:

- Site 1 was a manhole located on a nature strip over a vitrified clay pipe (DN 150mm) that received wastewater from 7 households. Flow on this site was intermittent throughout the day. The original wastewater level was too low for the instrumentation to collect samples, hence a weir was constructed in the manhole to allow sampling probes to be immersed in the wastewater.

- Site 2 was a manhole located over a vitrified clay pipe (DN225mm) prior to entry into South East Water's SPS 378 pump station at Lanena Court, which collected the wastewater from 163 households and had 24h flow.

- Site 3 was a manhole located on a public reserve over a vitrified pipe (DN 375 mm) which collected wastewater from 697 households and had 24h flow.

The relative position of the manholes is shown in Figure 3. Each site was fitted with an automatic wastewater sampling device (Isco model 6712 autosampler) and a flow and conductivity meter supplied by ADS Environmental Services.

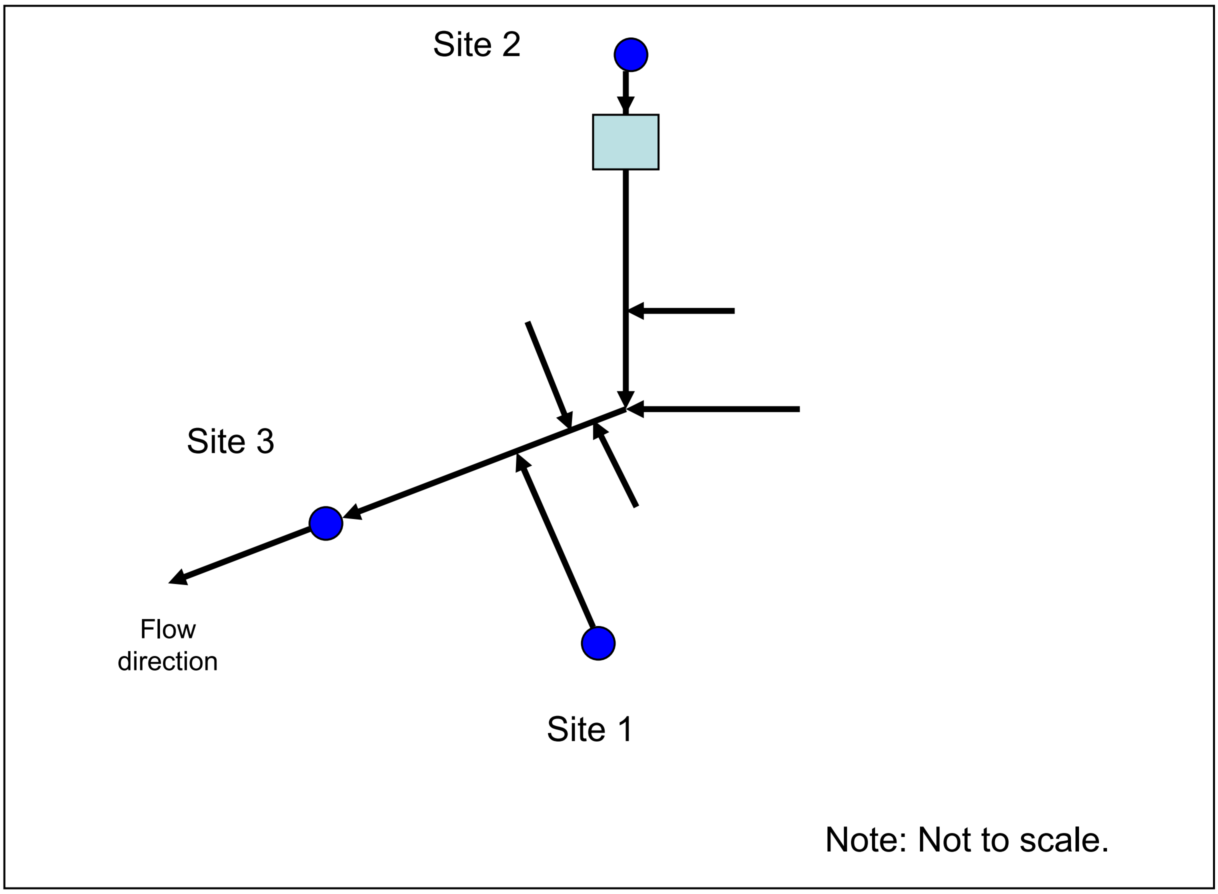


Figure 3: Diagram showing the relative position of sampling sites.

3.3. Experimental

3.3.1. Sampling period

The winter sampling period for each site was conducted from June to July 2008 over 4 weeks. This period included:

(a) Week 1: Flow monitoring for evaluation of flow and wastewater level in each sewer;
(b) Week 2: Autosampler start up and verification of operating conditions. Commissioning and equipment troubleshooting.
(c) Week 2-3: Collection of daily composite samples for inorganics and physical – chemical parameters: metals, salts, colour, etc.
(d) Week 4: Collection of daily composite samples for organic contaminants which will be covered in future publications and evaluation of daily profiles over a 24h period.

Rainfall and air temperature data from the Bureau of Meteorology weather station were also monitored to determine the impact of inflow and infiltration on the wastewater (BOM 2008). The data collected in this study was compared to data collected for the same sites during February and March 2008.

3.3.2. Methodology

Flow and conductivity

Flow and conductivity were monitored continuously at each site using an ADS flowmeter and a conductivity meter connected to a data logger within each of the manholes. The flow and conductivity meters were installed and calibrated by ADS Environmental Services. Flow and conductivity were monitored continuously over the sampling period at 5 min intervals, data was downloaded weekly.

Wastewater sampling

Wastewater samples were collected for evaluation of colour, TDS, pH, nutrients, and selected inorganic contaminants using automatic samplers. Three auto-samplers (two Isco model 6712 samplers and one Sigma model 9000 sampler) were fitted with a strainer at the end of the line and twenty-four 1L disposable polyethylene bottles for metal analysis. The sampling port and strainer were permanently immersed in wastewater.

At each manhole, wastewater samples were collected on an hourly basis over a 24h period using an automated sampler filled with ice. Samples were collected and transported to the CSIRO laboratories daily (Highett, Victoria).

Samples were collected as hourly composites. At site 1, between 0.5 to 1.0 L was collected every hour depending on available flow. At sites 2 and 3, 0.25 L was collected every 15 min to prepare an hourly composite. Hourly samples were used to prepare a 24-hour daily composite based on their proportional contribution to the average diurnal flow rate profile at each site.

Chemical analysis

Selected hourly and daily composite samples were analysed for metals, inorganics, TDS, pH, total and non-biodegradable colour, fluoride, chloride, total kjeldahl nitrogen and total phosphorus.

Tap water for use as blanks was sampled from garden taps located at sites 1 and 2. Water was allowed to run continuously for 10 min to flush the line, before a grab sample was collected using acid washed bottles.

Samples were preserved according to the requirements for analysis using standard methods for water and wastewater (APHA/AWWA 1998):

(a) Total Metals by ICP-AES/MS at the CSIRO laboratories (samples preserved to pH 2 with HNO_3);

(b) pH, colour, TDS, fluoride, chloride (no preservatives);

(c) Total phosphorus and Total Kjeldahl nitrogen (preservation with H_2SO_4 to pH 2);

Elemental analysis

Wastewater and water samples as received were analysed for fluoride and chloride in a NATA accredited laboratory using methods APHA 4500-F, C and WSL respectively.

Other individual elements were analysed at the CSIRO laboratories after sample digestion as per method 3030E (APHA/AWWA 1998).

A Varian Liberty Series II ICP-AES with a 40 MHz free running RF generator and a 0.75 m Czerny- Turner monochromator was used for determination of:

- Aluminium (Al), boron (B), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), lead (Pb), sulphur (S), tin (Sn) and zinc (Zn).

A Thermo X series ICP-MS was used for determination of:

- Arsenic (As), selenium (Se), antimony (Sb) and mercury (Hg), which were expected at low concentrations; and

- For verification of concentrations of cadmium, copper, lead, nickel and tin in samples which were below the detection limit of the ICP-AES.

Detection limits for these two instruments are outlined in Table 2.

Table 2: Detection limits for elemental analysis

Metal	*Limit of detection LOD ICP-AES (mg/L)*	*Limit of detection LOD ICP-MS (μg/L)*
Aluminium	0. 01	0. 01
Antimony*	-	2
Arsenic*	-	5
Boron	0.02	-
Cadmium	0.002	0.5
Calcium		-
Chromium	0.005	-
Cobalt	0.005	-
Copper	0.01	5
Iron	0.05	-
Lead	0.04	0.5
Magnesium		-
Manganese	0.001	-
Mercury*	-	2
Molybdenum	0.02	-
Nickel	0.1	-
Phosphorus	0.05	-
Potassium	0.01	-
Selenium*	-	5
Sodium		-
Sulphur		-
Tin	< 0.01	-
Zinc	< 0.001	-

*Note: Analysis by ICP-MS.

Physical- chemical parameters

The pH and conductivity were measured on samples as received using a multi-parameter sonde which was calibrated daily using standard solutions as reference. The sonde had an accuracy of ±0.2 pH units and an operating range of 1 to 14 pH units at 20°C.

Electrical conductivity was measured in the sewer and also verified for samples as received in the laboratory with the sonde (accuracy ±0.5% of reading or $\underline{+}$0.001mS/cm with an operating range of 0 to 100mS/cm at 20°C).

True Colour

Total True Colour of samples as received was measured in Platinum-Cobalt units (Pt-Co) after sample filtration (GF/C glass fibre filter of 0.45μm pore diameter) using a Hach DR/2000 photometer for samples of low coloration. Calibration of the Hach photometer was performed using platinum cobalt standards prepared according to Method 2120B (APHA/AWWA 1998)

Non-biodegradable colour, the colour that remains after 45 min aerobic digestion of wastewater samples, was also determined for a set of diurnal composite samples from one of the sites for comparison with total colour. Digestion was conducted at a Melbourne NATA accredited laboratory.

Total Dissolved Solids

Total dissolved solids (TDS) was analysed using APHA standard method 2504c (APHA/AWWA 2008) at CSIRO laboratories (Highett, Victoria).

Nutrients

Total Kjeldahl Nitrogen (TKN) was analysed using APHA method 4500-N Org, B (APHA/AWWA 2008) at a Melbourne NATA accredited laboratory.

Total phosphorus (TP) was analysed using APHA method 4500 (APHA/AWWA 2008) at CSIRO laboratories (Highett, Victoria).

Quality control

For quality control a replicate sample was included with every batch of 20 samples analysed. A blank sample was also prepared for every batch of samples analysed.

Data analysis

Data was analysed using standard deviation and Z-scores. Where Z-scores are defined as:

$$Z \equiv \frac{(x_i - \mu)}{SD} \qquad \text{Equation (1)}$$

Where: Z = Z-score

x_i = observed parameter

μ = mean of the population

SD = standard deviation of the population

4. RESULTS

The catchment was monitored during summer, in the months of February and March, and during winter in the months of June and July 2008.

Results obtained during the experimental period are discussed in this chapter. The discussion is structured as follows:

(a) Section 5: Climate characteristics of the sampling periods

(b) Section 6: Analysis of wastewater flow in the catchment

(c) Section 7: Analysis of the wastewater quality from day to day and over 24 h in the catchment.

Detailed data can be found in the appendices.

5. CLIMATE COMPARISON

Samples were collected over two seasons, summer and winter. Summer was represented by collecting samples during February and March, and winter in June and July 2008.

The summer period was characterised by lower rainfall and mean temperatures that were on average 10°C higher than in winter.

In February 2008, the daily average minimum and maximum temperatures were 15.2 and 23.2 °C and only 9 days of rain were recorded with an average daily rainfall of 1.46mm for the month. For March 2008 the daily average minimum and maximum temperatures were 14.5 and 24.7 °C and only 6 days of rain were recorded with an average daily rainfall of 0.31 mm for the month.

In June 2008, the daily average minimum and maximum temperatures were 10.1 and 14.8 °C and 12 days of rain were recorded with an average rainfall of 2.13 mm per day and a rainfall of 49.1mm for the month. For July 2008 the daily average minimum and maximum temperatures were 7.5 and 13.0 °C and 16 days of rain were recorded. Rainfall was 83.7 mm for the month i.e. an average of 2.79mm per day. These values are shown in Table 3 and Figure 4 .

Table 3: Major weather parameters during summer and winter sampling periods (Bureau of Meteorology 2008)

Month	*Minimum temperature for the month (°C)*	*Maximum temperature for the month (°C)*	*Month rainfall (mm)*
Feb-08	11.7	32.8	36.6
Mar-08	9	37.1	9.6
Jun-08	5.5	17.7	49.1
Jul-08	1.8	17.9	83.7

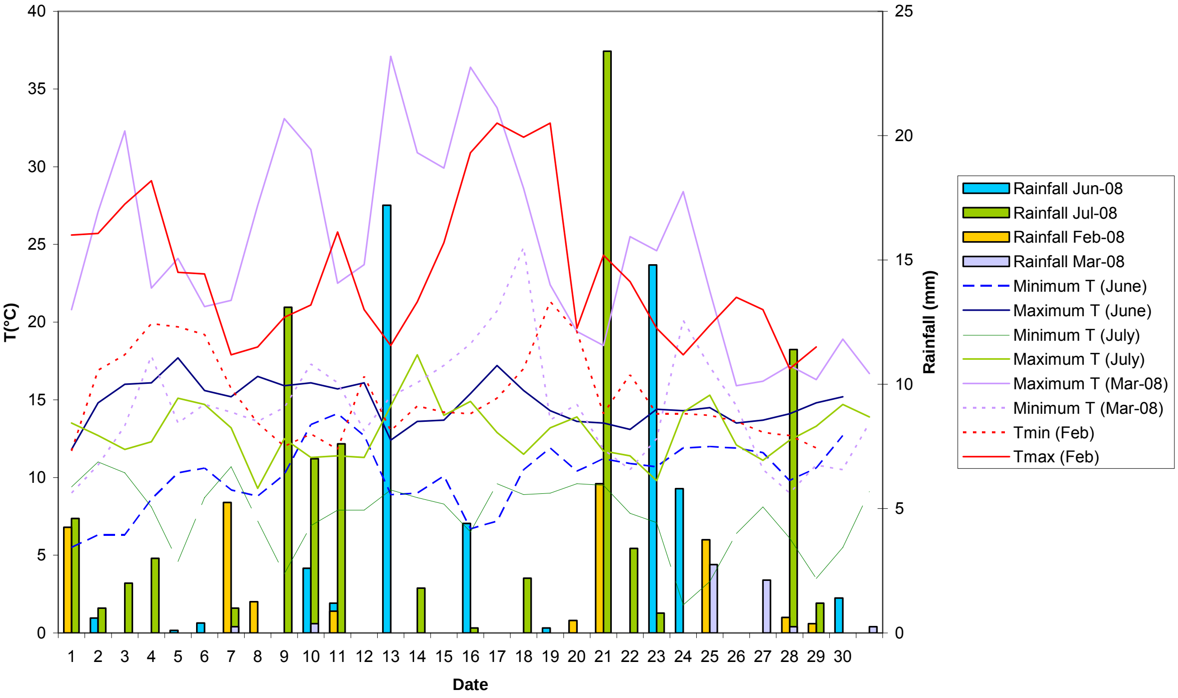


Figure 4: Rainfall and temperature distribution during summer and winter periods measured at Frankston weather stations 086079 and 086371 (BOM 2008).

6. WASTEWATER FLOW

The flow profiles for the three sites were monitored between the 22nd February to the 28th March 2008 and the 17th June to the 14th July 2008. Monitoring in the initial week was used to determine the typical flow profile for the catchment. Detailed analysis of the flow profiles for each of the sites has been conducted in an earlier report in this series (Tjandraatmadja *et al.* 2009). Therefore this report will focus on the comparison between summer and winter.

Overall flow rate displayed a reproducible diurnal profile, with some variability during weekends at sites 2 and 3.

The typical diurnal flow profiles for sites 1 to 3 over a week are shown in Figure 8 to Figure 10. An example of the actual monitoring profile is shown in Appendix A. Table 4 compares the average winter flow with the summer flow for the monitored period for sites 2 and 3. Flow at Site 1 displayed too much variability from one day to another and was not included in the overall analysis of composite samples. The flow rate was lower in winter compared to summer.

Winter was characterised by less flow of wastewater than summer. At site 2 the average flow was 0.38ML/week in summer compared to 0.25ML/week in winter, an observed reduction in volume of 33%. At site 3 the observed decrease in flow rate was less severe, being on average 5.7%, as the average flow decreased from 2.0 ML/week to 1.89ML/week from summer to winter.

The average daily flow rate observed for each day of the week is shown in Figure 5. During summer, Friday was the day with the lowest discharge of wastewater in the week and larger flow rates were recorded from Saturday to Tuesday.

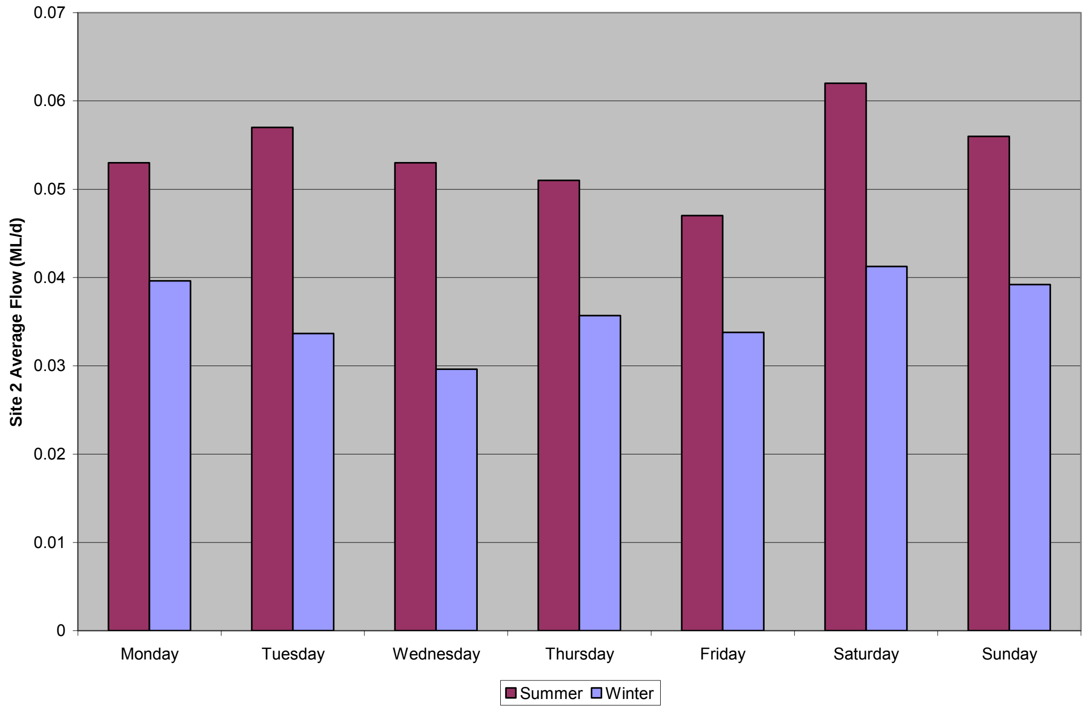
In winter, wastewater discharged on Wednesdays was lower than the rest of the days in the week. The wastewater volume discharged on Monday and Tuesday remained similar to that from Thursday and Friday.

At site 3, winter flows were typically higher during Saturday and Sunday than during weekdays. Whilst during summer, Tuesdays displayed flows as high as weekends at both sites. The least flow was observed on Friday during summer and on Wednesday during winter.

The reduction in flow rate from summer to winter was more pronounced during weekdays than in weekends. As shown in Table 4, on Tuesday and Wednesday the difference was greater than 40% at site 2 and greater than 8.6% at site 3.

Table 4: Comparison of winter and summer flows

Day of the week	*Site 2 (163households)*			*Site 3 (697households)*		
	Q_{winter}	ΔQ		Q_{winter}	ΔQ	
	ML/d	*ML/d*	*% Q_{summer}*	*ML/d*	*ML/d*	*% Q_{summer}*
Monday	0.040	-0.013	-25.2	0.266	-0.024	-8.4
Tuesday	0.034	-0.023	-40.9	0.270	-0.028	-9.6
Wednesday	0.030	-0.023	-44.1	0.260	-0.024	-8.6
Thursday	0.036	-0.015	-30.0	0.263	-0.003	-1.1
Friday	0.034	-0.013	-28.1	0.263	-0.010	-3.8
Saturday	0.041	-0.021	-33.4	0.284	-0.010	-3.3
Sunday	0.039	-0.017	-30.0	0.283	-0.014	-4.7
Week average	0.036	-0.02	-33.1	0.270	-0.02	-5.6



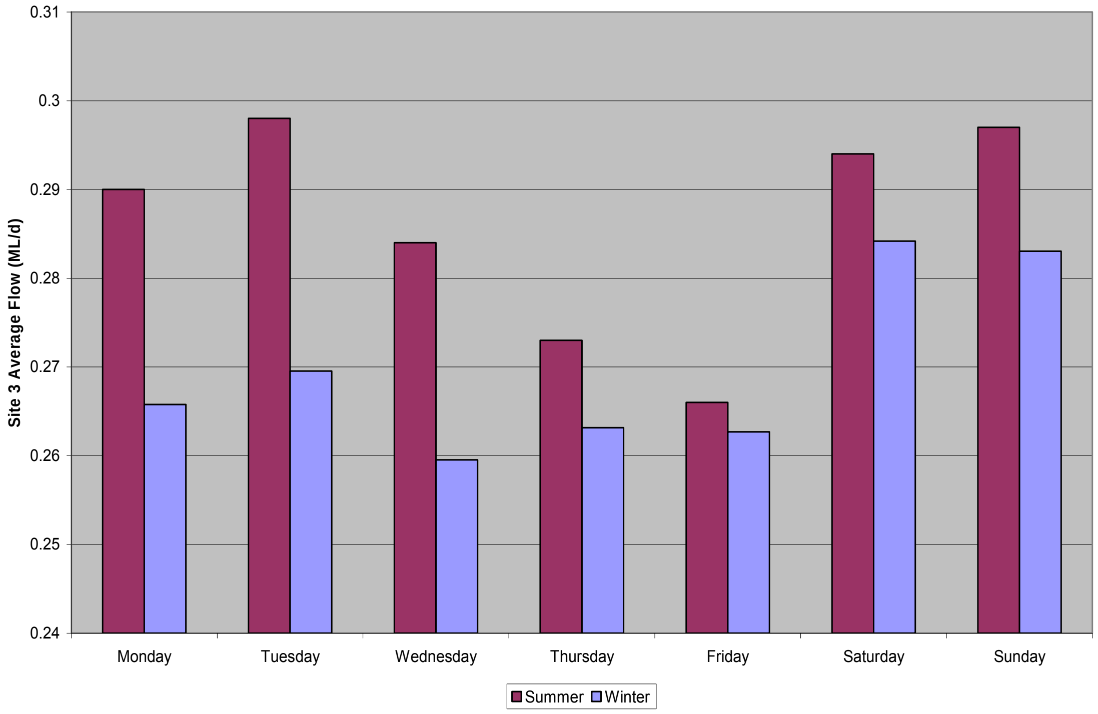


Figure 5: Comparison of average daily flow at site 2 and 3 during summer and winter 2008.

6.1. Flow profile over 24h

As seen for the catchment of 697 households, the daily flow rate profile over a 24h period followed a similar profile for both the summer and winter periods, characterised by a sharp morning peak and a broader afternoon peak (Figure 6). During both seasons householders were more likely to rise later in the day during weekends, as the increase in morning flow was delayed one to two hours compared to weekdays.

The morning peak time shifted later into the day by a one to two hours period from summer to winter (accounting for day light savings), while the afternoon peak remained constant irrespective of the season.

In summer the hourly flows during the morning wake up period also showed a wider spread in time generating a wider peak over time, but in winter this was narrowed to the period of 7 to 11am during weekdays.

At site 2 the flow rate started to increase from 3am reaching its peak at 6-7am for weekdays in summer, whilst in winter this was observed after 4am with the maximum flow observed at 8am.

At site 3 the morning peak was from 4-9am, with the maximum flow at 9am. In summer between 9 to 12 pm there were spikes in flow generating localised maximum peaks at 11am and later at 1pm in the afternoon.

In winter, there were also 2 intermediate peaks (one at 8am and a larger peak at 10am).

6.2. Impact on daily flow

To determine how the pattern of flow impacts the total daily flow, the relative variation in flow on an hourly basis was examined for sites 2 and 3 in Figure 7.

The bars below and above the x-axis indicate a higher/lower hourly load in summer compared to winter for the specified hour.

As seen in the figure, the change in hourly contribution to the daily flow rate was less than 2% at any time of the day for site 3, and whilst slightly higher at site 2 during the morning period , it was still less than a 6% change compared to the summer contribution .

The flow from 4am to 6am contributes less to the total daily flow in winter than in summer, with the flow contribution being less than 6% for site 2 and less than 2.2% for site 3. On the other hand, the flow at 8am at site 2 reflected a 6% increase from summer. For site 3, the average change was -5.7%, ranging from 1.2% to 9.5% for the different days of the week. On average winter varied -5.70% compared to summer.

Overall, the contribution of hourly flow rates to the total daily flow was similar in both seasons ranging from 0.31% to 13% for site 2 and between 0.6% to 9% for site 3.

6.3. Impact of catchment Scale

Scale effects, such as smoothing of peaks and troughs in flow as the number of connections increased, had been observed in both summer and winter. Smaller catchments typically had higher and more pronounced concentration peaks as seen in Figure 8 to Figure 10.

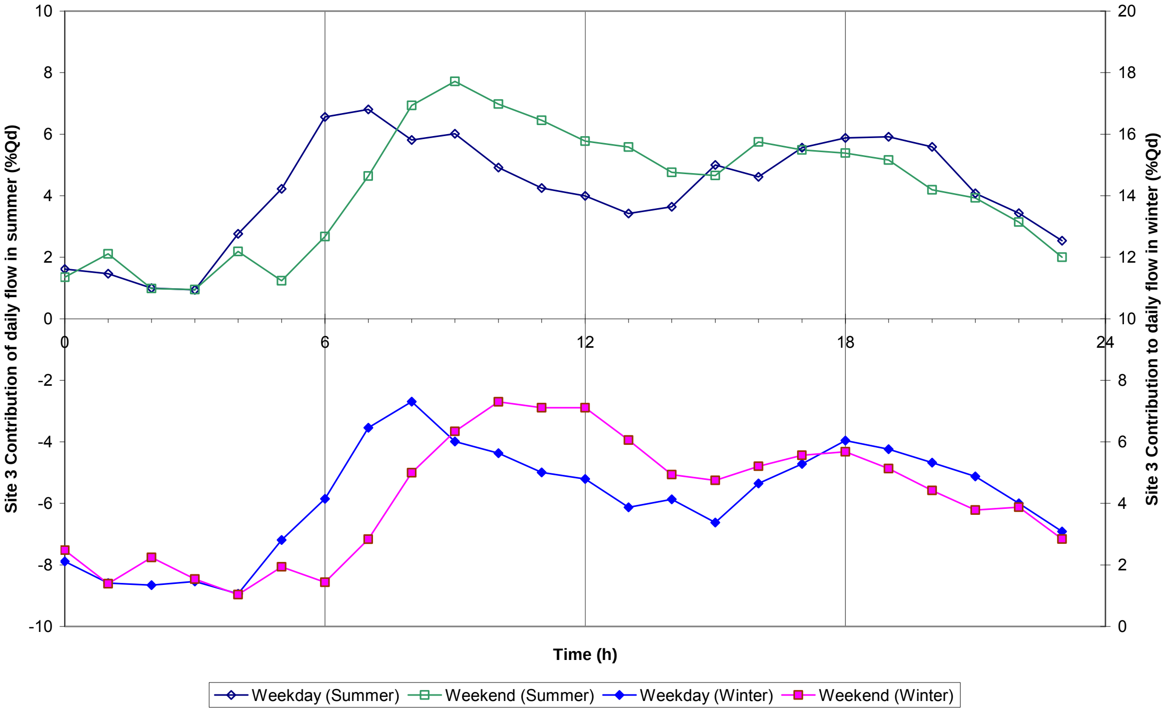
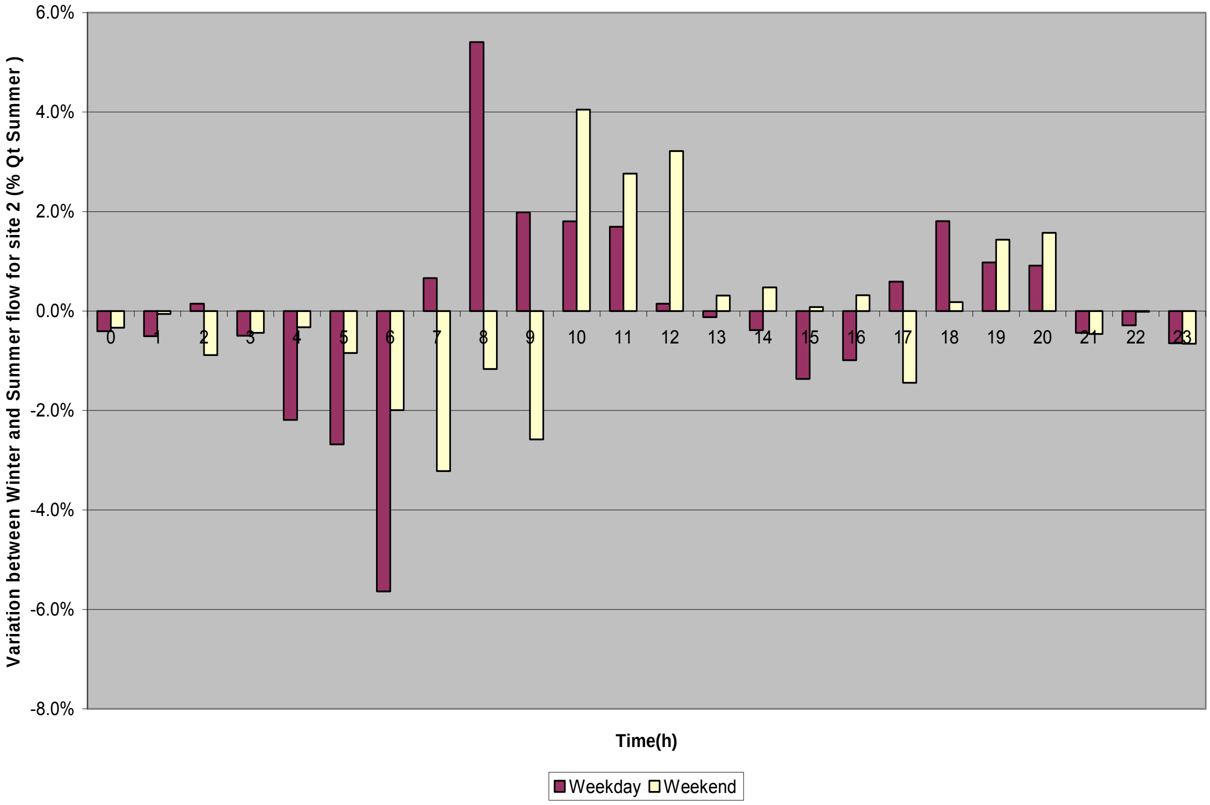


Figure 6: Average flow over 24h at Site 3 in summer and winter.



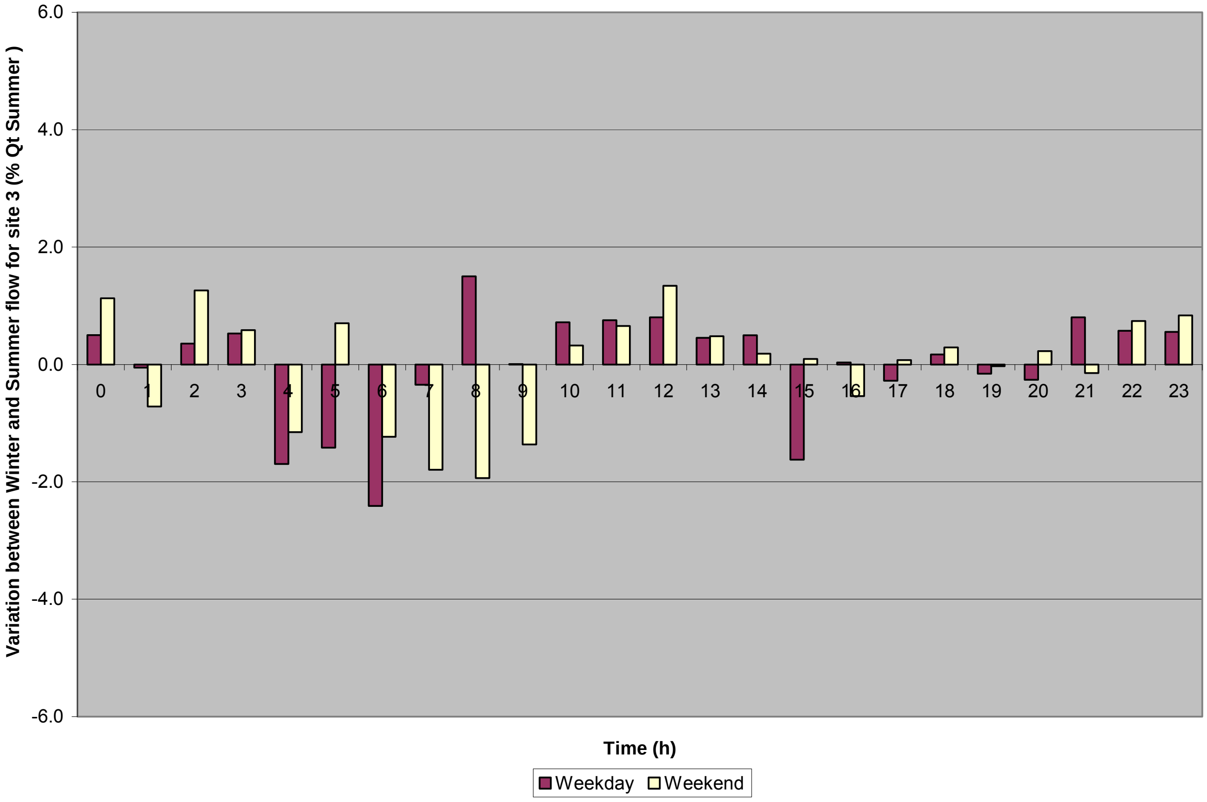
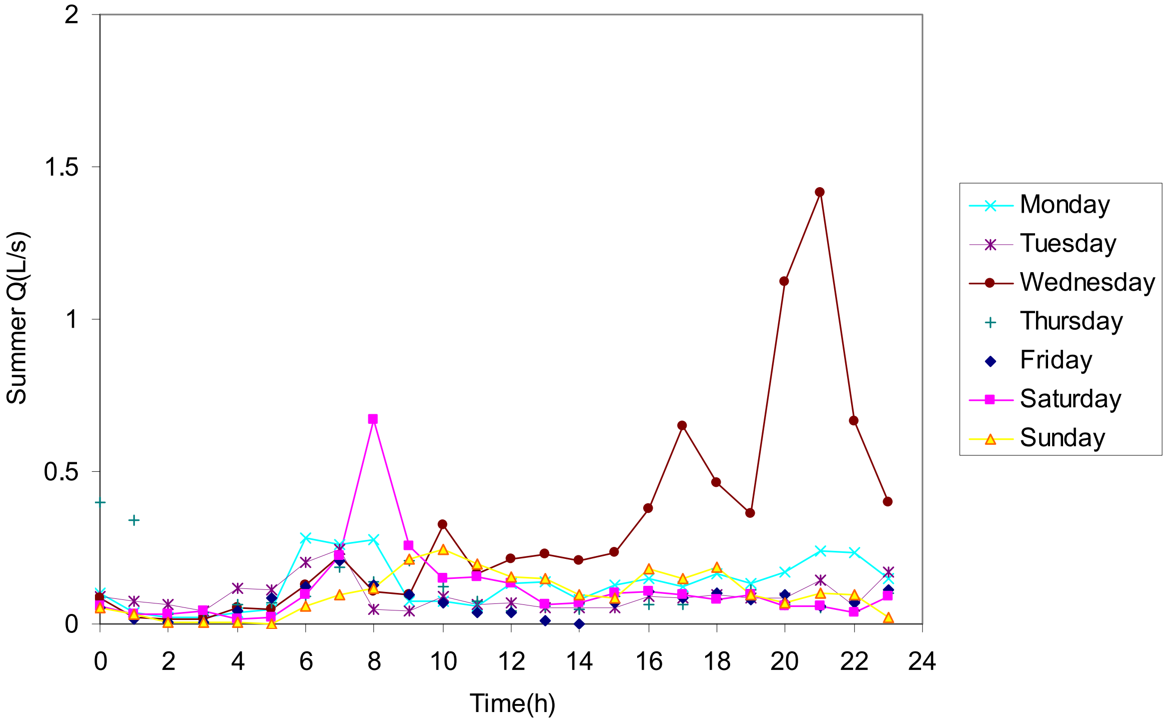


Figure 7: Difference between summer and winter flows for sites 2 and 3.



