



Characterisation of priority contaminants in residential wastewater

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EXECUTIVE SUMMARY

Context and purpose

Wastewater quality affects the lifetime of sewerage assets, the operation of wastewater treatment plants, and the beneficial reuse of biosolids and effluent.

Water conservation and reuse increase the need to understand and control elements in wastewater that impact biosolids reuse and effluent quality. Among these elements, water authorities have identified as priority parameters of interest: arsenic, antimony, boron, cadmium, copper, chromium, chloride, fluoride, iron, lead, mercury, molybdenum, nickel, nitrogen, phosphorus, selenium, sodium, tin, zinc, total dissolved solids and colour.

Whilst monitoring of trade waste is a routine activity carried by water authorities, less information is available on the contribution of domestic wastewater to contaminant loads reaching wastewater treatment plants. The quality of residential wastewater is directly linked to householder attitudes and water consumption patterns. A few studies have been carried out on metal contaminants in wastewater in Australia mainly in the 1990s.

Since that time, given the current climate of water restrictions and water demand management, households have been urged to decrease their potable water consumption and reuse grey water. The impact of such measures on the concentration of priority contaminants in wastewater is not yet known. Yet they could impact wastewater quality and flows, and its beneficial reuse.

This research aims to increase understanding of the characteristics of wastewater generated in a residential catchment subject to water restrictions. In particular it aims to describe investigations into how wastewater quality changes over time and how it compares with earlier studies in the literature.

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 to evaluate the relevance of the outputs from a Base case model to the current wastewater discharged in a Melbourne residential development. The Base case model will serve as the basis for the evaluation of contaminant reduction strategies in a future report.

Research method

A residential sub-catchment located in the South-East of Melbourne was monitored for flow and priority contaminants from the 24th February to the 27th March 2008.

The catchment selected was an enclave of 697 households built after the 1970s. The sewerage reticulation main is comprised mainly of vitrified clay and was subject to low infiltration.

Monitoring was conducted at three sampling locations within the sub-catchment, sites 1, 2 and 3, which received sewage from 7, 163 or 697 residential households, respectively. Monitoring was comprised of:

- (a) Week 1: Evaluation of the typical flow and wastewater levels;
- (b) Week 2: Equipment commission and verification of operating conditions;
- (c) Week 2-3: Collection of daily composite samples for inorganics and physical – chemical parameters such as metals, salts, colour, etc.
- (d) Week 4: Evaluation of hourly profiles over a 24 hour period.

In total, 11 and 12 diurnal composite samples were prepared for sites 2 and 3 for elemental analysis and 8 days of hourly profiles for sites 1 and 2. Flow and electrical conductivity were continuously monitored over the entire period.

Volumetric flow was monitored continuously in the sewer. Chemical composition was determined using samples collected from the 3 locations within the catchment as hourly composites and either analysed as received or combined into a daily composite sample. Wastewater was analysed for flow rate, conductivity, colour, metals and ionic species (arsenic, antimony, boron, cadmium, copper, chromium, chloride, fluoride, iron, lead, mercury, molybdenum, nickel, nitrogen, phosphorus, potassium, selenium, sulphur, sodium, tin and zinc), and total dissolved solids using standard methods. Colour was characterised as total and non-biodegradable colour.

The data obtained characterised the quality and flow conditions of the catchment in the current environment of 3a water restrictions under dry weather flow.

This report outlines the process of catchment selection, the monitoring procedure and the findings of the study.

Findings

Wastewater flow followed a typical diurnal curve with peak flows occurring from 5am to 8am and from 5pm to 8pm during the week. During weekends the morning peak flow occurred a couple of hours later in the day.

Wastewater in the catchment had mean pH values and corresponding standard deviations of 7.04 ± 0.22 , electrical conductivity of $870 \pm 59 \mu\text{S}/\text{cm}$ and 77 Pt-Co units of colour. Colour could be reduced on average by 37% following aerobic digestion, which is the basis for the treatment process adopted at the Melbourne Eastern Treatment plant.

The most significant increases in concentration from tap water to wastewater were verified for nitrogen, phosphorus, potassium, sulphur, chloride and sodium. Their average concentrations in wastewater were respectively 384, 41, 33, 7, 6 and 3 times those found in tap water.

On the other hand, the concentrations of contaminants such as antimony, arsenic, cadmium, cobalt, mercury, selenium, tin and molybdenum were below the limits of detection of current analytical instrumentation. Lead was detected in 76% of the samples at low concentrations and close to the detection limit ($0.5\mu\text{g}/\text{L}$).

Concentrations of boron, sodium and phosphorus were lower in this catchment and chromium, nickel and fluoride concentrations were higher than those reported in previous studies (Connor and Wilkie 1995 and CWW 2007).

Total dissolved solids was only 12% higher compared to studies conducted in Melbourne in 1995, but lower by 30% compared to a 2006-2007 study conducted in the west of Melbourne (CWW 2007).

The source of such discrepancy has not been ascertained, but it is hypothesized that either greater infiltration into sewer from groundwater took place in the Western study or that

household practices, e.g. diversion of washing machine grey water might be practiced in this catchment. Further investigation may be required.

Concentrations of individual elements changed from one day to another and from week to week. Part of the variability is attributed to the multitude of wastewater dischargers and also to the unpredictability of household wastewater quality.

The day of the week had no significant affect on the concentration of priority contaminants in the catchment. This is contrary to previous studies reported in the literature.

The concentrations changed during each hour of the day. Concentrations were higher in the hours from 5am to midnight. However, the concentration and load distribution during this period varied for each element.

For nitrogen and phosphorus the highest concentrations were observed in the morning, with 70% of the mass load of the contaminants entering the sewer in that period. These were attributed to human excretion. Whilst the concentrations of aluminium, iron copper, sodium, sulphur and zinc were more evenly distributed during the day, which indicates that their generation is likely to be associated with household activities. Variability was also observed across the different sites within the catchment, which was expected given the number of connections for each sampling site: 7, 163 and 697 connections.

Key findings

The majority of the contaminant concentrations were within a similar range to values recorded in earlier Melbourne studies (Connor and Wilkie 1995, CWW 2007).

Arsenic, antimony, cadmium, cobalt, mercury, selenium, tin and molybdenum were below the limits of detection, which is similar to results reported in the literature for earlier Melbourne studies.

Lead was detected at concentrations close to the detection limit of 0.5µg/L.

Boron, sodium and phosphorus were detected at lower concentrations;

Chromium, nickel and fluoride concentrations were detected at higher concentrations than those reported in the literature (Connor and Wilkie 1995 and CWW 2007).

Total dissolved solids in this catchment was only 12% higher compared to studies conducted in 1995, but 30% lower compared to a 2006-2007 study conducted in the west of Melbourne (CWW 2007).

Recommendations

This report provides a snapshot of the quality of wastewater in a domestic catchment.

To gain a greater understanding of the statistical significance of the data collected in relation to wastewater quality throughout the year, and to complete further investigations and to explore if any correlation between priority contaminants could be established over time, it is recommended that sampling time be extended into the future.

This could be achieved, for instance, by verification of quality during other seasons of the year, e.g. during wet weather flow, as during such times less diversion of grey water would be expected.