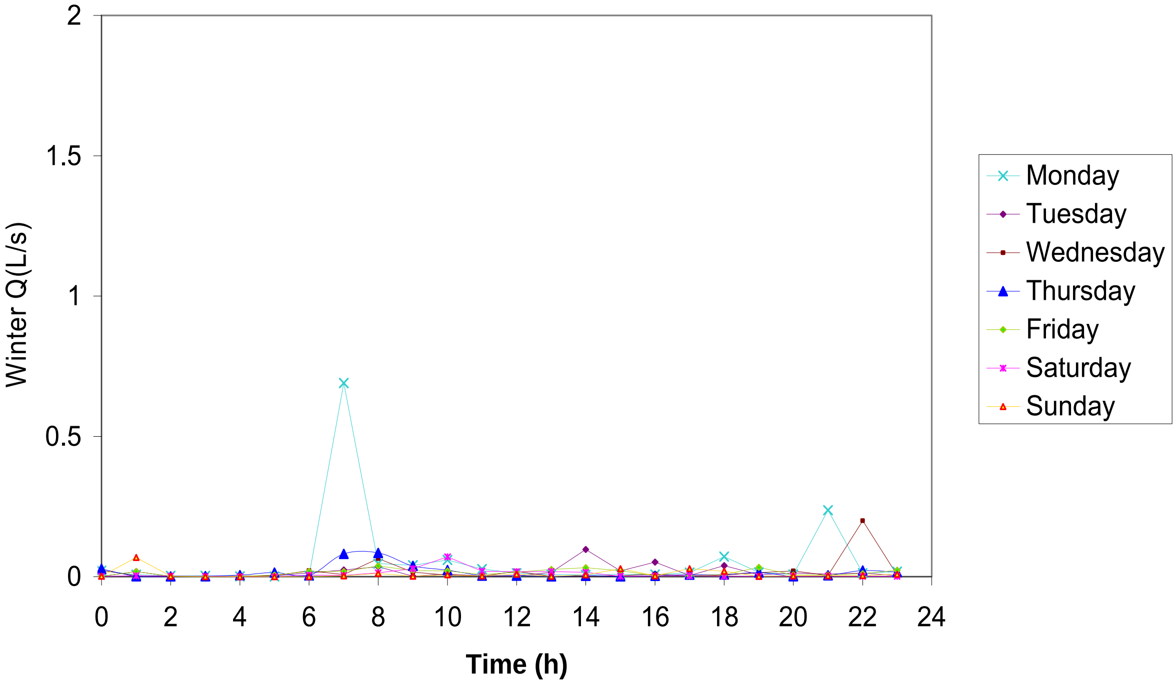
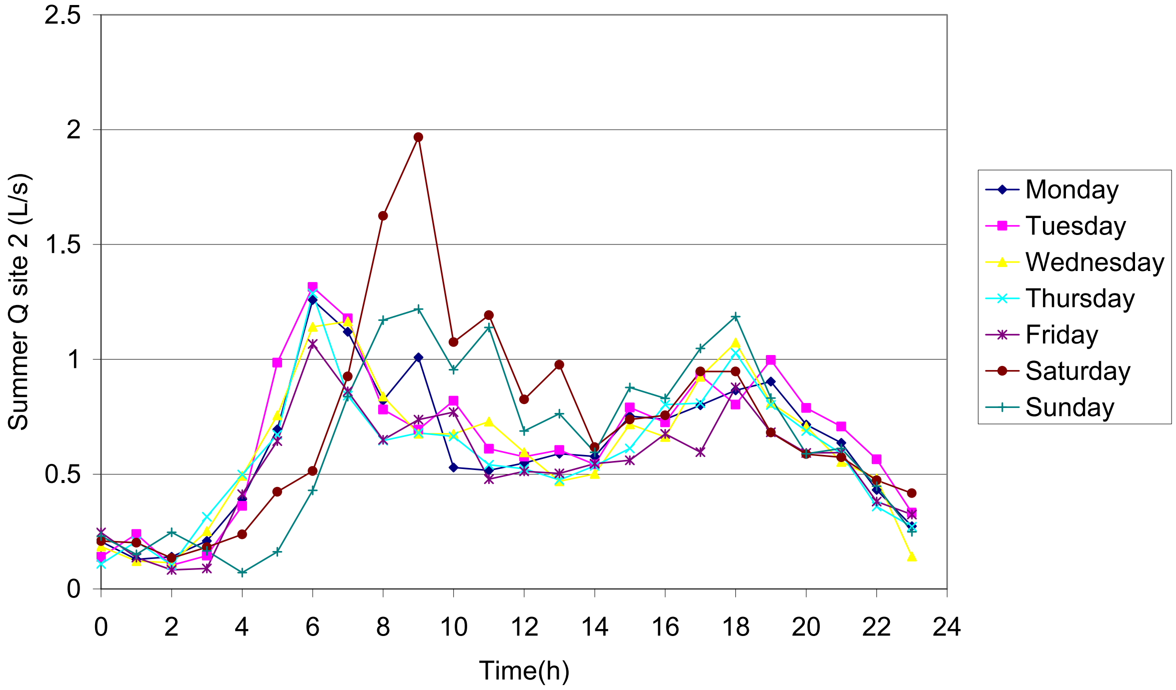


Figure 8: Diurnal flow profile for 7 households



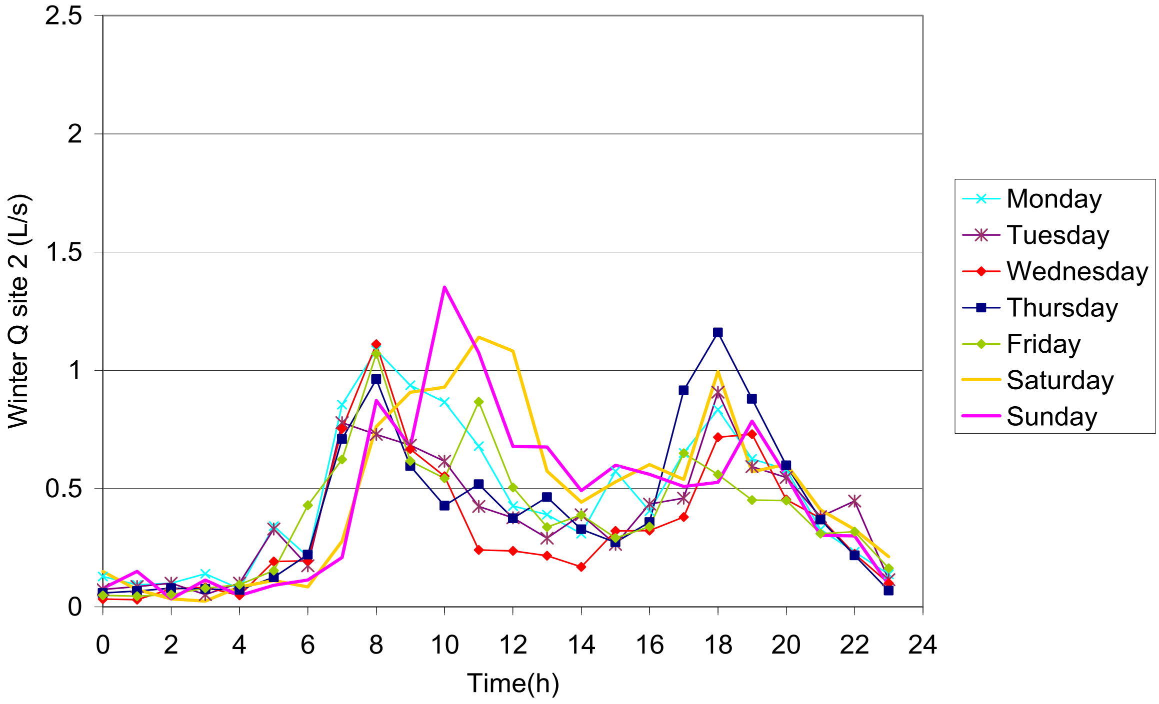


Figure 9: Diurnal flow profile for 163 households

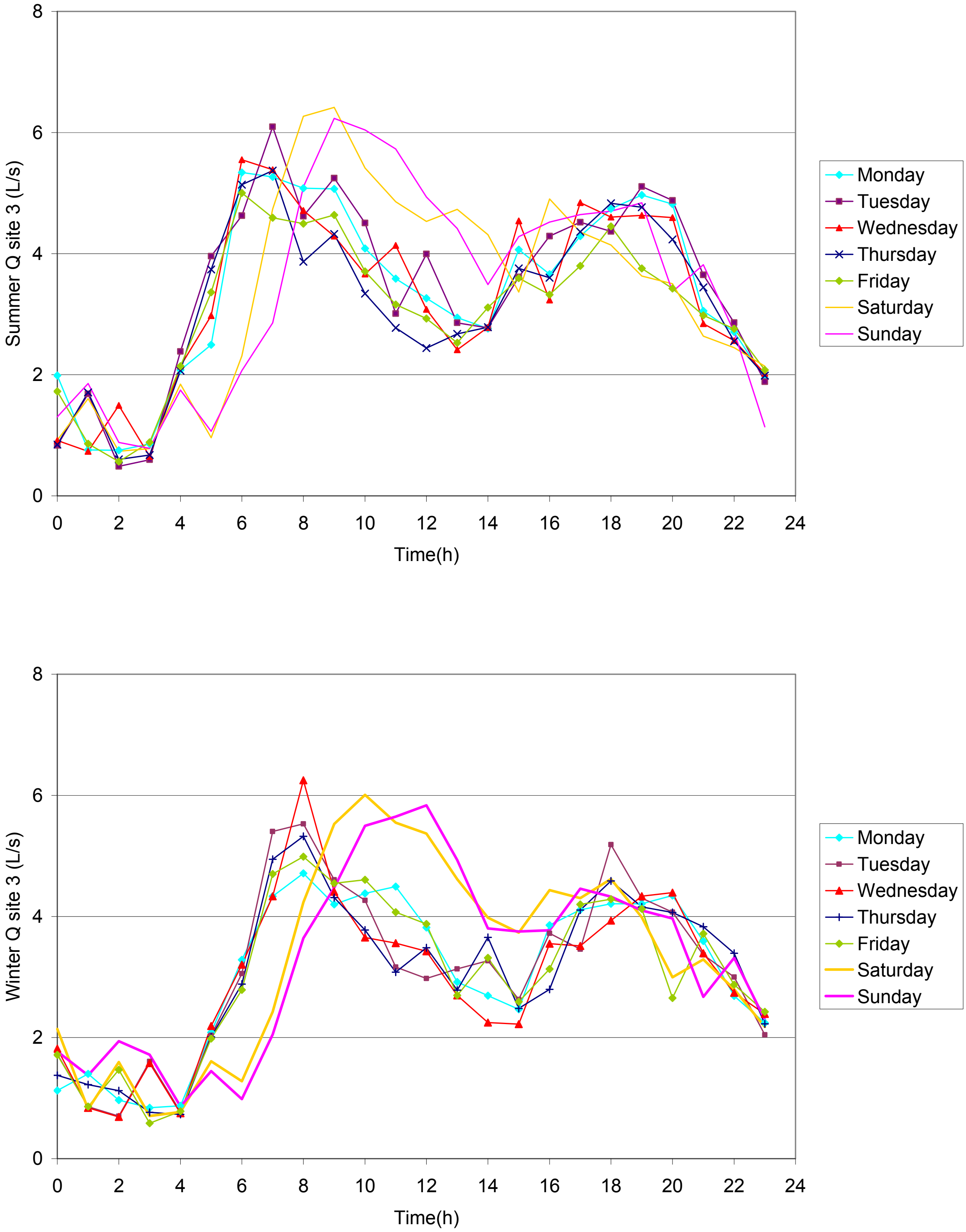


Figure 10: Diurnal Flow profile for 697 households

7. WASTEWATER QUALITY

The quality of wastewater collected during the period of June to July is evaluated in this section. Parameters monitored included pH, conductivity, colour, TDS and specific elements such as Sb, As, B, Cl, Cr, Cu, Cd, Fe, F, Pb, Hg, Mn, Mo, Ni, Na, Se, Zn, TKN and TP. In addition parameters such as Al, K, Mg and S were also monitored for comparison.

The results are presented as:

(a) Concentration of 24h composite samples over a week to evaluate the daily characteristics of wastewater and to compare changes in wastewater quality through the week from one day to another; and

(b) Concentration of samples collected over a period of 24h, for verification of the concentration profile over a day on selected dates.

Four composite samples were collected from the 19th to the 29th June for site 1, but given the lack of reproducibility of the flow pattern at the site, the results from these samples are considered qualitative only and specific to the wastewater at each date of collection.

Thirteen composite samples were collected from the 19h June to the 19th July at site 2.

Fifteen diurnal composite samples were collected from the 28th June to the 15th July at site 3.

7.1. Physical-chemical characteristics

Selected physical-chemical parameters such as colour, pH, conductivity and TDS were recorded using 24h composite samples. Conductivity was also continuously recorded in the sewer for comparison.

7.1.1. True Colour

Total true colour and non-biodegradable colour were determined for wastewater from site 2 collected during the period from 24th February to the 17th March and from the 19th June to the 11th July. A total of 22 samples were analysed (10 in summer and 12 in winter). The summary of the colour results is shown in Figure 11 and Table 5.

The total true colour of the wastewater composites was on average 85 Pt-Co units, ranging from 59 to 140 Pt-Co units. Majority of the observations were within 1.5 standard deviations from the mean, the only exception was a reading recorded on the 27th July (3.35 SD).

Overall, the total colour of wastewater was lower in summer than in winter as seen in the mean values of 76 and 87 Pt-Co units for the respective seasons.

On the other hand, the non-biodegradable colour, i.e. the colour that remains after the sample is aerobically digested for a set period to simulate the ETP process, was consistent through the 2 seasons. The mean for both seasons was 51 Pt-Co units, but larger variability occurs in winter as seen by the larger standard deviation, which was 89% larger than that recorded in summer (Table 5).

The SD for non-biodegradable colour was 17 Pt-Co units in winter and 9 Pt-Co units in summer as seen in Table 5. Hence greater variability was observed from one day to another during the colder weather for colour.

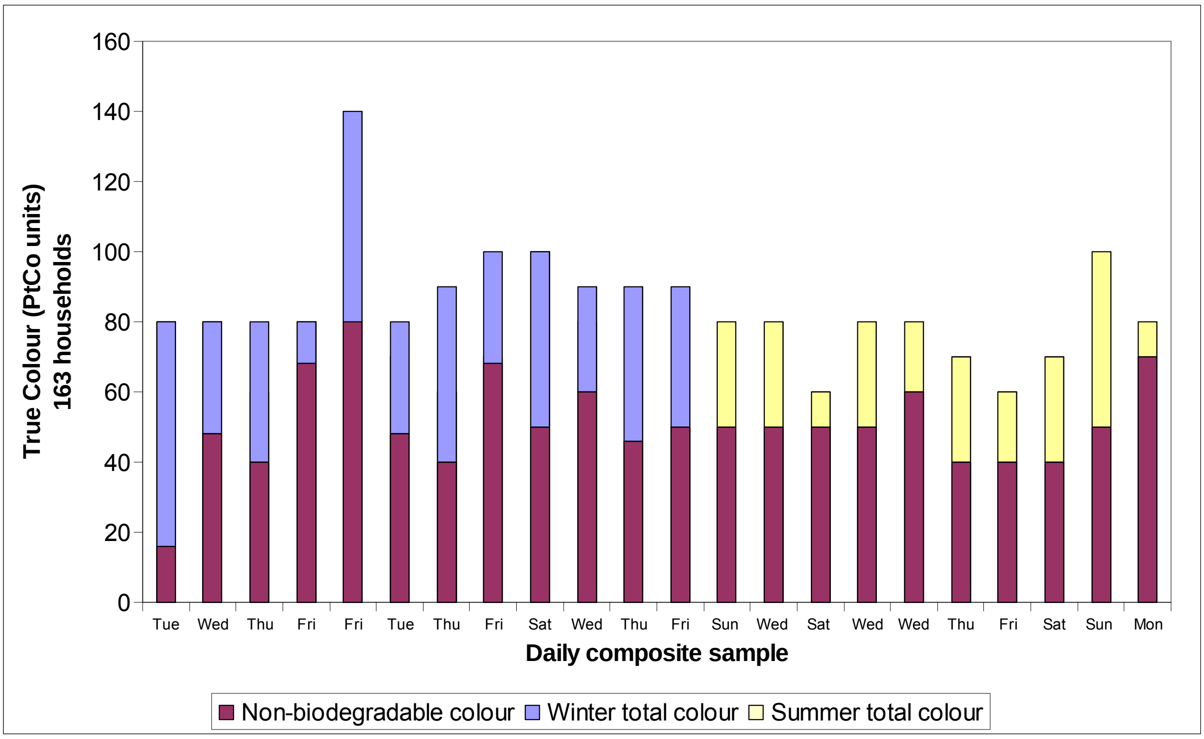


Figure 11: Total and non-biodegradable colour for composite samples from site 2 (163 households) in summer and winter.

Table 5: Analysis of colour data for site 2.

	Total colour (Pt Co units)			*Non-biodegradable colour (Pt Co units)*		
	Both seasons	*Summer*	*Winter*	*Both seasons*	*Summer*	*Winter*
Observations	22	10	12	22	10	12
Average	85	76	87	51	50	51
SD	17	12	17	13	9	17
Upper CL(90%)	116	98	124	76	68	83
Lower CL(90%)	53	54	59	25	32	20

Given the difficulty in evaluating colour at site 1 (7 connections) using diurnal composite samples due to the variability in flow from one day to another, we decided to investigate the changes in colour at that site over 24h on pre-specified days.

The colour was monitored in 100 samples collected hourly from Wednesday 16th to Wednesday 23rd July. The colour variation observed over time is illustrated for the dates of Thursday 17tth to Saturday 19th of July 2009 in Figure 12. The rainfall during that period was 0.2, 2.2, 23.4 and 3.4mm for the respective dates of 16th, 18th, 21st and 22nd July as previously shown in Figure 4.

Figure 12 compares the colour recorded over 24h periods from Thursday to Saturday for site 1. Wastewater displayed significant variation in colour over 24h and from one date to another. The overall trend displayed for Friday and Saturday was similar with more intense colour in the afternoon. Thursday was characterised by wastewater of more intense colour from 11am to 4pm, Friday from 2pm until 9pm and Saturday had wastewater with increasing colour intensity at 8am and after 2pm.

The colour range and variability was more intense when examined closer to source than in the network, before dilution occurs. At site 1 (7 households), the colour ranged from 34 to 412 Pt-Co units, mean colour recorded per hour was 123 Pt-Co units and the standard deviation was also high at 53.3 Pt-Co units.

These values are much higher than those recorded for the colour of composite samples. It has to be noted however, that due to the weir used for sample collection at site 1, the colour observed for each sample on site 1 represents the colour of wastewater and potentially sediment accumulated in the weir and may not be a reflection of the true colour of wastewater. Therefore the results for site 1 should be seen as indicative of the trend in colour during the day, instead of absolute values.

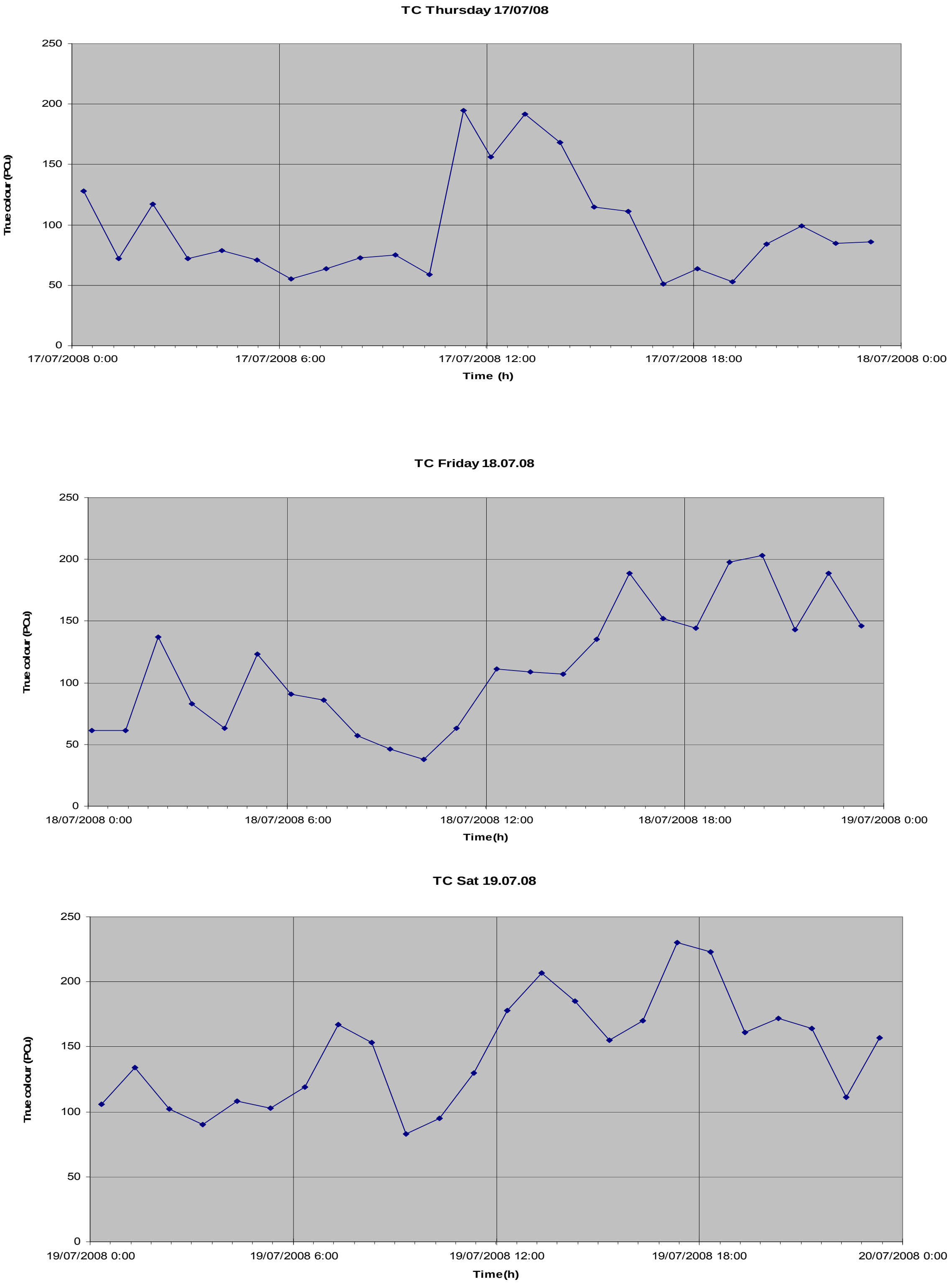


Figure 12: Colour profile at site 1 from Thursday 17^{tth} to the Saturday 19th of July 2009.

7.1.2. pH

The pH did not change significantly between summer and winter. The range recorded across the 3 sites over summer was 5.9 to 9.3; and during winter it was 6.3 to 8.8, within the normal variability range of the data.

The winter period was also used to evaluate the pH at site 1 (7 connections) and examine the variability observed directly from the source of the effluent.

The pH for site 1 was monitored from 12pm Wednesday 16th to 12pm Sunday 20th July and from 12pm Monday 21st to 10am Wednesday 23rd July on an hourly basis. During that period the pH ranged from 6.3 to 8.99, with a mean of 7.6 and standard deviation of 0.7, based on 139 data points. This is within the same range recorded for site 3 (697 households) which was 6.9 to 8.8, with a standard deviation of ±0.68.

Hence the pH of wastewater across the catchment was consistent, and wastewater closer to source was verified to be within the same range as the overall catchment.

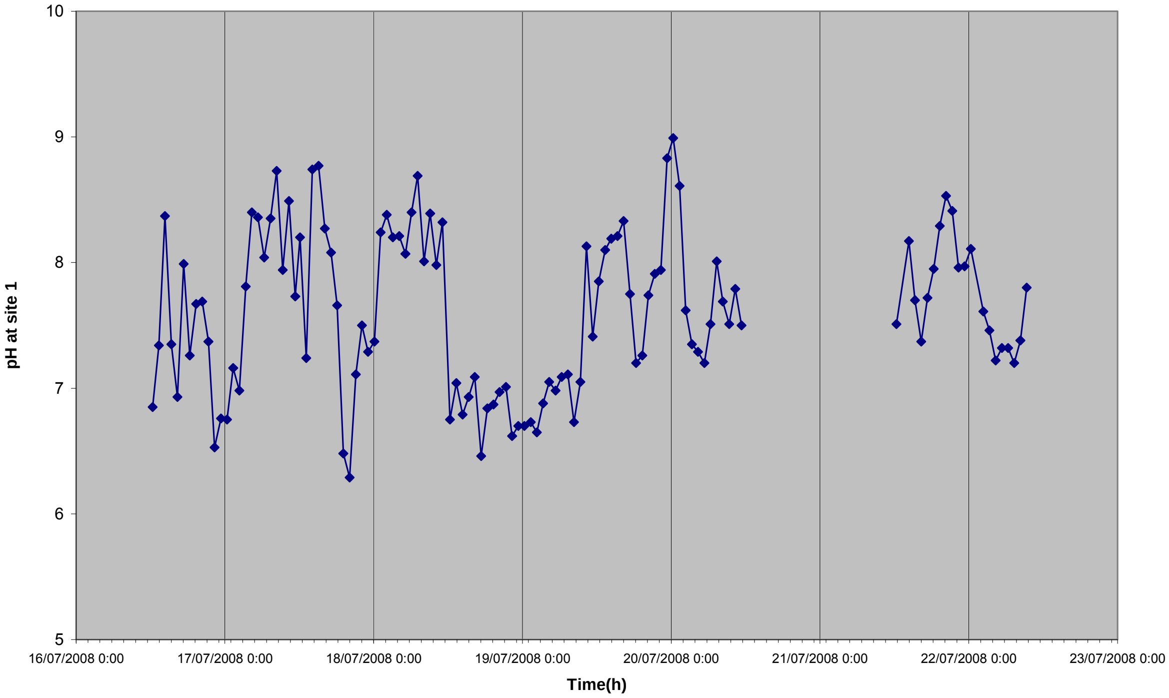


Figure 13: pH profile for site 1 for Wednesday 16.07.2008 to Wednesday 27.07.2008

7.1.3. Electrical conductivity

The electrical conductivity (EC) varied with the time of the day, the days of the week and specific dates. A summary of the conductivity of the two larger sites in the catchment is shown in Table 7 and Table 6.

In summer, the EC of composite samples ranged from 290 to 1822 µS/cm, with a mean EC values of 777 and 870 µS/cm for sites 2 and 3 (Table 6). In winter the EC ranged from 167 to 762µS/cm, with mean EC values of 307 and 600 µS/cm for sites 2 and 3 respectively.

When comparing winter and summer results, conductivity was lower in winter than in summer. At Site 2 the reduction in mean EC was 61%, which was within 2.1 standard deviations given the high variability in data.

At Site 3 the mean EC decreased from 870 to 600 μS/cm. The reduction in mean EC was 31%, which was equivalent to a change of 4.6 standard deviations as the variability of the data was lower in winter than in summer (Figure 14).

Overall, no trends in the EC between days of the week, weekends or weekdays could be verified given the standard deviation and the variance in EC readings on the different dates.

Over a period of 24h, a wider range of EC values was recorded. The variation in conductivity over that period is summarised in Table 7. Table 7 displays the summary of EC readings recorded at 5min intervals in the sewer at the sites of 163 and 697 households for the 4 week period. EC varied in samples from site 2 from 340 to 2150μS/cm in summer and from 363 to 1363μS/cm in winter, a wider range compared to composite samples as more severe differences would be expected over a 24h period.

Figure 15 shows the mean conductivity over 24h for a whole week for site 3. In general, conductivity was higher in the morning from 6am to 11am. Significant variability in EC values and in daily profiles was observed from one day to another, particularly for the smaller catchments.

The highest conductivity value observed in the week was on a Sunday.

Table 6: Summary of wastewater conductivity for composites from 2008

Season	*Number of households*	*EC for diurnal composites (μS/cm)*					
		Mon-Fri		*Weekend*		*Week*	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Summer	163	778	216	793	215	777	222
	697	878	69	848	13	870	59
Winter	163	291	76.6	347	10.6	307	69
	697	593	43.6	617	15.4	600	38.2

Table 7: Summary of sewer conductivity over 24h.

Season	*Number of households*	*EC readings over 24h (μS/cm)*			
		Mean	*SD*	*Median*	*Range*
Summer	163	977	291	940	340-2150
	697	782	82	780	530-1300
Winter	163	618.9	161.6	579	363-1363
	697	625.5	125	609.5	423-1024

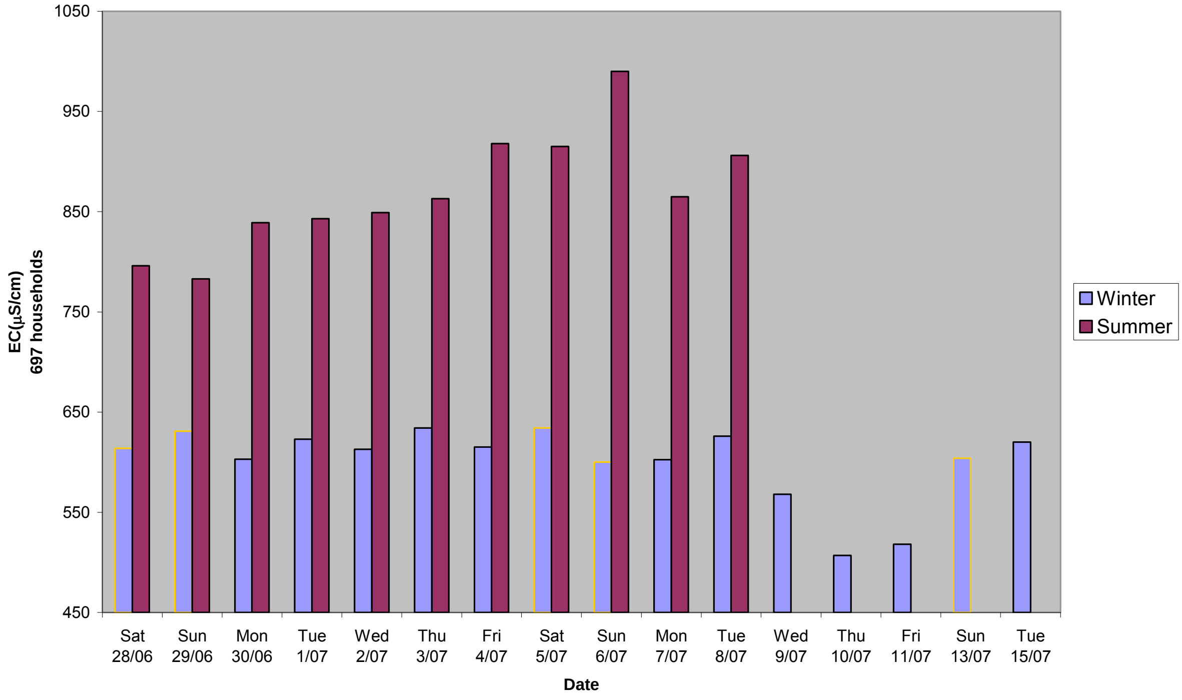


Figure 14: Conductivity at site 3 in summer and winter (697 households)

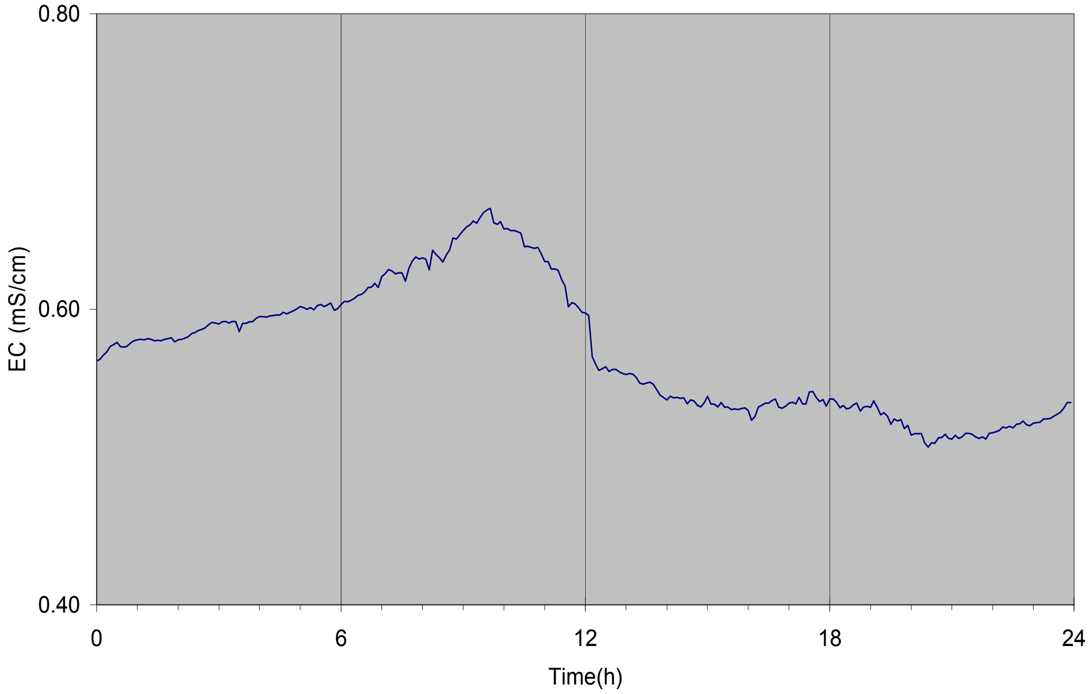


Figure 15: Mean EC over 24h for 697 households in winter.

7.1.4. Total Dissolved Solids

TDS concentrations were determined for composite samples collected over 24h.

Tap water in the catchment had a TDS concentration of 54.8mg/L ± 4.8 mg/L, whilst the TDS concentration in wastewater was between 6 to 11 times higher.

Composites

TDS concentrations were evaluated for daily composites of wastewater collected over 7 days from site 2 and 16 days from site 3. The summary of results is shown in Table 8.

TDS in wastewater composites ranged from 205 to 682 mg/L with a mean value of 409mg/L (SD 159mg/L) for both sites. However the TDS for individual sites differed markedly, the mean TDS at site 2, 619.6 mg/L (SD 44.5), was 49% larger than at site 3, 317.2 mg/L (SD 80.5) in winter.

TDS concentration for site 2 in winter was larger than in summer, but the corresponding TDS load per household was similar between the two seasons (mean load of 0.13kg/hh/d) as shown in Table 9.

At site 3 the corresponding load was lower in winter. In winter TDS was 0.11kg/d per household and in summer 0.17kg/d as shown in Table 9.

Over the week no trends in concentration were observed, i.e. no specific dates in the week consistently displayed higher concentrations as shown in Figure 16 and Figure 17 for summer and winter respectively. At site 3 weekend concentrations were often in the top quartile, but the same was true for concentrations during certain weekdays.

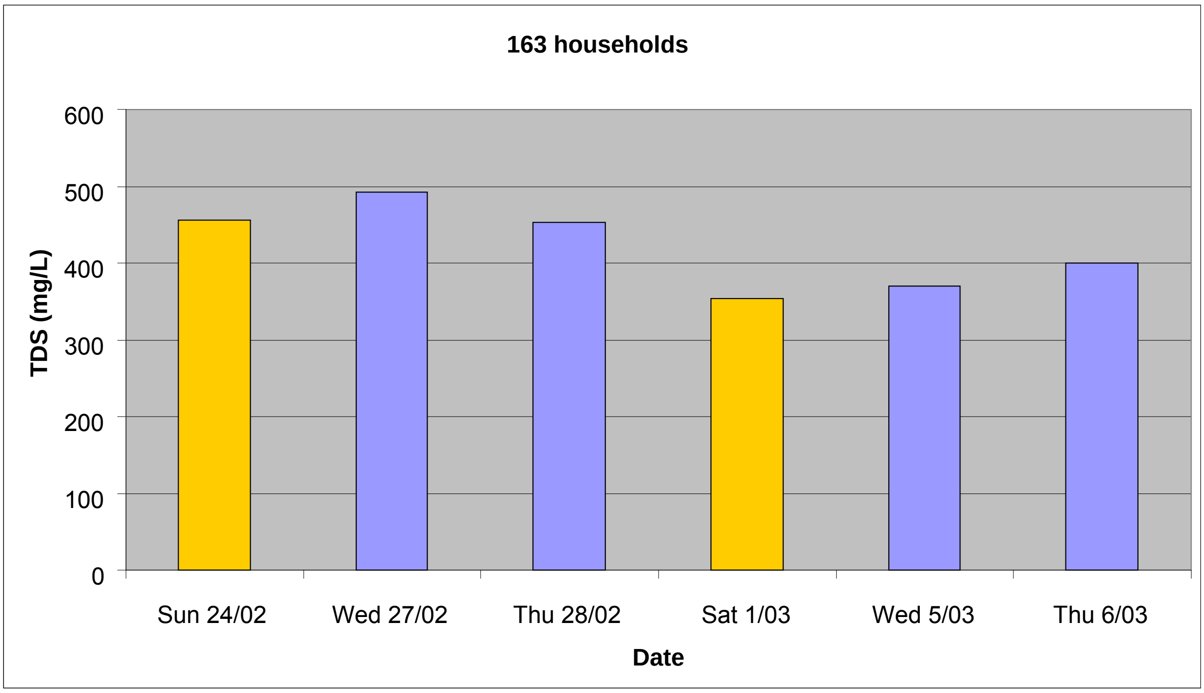
TDS was detected throughout the year. But the concentration of TDS varied between the two sites.

Table 8: TDS concentration for composite samples

TDS of diurnal composites (mg/L)					
Season	*Number of households*	*Mean*	*SD*	*Median*	*Range*
Summer	163	420.7	54.6	426.5	353-492
	697	418.6	47.4	406	330-492
Winter	163	619.6	44.5	605	564-682
	697	317.2	80.5	319.2	205-552

Table 9: Estimated TDS load in the catchment

TDS load (kg/hh/d)					
Number of households	*Season*	*Mean*	*SD*	*Lower Limit (90%)*	*Upper Limit (90%)*
163	Summer	0.13	0.01	0.11	0.16
	Winter	0.14	0.02	0.11	0.17
697	Summer	0.17	0.02	0.13	0.21
	Winter	0.11	0.02	0.08	0.14
All readings	Summer	0.16	0.03	0.11	0.20
	Winter	0.12	0.02	0.08	0.16



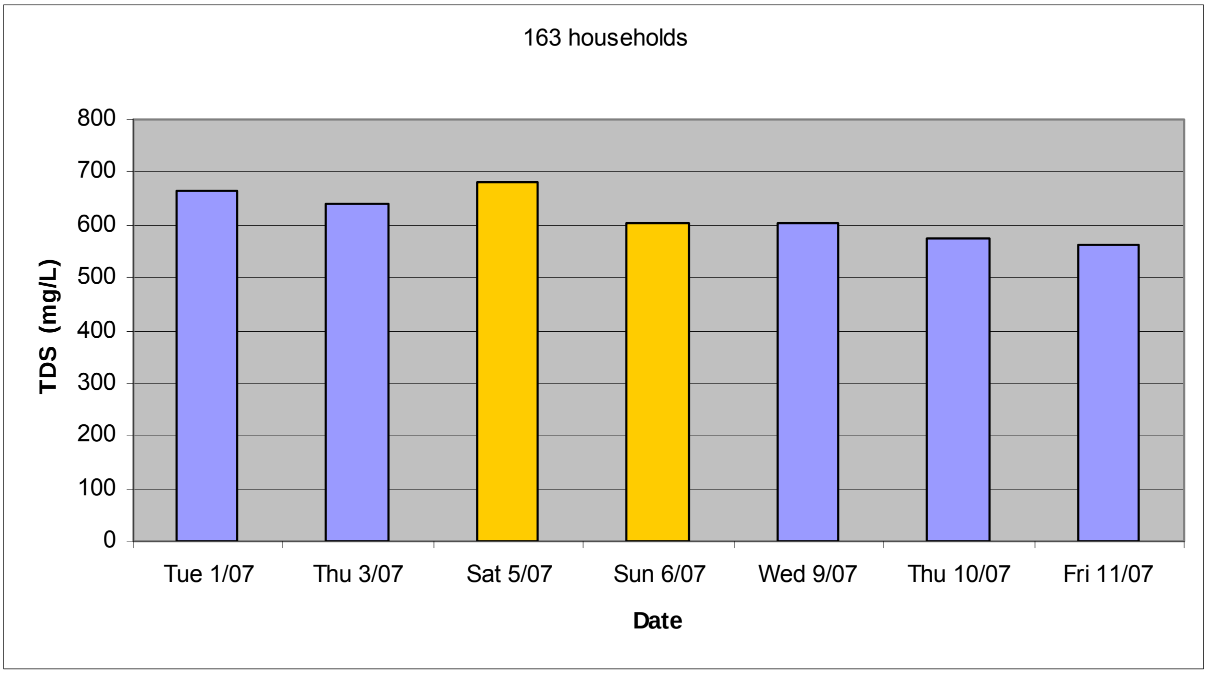
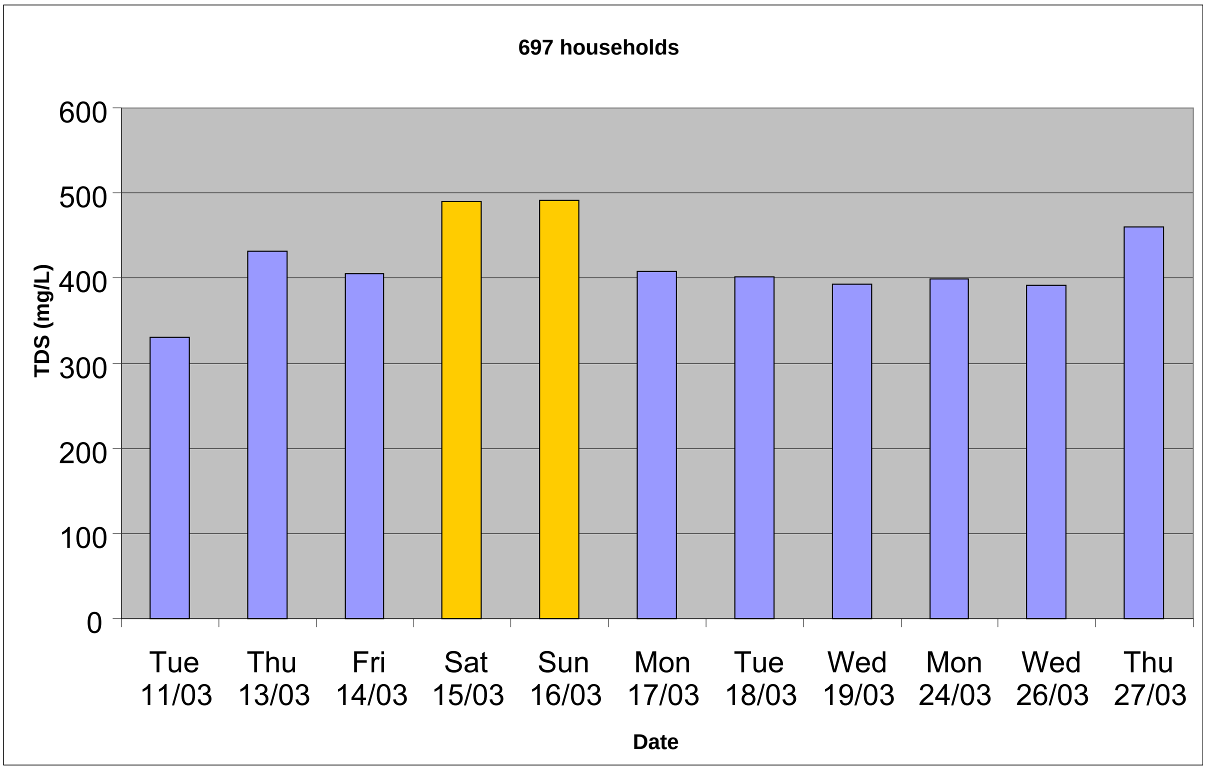


Figure 16: Daily TDS in wastewater from 163 households.



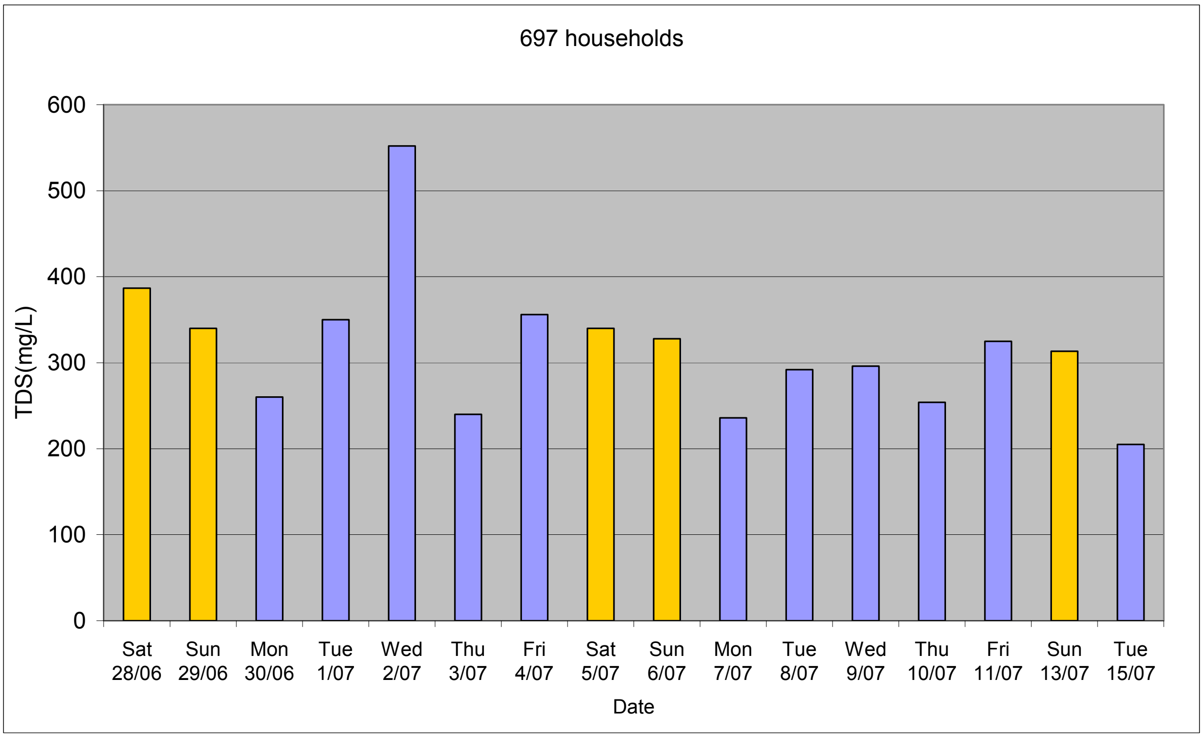


Figure 17: Daily TDS in wastewater from 697 households.

Hourly readings

Hourly readings were monitored for sites 2 and 3 for a minimum of 5 days during the end of June to the first weeks of July. During that period the minima and the maxima in hourly TDS concentrations in wastewater was 16.7mg/L and 800mg/L at site 2 and 144mg/L and 911mg/L at site 3.

The mean hourly concentration across the sites was similar, approximately 332mg/L as seen in Table 10. But the concentration ranges varied with site, with season and concentrations were subject to high variability during the day as seen in the high value of the standard deviations (equivalent to more than 36% of the mean) and in Figure 18 and Figure 19.

Table 10: Summary of TDS hourly distribution during a 24h period

	TDS (mg/L)			
Site	2 (163 households)		3 (697 households)	
Season	Summer	Winter	Summer	Winter
Mean	338	336	323	330
Minimum	88	16.7	88	144
Maximum	1042	800	745	911
Standard deviation	133.8	121.6	126	185.1
	(40% Mean)	(36% mean)	(39% Mean)	(56% mean)
Number of days	12	6	5	6

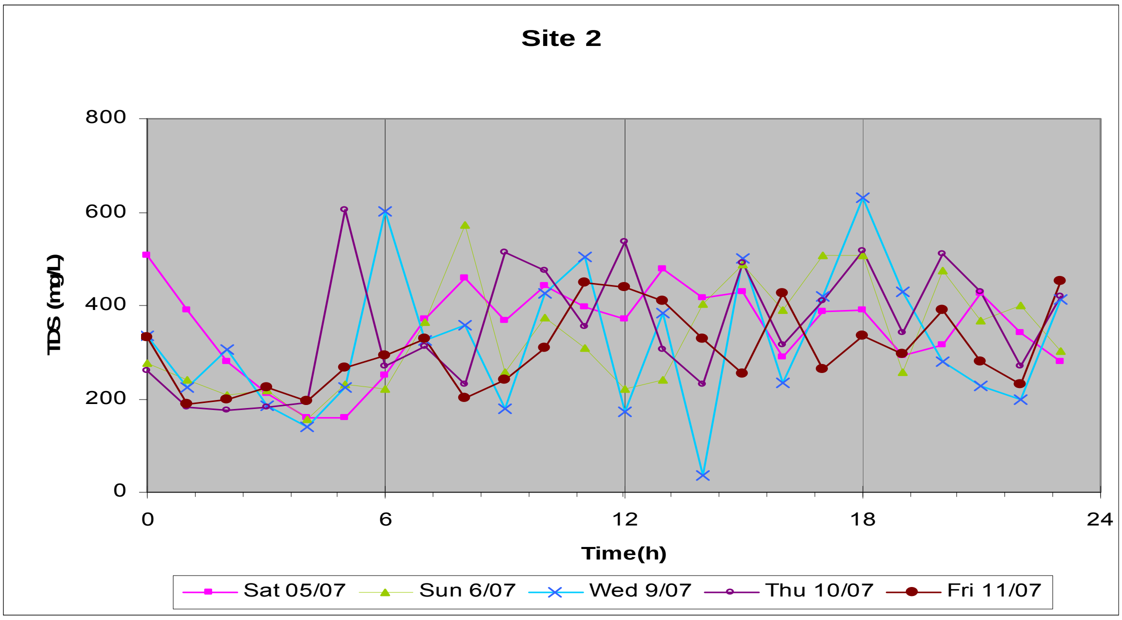


Figure 18: TDS concentration monitored over a 24h for site 2.

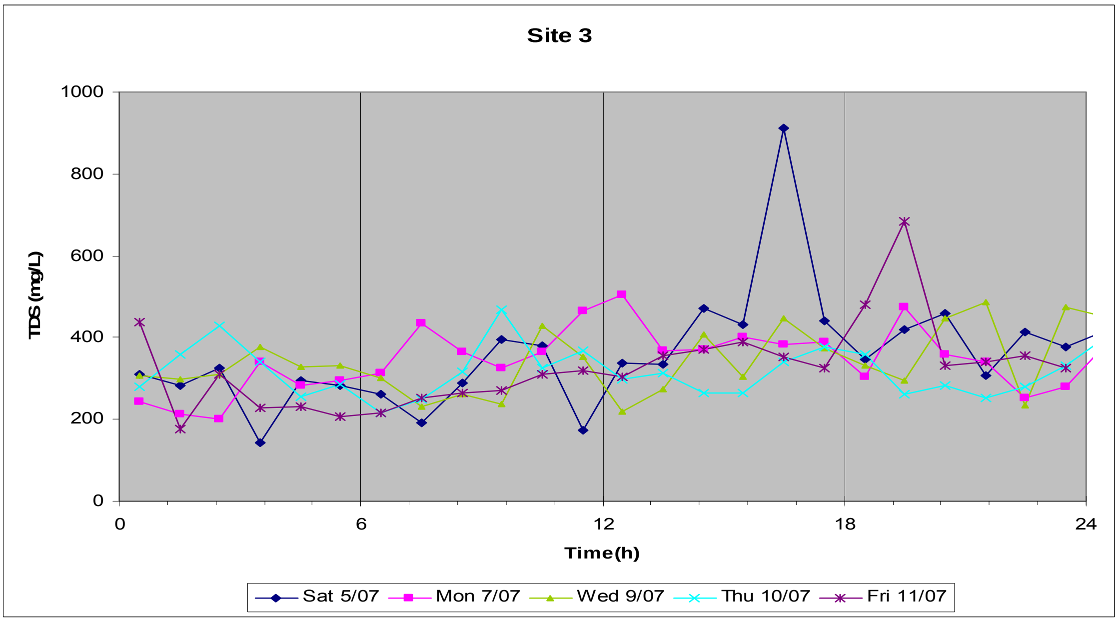


Figure 19: TDS concentration monitored over a 24h for site 3.

7.2. Elements

7.2.1. Weekly profiles

Weekly profiles of diurnal composites collected on different dates of the week at each site were evaluated for summer and winter.

Composite samples were analysed for the concentration of Al, As, Sb, B, Cd, Cl, Cr, Co, Cu, F, Fe, Mn, Hg, Pb, Mo, Ni, Na, Se, Sn, TKN, TP and Zn. The summary of results of the wastewater concentration for sites 2 and 3 are shown in Table 11 and Table 12. In Table 14, the summary of the composite data is shown alongside results from other studies. Concentrations across the two seasons were evaluated using a two-tailed t-test (α= 0.05) and are shown in Table 21 in Appendix E.

Table 11: Concentration of elements in wastewater for site 2

Site 2	*Concentration (mg/L)*						
Total number of samples=18	*Summer (24.02-17.03) C_S*		*Winter (19.06 -11.07) C_W*		*Difference*	*Z-score*	*Probability 2 tailed t-test (α=0.05)*
Parameter	*Mean*	*SD*	*Mean*	*SD*	*(C_S-C_W) * C_S^{-1}(%)*	*Basis summer SD*	*(%)*
Al	0.85	0.493	2.80	2.190	230	3.96	1.14
As	<0.005		<0.005		0		
Sb (µg/L)	<2		3.6	2.1	≥79%		0.09
B	0.108	0.050	0.09	0.03	22	-0.46	32.6
Ca	11.1	1.58	15.7	3.44	42	2.94	0.12
Cd	<0.001		<0.001		0		
Cl^{-1}	45.3	4.1	45.7	6.4	1	0.12	89.2
Co	<0.010		<0.003		0		
Cr (µg/L)	22.3	2.16	16.3	3.6	30	-2.8	47.6
Cu (µg/L)	80.8	25.17	70.3	33.8	13	-0.42	95.4
F	0.97	0.02	0.87	0.04	12	-2.12	0.2
Fe	0.294	0.188	0.73	1.36	-268	2.54	15.6
Pb (µg/L)	3.67	3.14	5.5	3.6	107	1.25	3.56
Mg	2.45	0.362	4.1	0.9	67	4.56	0
Mn	<0.001		0.017	0.035	1578		25.9
Hg	<0.002		<0.002		0		
Mo	<0.05		0.005	0.003	0		7.2
Ni (µg/L)	21.17	3.55	17.5	4.9	17	-1.03	10.3
N (as TKN)	79	15.7	67.2	6.3	15	-0.75	2.95
K	15.8	2.01	21.0	2.5	33	2.6	0.04
P (as TP)	13.3	3.1	20.3	13.7	53	2.3	9.2
Se	<0.007		<0.005		0		
Na	56.4	3.213	67.5	13.2	20	3.46	1.6
S	10.6	1.307	16.95	2.61	60	4.88	0
Sn	≤0.015	0.036	<0.005		0		38.9
Zn	0.34	0.386	0.23	0.212	32	-0.29	53.7
TDS	421	54.6	620	44.5	47	3.64	0

Table 12: Concentration of elements in wastewater for site 3

Site 3	*Concentration (mg/L)*						
Total # samples 27	*Summer (11.03-27.03) C_S*		*Winter (28.06-15.07) C_W*		*Difference*	*Z-score*	*Probability 2 tailed t-test (α=0.05)*
Parameter	*Mean*	*SD*	*Mean*	*SD*	*$(C_S-C_W) * C_S^{-1}(\%))$*	*Basis summer SD*	*(%)*
Al	0.98	0.212	1.02	0.36	4	0.2	57.0
As	<0.005		<0.005		0		
Sb (μg/L)	<2		≤2		0		62.8
B	0.096	0.034	0.06	0.03	35	-1.01	3.5
Ca	12.2	0.974	14.6	0.8	20	2.48	0
Cd	<0.001		<0.001		0		
Cl^{-1}	55.7	7.65	47.7	3.88	-14	-0.80	0.65
Co	<0.01		≤0.003	0.002	0		20.3
Cr (μg/L)	25.0	3.847	7.7	1.5	69	4.5	0
Cu (μg/L)	89.5	15.56	55	9	39	-2.24	0.49
F	1.04	0.08	0.88	0.02	17	-2.47	0
Fe	0.543	0.138	<0.01		≥ 98		0
Pb (μg/L)	4.2	2.86	<5		0		0.07
Mg	3.10	0.177	3.46	0.15	12	2.05	0.01
Mn	0.033	0.004	<0.0003		≥ 99		1.7
Hg	<0.002		<0.002		0		
Mo	<0.05		<0.003		0		33.3
Ni (μg/L)	22.1	1.81	<10		≥55		0
N (as TKN)	67.9	4.1	73	5	8	1.34	69.2
K	9.5	0.625	19.9	0.5	110	16.7	0
P (as TP)	11.7	0.8	15	1	29	4.34	0
Se	<0.007		<0.005		0		
Na	11.7	0.98	65.5	5.3	459	55.08	0
S	12.5	1.068	14.2	1.6	14	1.59	0.06
Sn	<0.050		<0.005		0		
Zn	0.172	0.031	0.185	0.021	8	0.43	35.7
TDS	419	47.4	337	38.8	19	1.71	0.04

7.2.2. Aluminium

The concentration of aluminium in wastewater was larger than in the tap water of the catchment in winter which was 0.047mg/L (SD 0.0088 mg/L).

At site 2, the mean aluminium concentration was 2.80mg/L and 0.849mg/L respectively in winter and summer. Winter was characterised by a high standard deviation compared to summer (SD_w 2.19mg/L, SD_S 0.49mg/L), as there were a number of days when concentrations were greater than 3mg/L. This is a significant difference between the two seasons based on a 95% confidence limit.

The mean aluminium concentrations in wastewater for the two seasons were similar for site 3, when evaluated using a 2-tailed t-test, being 1.02 mg/L and 0.975mg/L in winter and summer respectively, the variation was only 4% (equivalent to less than 0.2 SD) as seen in Table 12.

7.2.3. Antimony

Antimony in wastewater is either close to or below the detection limit.

The number of wastewater composites with antimony concentrations below the detection limit (2μg/L) was 82.4% and 53.6% of all samples for summer and winter respectively.

At site 3, antimony was at the detection limit for 18.8% of samples (3 days out of 16) in winter. But at site 2, it was detected in 11 out of 13 days, the mean concentration of antimony was 3.58μg/L, but the standard deviation was high (2.2 μg/L). During summer, antimony was below detection at both sites.

Hence detection was more frequent in the smaller size catchment (163 households).

7.2.4. Arsenic

Arsenic was below the detection limit of 5 μg/L in all residential wastewater and water samples analysed in both seasons.

7.2.5. Boron

Boron was detected in all summer samples and in 96.3% of winter samples.

The concentration of boron in residential wastewater was consistent between the two seasons for site 2, but lower for site 3 in winter. Overall the concentration of boron was less than 0.10 mg/L as in other studies (CWW 2007).

At site 2, the concentration of boron was 0.09mg/L and 0.11mg/L in winter and in summer respectively. The difference of 22%, was within normal data variability (<0.46SD) given the data's standard deviation and the t-test.

Whilst at site 3, concentrations were 0.063mg/L (SD 0.031) in winter and 0.096mg/L (SD 0.034) in summer. This is equivalent to a reduction of 35% from summer to winter. There were also 2 days out of 16 in winter when the samples was below the detection limit (LOD 0.03mg/L).

7.2.6. Calcium

Calcium was present in all samples collected.

At site 2, the concentration of calcium was 15.7mg/L and 11.09mg/L in winter and in summer respectively. The increase of 42% was equivalent to 2.94 SD. Data variability was twice greater in winter (winter SD 3.4 and summer SD 1.6) for that site.

At the larger catchment, site 3, the mean concentration was 14.6mg/L and 12.2mg/L in winter and in summer respectively. The difference of 20% was greater than 2 SD and statistically significant.

7.2.7. Cadmium

Cadmium was below the detection limit of 1μg/L in all water and wastewater samples analysed.

7.2.8. Cobalt

The concentration of cobalt in wastewater was below the detection limit (<0.003mg/L) on most days. No cobalt had been detected during summer, whilst in winter it was detected on only two occasions out of sixteen at 0.004 and 0.009mg/L, i.e. 7% of all samples.

7.2.9. Chloride

Chloride was detected in all samples.

The concentration of chloride in wastewater was within the same range across the two seasons. At Site 2, the mean chloride concentration was 45.7mg/L and 45.3mg/L in winter and in summer respectively. The difference of only 10% was equivalent to only 0.12 SD. Whilst at Site 3, means of 49.6mg/L and 55.7mg/L were recorded in winter and in summer. The difference of 14% was statistically significant given the lower SD in winter.

The range (45-55mg/L) was consistent with other Melbourne studies conducted in recent years (CWW 2007, Connor and Wilkie 1996).

7.2.10. Chromium

Chromium was detected in all wastewater samples, but the concentration of chromium was lower in winter than in summer. At site 2, the mean concentration of chromium was 0.0163mg/L and 0.0223mg/L in winter and in summer respectively. The 27% reduction was equivalent to 2.78 SD.

At site 3, the concentration of chromium in winter was 69% lower than in summer. In winter it was 0.0077mg/L and in summer 0.025mg/L, a difference of more than 4.6 SD.

The concentrations were higher than the range observed in other Melbourne studies (Z>3 for site 3), 0.006mg/L in CWW (2007) and 0.003mg/L in Connor and Wilkie (1995).

7.2.11. Copper

Copper was detected in all wastewater samples.

No significant change in copper was observed between the two seasons for site 2. At site 2, the mean copper concentration was 70.33μg/L and 80.83 μg/L in winter and in summer respectively, the decrease of 13% was equivalent to 0.42 SD, i.e. within the expected normal data variability.

At site 3, the mean copper concentration in winter was 54.7 μg/L and in summer 89.5 μg/L, i.e. a decrease of 39% and equivalent to 2.24 SD.

7.2.12. Fluoride

The concentration of fluoride changed across the seasons.

At site 2, the mean fluoride concentration in winter was 0.87mg/L and in summer 0.99mg/L. the decrease of 12% was equivalent to 2.1 SD.

Whilst at Site 3, the mean fluoride in winter was 0.88mg/L and in summer it had been 1.04mg/L, equivalent to a reduction of 20% from summer and more than 3 standard deviations. Summer concentrations had more variability (SD 0.07 mg/L) compared to winter ones (SD 0.02mg/L).

The probability of the means being the same given the SD based on the t-test was less than 0.02% for both sites.

7.2.13. Iron

The concentration of iron, 0.2-0.3mg/L, was the lowest in this study by 18 to 60% compared to the other studies (CWW 2007, Connor and Wilkie 1995) .

In summer the mean had been 0.543mg/L at site 3 and 0.294mg/L at site 2, with 88% of wastewater samples within detection limits. The SD was high at 0.138 mg/L and 0.188mg/L for the two respective sites.

In winter the concentration of iron was below detection (LOD < 0.01mg/L) at site 3, whilst at site 2 the mean concentration increased to 0.73mg/L, but the data was subject to a much higher variability (SD 1.36mg/L) compared to summer.

7.2.14. Lead

Lead was detected either at or close to detection limit in Frankston. But concentrations and frequency of detection changed across the seasons.

The frequencies of detection were 70% and 28.6% in summer and winter respectively.

At site 2 in summer it had been detected on four out of six days at less than 7μg/L. In winter it was detected on seven out of twelve days at concentrations lower than 7.57μg/L with a mean of 5.5μg/L. The increase in concentration was equivalent to 50% (t-test t>2.5).

At site 3, lead was detected only once in 16 days at the detection limit (5μg /L) during winter sampling. Whilst in summer it was detected on 8 days of a total of 11, the mean was 5.6 μg/L and the SD 1.075.

7.2.15. Magnesium

Magnesium was detected in all wastewater samples and was subject to seasonal variations.

The concentration of magnesium was 4.1mg/L and 2.45mg/L in winter and in summer respectively, equivalent to an increase of 67% (4.56 SD) at site 2.

At site 3, the concentration of magnesium in wastewater in winter and in summer was 3.46mg/L and 3.10mg/L respectively, i.e. equivalent to an increase of 12% or 2.05 SD.

7.2.16. Manganese

Manganese was below detection during winter (<0.0003mg/L) for 82.9% of samples. At site 2 only one sample was above the detection limit, whilst at site 3 it had been detected on only 3 samples at about 0.032mg/L. In summer it was detected in 29.4% of the samples.

7.2.17. Mercury

Mercury was below the detection limit [Hg]< 2μg/L for all samples in both seasons.

7.2.18. Molybdenum

Molybdenum had been below the detection limit in wastewater during summer. But during winter it was detected at site 2 on four days at up to 0.004mg/L and once at site 3 at 0.037mg/L, this is equivalent to 17.9% of samples.

7.2.19. Nickel

Nickel was detected in all summer samples and in 46% of winter samples.

The concentration of nickel across winter and summer was similar for site 2. In winter the mean concentration at site 2 was 17.5 μg/L and in summer 21.17μg/L, this corresponds to a reduction of 17%, and was equivalent to 1.03 SD (t<2.16).

At the larger catchment, site 3, the concentration of nickel differed between the two seasons, during winter it was below the detection limit (<10μg/L), but had been on average 22μg/L ± 1.8μg/L in summer.

7.2.20. Nitrogen

Nitrogen as TKN was detected throughout the year.

TKN concentrations were similar across the two seasons for site 3.

At site 2 the mean TKN was 67mg/L and 79mg/L in winter and in summer respectively, corresponding to a decrease of 5%, but greater than 2.3 SD. The variability in winter (SD=6.29) was lower than in summer (SD=16).

Whilst at site 3 the mean TKN concentration was 73mg/L and 68mg/L L in winter and in summer respectively. This represents a change of less than 8%. Results were also within 2 SD for both populations.

7.2.21. Phosphorus

Phosphorus was detected throughout the year.

The phosphorus concentration was slightly higher in winter than in summer. At Site 2 the mean TP in winter was 20.32mg/L compared to 13.25mg/L for summer, representing an increase of 53% (2.3 SD). However, winter concentrations also had higher variability, illustrated by the large difference in SD; winter SD 13.66 mg/L, and summer SD 3.08mg/L.

At Site 3 the mean TP in winter was 15mg/L and in summer 12mg/L, representing an increase of 29% between the two seasons, which was significant (t>2.06) given the lower SD for site 3, respectively 1.28mg/l and 0.79mg/L for summer and winter respectively.

7.2.22. Potassium

Potassium was detected in all samples.

The concentration of potassium was higher in winter than in summer.

At site 2 the concentration was 33% lower in winter than in summer. The mean concentrations were 15.77mg/L and 20.99mg/L in winter and summer respectively, i.e. equivalent to 2.6 SD.

At site 3 the concentration increased in winter by 110% to 19.9mg/L compared to summer 9.46mg/L.

7.2.23. Selenium

Selenium was below the detection limit (< 7µg/L) for all samples, winter and summer.

7.2.24. Sodium

Sodium was detected in all samples.

The concentration of sodium in winter was consistent across the 2 sites at 66.7mg/L. This concentration was lower than the 80mg/L previously reported in Connor and Wilkie (1995) and City West Water (2007).

At site 2 the concentration of sodium was 20% higher in winter at 67.49mg/L than in summer 56.37mg/L. The increase corresponded to 2.46 SD (t>2.16).

Whilst at site 3, the increase was significantly higher at 459%, to 65.5mg/L compared to 11.7mg/L in summer (t>2.12).

7.2.25. Sulphur

Sulphur was detected in all samples and the concentration increased from summer to winter.

At site 2, the concentration of sulphur in winter, with a mean of 16.95mg/L, was 60% higher than in summer at 10.57mg/L. The increase corresponded to 4.88 SD.

Whilst at Site 3 the concentration of sulphur from summer to winter, increased by +14% and within 1.59 SD. In winter it was 14.55 mg/L and in summer 12.55mg/L.

7.2.26. Tin

Tin was detected in 5.9% and 7.1% of the samples collected in summer and winter.

At site 2 tin was detected in only 2 samples at the detection limit (0.005mg/L) in winter and in summer once only at 0.088mg/L. At site 3 tin was below the detection limit in both seasons.

7.2.27. Zinc

Zinc was detected in all samples and the concentration of zinc was similar in both seasons.

At Site 2 it was 0.23mg/L in winter and 0.34mg/L in summer, corresponding to a decrease of 32%, but not a significant variation as it was less than 0.29 SD.

Whilst at site 3, it was 0.185mg/L and 0.172mg/L for winter and summer respectively. The difference of 8% was minimal equivalent to only 0.43SD.

7.3. Comparison of same day concentrations at two sites

To evaluate the changes that occur to wastewater as it travels through a catchment in more detail, we determined the concentration of priority contaminants in wastewater composite samples collected over 7 days.

The wastewater samples were collected at both sites on the same dates over a period of 7 days. The dates on which samples were collected in July included Tuesday 1st, Thursday 3rd, Saturday 5th, Sunday 6th, Wednesday 9th, Thursday 10th and Friday 11th.

These results are shown in Figure 20 to Figure 31.

As verified in other sections, arsenic, cadmium, mercury, nickel and selenium, were below the detection limit at both sites.

Some elements were detected at site 2 on some dates but not at site 3. For instance, tin and iron were found at the detection limit of 0.005mg/L and over 50 times the detection limit on two occasions respectively Tuesday 1st and Thursday 3rd July and Saturday and Sunday 5th and 6th at site 2, but were not detected at site 3.

Antimony (Sb) was measured at concentrations between 2 to 6µg/L at site 2 on five occasions (Thursday 3rd, Saturday 5th, Sunday 6th, Wednesday 9th and Thursday 10th July), but at site 3 only at the detection limit on the weekend of the 5th and 6th .

Whilst for boron, calcium, chloride, cobalt, copper, fluoride, sodium, nickel, sulphur, nitrogen and zinc the concentrations at both sites were very similar.

Aluminium, boron, chromium, sulphur and TDS were present at higher concentration at site 2, with chromium and TDS displaying the largest variation between the 2 sites.

Table 13 shows the correlation factors between the concentrations of elements recorded during that period, when concentrations at both sites were within detection limits.

High and positive correlations were observed for chloride (0.7549), sodium (0.7642) and potassium (0.8318) indicating a strong linear dependency between the concentrations at the two sites for that specific date.

A positive but lower correlation was observed for phosphorus (0.5966), silicon (0.6796), sulphur (0.5840) and zinc (0.5088). Copper on the other hand had a negative correlation (-0.6507), i.e. as concentration increased for one site, the concentration of copper at the other site decreased.

TKN and TDS concentrations were also positively correlated between the 2 sites, with the respective correlation factors of 0.3904 and 0.3276.

Whilst Al, B, Ca, Cr, F and Mg had low correlation factors (closer to 0), showing weak linear dependency between the concentrations at the two sites.