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NOMENCLATURE

ADWF	Average dry weather flow
Al	Aluminium
As	Arsenic
B	Boron
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
C_{tw}	Concentration in tap water
C_{ww}	Concentration in wastewater
Cu	Copper
DI	Ductile iron
DN	Nominal diameter
EC	Electrical conductivity
F	Fluoride
Fe	Iron
Hg	Mercury
ICP-AES	Inductively coupled plasma with atomic emission spectroscopy
ICP-MS	Inductively coupled plasma mass spectroscopy
K	Potassium
LL	Lower confidence limit
LOD	Limit of detection
μ	Mean
Mg	Magnesium
Mo	Molybdenum
Mn	Manganese
Na	Sodium
NBC	Non-biodegradable colour
Ni	Nickel
PE	Polyethylene
Pb	Lead
Pt	Platinum
PVC	Poly(vinyl chloride)
PWWF	Peak wet weather flow

Q	Volumetric flow in L/d
S	Sulphur
Se	Selenium
St.Dev	Standard Deviation
Sn	Tin
TC	Total colour
TDS	Total dissolved solids
TKN	Total Kjeldahl nitrogen
TP	Total phosphorus
UL	Upper confidence limit
uPVC	Unplasticised poly(vinyl chloride)
Z	Z-score
Zn	Zinc

1. INTRODUCTION

Wastewater quality impacts the lifetime of sewerage pipe assets, the operation of wastewater treatment plants, and the capacity for beneficial reuse of biosolids and effluent. Among the major quality parameters in wastewater, water authorities in Victoria have a particular interest in 'priority contaminants', i.e. substances that could endanger public health, cause damage to the sewerage system, adversely impact sewage treatment, the environment and/or prevent the recycling of effluent and biosolids. The contaminants of interest in this study are: 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.

Metals, such as copper, zinc, cadmium, lead, mercury and arsenic are partitioned into the sludge during wastewater treatment, and if present in sludge at higher than prescribed concentrations can prevent its beneficial reuse, condemning the biosolids to disposal at landfill.

Control of TDS and associated salts is essential for wastewater treatment plants to achieve the Victorian Government's targets for effluent reuse in irrigation and reduction in water consumption.

Nitrogen and phosphorus are essential nutrients for plant growth. Parameters such as boron, chloride, sodium and its ratio towards calcium and magnesium can impact soil and plant health.

Metals such as boron, copper, cobalt, iron manganese, molybdenum and zinc are essential micronutrients for plant health in trace amounts, but can cause plant toxicity at high concentrations. Whilst arsenic, cadmium, chromium, mercury, lead, tin and selenium can accumulate in plants and in higher organisms via the food chain.

Colour impacts the aesthetics of recycled effluent and the perception of customers receiving recycled water, and thus could influence their willingness to use recycled water.

Hence control of metal contaminants is required to facilitate reuse of biosolids and effluent from Melbourne's two major treatment plants. To understand how to better utilise and treat wastewater, it is important to understand the variation and changes in wastewater quantity and quality. The traditional wastewater service model is based on the collection of all wastewater streams (trade waste, domestic and commercial) at a centralised location for treatment. However, in recent years greater emphasis is being placed on alternative management strategies such as source control.

To increase the reuse of wastewater it is also necessary to understand the characteristics of wastewater and the origin of contaminants in it.

As rigour and control of trade waste limit industrial discharges to sewage, the contribution of non-industrial sewage streams (domestic wastewater, run-off and commercial wastewater), will come under increased scrutiny.

In countries such as the UK, the Netherlands and Sweden, control of air and trade waste emissions in the last 2 decades has resulted in significant reduction of heavy metals from industrial sources (Icon 2001). In Stockholm, Sweden, industrial sources contribute to less than 4% of the total heavy metal load reaching treatment plants (Mattson *et al* in Sörme *et al*

2003). In many instances, stormwater run-off and domestic sewage have been identified as the major sources for many metals such as copper, lead and zinc reaching treatment plants (Icon 2001, Gray and Becker 2002).

Domestic wastewater is recognised as the main source of the nitrogen load reaching wastewater treatment plants (Metcalf and Eddy 1998), but there is significant uncertainty in regards to the contribution of metal contaminants in domestic wastewater to treatment plants (Eriksson *et al*, Comber and Gunn 1996, Palmquist and Hanæus 2005, Rule *et al* 2006, Sörme and Lagerkvist 2002, Wilkie *et al* 1996).

Part of this difficulty stems from lack of data. Background levels are difficult to estimate and the characterisation of priority contaminants in domestic sewage is costly to monitor as sources are diffuse, concentrations low and subject to high variability and can also be impacted by diffuse sources such as stormwater run-off, exfiltration and infiltration.

A number of field studies have been conducted on the quality of wastewater collected in residential sewage networks 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). Studies conducted in Adelaide in 1994 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 as significant (Lock 1994).

Recent desktop assessments by Melbourne's water utilities suggest that domestic sewage contributes to a significant proportion of cadmium, mercury, copper, zinc 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 2006). However, significant uncertainty exists in the assessment of the loads due to the variability in concentration from day to day and the contribution from unaccounted sources to wastewater loads (TWRG 2005). Hence, further information is required on the true contribution from residential catchments.

Wastewater quality is complex and can be influenced by many factors, such as sampling location, lifestyle of residents, days of the week and sampling time. A few studies have attempted to investigate temporal variations in wastewater quality. For example, using Melbourne data collected in 1994 by Connor and Wilkie for a number of mixed catchments, Pantsar-Kallio *et al* observed higher concentrations of phosphorus and nitrogen during weekends and higher metal concentrations during weekdays (Pantsar-Kallio *et al* 1999).

Wilkie and colleagues (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, but high readings of lead, nickel and chromium were 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).

Changes in household water consumption and householder behaviour are also factors which can impact wastewater quality. In recent years, within a policy climate of water restrictions and water demand management, households have been encouraged to play a key role in water conservation. Media campaigns promoting shower head exchange, diversion and reuse of grey water to garden and showering with a bucket are examples of many strategies that householders have been encouraged to adopt in Melbourne. As a result, householder attitudes and water consumption patterns would have been expected to have changed since the 1990s, when the major studies were conducted in Australia. Yet how such changes have and will impact wastewater quality and flows are not yet clear. In particular, it remains to be verified if the trends observed in earlier studies are still applicable.

This research aims to gain a better understanding of the current wastewater quality and flow patterns generated in a domestic catchment in Melbourne under the climate of water restrictions and to develop a quality baseline for comparison with other studies.

The data generated will be used in a future study for calibration of models and scenarios regarding wastewater generation and the evaluation of strategies for future wastewater management.

Selection of the catchment was aimed to provide a representative sample of the residential population of Melbourne and its wastewater.

In selecting the catchment characteristics we aimed to incorporate the most common attributes observed across Melbourne for housing and household type, and population characteristics (income and age distribution of residents).

In selecting catchment scale the aim was to minimise the influence from non-household contaminant sources, such as commercial sources of wastewater and groundwater infiltration.

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. A brief summary of the overall project structure is shown in Figure 1.

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:

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

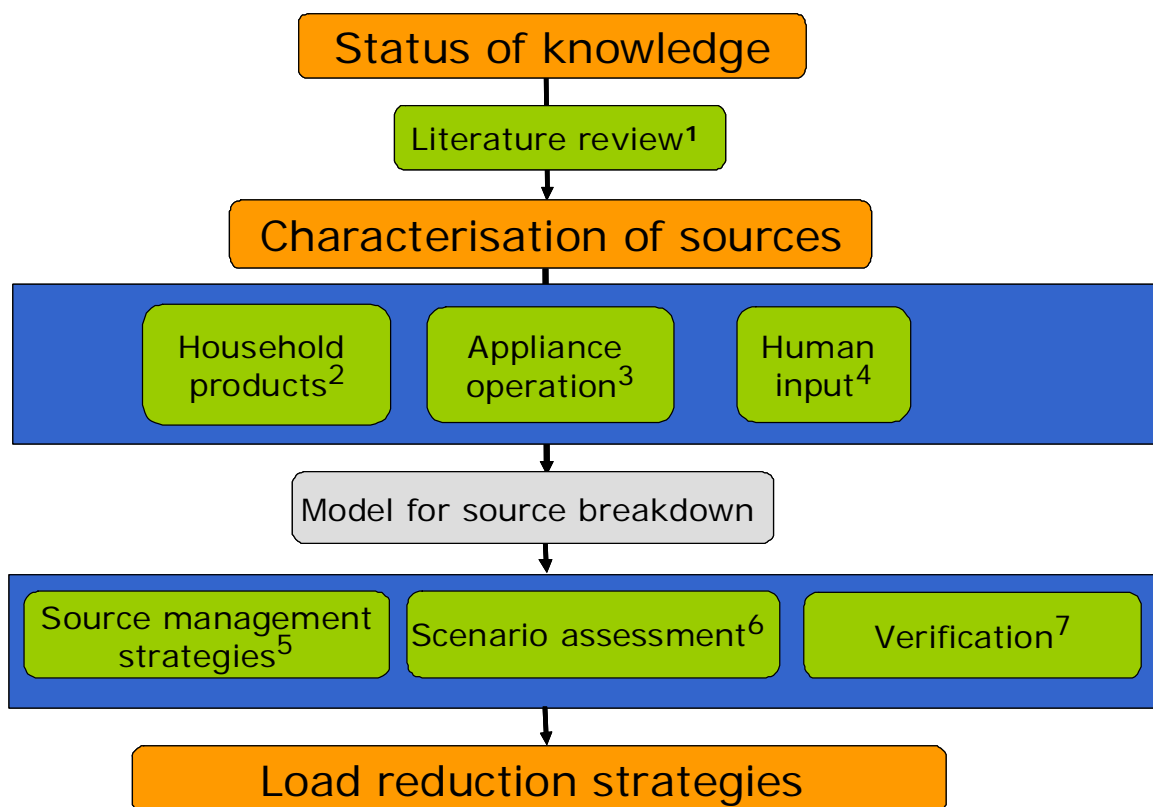


Figure 1: Summary of “Sources of contaminants in domestic wastewater” project

2. REPORT STRUCTURE

The report is structured as follows:

- (a) Section 1: Introduction
- (b) Section 2: Report structure – outlines the major sections of the report.
- (c) Section 3: Methodology - explains the process of catchment selection and experimental methodology including sample collection and analysis;
- (d) Section 4: Results – outlines the principles adopted in characterising wastewater in the catchment;
- (e) Section 5: Wastewater flow – describes the diurnal patterns of wastewater flow rate within the catchment;
- (f) Section 6: Impact of catchment scale – considers the influence of catchment size (scale) and days of the week on wastewater quality and quantity;
- (g) Section 7: Wastewater quality – explores the quality characteristics of wastewater from day to day and over 24 h in the catchment for the most abundant contaminants.
- (h) Section 8: Comparison with earlier Australian studies;
- (i) Section 9: Discussion;
- (j) Section 10: Conclusions;
- (k) Appendix A: Details of site installation;
- (l) Appendix B: Weather observations for Frankston during sampling period;
- (m) Appendix C: Flow profiles for sampling site 3;
- (n) Appendix D: Diurnal composites for site 2;
- (o) Appendix E: Analysis of standard deviation for TDS.

3. METHODOLOGY

This section details the methodology adopted for monitoring the flow volumes and the quality of wastewater from a residential catchment located in Frankston North during the period of February to March 2008. The monitoring was conducted during Melbourne's dry weather period.

In this part of the report, we detail the:

- Selection of catchments to make the results representative of residential wastewater discharge;
- Choice of equipment used;
- Design of the field monitoring procedure applied; and
- Analytical methods employed in the experimental program.

3.1. Catchment selection

The choice of catchments aimed to ensure that the wastewater monitored would be:

- (a) Representative of residential wastewater discharge only; i.e. without other sources of interferences, such as groundwater infiltration and non-residential wastewater such as trade or commercial waste; and
- (b) Characteristic of the largest population segments in Melbourne.

The population's socio-demographic characteristics, housing patterns in the greater Melbourne region and the implications to wastewater were summarised in Tjandraatmadja and Diaper (2007). The report established that the predominant housing characteristics in Melbourne were:

- (a) Detached housing – houses 74% of the population,
- (b) Average household size of 2.58 inhabitants in most areas, but inner Melbourne,
- (c) Families with children, couples and lone person households representing 35%, 22.9% and 22.3% of households, respectively, comprise the majority of household types and
- (d) Median income of households in the range of \$1180 to \$1416¹ per week.

These were considered the preferred socio-demographic traits in selecting a catchment.

Catchment selection also had to consider practicalities such as travel distance from the CSIRO laboratories.

As a result, a set of criteria were defined to guide the choice of catchments. These included:

- (a) Residential catchment with no trade waste customers or wastewater of medical origin, etc;
- (b) Average household income in the range of \$1148 to \$1416 per week, which is representative of the median income of majority of households in Melbourne (Tjandraatmadja and Diaper 2007).

¹ Average income of \$1000 to \$1200 per week in 2001 indexed for inflation.

- (c) Catchments with detached housing were preferable;
- (d) Sewer infrastructure made of consistent materials, preferably non-metallic to minimise the contribution from pipe corrosion;
- (e) Infrastructure constructed after 1970;
- (f) Sewer network of good condition grading and subject to low infiltration;
- (g) Preference given to gravity catchments.
- (h) Location in the southern suburbs to facilitate access to CSIRO laboratories.

Potential catchments for investigation were initially identified through evaluation of sewerage network data in collaboration with South-East Water Limited, the local water authority, based on criteria (a), (b) and (g). The shortlisted options were then characterised based on the remainder criteria and site inspections.

Sampling locations within a selected catchment also had to fulfil specific technical requirements. These included a specified number of connections, the location of manholes in easy to access areas (e.g. public land, nature strips), a minimum pipe size DN150 for the installation of sampling equipment, and sufficient flow for sample collection.

3.2. Selected Catchment

A suitable sub-catchment was identified in Frankston North along the Mornington Peninsula coastline. This was an isolated residential sub-catchment located to the north of Skye Rd. The catchment location and its major characteristics are outlined in Figure 2 and Table 1, respectively.

3.2.1. Household characteristics

The Frankston area is characterized by 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 residential zone 1 and 2. It was comprised of stand alone houses and no multi-dwelling developments were present in the area; thus each sewer connection was representative of one household.

3.2.2. Assets

The sewer network had been installed in two stages, from 1970 to 1979 and from 1980 to 1989. It was predominantly made of vitreous clay pipe, with small amounts of PVC, polyethylene (PE) and some ductile iron (DI) pipe after a pump station (SEWL 2006). The network had a condition grading 1, and it was subject to the lowest infiltration band (0-5L/m/d). Soil in the catchment was characterised as sandy, and therefore expected to have good drainage.

The sewerage was a gravity collection network, with one pressure main and a pump station located at Lanena Court.