Table 13: Correlation between concentrations at site 2 and 3 from 1-11.07.08

Element	*Correlation factor*	*Element*	*Correlation factor*
Al	0.0817	Mg	0.1151
B	0.1651	TDS	0.3276
Ca	0.2866	TKN	0.3904
Cl	0.7549	TP	0.5955
Cr	-0.2243	Si	0.6796
Cu	-0.6507	Na	0.7642
F	0.0986	S	0.5840
K	0.8318	Zn	0.5088

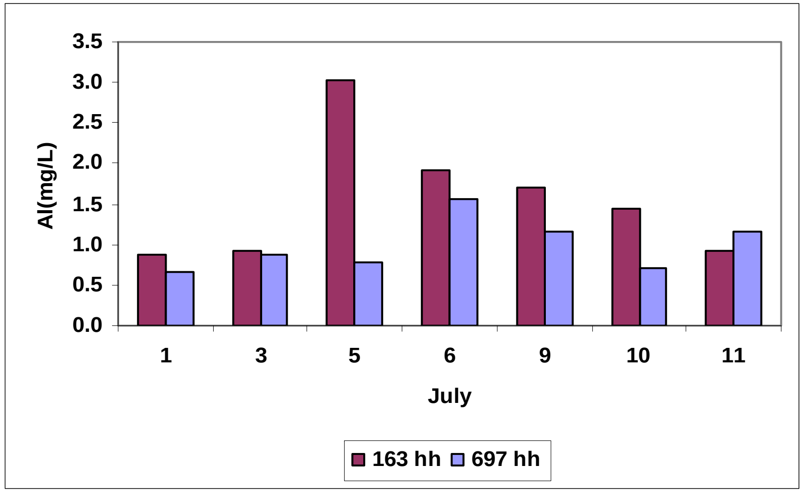


Figure 20: Al concentration at sites 2 and 3 on equivalent days in winter.

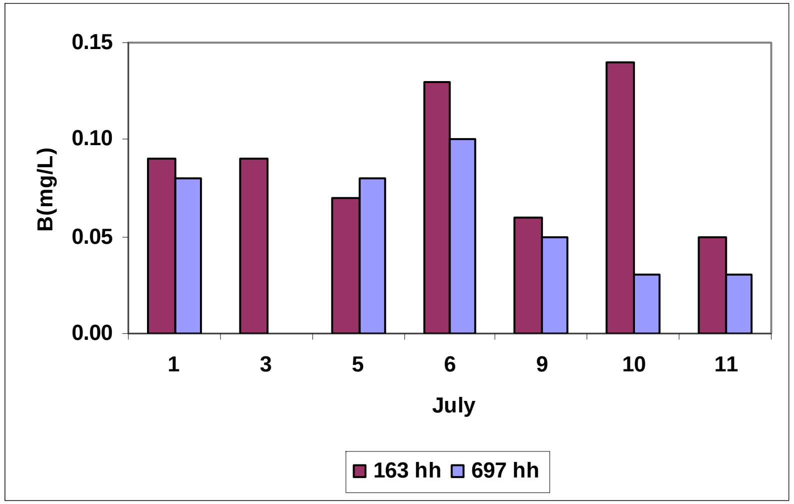


Figure 21: B concentration at sites 2 and 3 on equivalent days in winter.

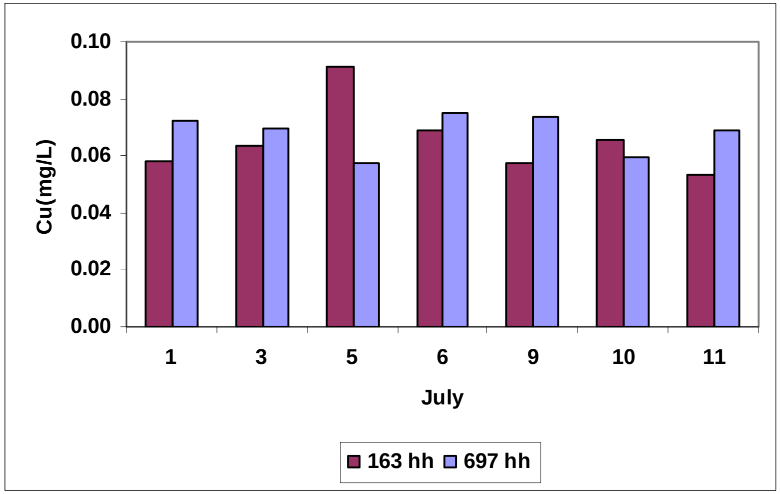


Figure 22: Cu concentration at sites 2 and 3 on equivalent days in winter.

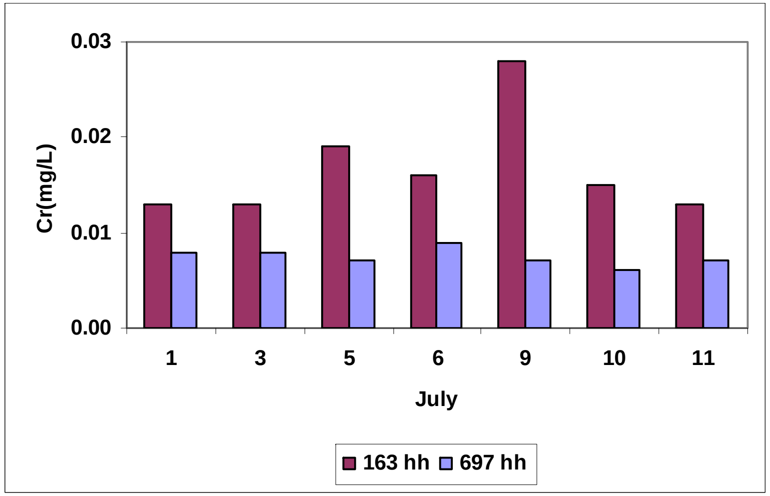


Figure 23: Cr concentration at sites 2 and 3 on equivalent days in winter.

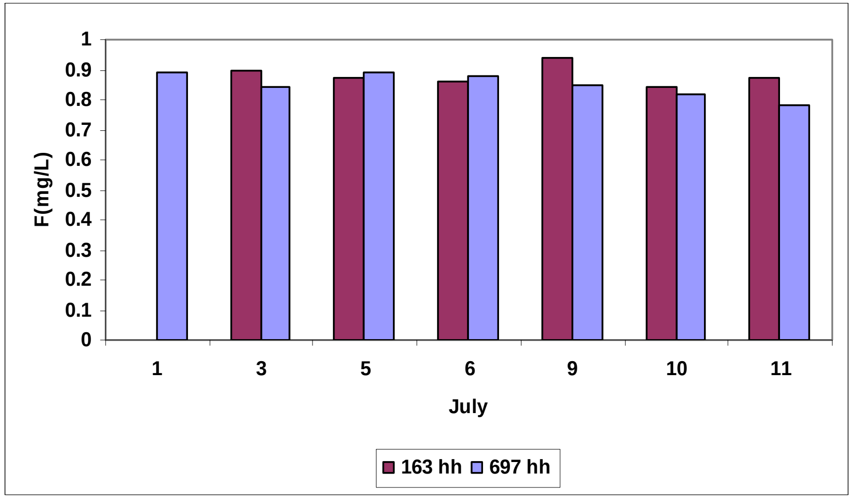


Figure 24: F concentration at sites 2 and 3 on equivalent days in winter.

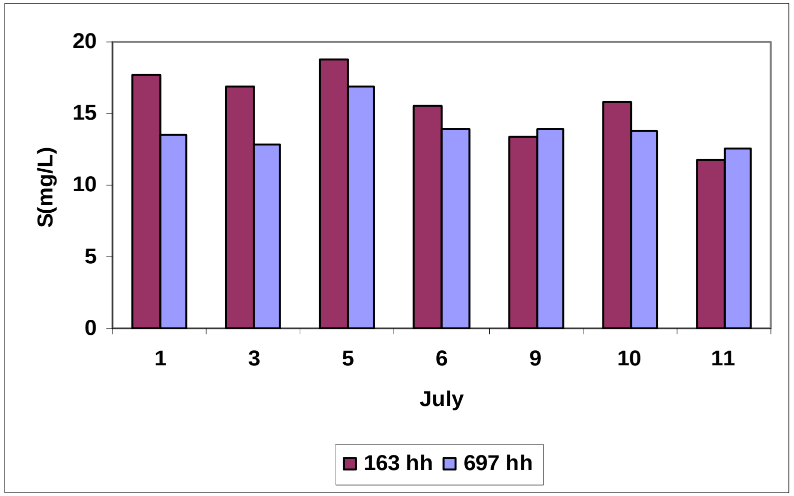


Figure 26: S concentration at sites 2 and 3 on equivalent days in winter.

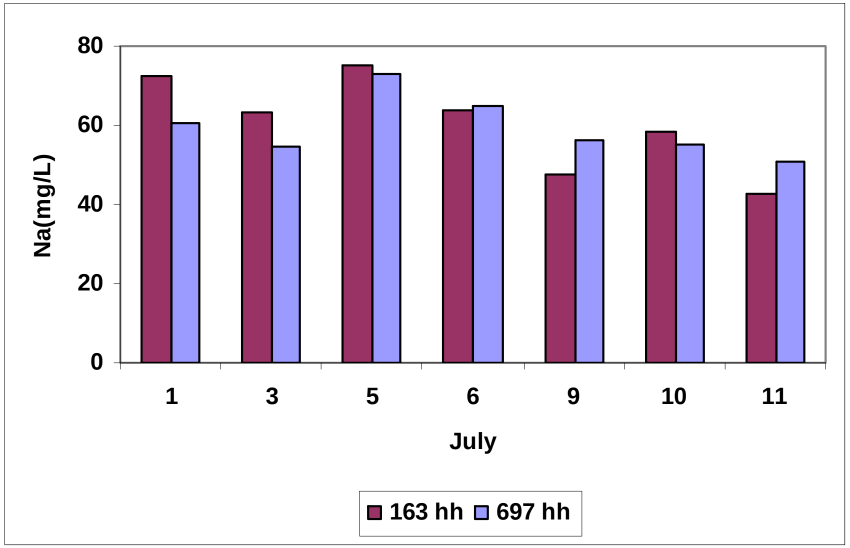


Figure 25: Na concentration at sites 2 and 3 on equivalent days in winter.

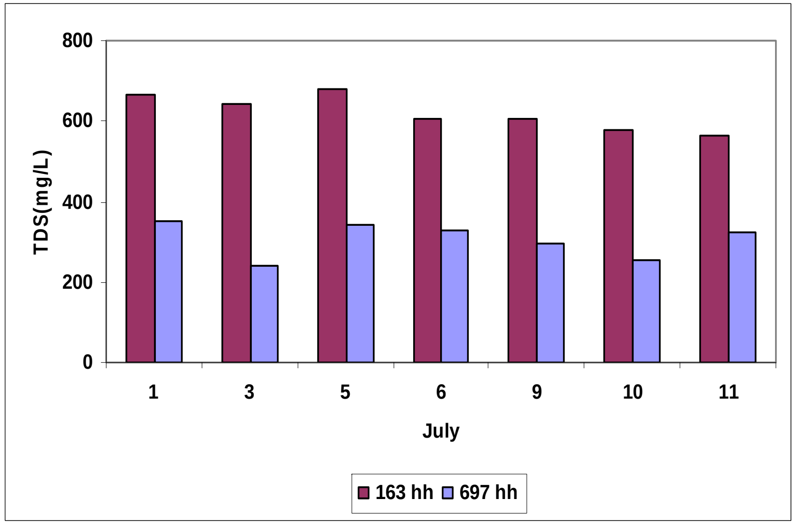


Figure 27: TDS concentration at sites 2 and 3 on equivalent days in winter.

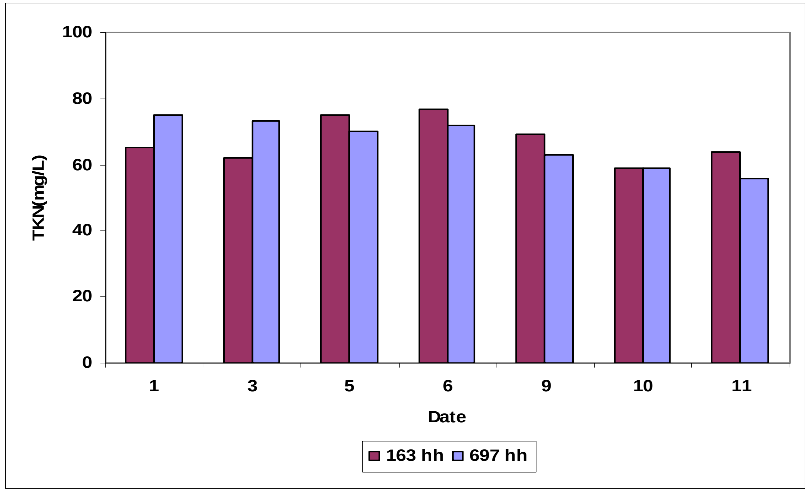


Figure 28: TKN concentration at sites 2 and 3 on equivalent days in winter.

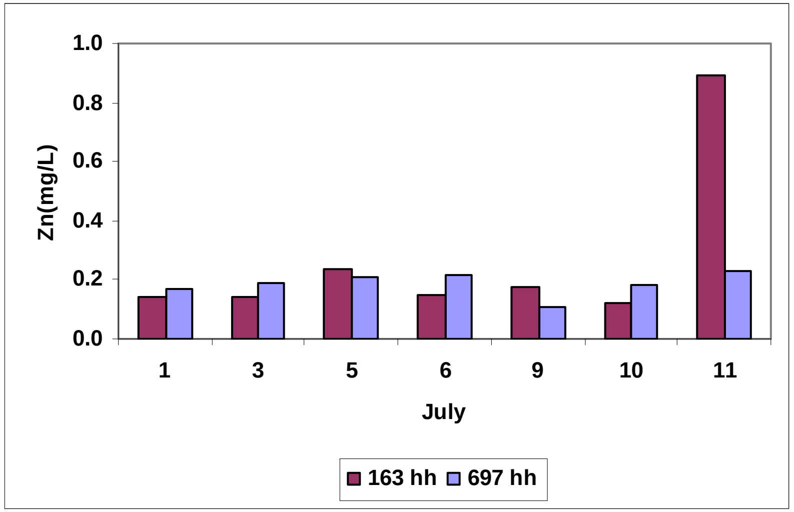


Figure 30: Zn concentration at sites 2 and 3 on equivalent days in winter.

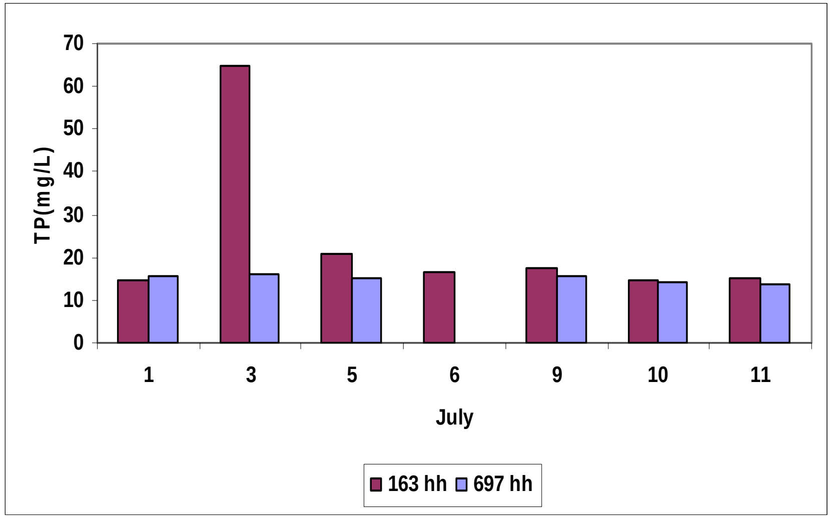


Figure 29:TP concentration at sites 2 and 3 on equivalent days in winter.

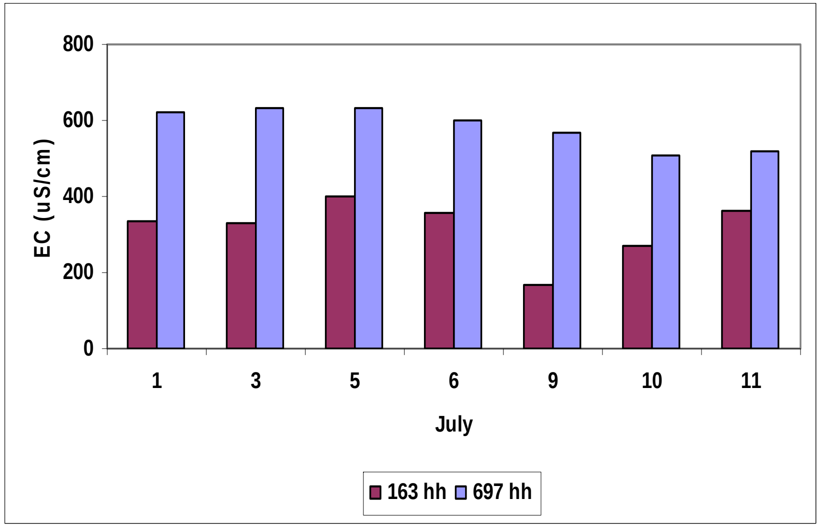


Figure 31: EC concentration at sites 2 and 3 on equivalent days in winter.

7.4. Diurnal profiles

Given the verification of priority contaminants in wastewater composites in section 7.2, the next step is to understand how such concentrations vary through the day.

The pattern of release of contaminants in wastewater over 24h had been investigated for a single day (Sunday) in a previous report of this series in order to help understand their distribution patterns throughout the day and identify potential associations with different household sources (Tjandraatmadja *et al.* 2009). This analysis had revealed distinct profiles, for:

(a) Nitrogen, phosphorus and potassium, which were associated with human excretion and characterised by a daily concentration maxima from 6-10am, with a morning maximum.

(b) Aluminium, copper, iron, sodium, sulphur and zinc characterised by an even concentration distribution throughout the day likely to be associated with other household sources and activities, and

(c) The group of contaminants present at low concentrations (often below detection limits): arsenic, cadmium, chromium, mercury, molybdenum, nickel, lead, selenium and antimony.

In this report the procedure was repeated for a weekday for comparison with previous results (a weekend day, Sunday). In addition detection limits were also lowered for some of the elements in group (c).

Wastewater from site 2 (163 households) and site 3 (697 households) was sampled on a Thursday 10th July. Hourly samples were collected and analysed for aluminium (Al), antimony (Sb), arsenic (As), boron (B), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), iron (Fe), mercury(Hg), lead (Pb), molybdenum (Mo), nickel (Ni), total phosphorus (TP), selenium (Se), sulphur (S), tin (Sn), sodium (Na) and zinc (Zn), and used to create diurnal concentration profiles. For TKN analysis was conducted with samples collected on Friday 27th June for site 2 and on the Tuesday 1st July for site 3.

This section compares the winter 24h concentration profile for site 2 and 3 on that day and as a reference shows the summer concentration profile for site 2 where available.

A few of the elements which have characteristically been below the detection limits of the analytical instrumentation (ICP-AES/MS) in composite and summer samples were also below detection in the hourly winter samples. These included As, Cd, Mn, Hg and Se. Ni was detected once at site 2, Co and Mo were occasionally detected in winter only.

Among the winter samples there were elements which were consistently detected throughout the day and others that displayed a profile characterised by random spikes in concentration at different times of the day.

The last group included elements such as Sb, B, Co, Cr, Pb, Ni and Sn which had not been detected in tap water. These elements were also more often detected in the wastewater from site 2. Their concentration pattern characterised by random concentration peaks during the day suggests that their origin is likely to be attributed to random and specific activities carried during the day, but which might not necessarily be daily routine activities.

In general, elements which had been detected in summer showed similar 24h profiles in winter. This was seem for Al, B, Na, Zn, TKN , TP and K which showed consistency in the shape of the concentration profile recorded during the day at both sites and in both seasons (summer and winter) despite small local variations in hourly concentrations.

As in summer, the smaller catchment, site 2, was characterised by sharper profiles, with concentration peaks that were larger in value and also more distinct. Whilst at site 3 dilution and attenuation given the larger number of households contributed to smoother peaks and generally lower concentrations. For instance, elements such as Cu, Na and S had a constant baseline at site 3 that was maintained for most of the day, whilst at site 2 there were sharper gradients in concentration throughout the day.

The profile of individual elements are discussed in the following sections.

7.4.1. Aluminium

Over winter, hourly concentrations of Aluminium (Al) at site 2 had a mean of 1.85mg/L, SD 1.04 and range of 0.15-3.6mg/L. At site 3 the mean was 1.23mg/L, SD 0.54 and the range was 0.54 – 2.47mg/L.

The concentration profile at both sites was characterised by a similar pattern during the day with concentration increasing from the morning to the afternoon (Figure 33). As observed n summer, the highest concentrations were registered in the afternoon after 12pm as shown in Figure 32. Between seasons, the major difference was an evening maximum concentration observed at midnight in summer, but at 11pm in winter.

The profile reinforces that sources other than water supply influence the concentration of Al in wastewater.

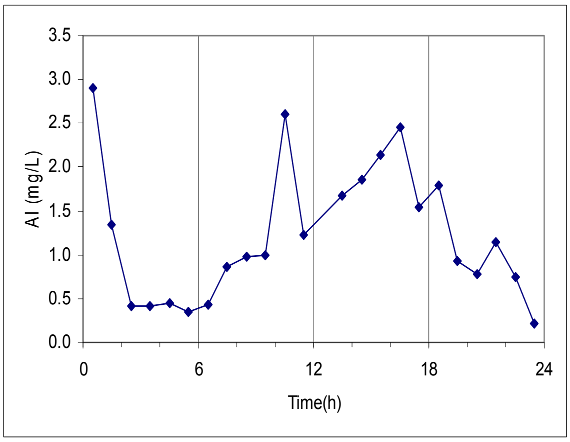


Figure 32: Diurnal concentration profile for aluminium on Sunday 24/02 (163 households).

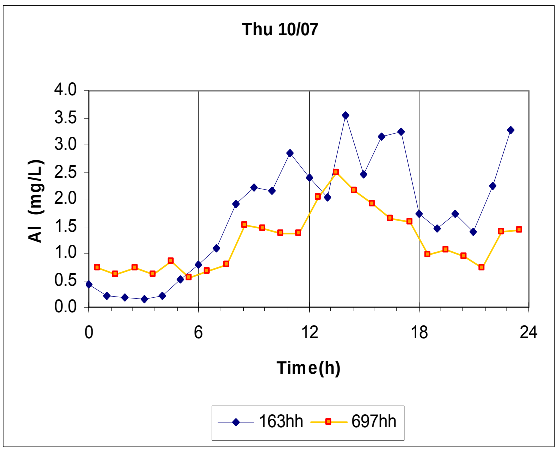


Figure 33: Diurnal concentration profile for aluminium on Thursday 10/07.

7.4.2. Antimony

Antimony (Sb) was detected mainly at site 2 and mostly in winter. The concentration increased after 7am, ranged between 3-4.5μg/L from 8am to 6pm and then decreased. This was followed by another spike from 7pm to 9pm (Figure 34). At site 3 a spike in the antimony concentration was detected only once at 9pm at the detection limit of 2μg/L.

Antimony was below the detection limit of 2 μg/L in all water and summer wastewater samples analysed.

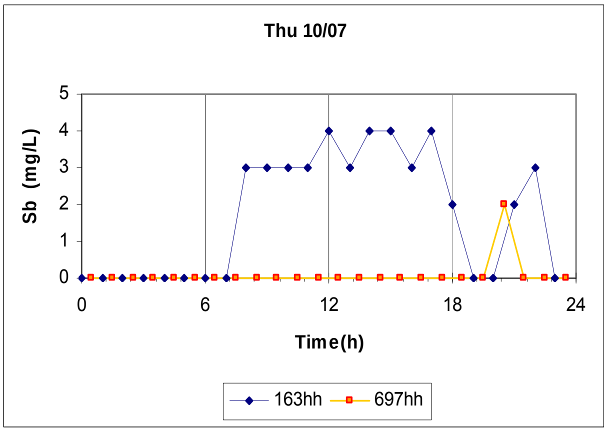


Figure 34: Diurnal concentration profile for antimony on Thursday 10/07.

7.4.3. Boron

Boron (B) had not been detected in wastewater generated on the Sunday 24th of February, but it was detected in winter.

The concentration profile was characterised by a flat baseline with concentrations below 0.1mg/L for most of the day. At site 2 concentration spikes were observed at 8am (0.7mg/L), 3pm (0.25mg/L) and 11pm (0.4mg/L). Site 3 on the other hand had a gradual build up in concentration in the afternoon between 12pm to 18pm, during which the highest concentrations of the day were recorded.

Concentration peaks were also more pronounced at site 2, with a maximum of 0.80mg/L compared to only 0.2mg/l for site 3.

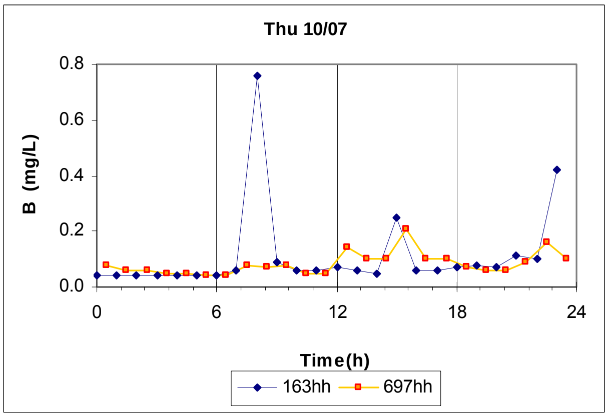


Figure 35: Diurnal concentration profile for boron on Thursday 10/07.

7.4.4. Calcium

The diurnal profile was characterised by low variation in calcium during the day (Figure 36). The range of concentrations was 10.6 to 22.2 mg/l at site 2 and 112.5 to 18.6mg/L at site 3 and the hourly mean was similar at 15.2 and 15.4 mg/L for the respective sites. No significant change in profile was verified between winter and summer.

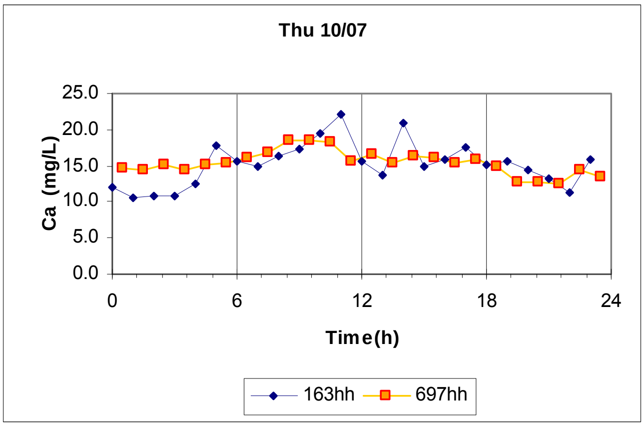


Figure 36: Diurnal concentration profile for calcium on Thursday 10/07.

7.4.5. Cobalt

Cobalt had not been detected in summer, but was detected in winter at concentrations close to the detection limit. In winter the concentration of cobalt was below the detection limit for majority of the day as seen in Figure 37, with random spikes in concentration recorded at different times of the day. Peaks at site 2 and 3 showed no correspondence, occurring at different times of the day, with the higher concentrations recorded at site 2. The maximum concentration was 0.04mg/L.

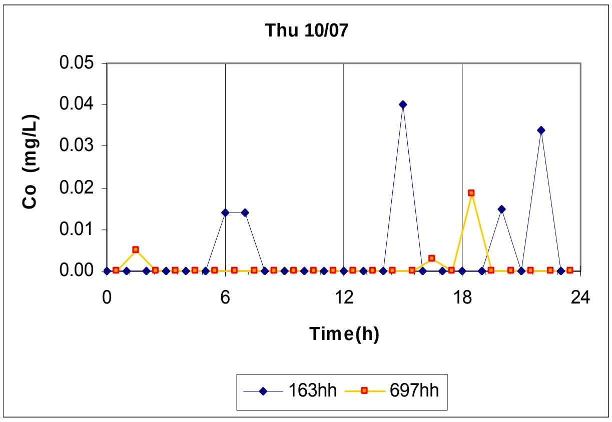


Figure 37: Diurnal concentration profile for cobalt on Thursday 10/07

7.4.6. Chromium

Chromium (Cr) was detected at site 2 from 6am to 11pm, with a mean concentration of 0.008mg/L, however these values are close to the detection limit (0.002mg/L). During those hours the concentration increased from 6am to 5pm with local concentration peaks recorded at 10am-12pm, 1-2pm and 4-5pm. This was followed by a decrease in concentration after 5pm (Figure 38).

At site 3, the concentration of chromium was characterised by random spikes in concentration during the day. The three largest peaks were between 10-11am, 2-4pm and after 6pm, when the highest concentration of the day 0.025mg/L was observed.

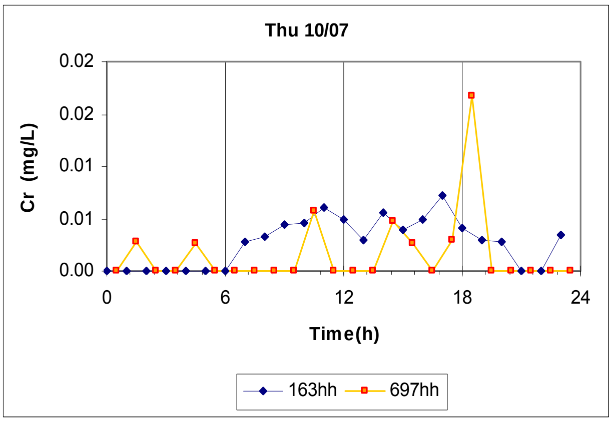


Figure 38: Diurnal concentration profile for chromium on Thursday 10/07

7.4.7. Copper

The copper (Cu) profiles for both sites were similar for most of the day, but for the period between midnight and 6am when the concentration at site 2 was the lowest in the day, whilst at site 3 it was the highest (Figure 40). At site 2, the concentration ranged from 0.04 to 0.13mg/L, with the period between 6am to 5pm registering the highest concentrations between 0.08 to 0.12mg/L.

At site 3 the range was 0.04 to 0.3mg/L, with concentrations greater than 0.2mg/L from midnight to 6am, but below 0.1mg/l for the rest of the day.

The respective means for sites 2 and 3 were 0.08mg/L (SD 0.02) and 0.12mg/L (SD 0.08).

The results are comparable to those recorded on the Sunday in summer for site 2. On that day the concentration of copper in wastewater had also been in a similar low range (<0.01 to 0.22 mg/L) with a mean 0.077± 0.04 mg/L and below 0.1mg/L for most of the day (Figure 39).

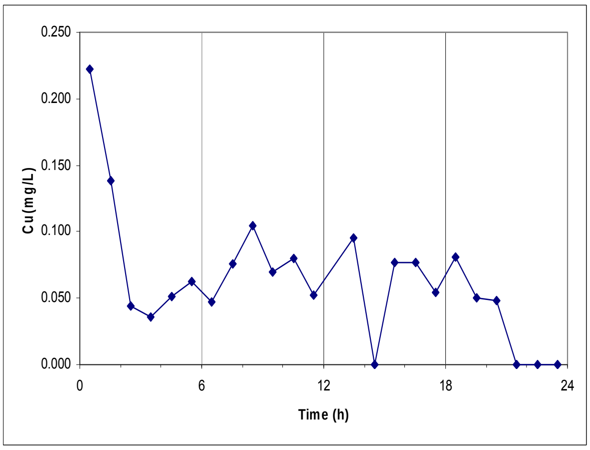


Figure 39: Diurnal concentration profile for copper on Sunday 24/02 (163 households)

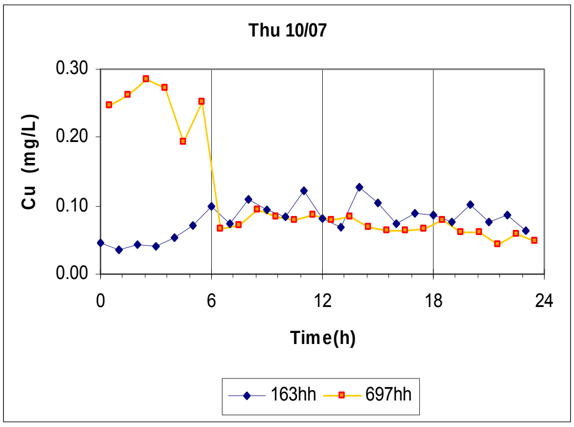


Figure 40: Diurnal concentration profile for copper on Thursday 10/07.

7.4.8. Lead

Lead (Pb) had not been detected in the summer samples.

In this set of winter samples lead was detected randomly during the day (Figure 41). At site 2, sporadic concentration spikes were recorded at 6am, 10am, 1pm, 2p, 5pm, 10pm and 11pm and ranged from 0.01 to 0.016mg/L. At site 3 only two peaks were recorded, one at 0.005mg/L and the other at 0.015mg/L.

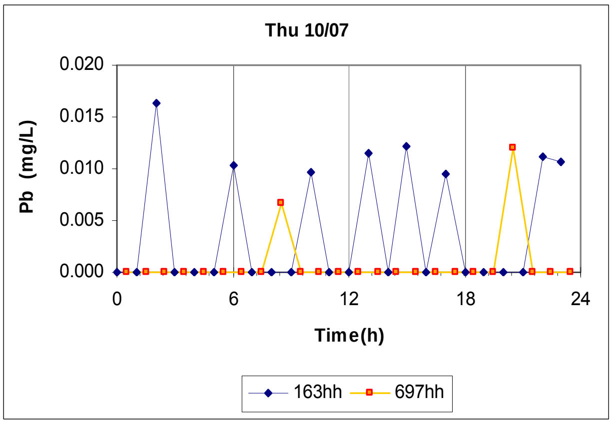


Figure 41: Diurnal concentration profile for lead on Thursday 10/07.

7.4.9. Potassium

The concentration of potassium (K) ranged between 10 to 30mg/L at site 2 and 15 to 30 mg/L at site 3 in winter. The respective means were 19.3 mg/L (SD 4.2) and 20mg/L (SD 4.1) along the day.

At site 2 the highest loads were recorded from 5am to 12pm, whilst at site 3 from midnight to 6am.

In summer, there had been a distinct maximum at 8am, which was not observed in the winter data set. However the data range was comparable, given the summer mean, standard deviation and range of 25.9mg/L, 6.83mg/L and 15.8 - 47mg/L.

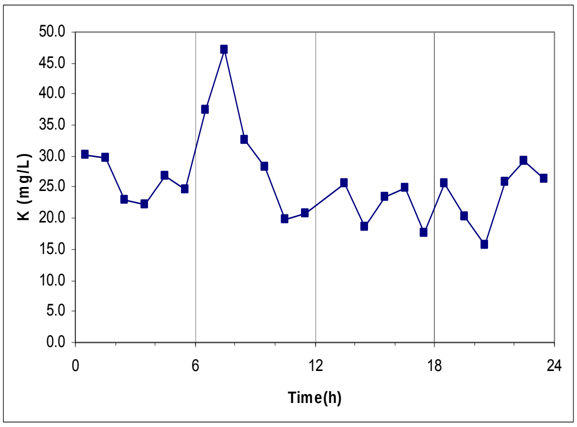


Figure 42: Diurnal concentration profile for potassium on Sunday 24/02 (163 households).

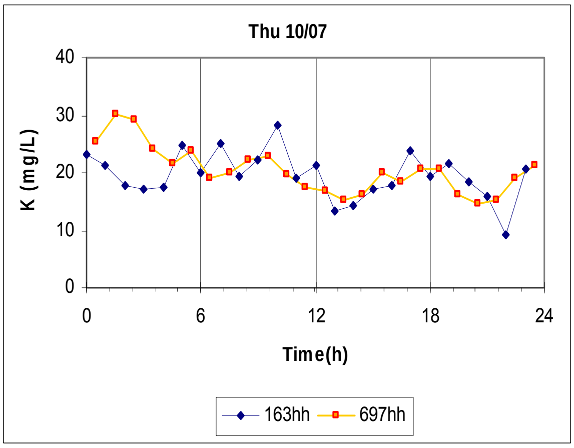


Figure 43: Diurnal concentration profile for potassium on Thursday 10/07.

7.4.10. Magnesium

Magnesium displays a similar concentration profile as aluminium, with concentration ranging between 3-5mg/L for both sites.

7.4.11. Manganese

Manganese was below the detection limit (0.5µg/L) for both sites during most of the day. The only exception was a peak at 11am for site 2 in winter.

7.4.12. Molybdenum

Molybdenum (Mo) had not been detected in summer wastewater. But during winter it was detected at site 2 on 4 days at concentrations up to 0.004mg/L and once at site 3 at 0.037mg/L (Figure 44).

On this specific winter date, hourly concentrations were below the detection limit for most of the day, but for the period between 7 to 11pm when the concentrations ranged between 0.092 and 1.114mg/L for site 2.