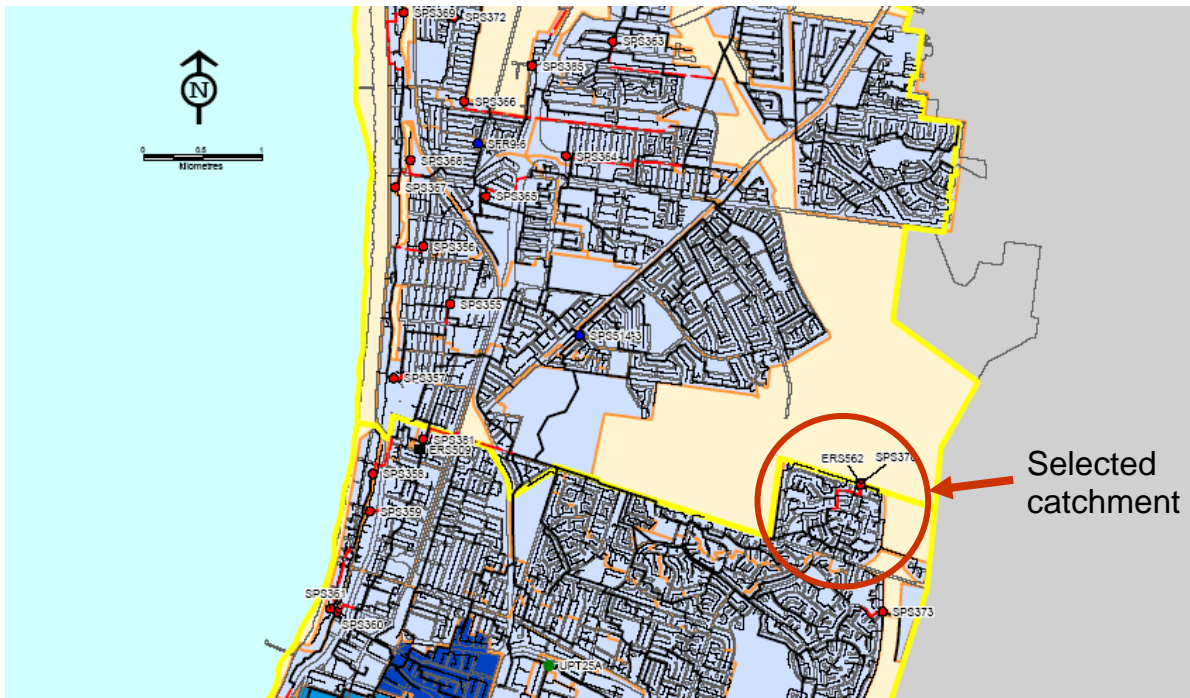


Figure 2 : Selected Catchment (SEWL 2006)

Table 1: Characteristics of selected network (SEWL 2006)

<i>Properties</i>	<i>Details</i>
Catchment type	Mainly gravity sewer, with the exception of 1 rising main.
Land use	Residential (R1Z and R2Z)
Pipe installation	1970 to 1979 and 1980-1989
Material	Vitreous clay, cast iron and ductile iron after pump station and small sections of polyethylene, PVC and uPVC
Pipe nominal diameter (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

3.3. Sampling sites

Three sites within the same catchment were selected as sampling points, each represented a progressively increasing number of connections to houses.

Suitable sites within the catchment were determined by the following factors:

- (a) Ease of access to manholes,
- (b) Suitable conditions for installation of monitoring instrumentation,
- (c) Good manhole condition; and
- (e) Minimal nuisance to residents in adjacent properties.

As a result, sampling sites were not necessarily linearly connected.

Three manholes were selected as sampling points:

- Site 1

The manhole was located on a nature strip over a Vitreous Clay DN 150mm pipe and received wastewater from 7 households. 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. Flow was intermittent during the day.

- Site 2

The manhole was located over a Vitreous Clay DN225mm pipe prior to entry into South East Water's SPS 378 pump station and collected the wastewater from 163 households. The sewer had 24h flow.

- Site 3

The manhole FGL57 was located on a public reserve over a Vitreous Clay DN 375 mm pipe which collected wastewater from 697 households. The sewer had 24h flow.

The relative position of the manholes is shown in Figure 3. Further details of the equipment installation at each manhole are described in appendix A.

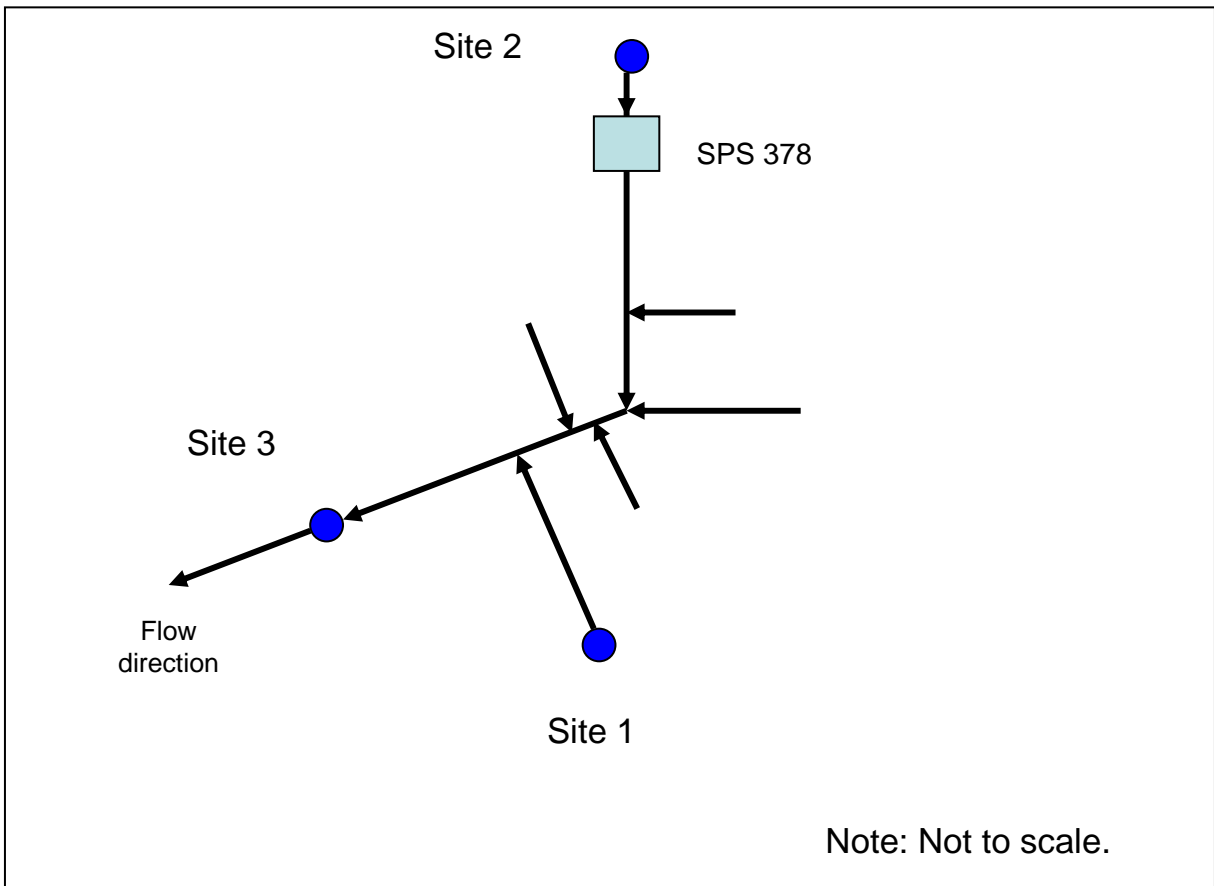


Figure 3: Diagram showing the relative position of sampling sites.

3.4. Experimental

Flow and conductivity were monitored continuously at each site using a flow meter and a conductivity meter connected to a data logger within each of the manholes. Wastewater samples were collected for evaluation of colour, total dissolved solids (TDS), pH, nutrients, and selected inorganic contaminants.

3.4.1. Sampling period

The sampling period for each site was distributed over 4 weeks. This included:

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

Unexpected events such as blockages in the line caused interruptions in the sample collection schedule. As a result samples were collected between the 22nd February to the 28th March 2008, but sampling dates varied for each of the sites.