At site 3 only one event occurred between 6 -7pm at concentrations of 0.023mg/L.

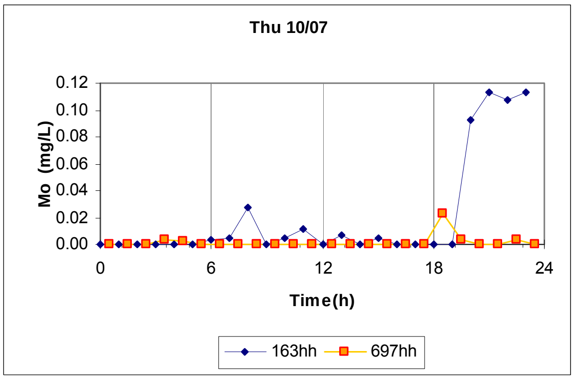


Figure 44: Diurnal concentration profile for molybdenum on Thursday 10/07.

7.4.13. Nickel

Nickel was below detection in summer, while in winter it was only detected once at site 2 (at 1am).

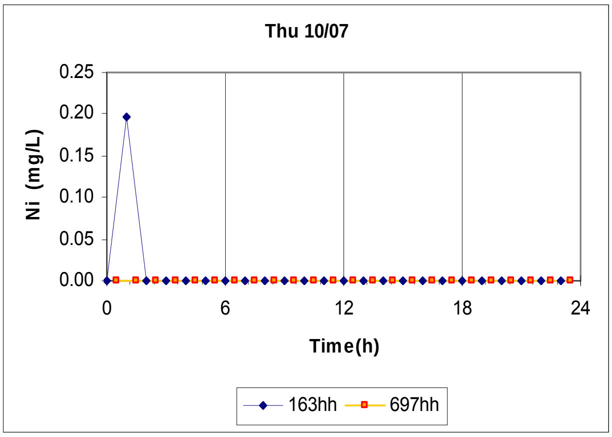


Figure 45: Diurnal concentration profile for nickel on Thursday 10/07.

7.4.14. Sodium

The sodium (Na) profile was similar in both seasons. It typically increased after 6am to a broad peak between 11am to 4pm, decreasing afterwards (Figure 46).

The concentration ranged from 6.6 to 114mg/L and 34 to 86mg/L for sites 2 and 3 respectively, with respective means of 50.3mg/L (SD 34.7) and 59 mg/L (SD 13.6). These were comparable to the summer concentration mean of 58.18 ± 17.01mg/L at site 2.

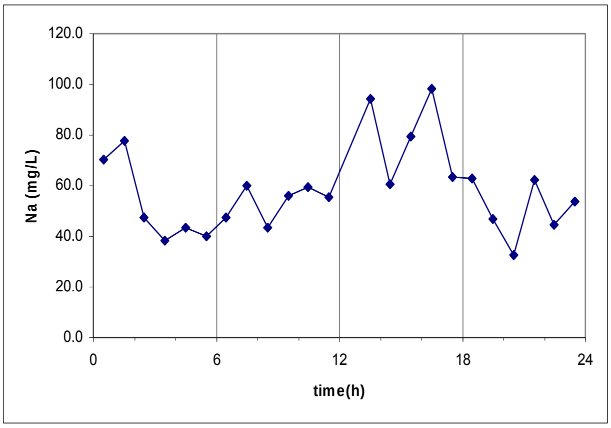


Figure 46: Diurnal concentration profile for sodium on Sunday 24/02 **(163 households).**

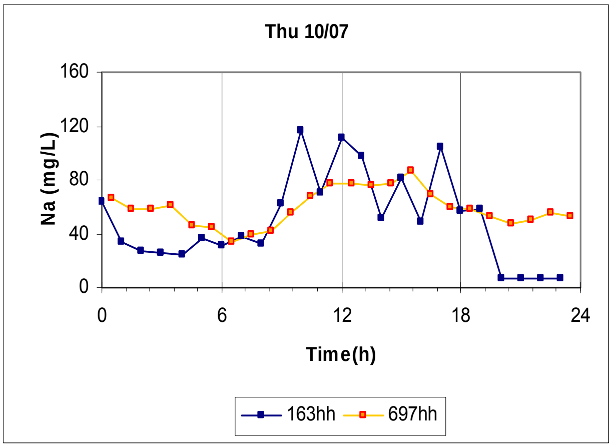


Figure 47: Diurnal concentration profile for sodium on Thursday 10/07.

7.4.15. Sulphur

Similar trends were observed for sulphur (S) at the 2 sites for the majority of the day but for the period between 8pm to midnight (Figure 49).

At site 2, sulphur ranged between 10- 29mg/l for the most of the day, but was below detection between 8pm to 10pm. The hourly mean for the day was 12.7mg/L (SD 8.7mg/L). The highest concentrations were recorded after 9am, with local peaks at 10am (29mg/L), 12pm (27.5mg/L), 3pm (22.5mg/L) and 5pm (25.3 mg/L). The profile for S at site 2 was very similar to the profile for Na.

At site 3 the sulphur concentration continued to increase after 8pm ranging from 8.8 to 38mg/L during the day. The mean was 18.6mg/L (SD 9.2).

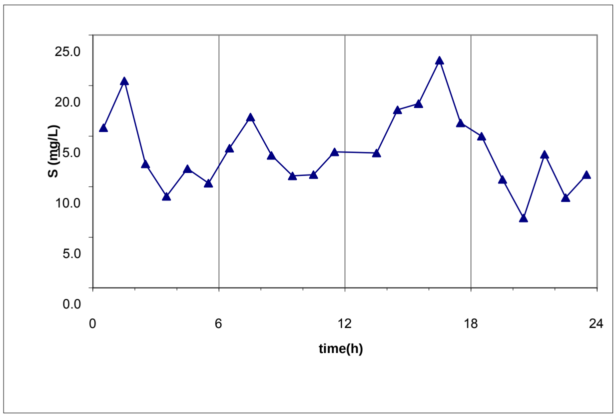


Figure 48: Diurnal concentration profile for Sulphur on Sunday 24/02 (163 households).

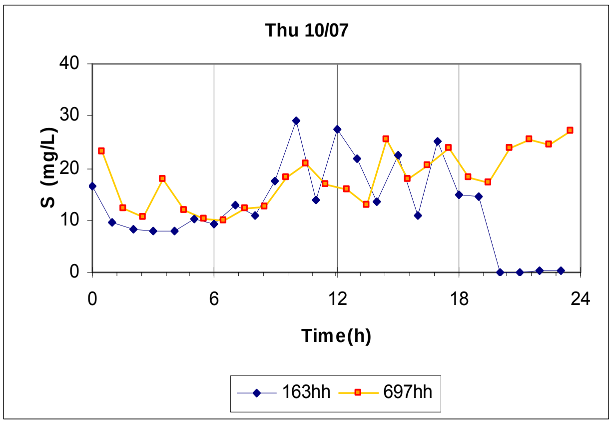


Figure 49: Diurnal concentration profile for sulphur on Thursday 10/07.

7.4.16. Tin

In summer the concentration of tin was below the limit of detection. Similarly, in winter, tin was below the detection limit for most of the day, but had occasional spikes in concentration.

At site 2 the concentration increased after 7pm reaching a maximum of 0.14mg/L at 11pm. At site 3 it was characterised by random spikes, with a maximum of 0.025mg/L at 9pm.

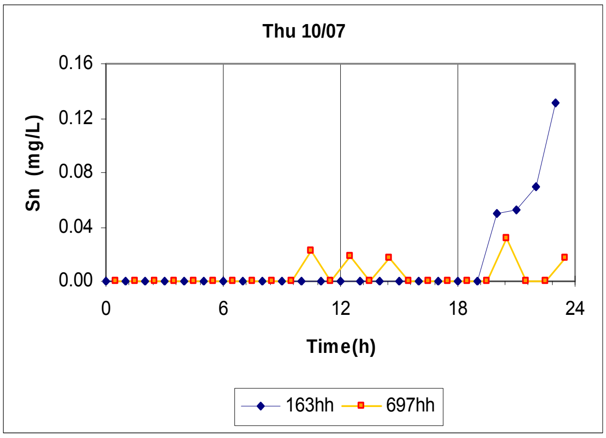


Figure 50: Diurnal concentration profile for tin on Thursday 10/07

7.4.17. Total Kjeldahl nitrogen

The TKN concentration profile exhibited the same diurnal trend in both seasons. The TKN profile was characterised by the main peak in the morning around 6am to 8am (Figure 51). However as the concentrations for sites 2 and 3 were taken on different dates they will be considered independently.

The hourly concentrations ranged from 32 to 200mg/l at site 2 on the Friday and 41 to 96mg/L at site 3 on a Thursday.

Site 3 displayed the typical TKN profile, with higher concentrations recorded in the morning.

On the Friday 27th June, maximum concentration of the day, 200mg/L, was observed at 5pm. This afternoon peak was not observed on any of the other dates.

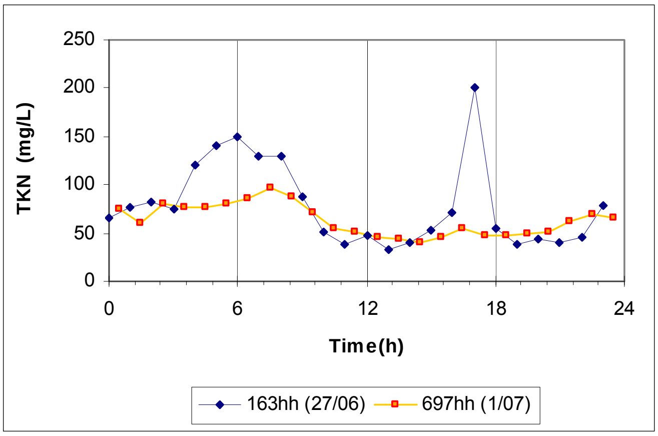


Figure 51: Diurnal concentration profile for TKN at site 2 and 3 on a weekday

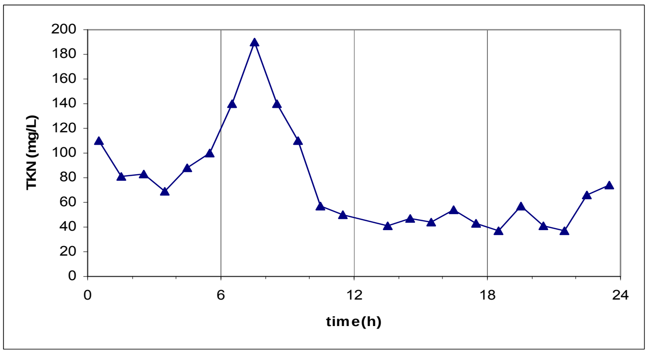


Figure 52: Diurnal concentration profile for TKN on Sunday 24/02/08.

7.4.18. Total Phosphorus

The 24h profile for the concentration of Total phosphorus (TP) recorded on 10th July is shown in Figure 53. TP varied during the day between the ranges of 7.6 to 27 mg/l and 11.2 to 23mg/L for sites 2 and 3 respectively. The hourly means were 12.9 mg/L (SD 5.0) for site 2 and 15.3mg/L (SD 2.7) for site 3.

Hourly concentrations over the day were similar to those observed in summer and shown in Figure 53.

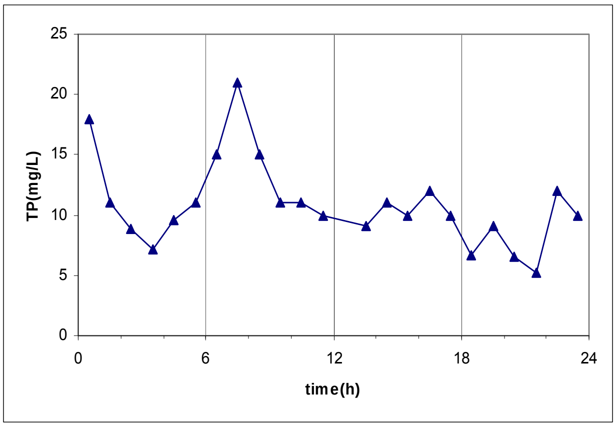


Figure 53: Diurnal concentration profile for phosphorus (163 households).

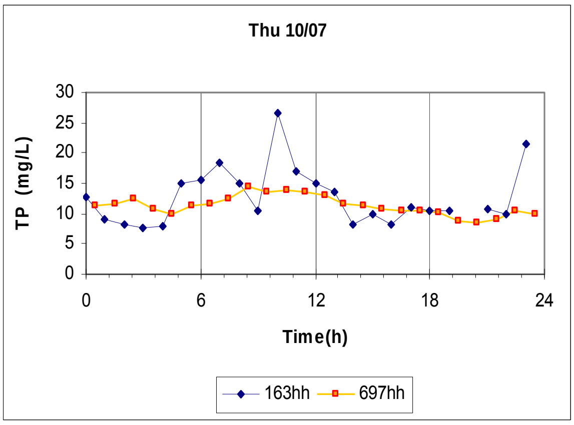


Figure 54: Diurnal concentration profile for total phosphorus on Thursday 10/07

7.4.19. Zinc

The highest concentrations of the day were verified from 6am to 8pm at both sites (Figure 56). The concentration ranges were 0.04 to 0.16mg/l and 0.02 to 0.23mg/L at site 2 and site 3 respectively. The respective mean concentrations were 0.136 mg/L (SD 0.054) and 0.11 mg/L (SD 0.034).

Concentrations had been higher in summer (mean of 0.480 ± 0.481 mg/L and median 0.285mg/L)

The profile was characterised by multiple peaks in concentration during the day with higher values observed during the afternoon. However, the winter results did not exhibit concentrations as high as those observed during the summer (Figure 55).

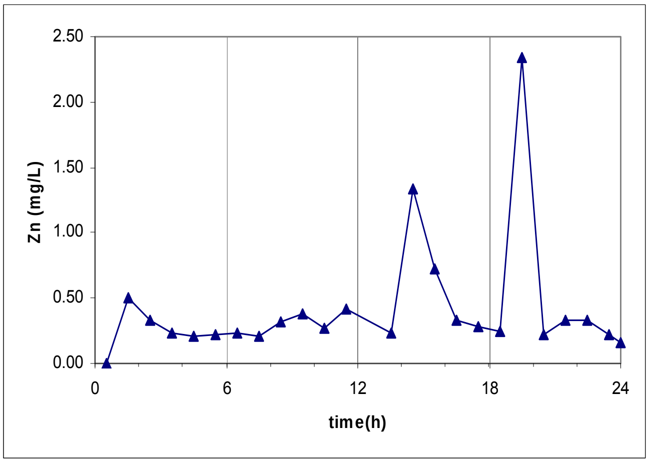


Figure 55: Diurnal concentration profile for zinc (163 households).

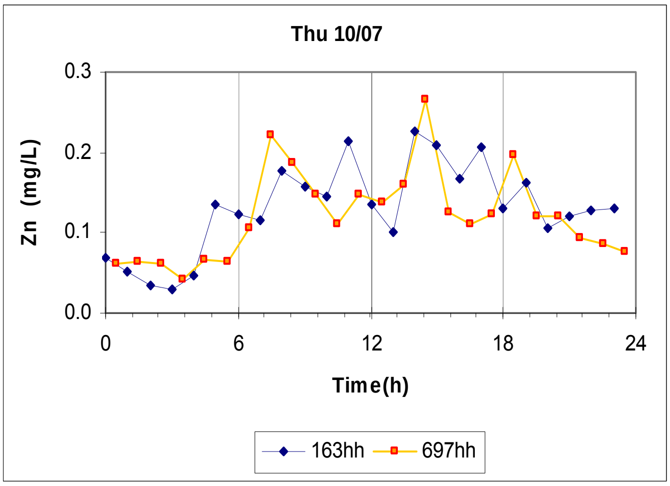


Figure 56: Zn load in wastewater for 163 households

Table 14: Summary of mean wastewater quality data for selected domestic catchments In Melbourne.

Reference	*Connor and Wilkie 1995*		*CWW 2007*				*This study*							
Location	Melbourne		Melbourne West				South-East Melbourne							
Size			9651 connections				697 connections				163 connections			
Time	1994		Nov-Dec 2006		May 2007		Feb-Mar 2008		Jun-Jul 2008		Feb-Mar 2008		Jun-Jul 2008	
Concentration (mg/L)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Al	0.745	0.352	1.116	0.33	0.499	0.381	0.975	0.212	1.017	0.357	0.849	0.493	2.80	2.19
As	0.002	0.001			0.002	0	<0.005		<0.005		<0.005		<0.005	
B	0.263	0.206	0.174	0.13	0.094	0.049	0.096	0.034	0.063	0.031	0.084	0.0401	0.09	0.03
Ca	9.261	2.45	12	0.926	10.99	1.498	12.2	0.974	14.62	0.807	11.09	1.5781	15.73	3.44
Cd	0.0005		<0.002		<0.002		<0.01		<0.001		<0.001		<0.001	
Cl	nd		45.55	14.38	43.1	8.33	55.7	7.656	47.7	3.88	45.33	3.08	45.71	6.42
Cr	0.003	0.002	0.006	0.001			0.024	0.004	0.0076	0.0014	0.023	0.0026	0.016	0.0036
Cu	0.062	0.015	0.1	0.1	0.136	0.163	0.11	0.023	0.055	0.0086	0.081	0.025	0.070	0.0338
Co	0.001		<5		<5		<0.01		<0.003		<0.01		<0.003	
F	nd		0.62	0.11			1.1	0.07	0.88	0.02	0.99	0.056	0.87	0.04
Fe	0.728	0.373	0.613	0.012	0.358	0.305	0.204	0.138	<0.01		0.294	0.188	0.73	1.36
Pb	0.013				0.003	0.001	≤0.0056	0.001	<0.005		0.005	0.001	0.008	0.0036
Mg	4.925	1.655	3.7		4.081	0.465	3.096	0.177	3.460	0.154	2.448	0.362	4.10	0.86
Mn	0.048	0.013	0.043	0.006	0.032	0.005	0.033	0.004	<0.0003		<0.001		<0.06	
Hg	nd		<0.001		<0.001		<0.002		<0.002		<0.002		<0.002	
Mo							<0.050		<0.003		<0.050		≤0.004	0.002
Ni	0.004	0.002	0.006	0.001			0.022	0.002	<0.01		0.021	0.003	0.0175	0.0049
N (asTKN)	57.23	21.66	51	27.41	56	5.151	67.9	11.7	73.4	4.9	79	13.25	67.2	6.3
P (as TP)	22.4	11.3	26.1		24.357	8.177	11.7	0.786	15.1	1.28	13.25	3.079	20.3	13.66
K	16.785	7.285	17.6	1.121	18.214	0.893	9.458	0.625	19.884	0.500	15.77	2.009	20.99	2.54
Se	<0.01		0.008	0.001			<0.007		<0.005		<0.007		<0.005	
S	nd		nd				12.6	1.06	14.2	1.6	10.6	1.3	17.0	2.6
Sn	<0.00469	0.00259					<0.05		<0.005		≤0.015	0.036	<0.005	
Na	87.28	28.52	76	6.23	80.0	7.9	11.7	0.976	65.5	5.32	56.5	3.21	67.5	13.23
Zn	0.169	0.076	0.145	0.027	0.095	0.029	0.172	0.031	0.185	0.021	0.34	0.386	0.230	0.212
TDS	nd		657.33	301.9	635	86.1	418	47	337.2	38.8	421	54.6	619.6	44.5
EC(µS/cm)	nd		878		806.8	76.2	870	59	617.14	13.03	777	222	619.57	44.5
pH	nd		7.407		7.14	0.195	6.9	0.26	7.88	0.68	6.95	0.44		

8. DISCUSSION

The wastewater quality of a residential catchment of 697 households located in the suburb of Frankston in the south-east of Melbourne was monitored during February to March (summer) and June to July (winter) in 2008 to determine if seasonality effects could be captured in the data.

The two monitoring periods in particular were characterised by differences in rainfall and daily temperatures. Rainfall was higher in winter (132.8mm) compared to summer (46.2mm) for those 2 months investigated.

The winter monitoring aimed to increase the pool of data initially collected in summer and to investigate the quality during wet weather flow and when greater precipitation would be expected, under such conditions practices such as grey water diversion for irrigation would have been less likely to occur at the household scale.

Wastewater monitoring was conducted at 3 manholes in the catchment to encompass sewage generated by 7, 163 and 697 connections. These are referred to as sites 1, 2 and 3. Results from the two larger catchments were used for comparison of seasonality, whilst the smallest catchment was used mainly for verification of data on physical-chemical characteristics of wastewater generated close to source.

8.1.1. Wastewater flow

The 24h wastewater flow profile for the catchment followed the typical pattern described in the literature (Metcalf and Eddy 2003) during both seasons, with most of the flow recorded from 5 am to midnight and two main peaks observed from 7 to 10am and from 4 to 9pm. During weekends the time of the morning peak flow shifted backward an 1h, reflecting the later rise of householders.

During winter the time when the morning peak occurred shifted by approximately one to two hours later, but the timing of afternoon peaks was not affected. Thus, an indication inhabitants in the catchment tend to rise later in winter than in summer.

Wastewater flow was lower in winter than in summer. In the largest catchment (697 households), the reduction was only 5.7% in weekly flow; at the 163 households catchment the reduction was more significant at 33% of the summer weekly flow.

Examination of the flow variation in wastewater on each day of the week for site 3, showed that the reduction in wastewater generated between the two seasons was more significant from Monday to Wednesday than from Thursday to Sunday. In the first case the variation ranged between -8.4% to -9.6% and in the second from -1.1% to -4.7%.

Yet, the variation in flow from one day of the week to another was less pronounced at site 2.

8.1.2. Priority contaminants

As expected, the variability in wastewater quality observed in summer was also applicable to winter data.

Colour

Colour in wastewater was generally more intense in winter (mean 87 ± 17Pt-Co units), with on average 41% prone to removal by aerobic treatment. In summer mean colour in wastewater had been 76 ± 12 Pt-Co units, with on average 34% removable through aerobic digestion. A two sample t-test indicates that the difference in total colour between seasons was statistically significant.

Winter samples were subject to larger variability from day to day for both the true and non-biodegradable colour given the SD 17 Pt-Co units. The non-biodegradable colour was however similar across the two seasons at 51 ± 13 Pt-Co units.

Elements

The frequency of element detection was evaluated for all composite samples collected during summer and winter for both sites 2 and 3. Site 1, given its proximity to the source, tends to display higher concentrations than sites 2 and 3. Therefore, hourly wastewater samples from site 1 were also used to check the concentrations for samples that were at or below the limit of detection, but were not included in the detection frequency estimates shown in this section.

Arsenic, cadmium, mercury and selenium

Winter results confirmed that arsenic, cadmium, mercury and selenium were below detection limits in residential wastewater. This was based on examination of wastewater collected during summer and winter, including diurnal hourly samples from all 3 sites. None of the samples had detectable traces of those elements.

Boron

Boron was detected in 95.6% of all wastewater samples collected. It was detected in all the samples collected in summer and in 92.8% of the samples collected in winter. The concentration of boron was less than 0.10 mg/L during both seasons. At site 2, the concentrations of boron in wastewater were similar during both seasons. But at site 3, the concentration of boron was 30% lower in winter. Such variation is within the expected data variance given the SD between the seasons.

Chromium

Chromium was detected in both seasons, but concentrations in winter were lower. The mean concentrations across the 2 sites in winter were 69.2% and 26.9% lower for sites 2 and 3. The reduction across seasons was statistically significant.

Iron, lead, manganese and nickel

The frequency of detection of iron, manganese, nickel, lead was higher in summer than in winter. In summer the detection frequency for each of those elements was respectively 88.2%, 29.4%, 100% and 70.6%, whilst in winter the frequency of detection was 21.4%, 7.1%, 46.4% and 28.6%.

Lead was the heavy metal most commonly found in wastewater. It was present either at or close to the limit of detection during both seasons on 44% of the 45 samples, with a significant change in frequency of detection of 70.6% in summer and 28.6% in winter. Although, more wastewater samples were collected in winter than in summer, respectively 39 and 17.

Nickel was detected on site 2 composites during both seasons but at site 3 only in summer.

Antimony, cobalt and molybdenum

The opposite was observed for antimony, cobalt and molybdenum. During summer cobalt and antimony were below detection and antimony was detected only in 17.6% of the samples, but during winter concentrations were either at or close to the detection limit on a larger number of sampling days. Overall, from a total of 45 samples collected over the 2 seasons at sites 2 and 3, these elements were detected at respective frequencies of 35%, 4% and 11%, although they were often not necessarily detected at sites 2 and 3 on the same date.

The higher concentrations of cobalt and molybdenum in winter may in part be caused by the volume of wastewater discharged. But differences in detection frequency and concentrations may also be influenced with the type of household activities, products used or even infiltration from stormwater run-off which may vary between seasons.

Fluoride

Fluoride which had been detected in wastewater, at concentrations on average 10% higher than in tap water in summer, was approximately 12% and 20% lower in winter for sites 2 and 3 at 0.88mg/L (SD 0.04 mg/L), i.e. similar to the concentration in tap water, yet concentrations were still higher than the 0.62mg/L (SD 0.11mg/L) recorded in the CWW 2007 study.

TDS, Phosphorus, nitrogen, chloride, sodium and zinc

Summer data had already established that the most abundant priority parameters detected in wastewater were TDS, phosphorus, nitrogen, chloride, sodium and zinc. These parameters were also similarly abundant in winter and were detected in all samples.

The concentration of TKN, differed by approximately +10% between the two seasons, which would be expected given its origin from anthropogenic activity. Mean concentrations were also at least 19% higher than nitrogen concentrations reported in previous Melbourne studies (Connor and Wilkie 1997 and CWW 2007).

Whilst the phosphorus concentration in catchment was higher by 30% in winter, bringing the concentrations at site 3 to 15mg/L and at site 2 to 20mg/L and closer to those observed in previous studies (Connor and Wilkie 1997 and CWW 2007).

TDS concentration varied between the sites 2 and 3. The mean TDS at site 3 (697 households) was 337mg/L, being 19% lower in winter than in summer, whilst at site 2 TDS in winter was 47% higher at 619mg/L. These results are still lower than those reported in the City West Water 2007 study conducted in the West of Melbourne (≈ 657mg/L) (Table 14).

The concentration of sodium which had differed between the two size catchments in summer was consistent across the 2 sites during winter with a mean of 64.2mg/L (SD 13.2mg/L) . The sodium concentration increased from summer to winter by 20% and 459% for the respective catchments of 163 and 697 households. But it was still lower than the 80mg/L reported in Connor and Wilkie (1995) and City West Water (2007).

The concentration of chloride was still between 45mg/L and 50mg/L at both sites. At site 2 the concentration of chloride in wastewater was similar in both seasons. But at site 3 the concentration was 14% lower in winter.

As for zinc, the variation in concentration from summer to winter was not statistically significant. It increased by less than +8% in the larger catchment, being 0.185mg/L (SD 0.021mg/L) for site 3 in winter. At Site 2, the change in concentration was less apparent, given the higher standard deviation for the site, 0.38mg/L and 0.21 mg/L in summer and winter respectively.

Sulphur

Sulphur was detected in all samples throughout the year. The concentration of sulphur was higher by 60% and 15% in winter for sites 2 and 3, being respectively 17mg/L and 13.7mg/L in winter.

Calcium, Magnesium and potassium

Calcium, magnesium and potassium were common to all samples collected. The concentrations of these elements, calcium, magnesium, potassium, were higher in winter. The increase in concentration at site 3 was approximately less than 20% for calcium and magnesium, but it doubled for potassium (19.8mg/L) and became comparable to concentrations recorded in other Melbourne studies.

Conductivity

Despite the increase in concentration of many of the ionic species, e.g. sodium, potassium, and chloride, EC was 30% lower in winter at 618μS/cm than in summer.

Scale effects

The concentration data gathered was in general similar for majority of the priority contaminants at the two sites (163 and 697 households).

Verification of the concentration of parameters measured on the same dates at the two sites indicates a strong linear dependency between concentrations at sites 2 and 3 for chloride, copper, potassium, sodium, sulphur, TP and zinc in winter and a weaker correlation for TDS and TKN with factors between 0.3 and 0.4.

The statistical analysis of the data also highlighted the variability from one site to another and the impact that catchment size has on individual results – for example, in summer the sodium concentration differed by more than 50% between the sites of 163 and the 697 households, but in winter the concentrations at the 2 sites were similar. Although site 2 feeds into the larger catchment, it represents only 23.4% of the total number of connections that feed into site 3. Hence, other parts of the catchment were likely to have had a significant impact on the final concentrations at site 3.

Catchment size has also proven to be important to the type of results that are gathered. The size of a catchment has inverse effects on data reproducibility and sensitivity.

In general, the variance in the data was larger for smaller catchments. The smaller catchment, site 1, comprised of 7 households has shown too much variability from one day to another to allow the collection of reproducible composite samples for the sampling period used. Greater reproducibility was achieved at the larger sites 2 and 3. Yet the standard deviation was often larger for site 2 than for site 3, as seen in Table 14.

On the other hand, as the catchment size decreased, the concentration of contaminants detected in wastewater often increased, thus increasing the probability of detection as seen from the higher frequency of detection for wastewater at site 2 compared to site 3.

In the comparison of the results from this study and the literature, it has to be noted that the earlier Melbourne studies monitored catchments of a significantly larger size. For instance, 9651 connections in the Melbourne west study (CWW 2007) and from 540 to 18,530 tenements in the 1995 study (Connor and Wilkie 1994).

Concentration distribution over time

Neither of the data gathered in summer or winter suggests the existence of concentration trends from one day of the week to another for this residential catchment.

The concentration of contaminants varied during a 24h day. Winter results confirmed the concentration profile of elements over 24h as observed in summer.

Elements associated with anthropogenic waste such as TKN and TP were characterised by maximum concentrations associated with maximum diurnal flows in both seasons.

Elements associated with household activity, such as copper, sodium and sulphur, had concentrations that were more evenly distributed during the day in both seasons.

Winter results also revealed the existence of another group comprised mainly of heavy metals such as lead, nickel, molybdenum and cobalt which were detected sporadically in composite samples and whose concentrations were detected only at random times of the day within a catchment. Molybdenum, cobalt and antimony were more often detected in winter than in summer, whilst the inverse applies to lead and nickel. It is uncertain at this stage, if that was caused by lower dilution given the lower volume of wastewater in the system, contribution from run-off or change in wastewater discharged by households (e.g. less diversion of greywater).

Overall, seasonal differences were verified in the data collected, particularly in regards to volumetric flows and the detection of heavy metals.

For the majority of elements differences in concentration between winter and summer were minimal. But concentrations of wastewater also differed at times between site 2 and 3 within a same season and in regards to trends across seasons.

When considering seasonal changes in the larger catchment (site 3), mean concentrations that were higher and statistically significant in winter included calcium, magnesium, potassium, lead, TP, sodium and sulphur,

Mean concentrations that were lower and statistically significant included boron, copper, chromium, chloride, fluoride, nickel, iron, TDS and EC.

Such variation could be caused by multiple factors including variability in the water source, water consumption patterns, wastewater discharge practices or even product use.

The data collected does not permit the determination of the causes for the changes observed and in order to understand this further it would be necessary to gain a deeper understanding of the behaviour within households in the catchment. This would require the use of social and behavioural research, e.g. surveys on household activities such as how many people divert greywater, have dishwashers, frequency of use, products adopted, etc, which was not covered within the scope of this study.

Potential impact of water restrictions

Differences have been observed in the results from this study and the 1995 one (Connor and Wilkie 1995) prior to introduction of water restrictions. For instance, a lower mean concentration of boron and sodium was recorded in this catchment. However, it is uncertain to what extent water restrictions currently in place would have impacted on those values.

In 2008, if less water is consumed per household, the concentrations of elements whose major sources exclude tap water would be expected to increase. Such would be the case for instance for sodium, phosphorus and nitrogen, if all other factors remained constant. However, other factors, such as changes in product formulation or household practices could also contribute to reduce the concentrations of those elements in wastewater.

Practices such as diversion of washing machine grey water to lawns, can also reduce the load of phosphorus and sodium in wastewater. Under such conditions, the overall discharge of wastewater in summer would be expected to be lower compared to winter. This could have contributed to the lower sodium and phosphorus verified in summer in this study. However, the wastewater discharge was lower in winter than in summer and there is uncertainty in what level of uptake grey water diversion had in the catchment.

Hence verification of mains water consumption would be required to verify if there has been a change in water consumption as well.

Hence, at this stage given the data it is not possible to quantify nor correlate the changes to any potential behaviour.

9. CONCLUSIONS

The wastewater in a residential catchment located in the South-East of Melbourne was monitored at 3 locations encompassing 7, 163 and 697 connections. Monitoring was conducted from February to March 2008 during dry weather and from June to July 2008 in wet weather.

In the verification of the wastewater generated in a domestic catchment the following aspects were investigated:

- Concentration of priority contaminants in wastewater in winter and summer;
- Daily changes in contaminant concentration, by examining wastewater quality on different days of the week; and
- Hourly variability of priority contaminants, by examining the concentration of selected contaminants during a 24 period;

The wastewater quality for priority contaminants in the catchment was characterised and can be defined as follows:

Wastewater flows

The wastewater flow profile in the catchment was characterised by peak flows around 7am to 10am and 4pm to 9pm. During weekends the time of the morning peak flow shifted to later in the day by 1 to 2 hours. During winter the time of the morning peak flow also shifted to later in the day by 1 to 2 hours.

The maximum relative volumetric flow contribution to the overall diurnal flow observed in summer was lower by 2.5% to 4% compared to the historic flow average for the region.

Wastewater flow was at least 5.6% and 30% lower in winter than summer for the catchments of 697 and 163 households respectively.

Priority contaminants

Compared to tap water, wastewater had more intense colour, higher concentrations for aluminium, boron, chloride, copper, cobalt, chromium, fluoride, lead, molybdenum, sodium, phosphorus, nitrogen, sulphur, zinc and TDS.

Colour

Non-biodegradable colour in the wastewater was similar between the two seasons, at 51 Pt-Co units, whilst total colour was 76 ± 12 Pt-Co units during summer and slightly more intense in winter at 87 ± 17 Pt-Co units, with on average 34% and 41% removable through aerobic digestion in each respective season.

Elements such as iron and manganese were not present in concentrations that contribute to any discoloration.

Elements

The majority of the priority contaminants were above detection limits during the sampling period.

But arsenic, cadmium, mercury and selenium were below the limits of detection during both seasons. Antimony, cobalt, tin, lead and molybdenum were detected on specific days only, either at or close to the limit of detection.

The frequency of detection of contaminants was generally higher in summer than in winter, but for antimony, cobalt and molybdenum for which the inverse was true.

The fluoride concentration was on average similar to that of tap water, being 10% higher in summer compared to winter.

The concentration of TDS decreased between the two seasons for site 3, but was higher in winter for site 2. It was still lower by 30% compared to wastewater collected in the west of Melbourne in 2006-07 (CWW 2007).

The electric conductivity, chloride, aluminium and calcium concentrations were comparable to those recorded in other 1995, 2006 and 2007 Melbourne studies. The concentration of boron and chloride decreased between seasons for site 3, but did not vary significantly at site 2.

The concentrations of zinc, calcium, magnesium, sodium and potassium in this study were higher in winter than in summer. Yet conductivity was lower in winter than in summer for both sites.

It was cogitated that greywater diversion to garden might be one of the causes for this variation, but this cannot be confirmed from the data gathered.

The concentration of copper in wastewater was 10% and 30% lower in winter for sites 2 and 3, but this was not significant for site 2 given the high standard deviation of the readings.

The concentration of nickel was similar in tap water and wastewater for the catchment, yet the concentrations in this catchment were higher than those reported in the literature, this variation is likely to be caused by differences in water infrastructure.

The phosphorus concentration observed in this catchment, 15.1mg/L for site 3, was also higher in winter, but still lower than earlier studies (CWW 2007).

The concentration of nitrogen (as TKN), which is mainly attributed to anthropogenic activity, was similar between the 2 seasons (only 10% higher in winter) and in agreement with values reported in the literature.

Weekly patterns

The sewage flow rate was generally higher during weekends than in weekdays in summer, but the same was not necessarily true in winter. Weekly trends in contaminant concentration, characterised by higher discharges for specific days of the week as reported in the literature (Wilkie *et al.*, 1996, Rule *et al.* 2006), were not observed in this catchment.

Scale effects

The size of the catchment impacts the spread and variability of the concentration data – in general as catchment size increased, less influence from individual dischargers was observed, resulting in narrowing of the data spread and consequently a lower standard deviation for the sample population.

Wastewater collected from the site with 7 connections displayed too much variability in data for the automatic collection of daily composites and the determination of weekly or diurnal trends. But the other two sites had reproducible wastewater flow patterns.

For parameters such as aluminium, arsenic, antimony , boron, calcium, cadmium, chloride, copper, fluoride, TDS, TKN, magnesium, manganese, potassium, lead, selenium, mercury and molybdenum, similar concentrations were verified between sites 2 and 3 (sites of 163 and 697 connections). But significant differences were evident for sodium between the 2 sites.

Diurnal distribution

The concentration of contaminants varied during the day due to the range of activities undertaken by householders

Nitrogen and phosphorus, have a strong correlation with human anthropogenic discharges and with the flow wastewater profile.

Parameters such as aluminium, copper, iron, sodium, sulphur and zinc were more evenly distributed throughout the major periods of the day. This suggests that release of those contaminants into wastewater is not associated with human excretion alone, and that household activities are likely to have an important role in their generation. In the case of zinc, the spikes in concentration previously observed in the afternoon in summer were not observed in winter.

Heavy metals, such as lead, nickel, molybdenum and cobalt, were less frequently detected in composite samples and were detected only at random times during the day. Hence, it would appear unlikely that they are released by a continuous source alone, such as tap water.

Final remarks

Overall, seasonal differences in the wastewater were verified for a number of parameters of interest, with the exception of TKN, zinc, non-biodegradable colour and elements that were mainly below the detection limit, such as As, Se, Cd and Hg.

The results also indicate that results can vary depending on catchment size, i.e. the number of connections, and also the range of concentrations measured.

The causes of inter-seasonal variation were not evaluated in this report, but could be explored in the future through social and household behaviour research.

Compared to the Connor and Wilkie study from 1995, this catchment exhibited lower concentrations of boron, lead, phosphorus, and sodium, but higher concentrations for chromium in wastewater.

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APPENDIX A – FLOW PROFILES

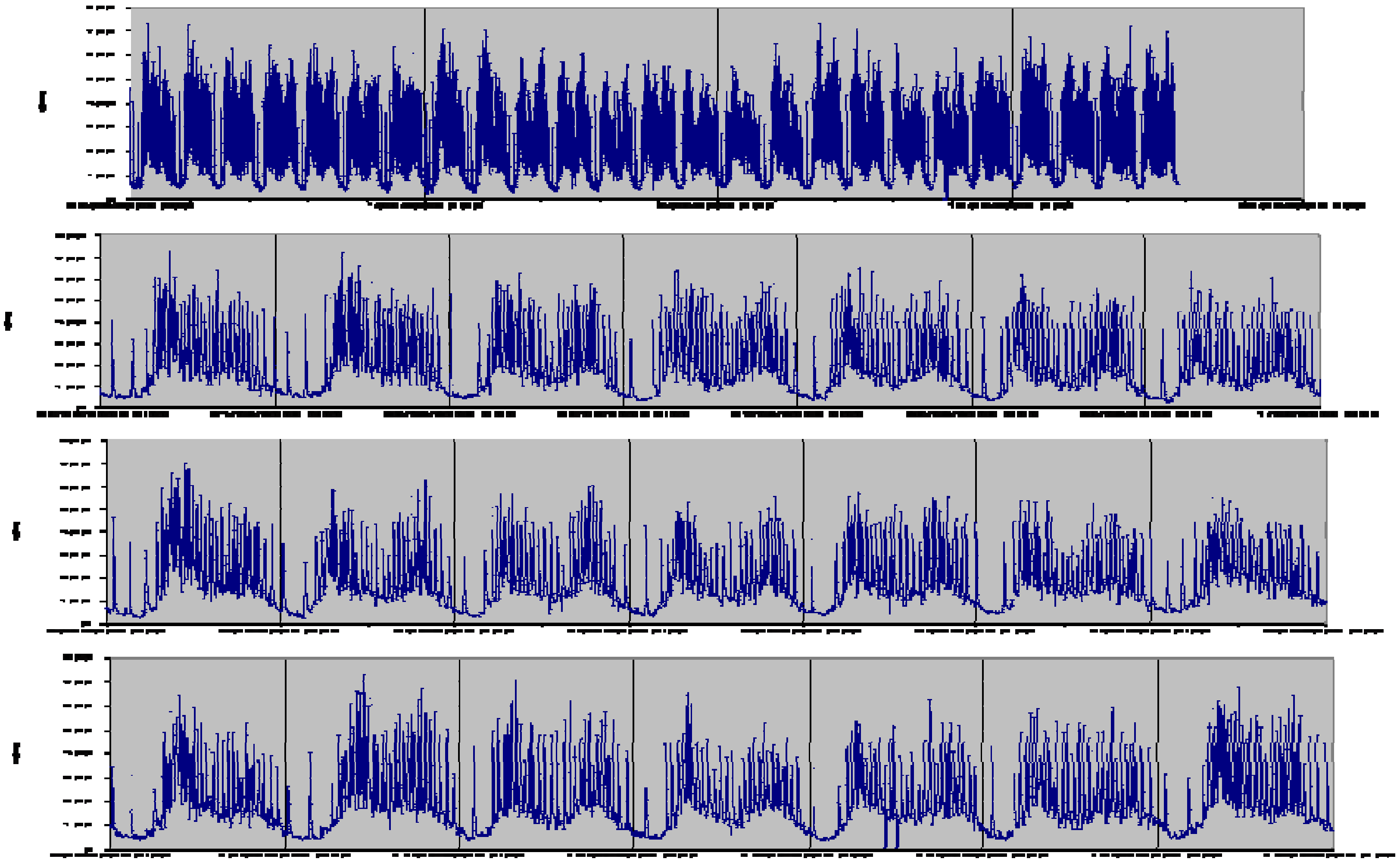
Table 15: Mean flow profile for site 2

Site 2	*Qaverage (L/s)*													
	Summer							*Winter*						
Time (h)	*Mon*	*Tue*	*Wed*	*Thu*	*Friday*	*Saturday*	*Sunday*	*Mon*	*Tue*	*Wed*	*Thu*	*Friday*	*Saturday*	*Sunday*
0	0.206	0.139	0.185	0.109	0.246	0.208	0.23	0.128	0.074	0.032	0.059	0.048	0.149	0.078
1	0.129	0.239	0.121	0.207	0.136	0.201	0.15	0.093	0.085	0.030	0.067	0.045	0.073	0.150
2	0.14	0.103	0.114	0.104	0.083	0.135	0.247	0.100	0.100	0.075	0.079	0.052	0.034	0.034
3	0.209	0.145	0.251	0.314	0.089	0.182	0.166	0.141	0.052	0.083	0.076	0.079	0.024	0.113
4	0.391	0.362	0.493	0.498	0.413	0.237	0.071	0.077	0.100	0.049	0.071	0.094	0.085	0.048
5	0.695	0.985	0.756	0.672	0.644	0.423	0.161	0.341	0.329	0.192	0.125	0.153	0.112	0.091
6	1.259	1.315	1.141	1.287	1.067	0.514	0.429	0.213	0.173	0.195	0.221	0.430	0.085	0.113
7	1.12	1.178	1.165	0.842	0.861	0.925	0.837	0.855	0.778	0.753	0.710	0.624	0.278	0.209
8	0.821	0.781	0.838	0.646	0.649	1.625	1.171	1.086	0.729	1.111	0.962	1.070	0.763	0.872
9	1.008	0.694	0.676	0.679	0.737	1.967	1.219	0.938	0.684	0.667	0.596	0.617	0.907	0.677
10	0.529	0.819	0.675	0.664	0.77	1.075	0.955	0.866	0.616	0.552	0.428	0.543	0.928	1.352
11	0.516	0.61	0.729	0.54	0.478	1.192	1.139	0.680	0.425	0.241	0.519	0.867	1.140	1.074
12	0.548	0.576	0.595	0.523	0.512	0.825	0.688	0.426	0.377	0.236	0.374	0.505	1.082	0.678
13	0.589	0.605	0.469	0.475	0.503	0.976	0.763	0.391	0.290	0.216	0.464	0.337	0.574	0.676
14	0.577	0.542	0.501	0.536	0.546	0.617	0.595	0.309	0.390	0.169	0.328	0.388	0.443	0.492
15	0.753	0.79	0.717	0.612	0.56	0.738	0.877	0.573	0.264	0.322	0.273	0.291	0.529	0.599
16	0.739	0.725	0.662	0.803	0.675	0.756	0.83	0.405	0.434	0.322	0.359	0.339	0.601	0.561
17	0.8	0.93	0.924	0.809	0.596	0.947	1.047	0.651	0.460	0.380	0.916	0.649	0.539	0.510
18	0.865	0.803	1.073	1.028	0.878	0.947	1.186	0.834	0.908	0.717	1.161	0.560	0.995	0.527
19	0.903	0.997	0.81	0.801	0.682	0.681	0.831	0.626	0.593	0.730	0.880	0.451	0.571	0.785
20	0.716	0.788	0.707	0.688	0.592	0.587	0.589	0.580	0.547	0.454	0.598	0.450	0.603	0.555
21	0.636	0.707	0.553	0.589	0.594	0.573	0.612	0.327	0.381	0.375	0.369	0.309	0.411	0.302
22	0.432	0.565	0.482	0.359	0.381	0.473	0.447	0.232	0.447	0.224	0.217	0.318	0.327	0.300
23	0.273	0.332	0.142	0.271	0.324	0.417	0.249	0.138	0.115	0.100	0.069	0.163	0.212	0.094
Total (ML/d)	0.053	0.057	0.053	0.051	0.047	0.062	0.056	0.040	0.034	0.030	0.036	0.034	0.041	0.039
Average (L/s)	0.619	0.655	0.616	0.586	0.542	0.718	0.645	0.459	0.390	0.343	0.413	0.391	0.478	0.454

Table 16: Mean flow profile for site 3

Site 3	***Qaverage (L/s)***													
	Summer							***Winter***						
Time (h)	*Mon*	*Tue*	*Wed*	*Thu*	*Friday*	*Saturday*	*Sunday*	*Mon*	*Tue*	*Wed*	*Thu*	*Friday*	*Saturday*	*Sunday*
0	1.986	0.832	0.912	0.846	1.725	0.918	1.304	1.126	1.723	1.816	1.374	1.712	2.140	1.769
1	0.757	1.685	0.734	1.709	0.859	1.605	1.855	1.399	0.856	0.838	1.222	0.859	0.816	1.375
2	0.753	0.486	1.493	0.602	0.563	0.736	0.88	0.968	0.701	0.687	1.124	1.465	1.595	1.939
3	0.856	0.595	0.653	0.674	0.884	0.778	0.785	0.842	1.605	1.577	0.766	0.587	0.704	1.716
4	2.078	2.386	2.144	2.069	2.139	1.845	1.745	0.872	0.773	0.749	0.731	0.783	0.769	0.862
5	2.494	3.958	2.976	3.738	3.361	0.96	1.067	2.083	2.036	2.191	2.011	1.981	1.610	1.444
6	5.341	4.627	5.551	5.139	5.004	2.31	2.069	3.285	3.056	3.204	2.882	2.787	1.277	0.984
7	5.267	6.096	5.386	5.37	4.593	4.736	2.858	4.332	5.402	4.330	4.945	4.703	2.425	2.048
8	5.08	4.619	4.714	3.866	4.495	6.267	5.103	4.712	5.529	6.248	5.323	4.987	4.231	3.642
9	5.07	5.248	4.289	4.323	4.637	6.416	6.232	4.197	4.605	4.409	4.310	4.547	5.526	4.473
10	4.085	4.506	3.662	3.34	3.707	5.414	6.041	4.379	4.264	3.651	3.776	4.604	6.007	5.498
11	3.587	3.011	4.135	2.773	3.161	4.859	5.729	4.492	3.164	3.558	3.080	4.070	5.548	5.649
12	3.264	3.993	3.08	2.44	2.926	4.533	4.937	3.816	2.977	3.424	3.482	3.876	5.369	5.835
13	2.944	2.857	2.412	2.675	2.527	4.733	4.414	2.918	3.133	2.697	2.782	2.696	4.614	4.931
14	2.764	2.773	2.783	2.786	3.111	4.313	3.488	2.690	3.268	2.247	3.654	3.317	3.980	3.802
15	4.065	3.614	4.542	3.758	3.595	3.365	4.28	2.465	2.630	2.222	2.482	2.591	3.733	3.751
16	3.661	4.29	3.234	3.6	3.322	4.903	4.523	3.858	3.721	3.552	2.796	3.131	4.434	3.769
17	4.288	4.519	4.842	4.36	3.796	4.357	4.645	4.108	3.458	3.512	4.107	4.196	4.302	4.459
18	4.74	4.366	4.602	4.831	4.449	4.14	4.702	4.209	5.186	3.932	4.587	4.287	4.618	4.327
19	4.969	5.109	4.632	4.767	3.756	3.632	4.84	4.208	4.301	4.334	4.156	4.126	3.984	4.099
20	4.818	4.88	4.596	4.235	3.425	3.501	3.374	4.345	4.072	4.395	4.065	2.654	2.993	3.967
21	3.053	3.649	2.845	3.444	2.981	2.638	3.816	3.593	3.364	3.392	3.829	3.713	3.290	2.672
22	2.708	2.86	2.564	2.555	2.757	2.446	2.708	2.688	3.000	2.738	3.393	2.875	2.797	3.317
23	1.936	1.886	2.022	1.985	2.079	2.14	1.139	2.239	2.046	2.390	2.226	2.424	2.176	2.297
Total (ML/d)	0.29	0.298	0.284	0.273	0.266	0.294	0.297	0.266	0.270	0.260	0.263	0.263	0.284	0.283
Average (L/s)	3.357	3.452	3.283	3.162	3.077	3.398	3.439	3.076	3.120	3.004	3.046	3.040	3.289	3.276

APPENDIX B – TYPICAL FLOW PROFILE FOR SITE 3



APPENDIX C – ELEMENTAL ANALYSIS OF COMPOSITES FOR SITE 2

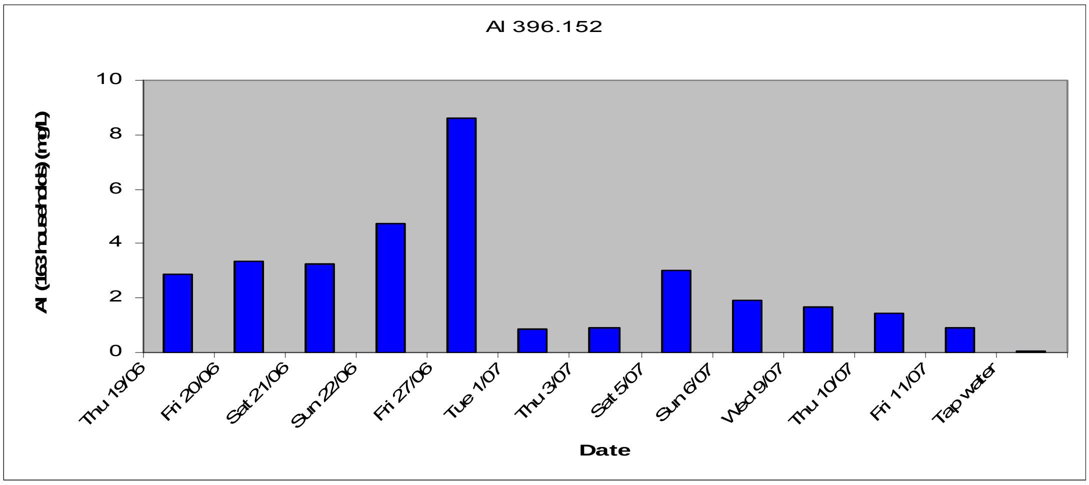


Figure 57: Concentration of Al in composites at site 2.

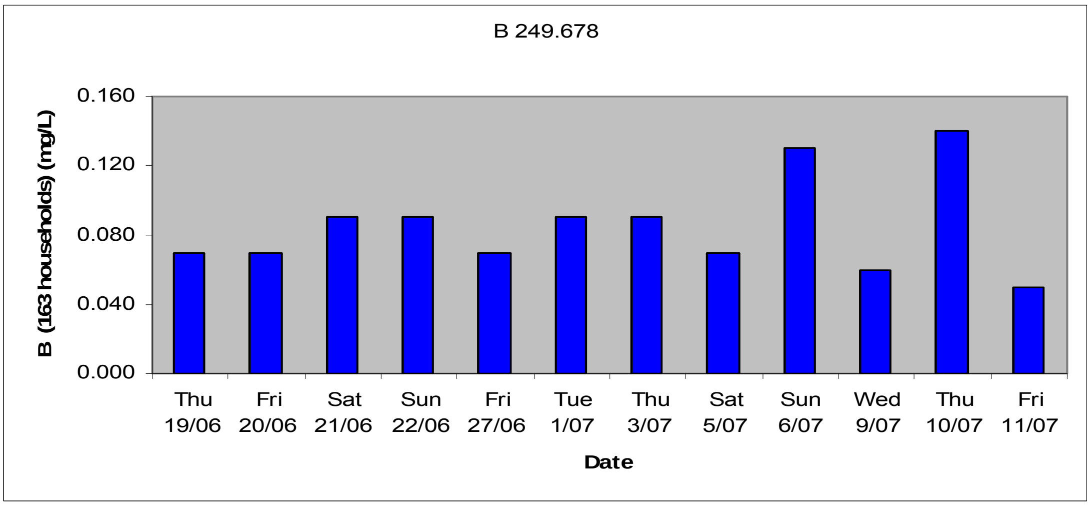


Figure 58: Concentration of B in composites at site 2.

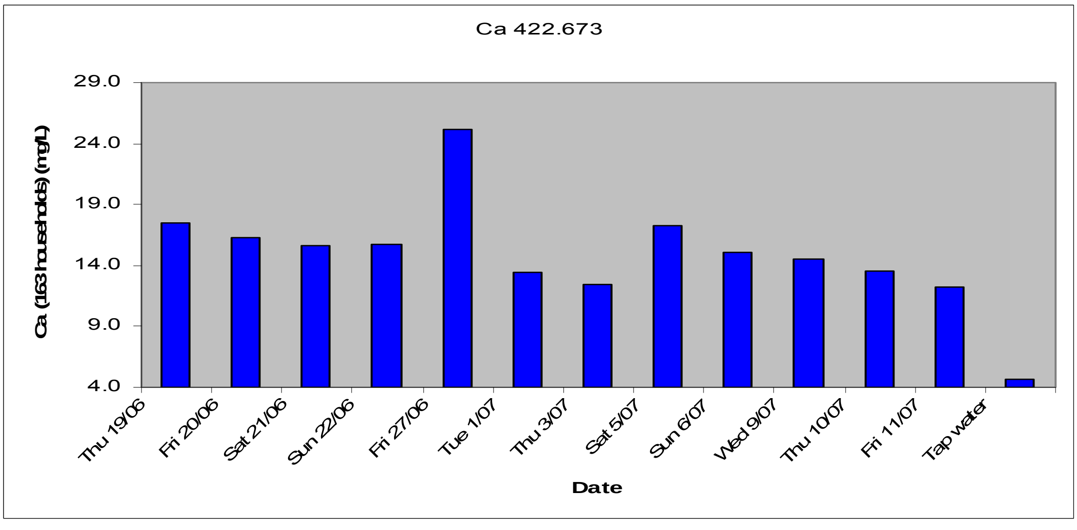


Figure 59: Concentration of Ca in composites at site 2.

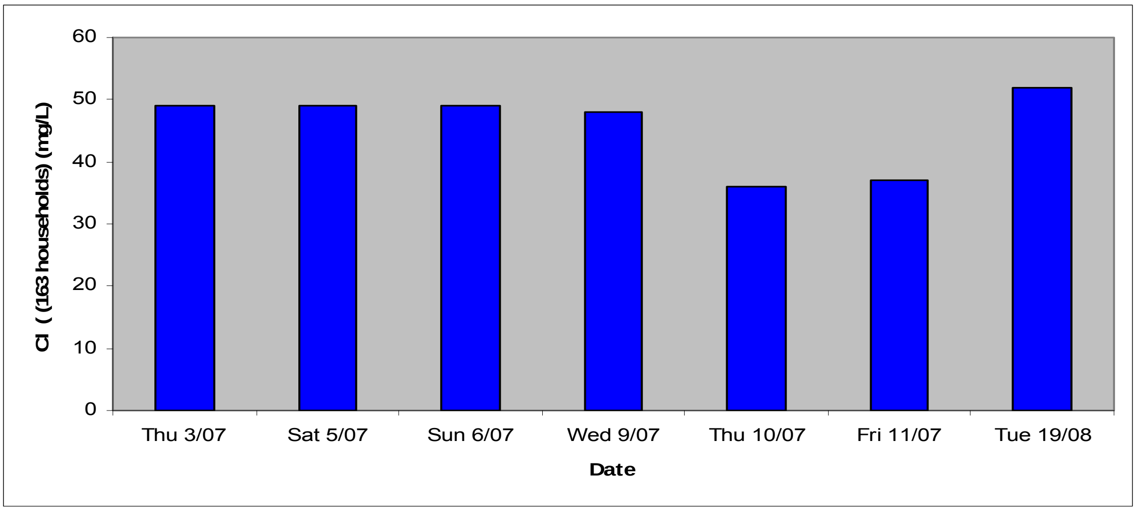


Figure 60: Concentration of Cl in composites at site 2.

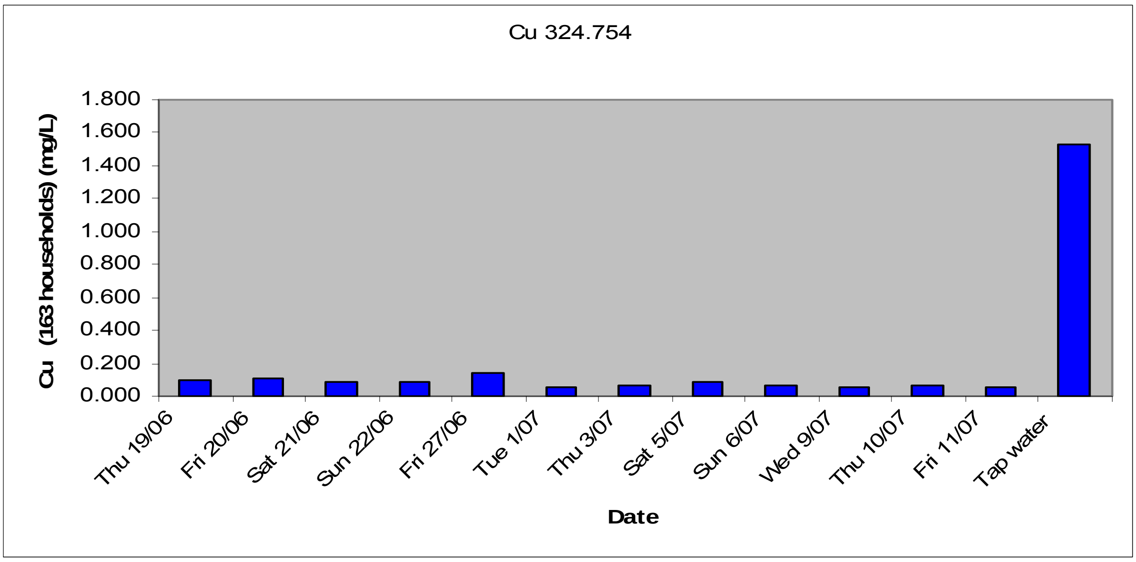


Figure 61: Concentration of Cu in composites at site 2.

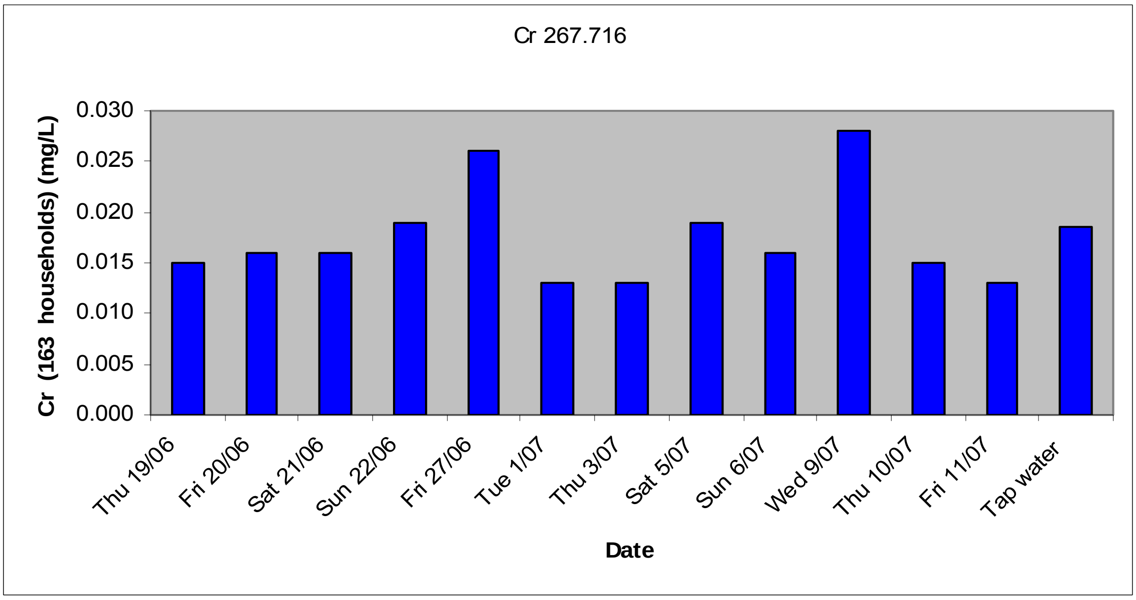


Figure 62: Concentration of Cr in composites at site 2.

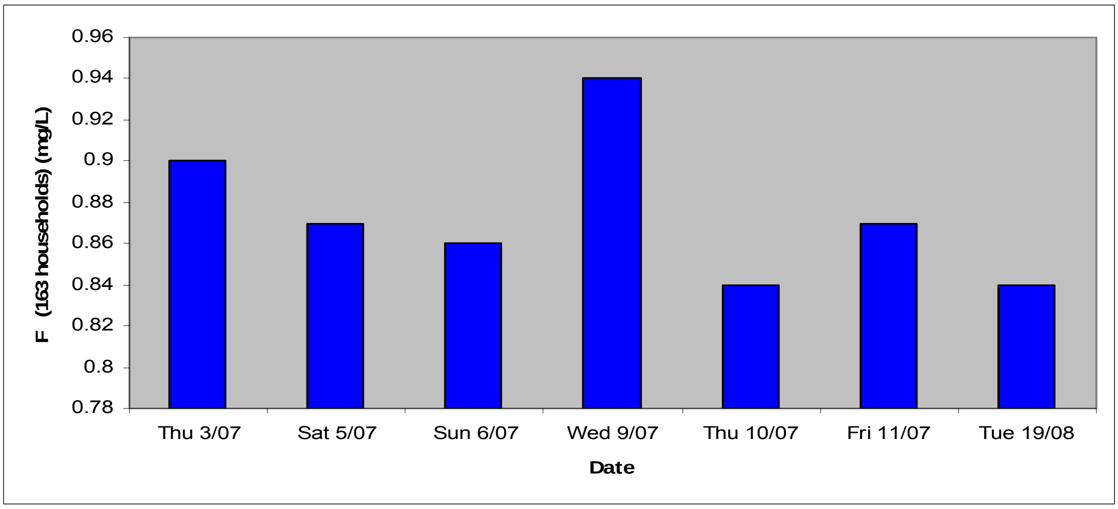


Figure 63: Concentration of F in composites at site 2.

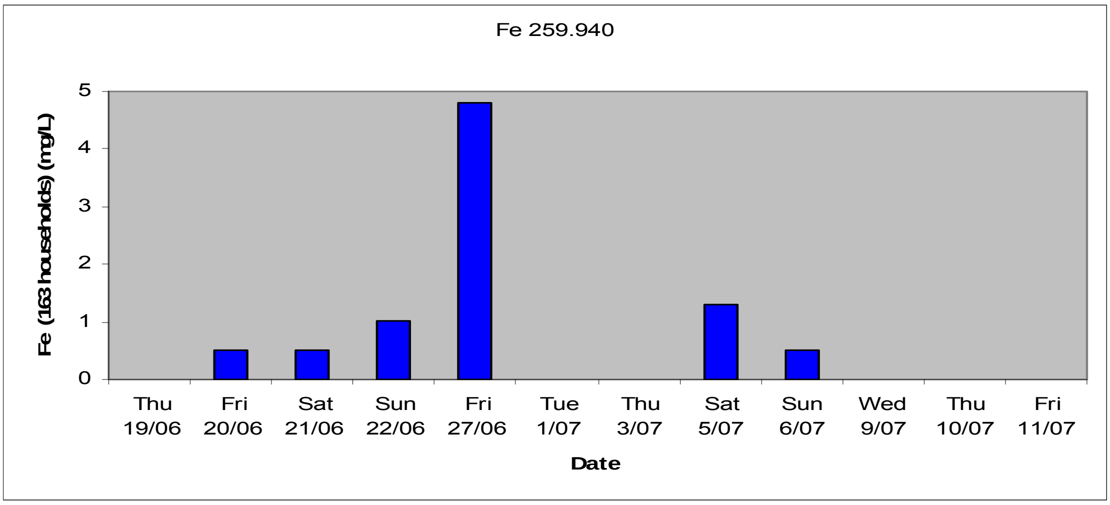


Figure 64: Concentration of Fe in composites at site 2.

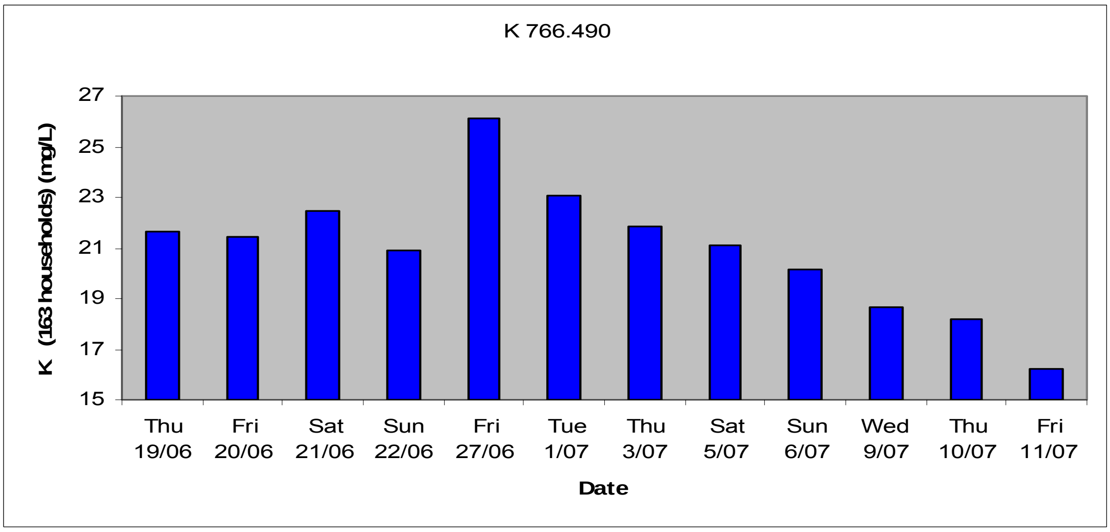


Figure 65: Concentration of K in composites at site 2.

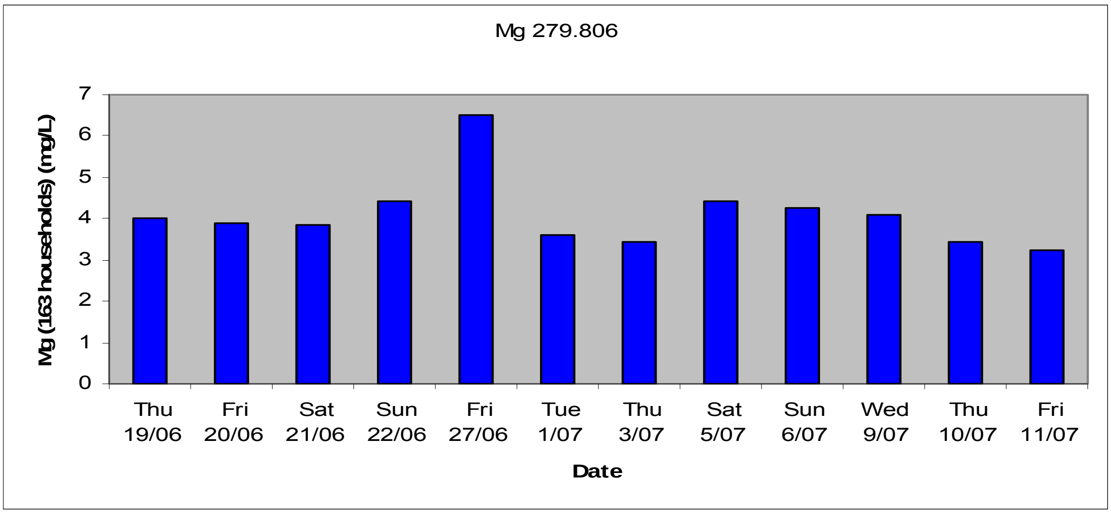


Figure 66: Concentration of Mg in composites at site 2.

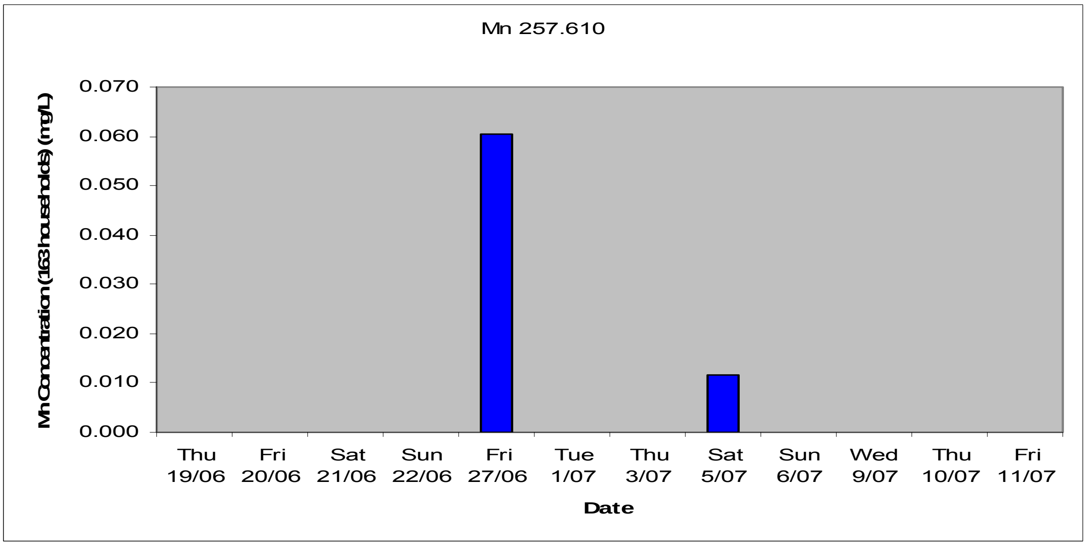


Figure 67: Concentration of Mn in composites at site 2.

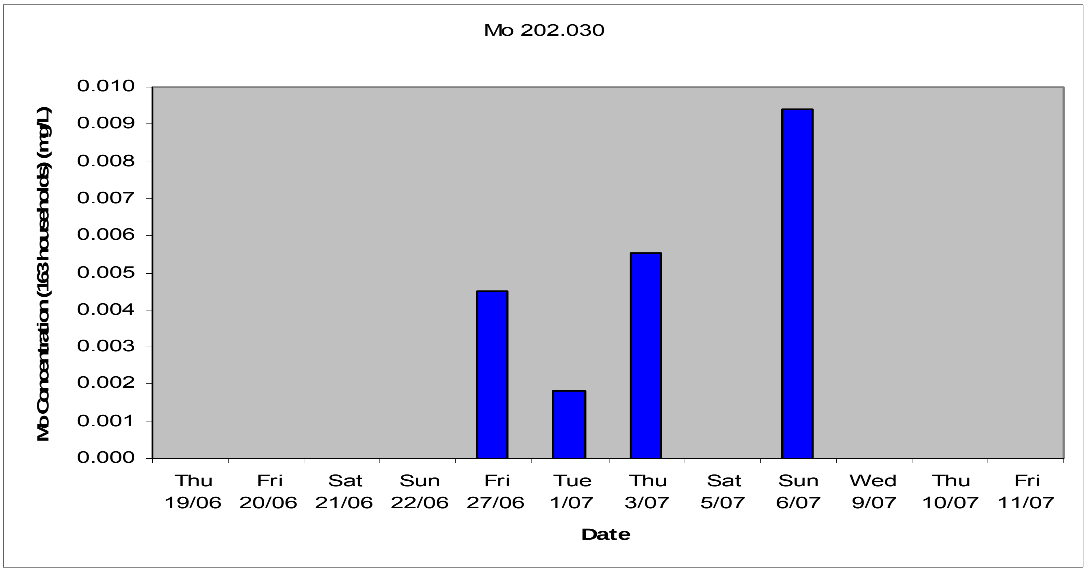


Figure 68: Concentration of Mo in composites at site 2.