Rainfall and air temperature data from the Bureau of Meteorology weather station were monitored to determine the impact of inflow and infiltration on the wastewater collected and

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

3.4.2. Flow evaluation

Equipment

ADS 3600 Flow and conductivity meter

Methodology

The flow and conductivity meters were installed and calibrated by ADS Environmental Services. Flow and conductivity were monitored continuously over the sampling period in 5 minute intervals and data was downloaded weekly.

3.4.3. Sample Collection

Equipment

Three automatic samplers were used, two Isco model 6712 and one Sigma model 9000. Autosamplers were fitted with a strainer at the end of the line and had twenty-four 1L disposable plastic bottles that were used for collection of wastewater for metal analysis. The typical set-up adopted is shown in Figure 4. Each autosampler was housed in a metal enclosure for protection against tampering (Figure 4).

Methodology

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.

Samples were collected as hourly composites. At site 1, between 0.5 to 1 L was collected every hour depending on available flow. At sites 2 and 3, 250mL were collected every 15 min to prepare an hourly composite. Hourly samples were combined to prepare a 24-hour daily composite based on their proportional contribution to the average diurnal flow rate profile at each site.

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 was sampled from garden taps located at sites 1 and 2. Water was allowed to run continuously for 5 min to flush the line, before a grab sample was collected using pre-conditioned bottles.



Figure 4: Autosampler installation at site 1

Sample Preservation

Samples were preserved according to requirements for each type of analysis as per standard methods for water and wastewater (APHA/AWWA 1998):

- (a) Total Metals by ICP-AES/MS (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);

3.4.4. Chemical Analysis

Elements

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 115 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

<i>Metal</i>	<i>Limit of detection LOD ICP-AES (mg/L)</i>	<i>Limit of detection LOD ICP-MS (µg/L)</i>
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	-

<i>Metal</i>	<i>Limit of detection LOD ICP-AES (mg/L)</i>	<i>Limit of detection LOD ICP-MS (µg/L)</i>
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. The sonde 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.

Conductivity was also measured in the sewer and also verified for samples as received in the laboratory with the sonde (accuracy $\pm 0.5\%$ of reading or ± 0.001 mS/cm with an operating range of 0 to 100 mS/cm).

True Colour

Total True Colour of samples as received was measured as Platinum-cobalt units (Pt-Co) after sample filtration (filter pore $0.45\mu\text{m}$ 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, i.e. the colour that remains after aerobic digestion of wastewater samples for 45min, was determined for a set of diurnal composite samples from one of the sites for comparison with total colour. Digestion was conducted at a NATA accredited laboratory according to Melbourne Water's method (Melbourne Water 2008).

Total Dissolved Solids

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

Nutrients

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

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

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 normalised using Z-scores. Where Z-scores are defined as:

$$Z \equiv \frac{(x_i - \mu)}{St.Dev} \quad \text{Equation (1)}$$

Where:

- Z = Z-score
- x_i = observed parameter
- μ = mean of the population
- St.Dev* = standard deviation of the population

4. RESULTS

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

- (a) Section 5: evaluates the wastewater flow in the catchment
- (b) Section 6: considers the influence of catchment size (scale) and days of the week on wastewater quality and quantity;
- (c) Section 7: explores the quality characteristics of wastewater from day to day and over 24 h in the catchment.
- (d) Section 8: compares the results from this study with the literature.

5. WASTEWATER FLOW

The flow profiles for the three sites were monitored between the 22nd February to the 28th March 2008. Monitoring in the initial week was used to determine the typical flow profile for the catchment.

The typical diurnal flow distribution profiles for that week, from Saturday to Friday, are shown for each of the respective catchments of 7, 163 and 697 connections in Figure 5, Figure 6 and Figure 7. As seen in Table 3, through the Z- scores, the majority of the peak and minimum flows on each day of the week at each site follows a normal data distribution ($-3 < Z < 3$), with the exception of site 1.

At site 1, the flow pattern of wastewater generated by 7 connections, was more sensitive to the influence of individual household discharges. Therefore, it was analysed separately, whilst the flow profiles for the other two sites were aggregated in the analysis.

(a) Sub-catchment of Seven households (site 1)

At site 1, the volume of wastewater generated was the lowest among the three sites. The mean, standard deviation and the median flow rates recorded in that manhole were 0.11L/s, ± 0.18 L/s and 0.07L/s during the sampling period.

Wastewater flows were spread over a 24h period with high flow occurring from 6am to 11pm. The period from midnight to 6am was characterised by the least flow on most days. Exceptions included Friday and Tuesday when a period of least flow was also observed in the afternoon (Table 3). The times of the minimum and maximum flows occurred at different hours in the day in this sub-catchment compared to the two larger ones.

A morning peak flow was typically observed between 6am and 8am, on most weekdays. In the weekend, the morning peak flows shifted by 1 to 2 hours later, occurring around 9am. In the afternoon and the evening, peak flows were recorded between 3pm and 6pm and between 8pm to 10pm on most days. Wednesday exhibited a peculiar flow pattern and provided the highest flow rate (1.5L/s) for the week (Figure 5).

The times of the maximum peak flow for the day varied for each day of the week, being respectively 10pm, 1am, 8:30pm, 1am, 11pm, 8am and 12pm from Monday to Sunday.

(b) Multiple households (sites 2 and 3)

Wastewater flowed continuously over the 24h period through the sewers at sites 2 and 3, these corresponded to the larger catchments of 163 and 697 connections. The typical flow

profiles for these sites are illustrated in Figure 6 and Figure 7. Actual flow readings for site 3 are shown in Appendix C and were consistent from week to week.

The period of least flow was from midnight to 4am, when majority of the population would be asleep (Table 3). The flow profiles for weekdays, Monday to Friday, followed a common pattern with maximum flows occurring at approximately 6am in the morning and a broader evening peak registered between 5pm to 8pm. These periods coincide with the wake up and start of the day and the end of the working day, i.e. return from school/work and evening meal.

During the weekend, the flow peaked between 7am to 10am, reflecting the fact that residents tend to rise later and often at different times. However, evening peak flows occurred at equivalent times during both weekend and weekdays.

Analysis of data variability using 'Z' factors in Table 3 confirms that the largest deviation from the maximum and minimum flows occurred during the weekend. Yet the data distribution was still within 2 standard deviations (98% confidence limit).

The mean flow rate observed during the full sampling period for site 2 was 0.64L/s (Stdev \pm 0.47) and the median was 0.57L/s. Whilst at site 3 the mean flow rate was 3.29 L/s, but the standard deviation was larger (\pm 2.32L/s) and the median was 2.60L/s.

Table 3: Analysis of maximum and minimum flow periods

		<i>Fri</i>	<i>Sat</i>	<i>Sun</i>	<i>Mon</i>	<i>Tue</i>	<i>Wed</i>	<i>Thu</i>
	<i>Number of house holds</i>							
		22/02	23/02	24/02	25/02	26/02	27/02	28/02
Time of minimum flow (h)	7	13:50	5:40	5:35	2:55	15:15	3:35	3:05
	163	3:20	3:25	3:50	1:00	3:05	2:15	0:20
	697	2:00	3:05	4:05	2:00	2:10	2:10	2:45
Time of maximum flow (h)	7	23:10	8:10	11:50	22:10	7:10	20:30	1:05
	163	6:40	9:20	8:50	6:50	6:45	17:30	6:55
	697	9:40	9:25	9:15	9:40	7:30	8:40	7:00
Maximum Q (as %Qd)	7	12.07	24.51	10.09	9.00	10.98	18.57	15.16
	163	8.20	11.42	7.87	8.48	8.36	7.88	9.16
	697	6.78	7.87	7.55	6.63	7.36	7.04	7.08
Z of Q Max (≤ 2.5)	7	2.78	4.19	2.00	1.87	2.96	3.15	3.17
	163	-0.46	2.13	-0.72	-0.23	-0.33	-0.71	0.31
	697	-0.94	1.57	0.84	-1.28	0.40	-0.33	-0.25
Q Minimum (as %Qd)	7	0	0.62	0.04	0.61	1.84	0.18	1.29
	163	0.64	0.78	0.46	0.87	0.65	0.77	0.74
	697	0.76	0.90	0.95	0.93	0.59	0.83	0.79
Z of Q Min (≤ 2.5)	7	-1.466	-0.731	-1.392	-1.374	-1.012	-0.872	-0.830
	163	-0.48	0.61	-1.83	1.25	-0.36	0.52	0.28
	697	-0.48	0.63	1.02	0.89	-1.87	0.05	-0.23

Note: Q – volumetric flow (L/d), Qd – Daily volumetric flow (L/d).