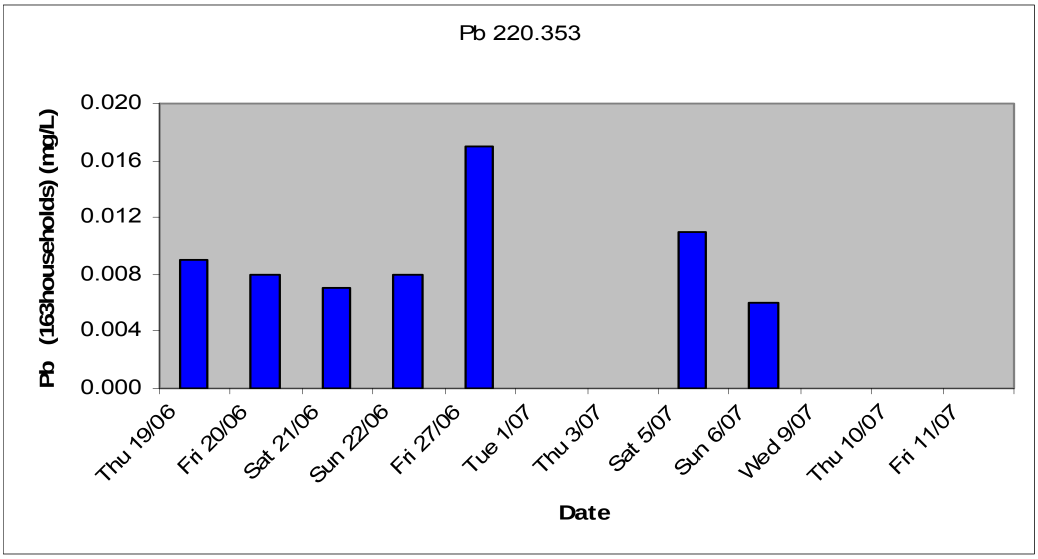


Figure 69: Concentration of Pb in composites at site 2.

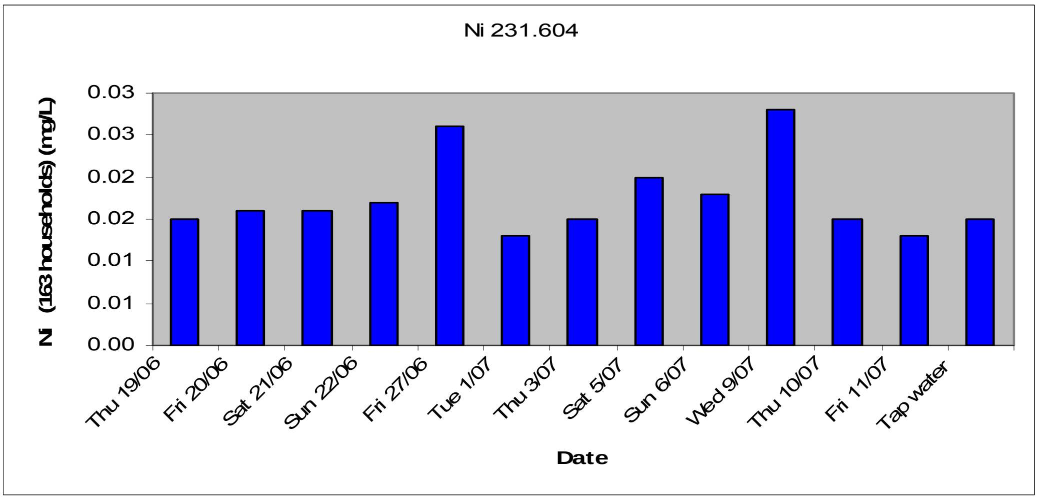


Figure 70: Concentration of Ni in composites at site 2.

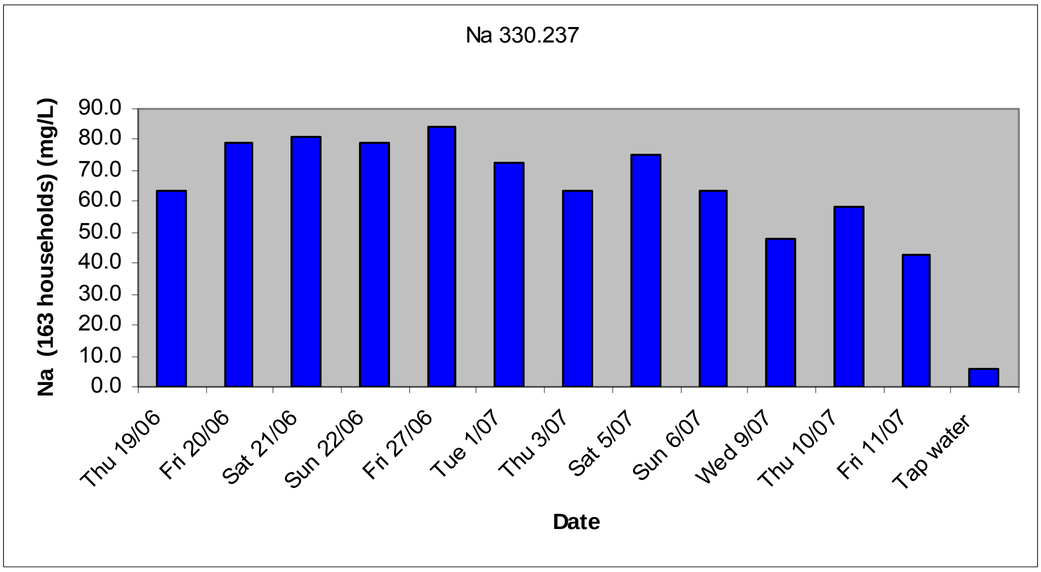


Figure 71: Concentration of Na in composites at site 2.

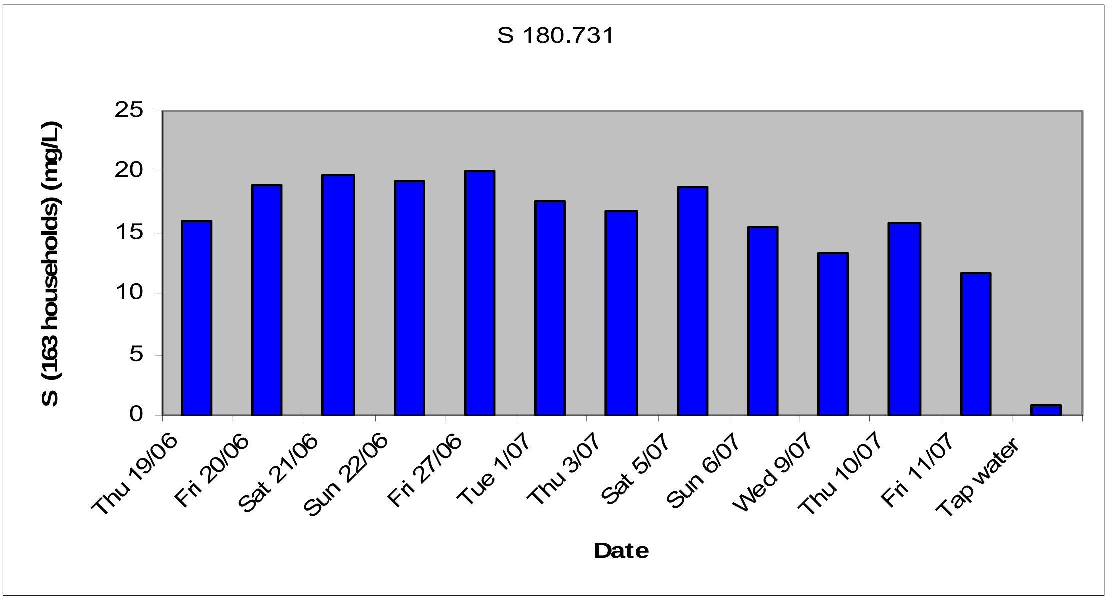


Figure 72: Concentration of S in composites at site 2.

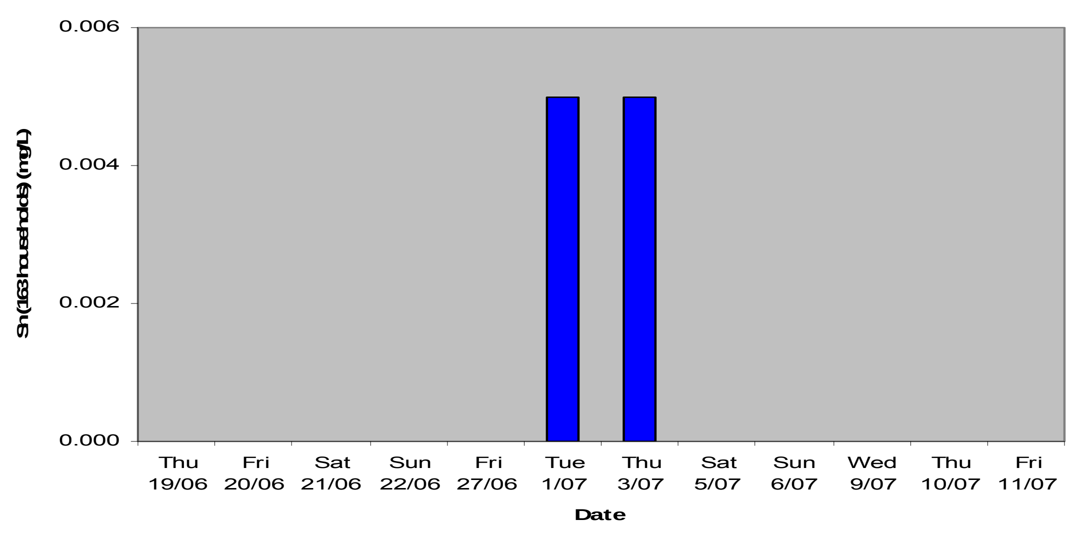


Figure 73: Concentration of Sn in composites at site 2.

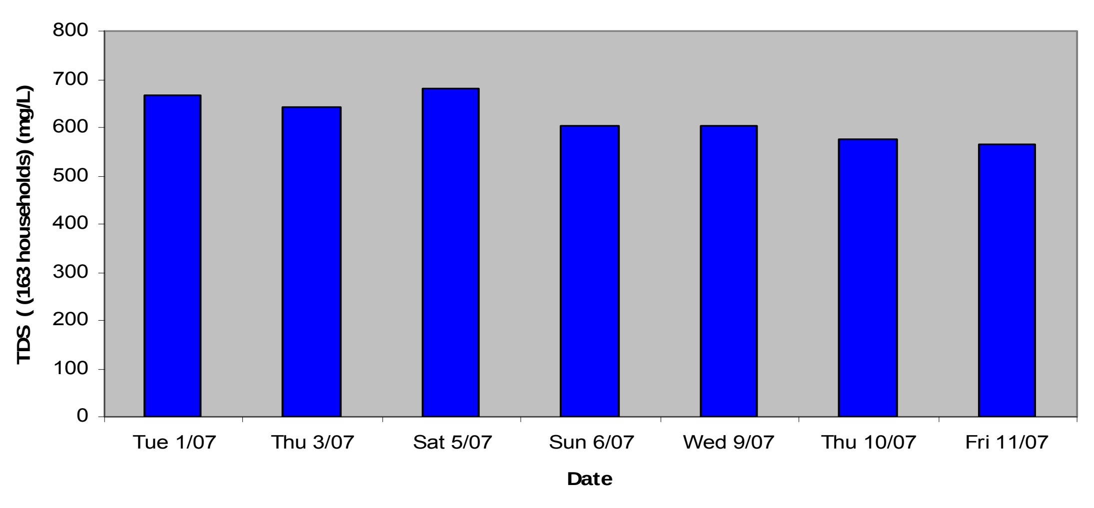


Figure 74: Concentration of TDS in composites at site 2.

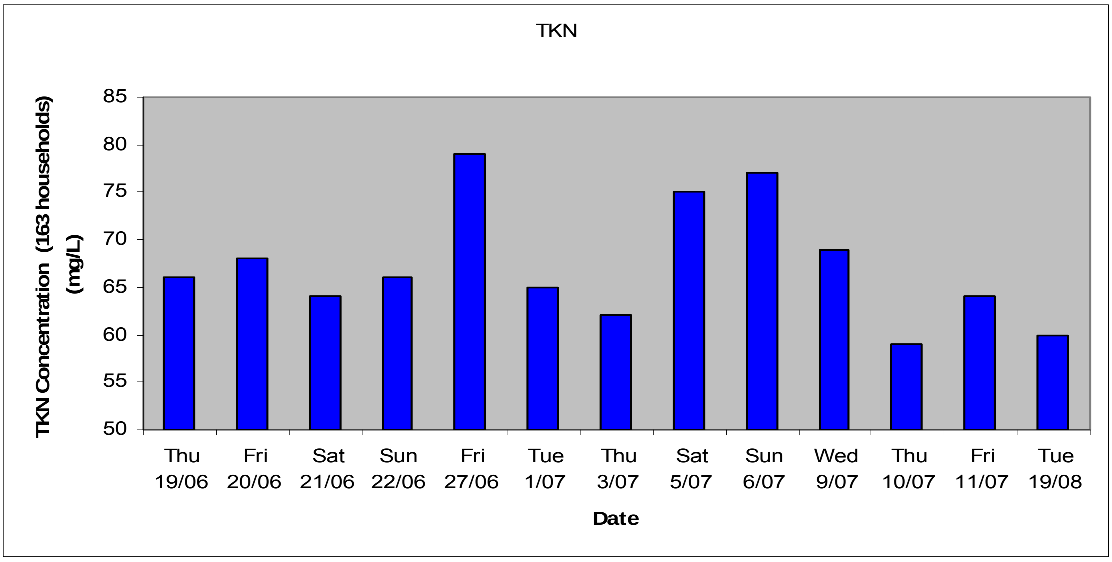


Figure 75: Concentration of TKN in composites at site 2.

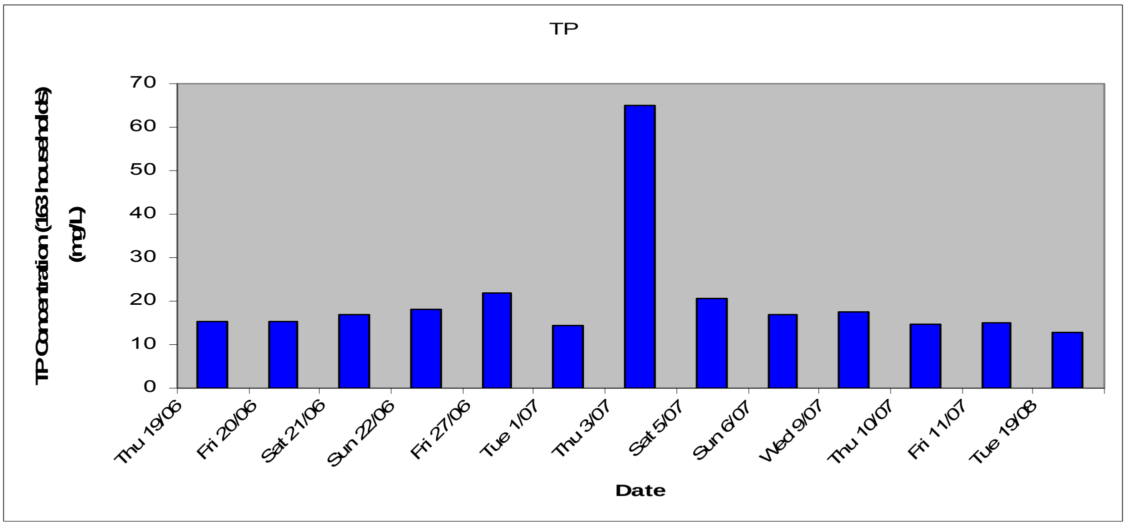


Figure 76: Concentration of TP in composites at site 2.

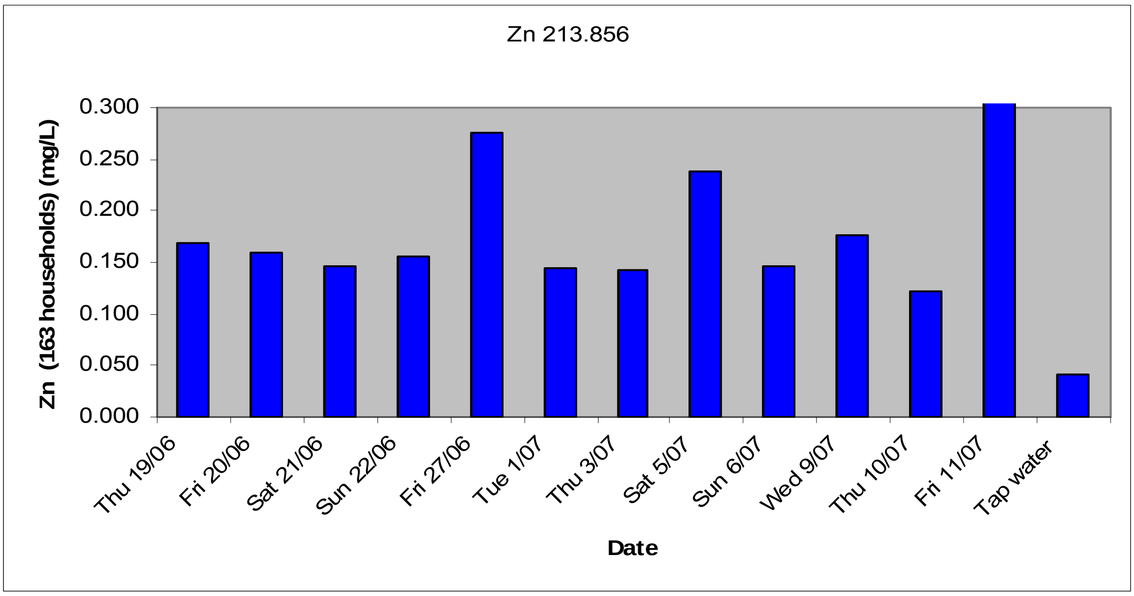


Figure 77: Concentration of Zn in composites at site 2.

APPENDIX D – ELEMENTAL ANALYSIS OF COMPOSITES FOR SITE 3

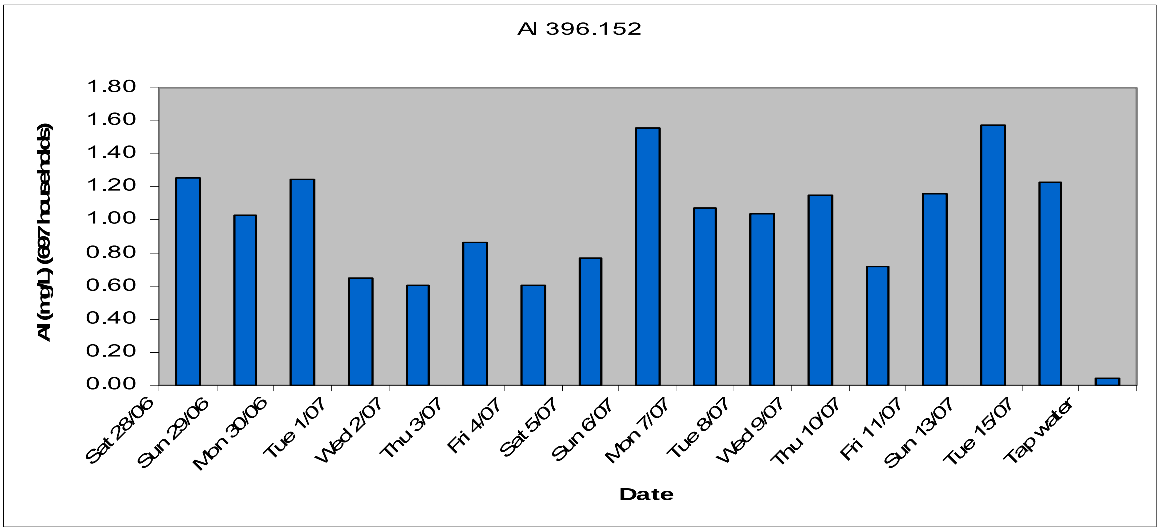


Figure 78: Concentration of Al in composites at site 3.

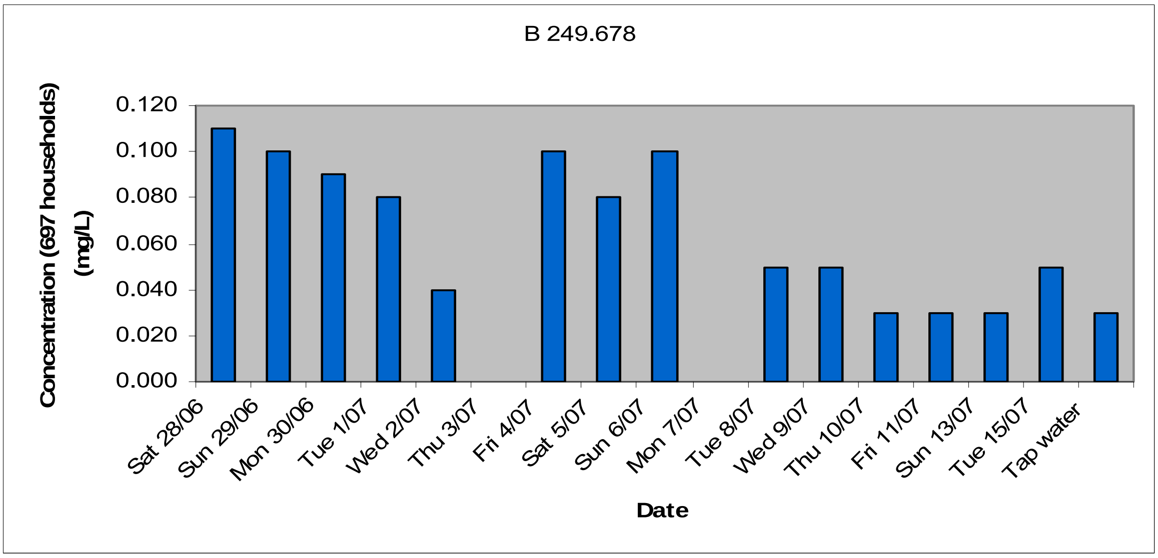


Figure 79: Concentration of B in composites at site 3.

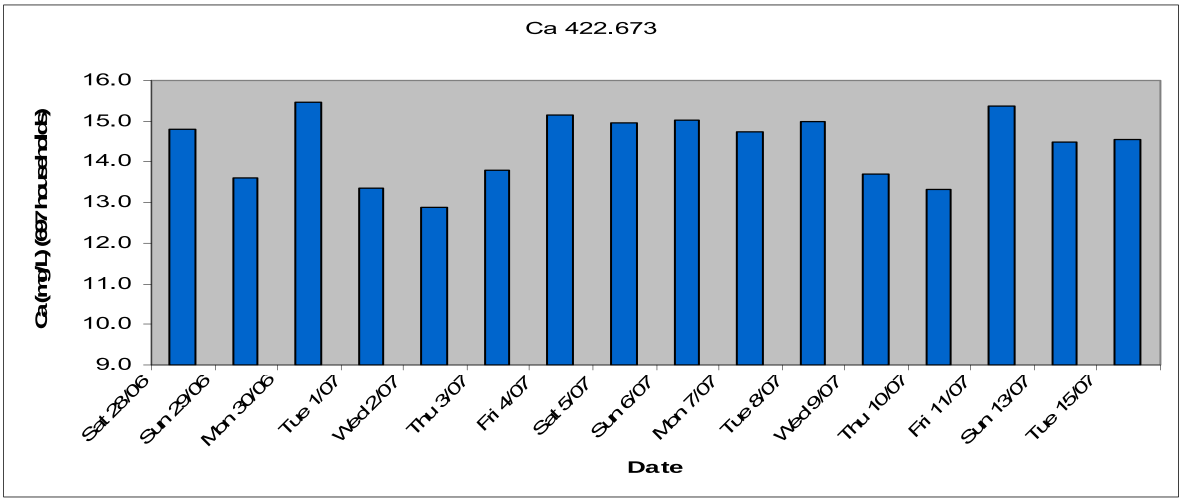


Figure 80: Concentration of Ca in composites at site 3.

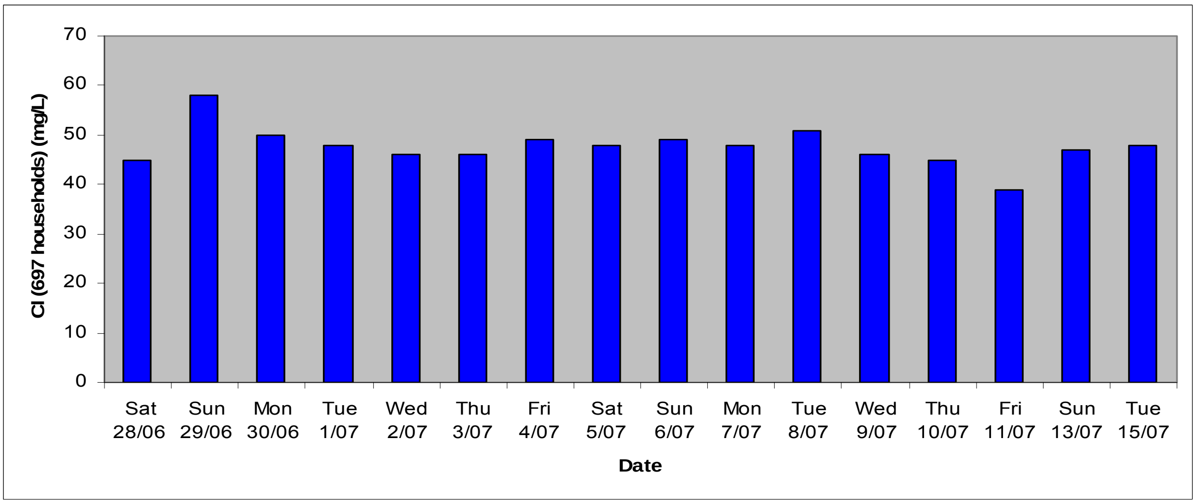


Figure 81: Concentration of Cl in composites at site 3.

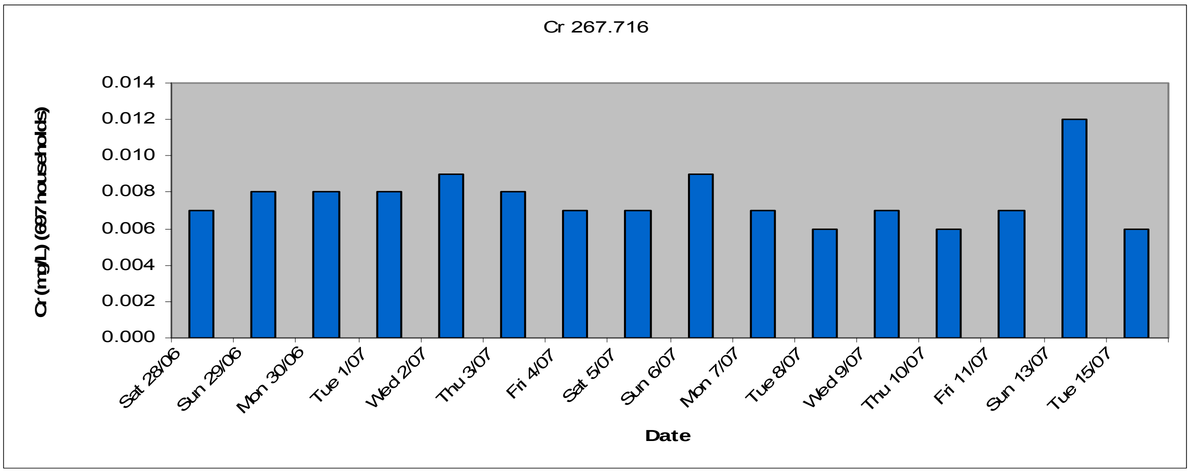


Figure 82: Concentration of Cr in composites at site 3.

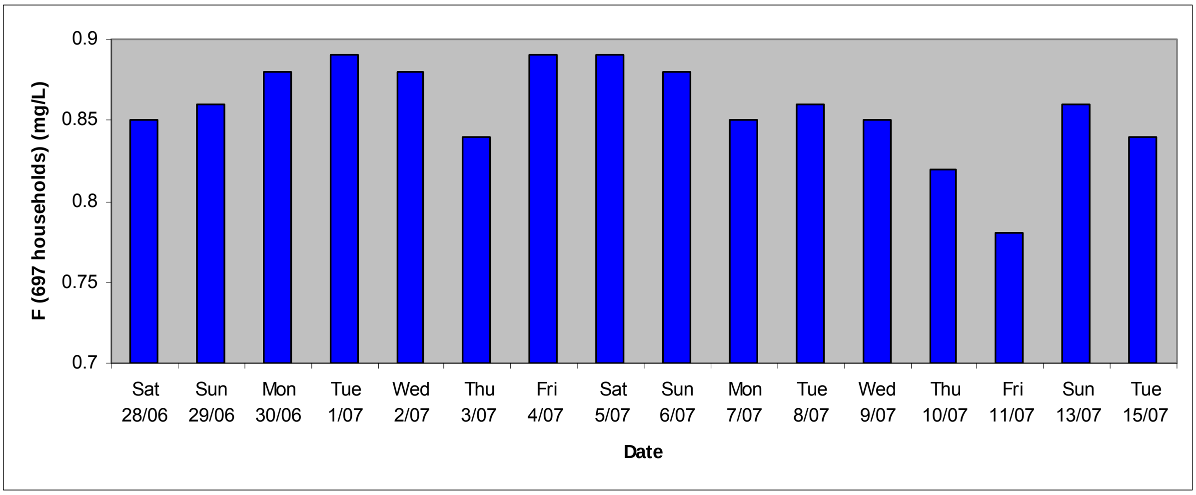


Figure 83: Concentration of F in composites at site 3.

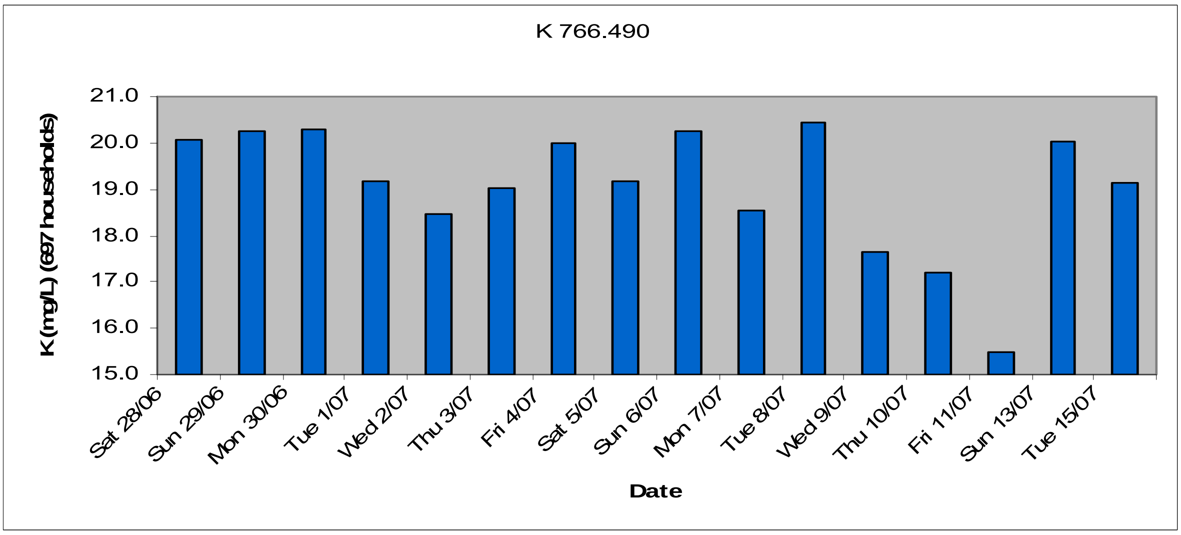


Figure 84: Concentration of K in composites at site 3.

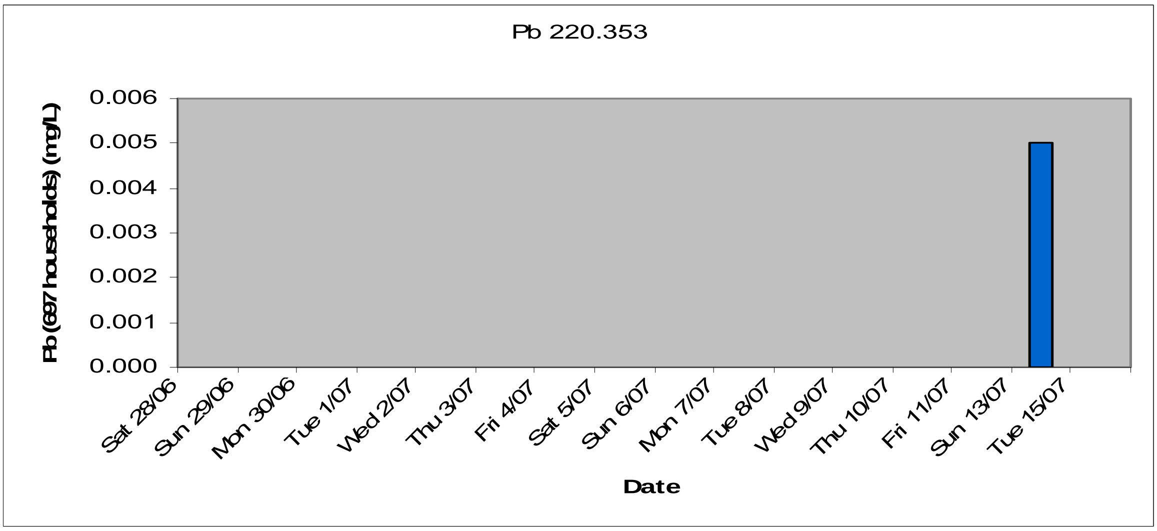


Figure 85: Concentration of Pb in composites at site 3.

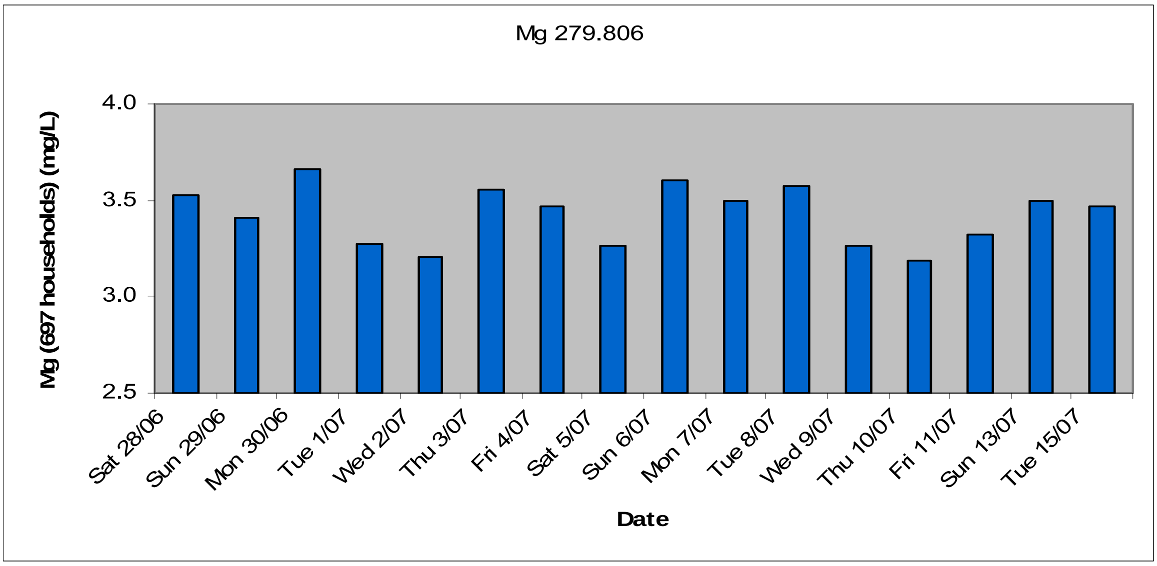


Figure 86: Concentration of Mg in composites at site 3.