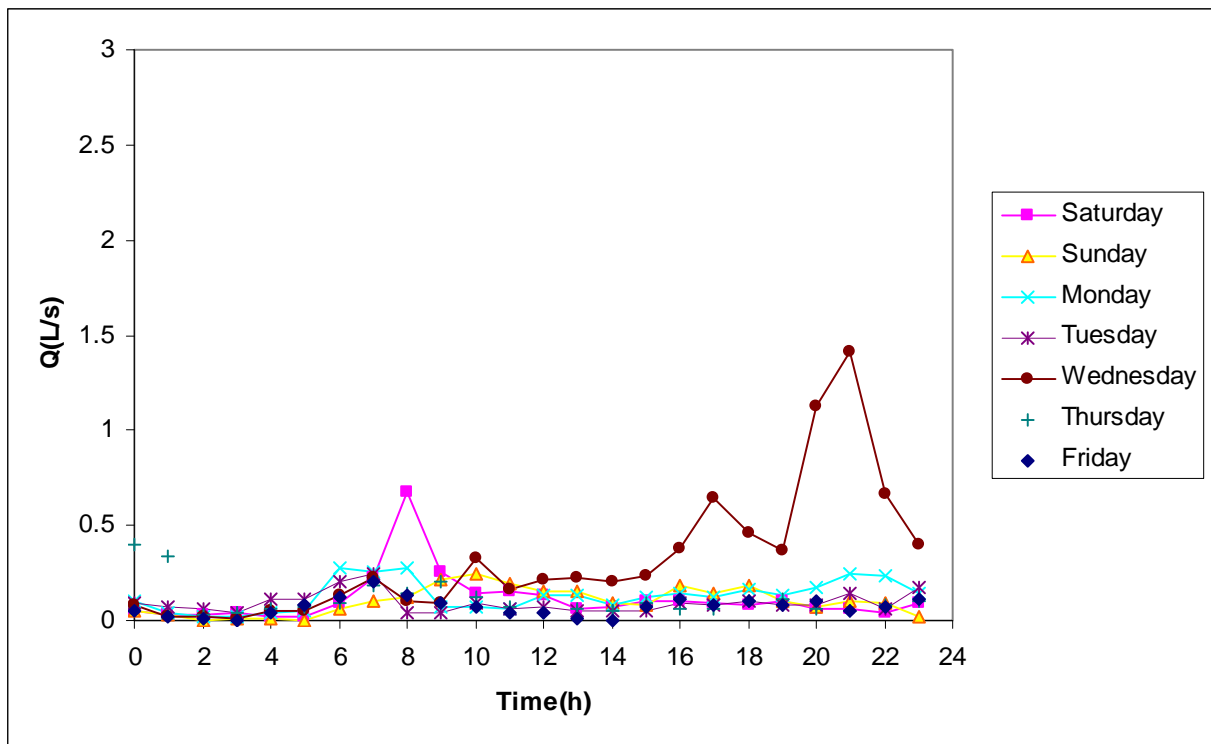


Figure 5: Diurnal flow profile for 7 households (22-28 Feb 2008)

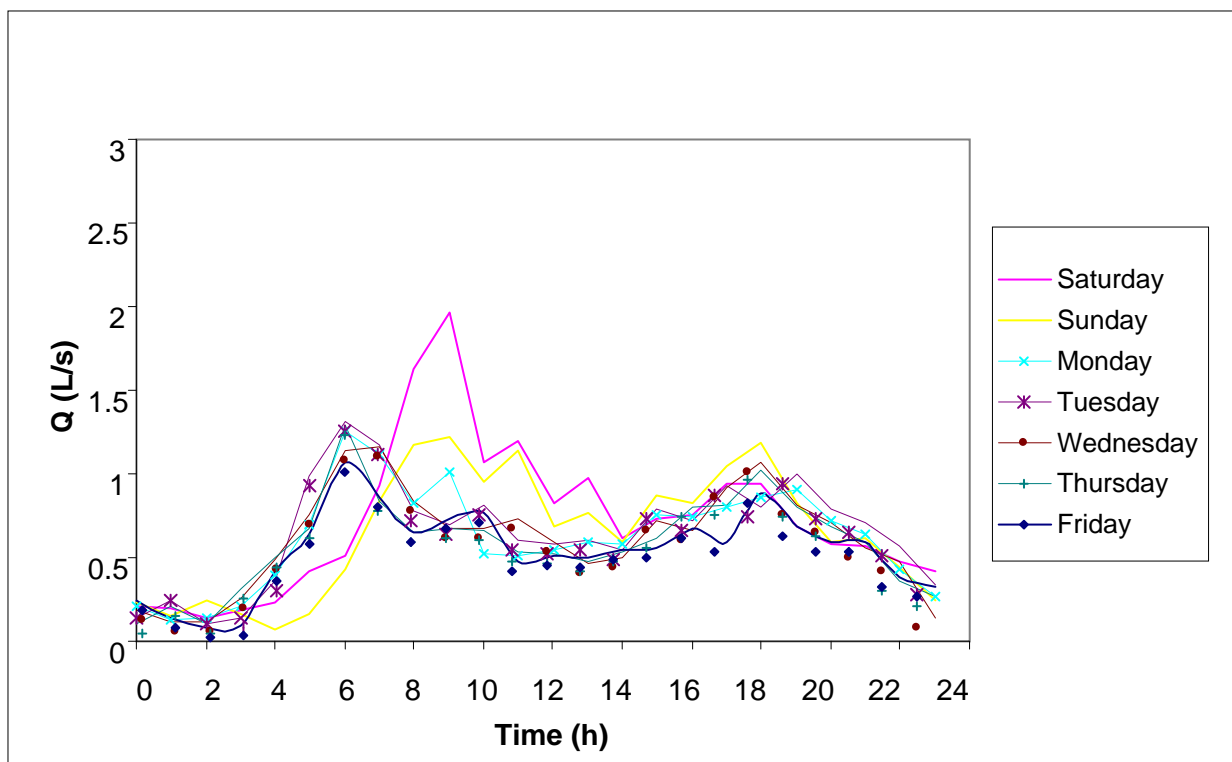


Figure 6: Diurnal flow profile for 163 households (22-28 Feb 2008)