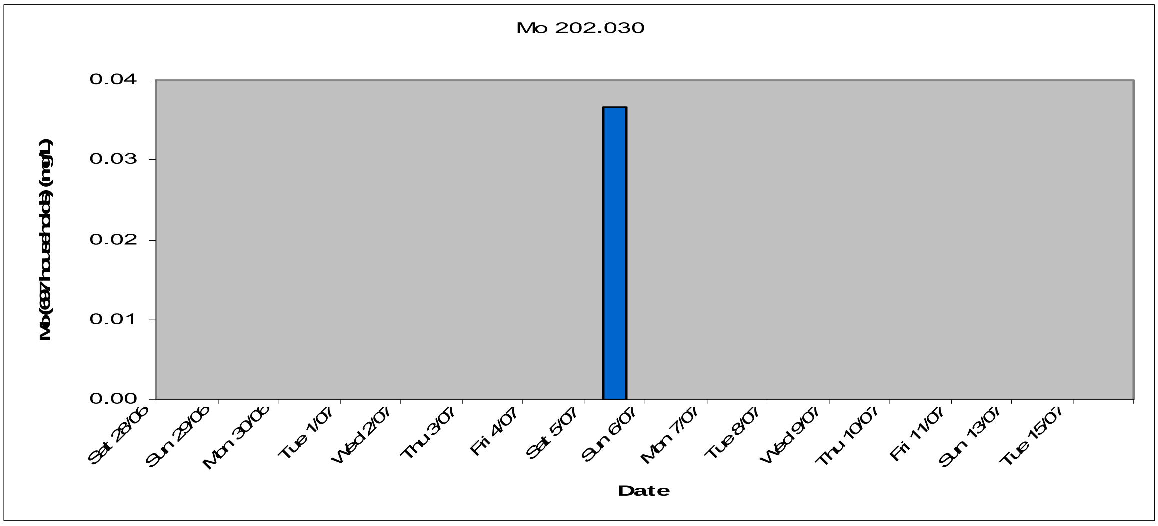


Figure 87: Concentration of Mo in composites at site 3.

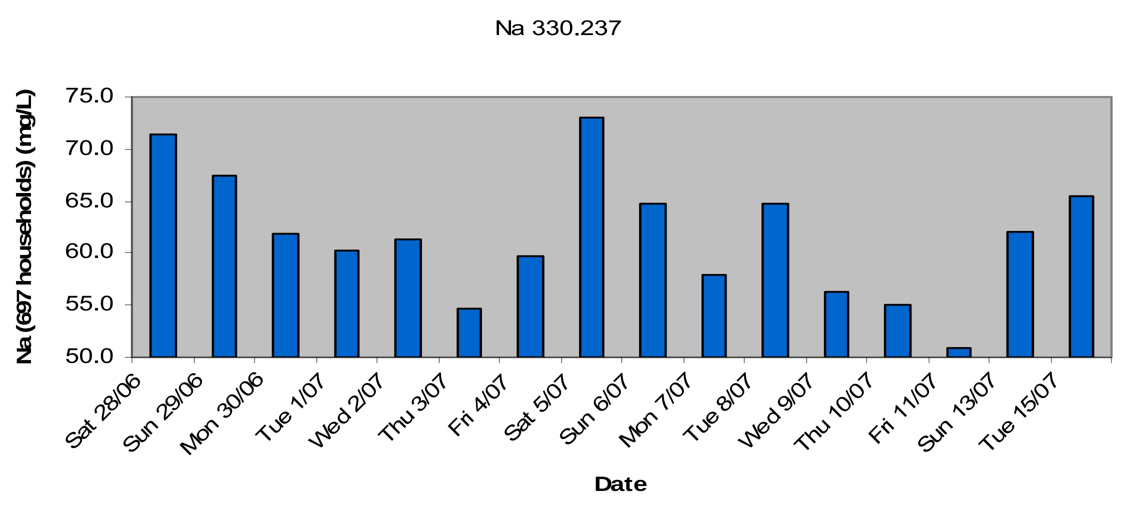


Figure 88: Concentration of Na in composites at site 3.

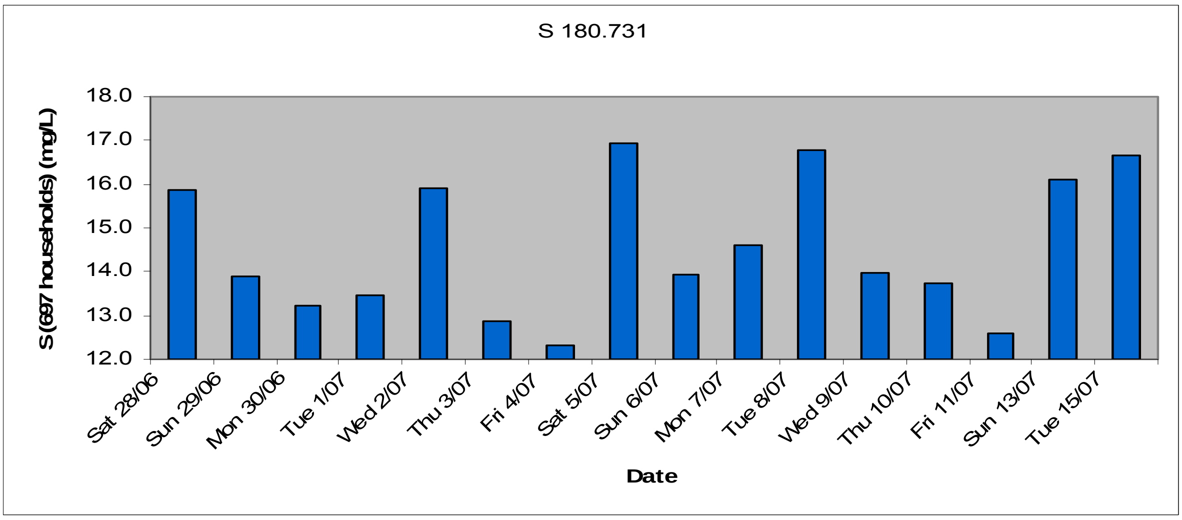


Figure 89: Concentration of S in composites at site 3.

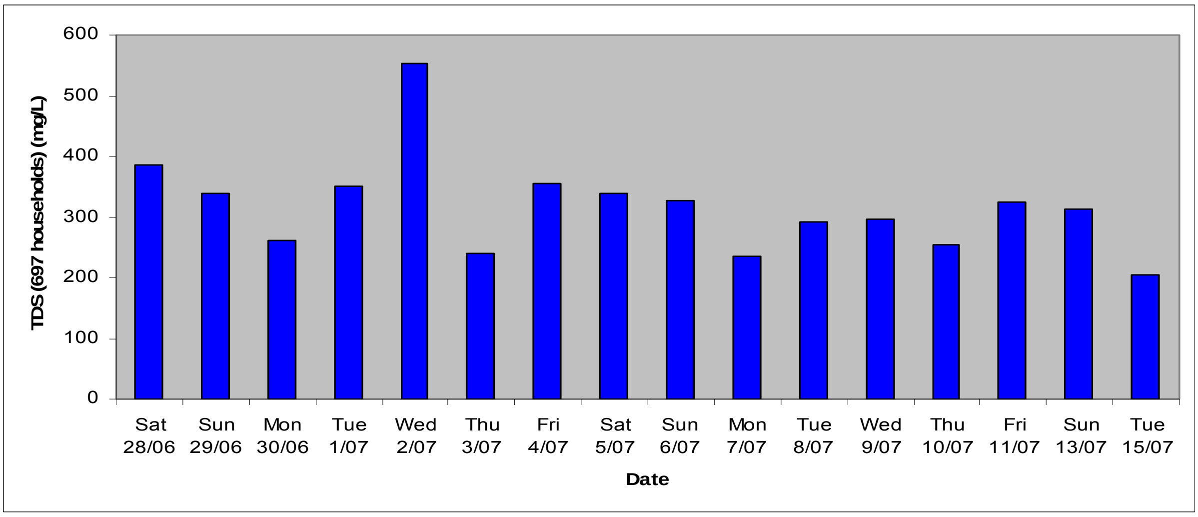


Figure 90: Concentration of TDS in composites at site 3.

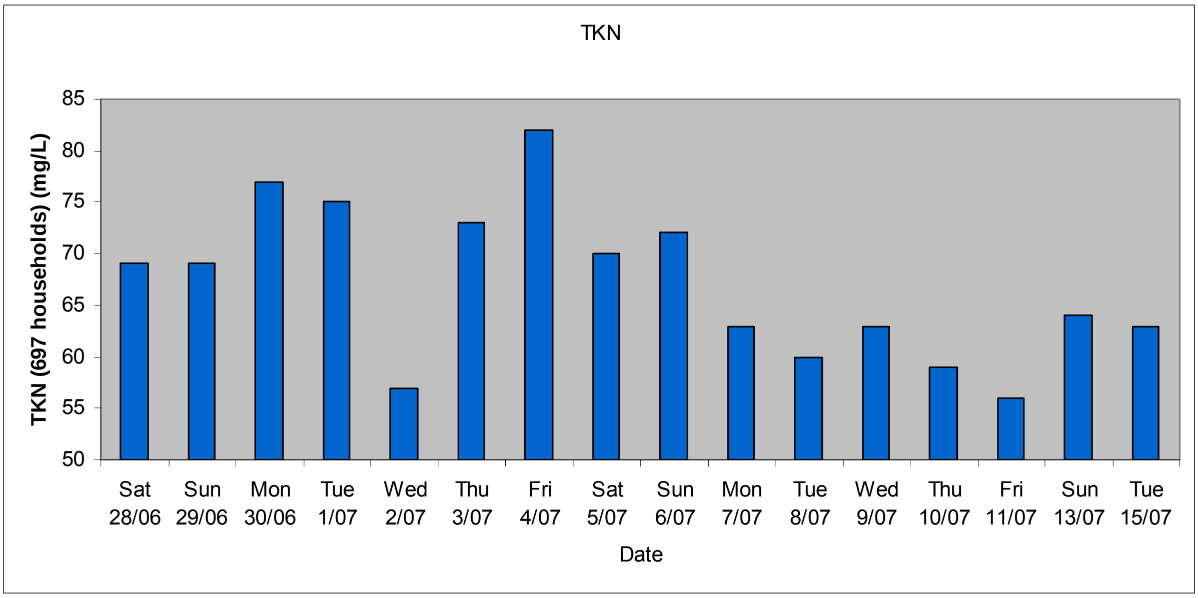


Figure 91: Concentration of TKN in composites at site 3.

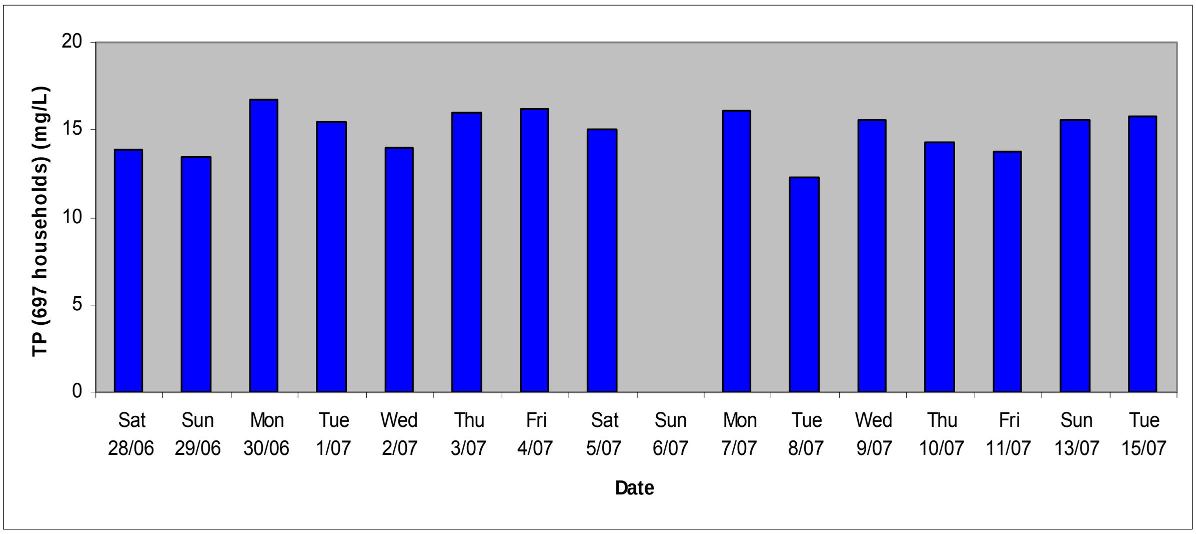


Figure 92: Concentration of TP in composites at site 3.

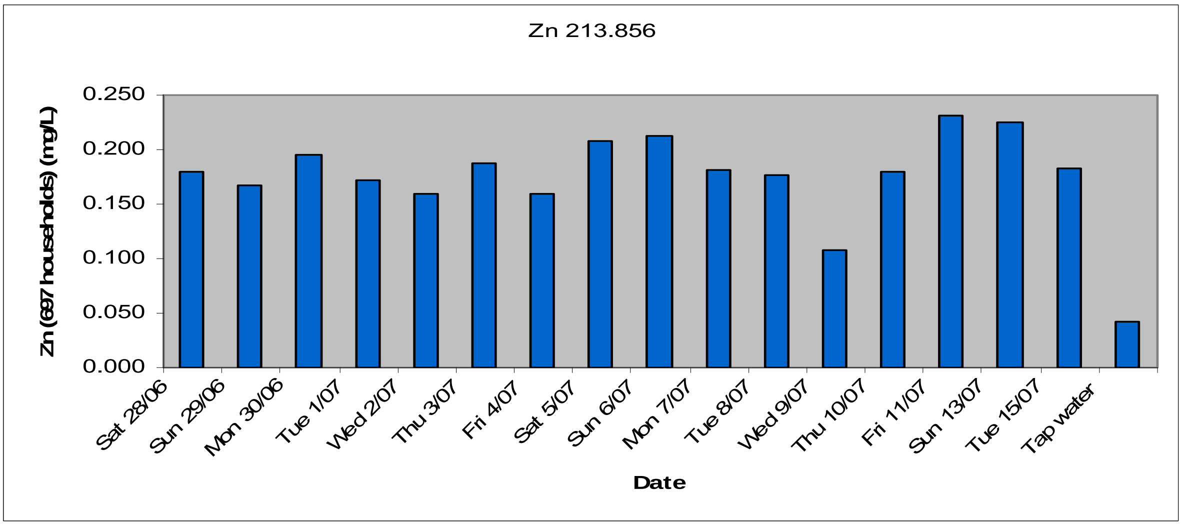


Figure 93: Concentration of Zn in composites at site 3.

APPENDIX E – DATA SUMMARY

Table 17: Composite data for site 2 (Al to TDS)

Sample	*Date*	*Al* mg/L	*Sb* μg/L	*As* μg/L	*B* mg/L	*Ca* mg/L	*Cd* mg/L	*Cl* mg/L	*Co* mg/L	*Cr* mg/L	*Cu* mg/L	*F* mg/L	*Hg* μg/L	*Se* μg/L	*TKN* mg/L	*TP* mg/L	*TDS* mg/L
1	Sun 24/02	1.49	<2	<5	0.09	12.6	<0.0005	nd	<0.01	0.022	0.113	nd	<2	<2	76	12	456
2	Wed 7/02	0.416	<2	<5	0.150	9.86	<0.0005	nd	<0.01	0.023	0.054	nd	<2	<2	66	10	492
3	Thu 28/02	1.12	<2	<5	0.19	13.0	<0.01	42	<0.01	0.021	0.094	1	<2	<7	75	12	453
4	Sat 1/03	1.24	<2	<5	0.08	11.7	<0.0005	nd	<0.01	0.024	0.101	nd	<2	<2	57	11	353.3
5	Wed 5/03	0.347	<2	<5	0.080	10.0	<0.0005	nd	<0.01	0.019	0.55	nd	<2	<2	70	12	370
6	Thu 6/03	0.480	<2	<5	0.060	9.31	<0.01	46	<0.01	0.025	0.068	1.1	<2	<7	75	11	400
7	Sat 12/03	nd	nd	nd	nd	nd	nd	50	nd	nd	nd	0.95	nd	nd	75	12	nd
8	Thu 13/03	nd	nd	nd	nd	nd	nd	47	nd	nd	nd	0.99	nd	nd	77	12	nd
9	Fri 14/03	nd	nd	nd	nd	nd	nd	42	nd	nd	nd	0.97	nd	nd	93	16	nd
10	Sat 15/03	nd	nd	nd	nd	nd	nd	45	nd	nd	nd	0.95	nd	nd	78	14	nd
11	Sun 16/03	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	86	16	nd
12	Mon 17/03	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	120	21	nd
14	Thu 19/06	2.855	3	<5	0.070	17.5	<0.001	nd	<0.003	0.015	0.099	nd	<2	<5	66	15.26	nd
15	Fri 20/06	3.371	4	<5	0.070	16.2	<0.001	nd	<0.003	0.016	0.107	nd	<2	<5	68	15.29	nd
16	Sat 21/06	3.260	4	<5	0.090	15.7	<0.001	nd	<0.003	0.016	0.091	nd	<2	<5	64	16.89	nd
17	Sun 22/06	4.737	3	<5	0.090	15.7	<0.001	nd	<0.003	0.019	0.087	nd	<2	<5	66	18.19	nd
18	Fri	8.606	9	<5	0.070	25.2	<0.001	nd	<0.003	0.026	0.137	nd	<2	<5	79	21.86	nd

Sample	**Date**	**Al** mg/L	**Sb** μg/L	**As** μg/L	**B** mg/L	**Ca** mg/L	**Cd** mg/L	**Cl** mg/L	**Co** mg/L	**Cr** mg/L	**Cu** mg/L	**F** mg/L	**Hg** μg/L	**Se** μg/L	**TKN** mg/L	**TP** mg/L	**TDS** mg/L
	27/06																
19	Tue 1/07	0.872	<2	<5	0.090	13.4	<0.001	nd	<0.003	0.013	0.058	nd	<2	<5	65	14.44	665
20	Thu 3/07	0.912	2	<5	0.090	12.4	<0.001	49	<0.003	0.013	0.064	0.9	<2	<5	62	65.0	641
21	Sat 5/07	3.037	6	<5	0.070	17.3	<0.001	49	<0.003	0.019	0.091	0.87	<2	<5	75	20.6	682
22	Sun 6/07	1.904	4	<5	0.130	15.1	<0.001	49	<0.003	0.016	0.069	0.86	<2	<5	77	16.7	605
23	Wed 9/07	1.695	2	<5	0.060	14.5	<0.001	48	<0.003	0.028	0.058	0.94	<2	<5	69	17.5	604
24	Thu 10/07	1.445	2	<5	0.140	13.5	<0.001	36	<0.003	0.015	0.065	0.84	<2	<5	59	14.6	576
25	Fri 11/07	0.919	<2	<5	0.050	12.3	<0.001	37	<0.003	0.013	0.053	0.87	<2	<5	64	15.1	564
26	Tue 19/08	2.855	3	<5	0.070	17.5	<0.001	52	<0.003	0.015	0.099	0.84	<2	<5	60	12.8	nd
Summer	Mean	0.849	<2	<5	0.108	11.09	<0.01	45.33	<0.01	0.0223	0.081	0.99	<2	<7	79	13.3	420.7
	SD	0.493			0.050	1.58		3.077		0.0022	0.025	0.056			15.7	3.08	54.6
Winter	Mean	2.80	3.58	<5	0.09	15.73	<0.001	45.71	<0.003	0.017	0.08	0.87	<2	<5	67.23	20.32	619.6
	SD	2.19	2.21		0.03	3.44		6.42		0.005	0.03	0.04			6.29	13.66	44.5

Table 18: Composite data for site 3 (Al to TDS)

	Date	Al	As	Sb	B	Ca	Cd	Cl	Co	Cr	Cu	F	Hg	Se	TKN	TP	TDS
Site 3		mg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	mg/L	mg/L	mg/L
1	Tue 11/03	0.918	<5	<2	0.100	12.9	<0.01	52	<0.01	0.027	0.103	1.1	<2	<7	66	11	330
2	Thu 13/03	1.121	<5	2	0.070	13.1	<0.01	50	<0.01	0.025	0.104	0.97	<2	<7	63	11	432
3	Fri 14/03	1.050	<5	<2	0.090	13.4	<0.01	48	<0.01	0.035	0.089	1	<2	<7	66	12	406
4	Sat 15/03	1.120	<5	2	0.110	12.9	<0.01	48	<0.01	0.025	0.102	1.1	<2	<7	64	12	490
5	Sun 16/03	1.017	<5	<2	0.070	13.1	<0.01	50	<0.01	0.024	0.094	0.92	<2	<7	68	11	492
6	Mon 17/03	0.920	<5	<2	0.050	11.0	<0.01	61	<0.01	0.025	0.084	1.1	<2	<7	63	11	408
7	Tue 18/03	0.925	<5	<2	0.110	11.9	<0.01	73	<0.01	0.023	0.093	1.1	<2	<7	68	11	402
8	Wed 19/03	0.446	<5	<2	0.080	11.5	<0.01	62	<0.01	0.020	0.055	0.97	<2	<7	76	13	393.3
9	Mon 24/03	0.926	<5	2	0.100	11.0	<0.01	60	<0.01	0.022	0.076	1.1	<2	<7	72	12	399
10	Wed 26/03	0.981	<5	<2	0.100	10.9	<0.01	55	<0.01	0.023	0.078	1.1	<2	<7	69	12	392
11	Thu 27/03	1.301	<5	<2	0.180	12.5	<0.01	54	<0.01	0.026	0.107	1.1	<2	<7	72	13	460
12	Sat 28/06	1.257	<5	<2	0.110	14.8	<0.001	45	<0.003	0.007	0.105	0.85	<2	<5	69	13.9	387
13	Sun 29/06	1.032	<5	2	0.100	13.6	<0.001	58	<0.003	0.008	0.068	0.86	<2	<5	69	13.5	340
14	Mon 30/06	1.247	<5	<2	0.090	15.5	<0.001	50	<0.003	0.008	0.077	0.88	<2	<5	77	16.8	260
15	Tue 1/07	0.653	<5	<2	0.080	13.4	<0.001	48	<0.003	0.008	0.072	0.89	<2	<5	75	15.5	350
16	Wed 2/07	0.602	<5	<2	0.040	12.9	<0.001	46	<0.003	0.009	0.069	0.88	<2	<5	57	14.0	552
17	Thu 3/07	0.866	<5	<2	<0.03	13.8	<0.001	46	<0.003	0.008	0.070	0.84	<2	<5	73	16.0	240
18	Fri 4/07	0.606	<5	<2	0.100	15.2	<0.001	49	<0.003	0.007	0.061	0.89	<2	<5	82	16.2	356
19	Sat 5/07	0.770	<5	2	0.080	15.0	<0.001	48	0.009	0.007	0.057	0.89	<2	<5	70	15.0	340
20	Sun 6/07	1.557	<5	2	0.100	15.0	<0.001	49	<0.003	0.009	0.075	0.88	<2	<5	72	nd	328
21	Mon 7/07	1.069	<5	<2	<0.03	14.7	<0.001	48	<0.003	0.007	0.074	0.85	<2	<5	63	16.1	236
22	Tue 8/07	1.035	<5	<2	0.050	15.0	<0.001	51	<0.003	0.006	0.069	0.86	<2	<5	60	12	292
23	Wed 9/07	1.151	<5	<2	0.050	13.7	<0.001	46	<0.003	0.007	0.074	0.85	<2	<5	63	15.5	296
24	Thu 10/07	0.714	<5	<2	0.030	13.3	<0.001	45	0.004	0.006	0.060	0.82	<2	<5	59	14.3	253.8
25	Fri 11/07	1.163	<5	<2	0.030	15.4	<0.001	39	<0.003	0.007	0.069	0.78	<2	<5	56	14	325
26	Sun 13/07	1.571	<5	<2	0.030	14.5	<0.001	47	<0.003	0.012	0.079	0.86	<2	<5	64	16	313.3
27	Tue 15/07	1.229	<5	<2	0.050	14.5	<0.001	48	<0.003	0.006	0.073	0.84	<2	<5	63	16	205
28	Sat 28/06	1.257	<5	<2	0.110	14.8	<0.001	45	<0.003	0.007	0.105	0.85	<2	<5	69	13.9	387
Summer	Mean	0.975	<5	<2	0.096	12.2	<0.01	55.7	<0.01	0.025	0.089	1.1	<2	<7	68	12	418.6
	SD	0.211			0.034	0.97		7.656		0.0038	0.016	0.07			4	1	47.4
Winter	Mean	1.033	<5	2	0.103	14.133	<0.001	47.69	0.003	0.008	0.072	0.86	<2	<5	67.00	14.9	317.1

SD	0.310		0.021	2.487		3.88		0.002	0.011	0.03		7.56	1.25	80.53

Table 19: Composite data for site 2 (Fe to Zn)

	Site 2 *Date*	*Fe* *mg/L*	*K* *mg/L*	*Mg* *mg/L*	*Mn* *mg/L*	*Mo* *mg/L*	*Na* *mg/L*	*Ni* *mg/L*	*Pb* *mg/L*	*S* *mg/L*	*Si* *mg/L*	*Sn* *mg/L*	*Zn* *mg/L*
1	Sun 24/02	0.503	16.9	2.65	<0.001	<0.05	56.0	0.020	0.006	10.3	1.85	<0.05	0.367
2	Wed 27/02	0.077	13.3	2.09	<0.001	<0.05	51.3	0.019	<0.005	8.92	1.61	0.088	0.122
3	Thu 28/02	0.211	16.8	3.08	<0.001	<0.05	54.3	0.025	0.006	10.0	1.81	<0.05	0.191
4	Sat 1/03	0.384	13.1	2.26	<0.001	<0.05	57.7	0.022	0.007	11.9	1.77	<0.05	1.105
5	Wed 5/03	<0.005	17.0	2.38	<0.001	<0.05	59.1	0.016	0.003	12.3	1.49	<0.05	0.117
6	Thu 6/03	<0.005	17.6	2.23	<0.001	<0.05	59.9	0.025	<0.005	9.82	1.66	<0.05	0.140
7	Thu 19/06	<0.01	21.6	4.02	<0.0003	<0.003	63.7	0.015	0.014	15.9	9.23	<0.005	0.168
8	Fri 20/06	0.52	21.4	3.91	<0.0003	<0.003	79.0	0.016	<0.01	18.8	9.99	<0.005	0.159
9	Sat 21/06	0.50	22.5	3.85	<0.0003	<0.003	80.7	0.016	<0.01	19.7	10.4	<0.005	0.147
10	Sun 22/06	1.01	20.9	4.40	<0.0003	<0.003	79.2	0.017	<0.01	19.2	11.5	<0.005	0.156
11	Fri 27/06	4.81	26.1	6.52	0.060	0.005	84.1	0.026	<0.01	20.1	17.9	<0.005	0.276
12	Tue 1/07	<0.01	23.1	3.59	<0.0003	0.002	72.3	0.013	<0.01	17.7	6.82	0.005	0.145
13	Thu 3/07	<0.01	21.9	3.44	<0.0003	0.006	63.5	0.015	<0.01	16.8	6.89	0.005	0.142
14	Sat 5/07	1.30	21.1	4.42	0.012	<0.003	74.9	0.020	0.011	18.8	9.93	<0.005	0.239
15	Sun 6/07	0.52	20.2	4.26	<0.0003	0.009	63.8	0.018	<0.01	15.5	8.65	<0.005	0.146
16	Wed 9/07	<0.01	18.7	4.10	<0.0003	<0.003	47.7	0.028	<0.01	13.3	7.10	<0.005	0.176
17	Thu 10/07	<0.01	18.2	3.45	<0.0003	<0.003	58.4	0.015	<0.01	15.8	6.80	<0.005	0.121
18	Fri 11/07	<0.01	16.2	3.23	<0.0003	<0.003	42.7	0.013	<0.01	11.7	5.47	<0.005	0.889
19	Thu 19/06	<0.01	21.6	4.02	<0.0003	<0.003	63.7	0.015	0.014	15.9	9.23	<0.005	0.168
Summer	Mean	0.294	15.77	2.45	<0.001	<0.05	56.37	0.0212	0.0037	10.6	1.70	0.015	0.34
	SD	0.188	2.009	0.362			3.214	0.0035	0.0031	1.3	0.14	0.036	0.386
Winter	Mean	0.73	20.99	4.10	0.006	0.004	67.49	0.018	0.010	16.95	9.23	<0.005	0.23
	SD	1.36	2.54	0.86		0.001	13.23	0.0048	0.001	2.61	3.30		0.21

Table 20: Composite data for site 3 (Fe to Zn)

	Site 3 Date	Fe mg/L	K mg/L	Mg mg/L	Mn mg/L	Mo mg/L	Na mg/L	Ni mg/L	Pb mg/L	S mg/L	Si mg/L	Sn mg/L	Zn mg/L
1	Tue 11/03	0.548	9.06	3.17	0.035	<0.05	11.3	0.023	0.007	11.4	3.66	<0.05	0.168
2	Thu 13/03	0.723	9.36	3.13	0.036	<0.05	11.4	0.021	0.005	12.1	3.82	<0.05	0.191
3	Fri 14/03	0.711	9.63	3.27	<0.001	<0.05	11.8	0.023	0.005	14.3	3.94	<0.05	0.205
4	Sat 15/03	0.657	9.45	2.99	0.036	<0.05	12.5	0.024	0.006	12.1	3.99	<0.05	0.218
5	Sun 16/03	0.582	9.55	3.22	0.032	<0.05	12.8	0.023	0.005	12.9	3.91	<0.05	0.184
6	Mon 17/03	0.494	8.66	2.90	0.027	<0.05	11.7	0.025	<0.005	12.0	3.62	<0.05	0.176
7	Tue 18/03	0.427	9.44	2.97	<0.001	<0.05	12.9	0.021	0.005	12.8	3.82	<0.05	0.170
8	Wed 19/03	0.289	8.57	2.82	<0.001	<0.05	10.8	0.019	<0.005	10.9	3.41	<0.05	0.113
9	Mon 24/03	0.390	10.9	3.42	<0.001	<0.05	12.9	0.020	0.005	14.2	3.81	<0.05	0.138
10	Wed 26/03	0.516	9.63	2.99	<0.001	<0.05	10.1	0.021	<0.005	12.1	3.75	<0.05	0.142
11	Thu 27/03	0.641	9.77	3.17	<0.001	<0.05	10.6	0.023	0.008	13.1	4.03	<0.05	0.184
12	Sat 28/06	<0.01	21.6	4.02	<0.0003	<0.003	63.7	<0.01	<0.005	15.9	7.90	<0.005	0.180
13	Sun 29/06	<0.01	21.4	3.91	<0.0003	<0.003	79.0	<0.01	<0.005	13.9	7.23	<0.005	0.167
14	Mon 30/06	<0.01	22.5	3.85	<0.0003	<0.003	80.7	<0.01	<0.005	13.2	7.37	<0.005	0.195
15	Tue 1/07	<0.01	20.9	4.40	<0.0003	<0.003	79.2	<0.01	<0.005	13.5	6.46	<0.005	0.171
16	Wed 2/07	<0.01	26.1	6.52	0.060	0.005	84.1	<0.01	<0.005	15.9	6.45	<0.005	0.160
17	Thu 3/07	<0.01	23.1	3.59	<0.0003	0.002	72.3	<0.01	<0.005	12.9	6.93	<0.005	0.188
18	Fri 4/07	<0.01	21.9	3.44	<0.0003	0.006	63.5	<0.01	<0.005	12.3	6.25	<0.005	0.159
19	Sat 5/07	<0.01	21.1	4.42	0.012	<0.003	74.9	<0.01	<0.005	16.9	7.21	<0.005	0.208
20	Sun 6/07	<0.01	20.2	4.26	<0.0003	0.009	63.8	<0.01	<0.005	13.9	7.73	<0.005	0.213
21	Mon 7/07	<0.01	18.7	4.10	<0.0003	<0.003	47.7	<0.01	<0.005	14.6	7.28	<0.005	0.182
22	Tue 8/07	<0.01	18.2	3.45	<0.0003	<0.003	58.4	<0.01	<0.005	16.8	7.21	<0.005	0.176
23	Wed 9/07	<0.01	16.2	3.23	<0.0003	<0.003	42.7	<0.01	<0.005	14.0	6.70	<0.005	0.108
24	Thu 10/07	<0.01	21.6	4.02	<0.0003	<0.003	63.7	<0.01	<0.005	13.7	6.74	<0.005	0.180
25	Fri 11/07	<0.01	21.4	3.91	<0.0003	<0.003	79.0	<0.01	<0.005	12.6	6.76	<0.005	0.231
26	Sun 13/07	<0.01	22.5	3.85	<0.0003	<0.003	80.7	<0.01	0.005	16.1	7.69	<0.005	0.225
27	Tue 15/07	<0.01	20.9	4.40	<0.0003	<0.003	79.2	<0.01	<0.005	16.6	7.45	<0.005	0.183
28	Sat 28/06	<0.01	26.1	6.52	0.060	0.005	84.1	<0.01	<0.005	15.9	7.90	<0.005	0.180
Summer	Mean	0.543	9.46	3.10	0.033	<0.05	11.7	0.0221	0.0042	12.55	3.8	<0.05	0.172
	SD	0.138	0.625	0.177	0.004		0.976	0.0018	0.0028	1.068	0.180		0.031
Winter	Mean	<0.01	20.99	4.10	0.006	0.004	67.49	<0.01	<0.005	14.554	7.086	<0.005	0.183
	SD		2.54	0.86		0.001	13.23			1.575	0.492		0.029

Table 21: Evaluation of seasonal variation for sites 2 and 3

Two sample t-test assuming unequal variance

Ho: μ (summer) = μ (winter)
H1: μ (summer) ≠ μ (winter)

Assume $\alpha = 0.05$

Site 2	Al	B	Ca	Cr	Cl	Cu	F	K	Ni	Pb	TP	S	Zn	TKN	TDS	Na	TC
df	13	6	16	5	9	10	8	13	13	5	13	16	7	15	10	13	21
t Stat	-2.94232	1.06211	-3.92245	25.3038	-0.13939	-0.0597	4.484494	-4.74545	1.748125	2.8550	-1.81731	-6.9132	0.65176	2.145567	-7.122	-2.754	-2.559
P(T<=t) two-tail	0.011439	0.32905	0.00121	1.8E-06	0.89221	0.953571	0.002044	0.000383	0.104002	0.0356	0.092284	3.49E-06	0.535361	0.048682	3.21E-05	0.0164	0.018
t Critical two-tail	2.160369	2.44691	2.11990	2.57058	2.26216	2.228139	2.306004	2.160369	2.160369	2.5706	2.160369	2.119905	2.364624	2.13145	2.2281	2.160	2.08
Accept Ho?	Yes	Yes	No	No	Yes	Yes	No	No	Yes	No	Yes	No	Yes	No	No	No	No

Site 3	Al	B	Ca	Cr	Cl	Cu	F	K	Ni	Pb	TP	S	Zn	TKN	TDS	Na
df	25	23	19	12	14	16	12	22	10	9	24	25	19	24	25	16
t Stat	-0.57566	2.77384	-6.10147	14.2529	3.21122	3.247871	8.602457	-24.6944	40.38797	4.3330	-8.01859	-3.94906	-0.85284	0.401424	4.1080	-32.4501
P(T<=t) two-tail	0.56999	0.01080	7.24E-06	6.96E-09	0.00628	0.005044	1.77E-06	1.56E-17	2.07E-12	0.0019	3.03E-08	0.000565	0.404371	0.69166	0.0004	4.98E-16
t Critical two-tail	2.059539	2.06866	2.09302	2.17881	2.14479	2.119905	2.178813	2.073873	2.228139	2.2621	2.063899	2.059539	2.093024	2.063899	2.0595	2.119905
Accept Ho?	Yes	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No

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