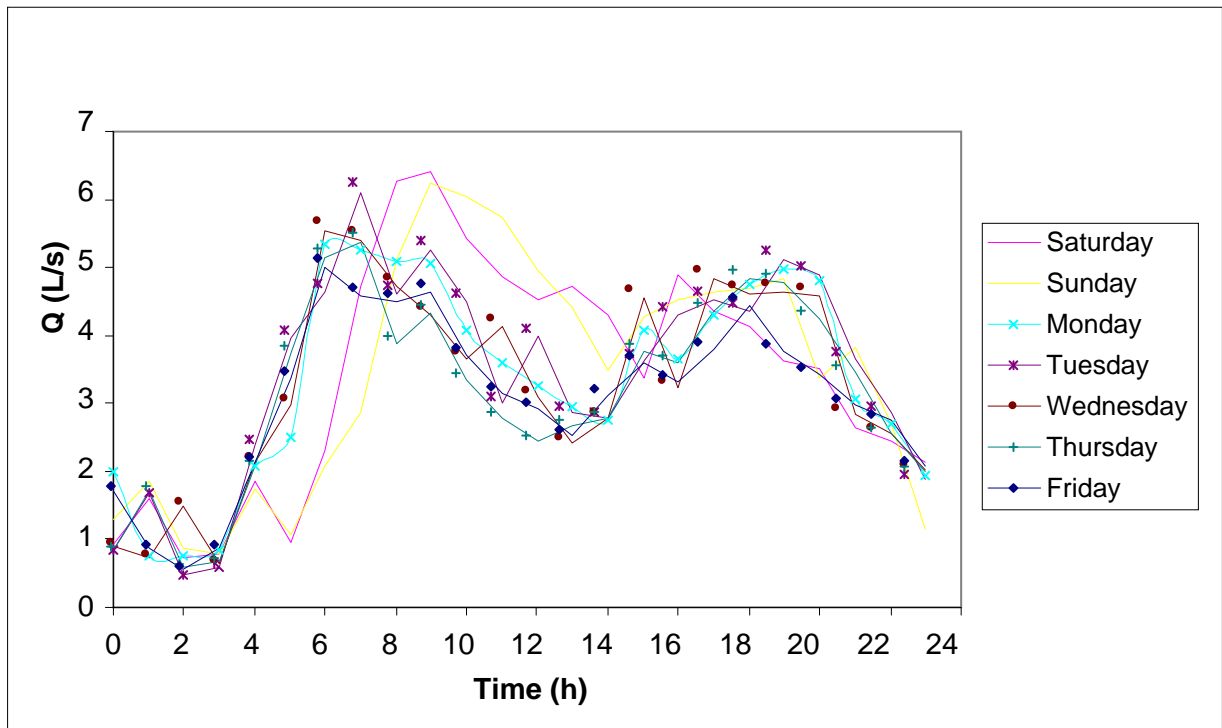


Figure 7: Diurnal Flow profile for 697 households (22-28 Feb 2008)

6. IMPACT OF CATCHMENT SCALE

Scale of a catchment, i.e. the number of connections discharging into sewer, impacts the flow rate and the shape of the volumetric flow profile.

The larger catchment, site 3, was characterised by larger flow rates than sites 1 and 2 as would have been expected (Figure 6 and Figure 7). For instance, in the week from the 22-28 February, the volumetric flow for the larger catchment was approximately three times that of the smaller one, i.e. the maximum flow was 6.2L/s for 697 connections compared to 2L/s for 163 connections.

The increase in number of connections resulted in attenuation of the peaks and troughs in the diurnal wastewater profile.

The diurnal patterns for sites 1 (7 households), 2 (163 households) and site 3 (697 households) in Figure 8, Figure 9 and Figure 10 show the relative contribution of the hourly discharge to the total daily flow. The relative flow, shown as a percentage of the daily flow, follows a similar pattern at the two larger scales. However, the contribution during the peak periods became less pronounced as the number of connections increased from 7 to 697 connections.

During peak flow the contribution to the daily flow ranged from 7.8% to 11.5% for 163 households and between 6.6% to 7.9% for the larger catchment of 697 households. Whilst in the 7 households catchment these peak contributions were more pronounced, representing between 5% to 25% of the daily flow (Figure 8, Figure 9, Figure 10).

Minimum flows contributed to less than 1.5% of the daily flow (Table 3). No significant outliers were detected as observed by the Z-scores for such periods. However, Saturday, showed the largest residual from the average flow for the three sites with Z-scores being respectively 4.2, 2.1 and 1.6 standard deviations for sites 1, 2 and 3.

The relative flow profiles for site 3 (697 households) were also compared to the historical flow profile for Frankston North determined between September to December 2004 shown in

Figure 10 (SEWL 2006). Whilst occurring during equivalent periods of the day, the flow contribution of the morning peak in 2008, as a percentage of daily flow, was 4% lower than in 2004. This is likely to be an indication of reduced water consumption by residents.

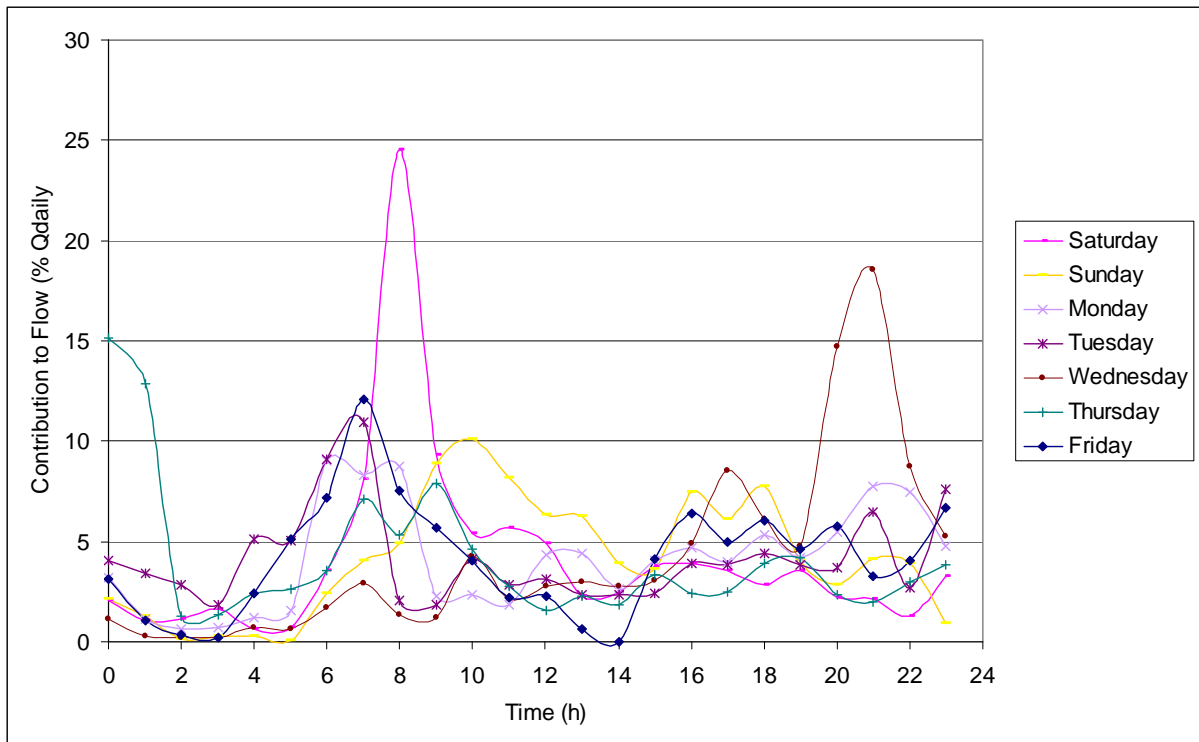


Figure 8: Diurnal profile for sub-catchment (7 households) in February 2008.

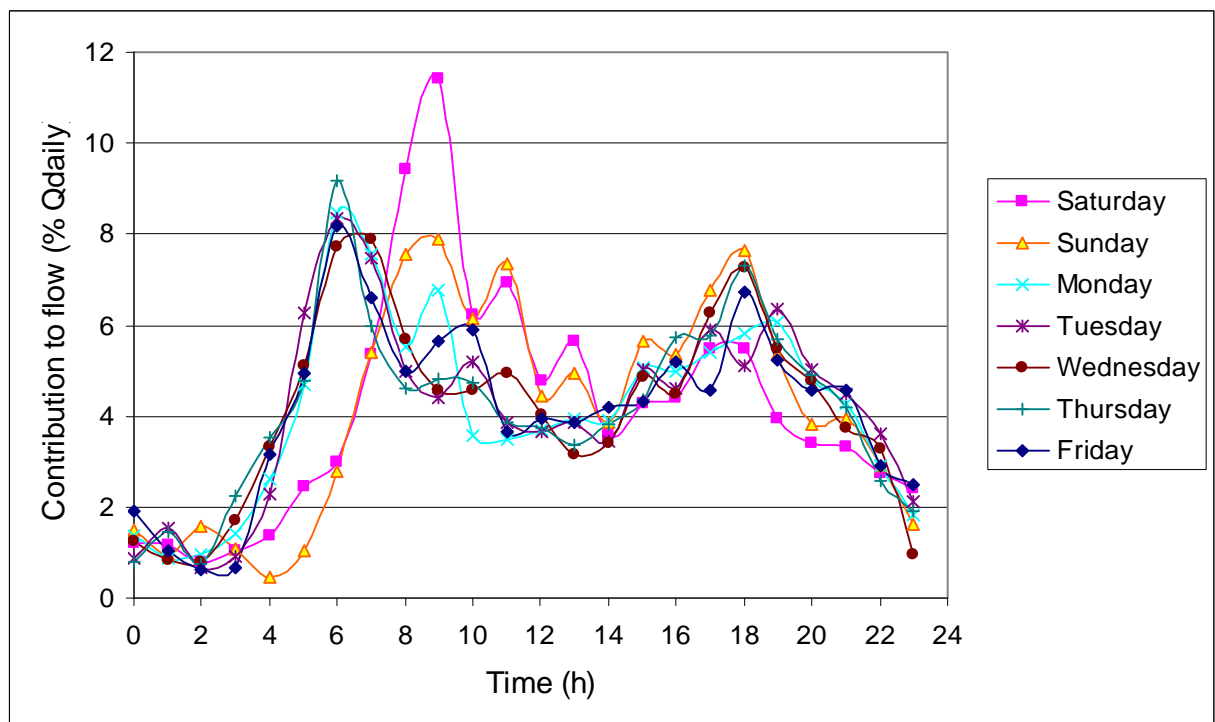


Figure 9: Diurnal flow profile for sub-catchment (162 households) in February 2008.

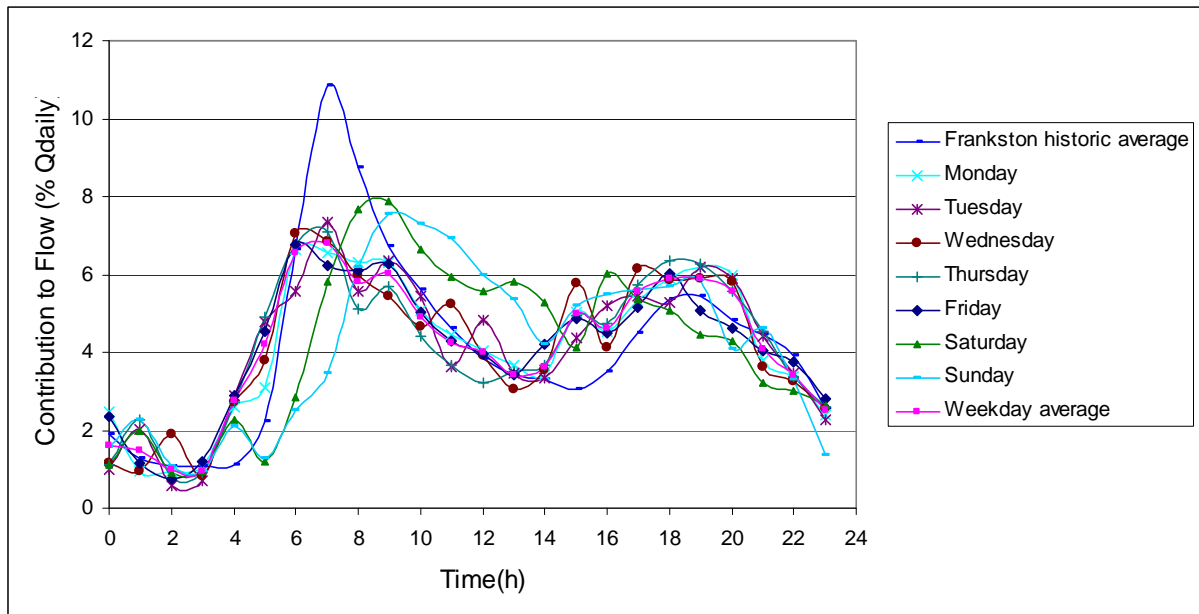


Figure 10: Diurnal profile for sub-catchment (697 households) in February 2008

7. WASTEWATER QUALITY

This section characterises the wastewater quality in the catchment during the period of February to March 2008. Parameters monitored included pH, conductivity, colour, TDS and specific elements such as As, B, Cl, Cr, Cu, Cd, Fe, F, Pb, Hg, Mo, Ni, Na, Se, Zn, TKN and TP. In addition parameters such as Al, K, Mg and S were also monitored for comparison.

Changes in quality that occur with time were monitored by two methods:

- (a) From one day of the week to another, using twenty-four hour composite samples; and
- (b) On an hourly basis, over a period of 24h, for selected parameters.

The twenty-four hour daily composites were used to evaluate the daily characteristics of wastewater and to compare changes in wastewater quality through the week from one day to another.

Technical problems including line blockages restricted the number and timing of samples that could be collected. Line blockages were caused by occasional deposition of fat, dirt and fibres at the strainer. They were unblocked by flushing the line and/or by manual removal of the debris. Incomplete sample collection runs over 24h which were interrupted by blockages were not used for preparation of sample composites and discarded.

In total 11 composites for site 2 and 12 composites for site 3 were collected.

Comparison of the timing and concentration profiles for the different contaminants can aid in the identification of major activities associated with their generation. Therefore, the hourly concentration of selected parameters was monitored to gain a greater understanding of their pattern of release throughout a 24h period. Due to cost constraints the hourly characterisation was carried on a selected set of samples only.

7.1. Physical-chemical characteristics

Selected physical-chemical characteristics 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 a set of 10 samples from site 2 (163 households). For comparison of variability, samples were taken randomly during the period from 24/02 to the 17/03.

The total true colour of the wastewater composites ranged between 60 to 100 Pt-Co units, with an average of 77 Pt-Co units. Whilst the non-biodegradable colour, i.e. the colour that remains after the sample is aerobically digested for a set period to simulate the Melbourne Eastern Treatment Plant process, was on average 50 Pt-Co units. The respective standard deviations of the samples were $\pm 18\%$ and $\pm 25\%$ for total and non-biodegradable colour.

Hence, the aerobic digestion contributed to a reduction in colour between 13% to 50% of the original colour in wastewater. However, the non-biodegradable colour readings were also subject to large data variability. As seen in Figure 11 and Table 4, the correlation between the total and biodegradable colour is not high (covariance factor = 0.42). The change in colour was not constant for samples collected on different days of the week, e.g. -13% and -17% change for a Saturday and a Monday, and neither for samples collected on the same day of the week, but on consecutive weeks, e.g. -38% and -28% for two Wednesdays.

This indicates that not all compounds in domestic wastewater responsible for colour formation are susceptible to aerobic degradation, and furthermore that the concentration of coloured compounds in wastewater varies from one day to another.

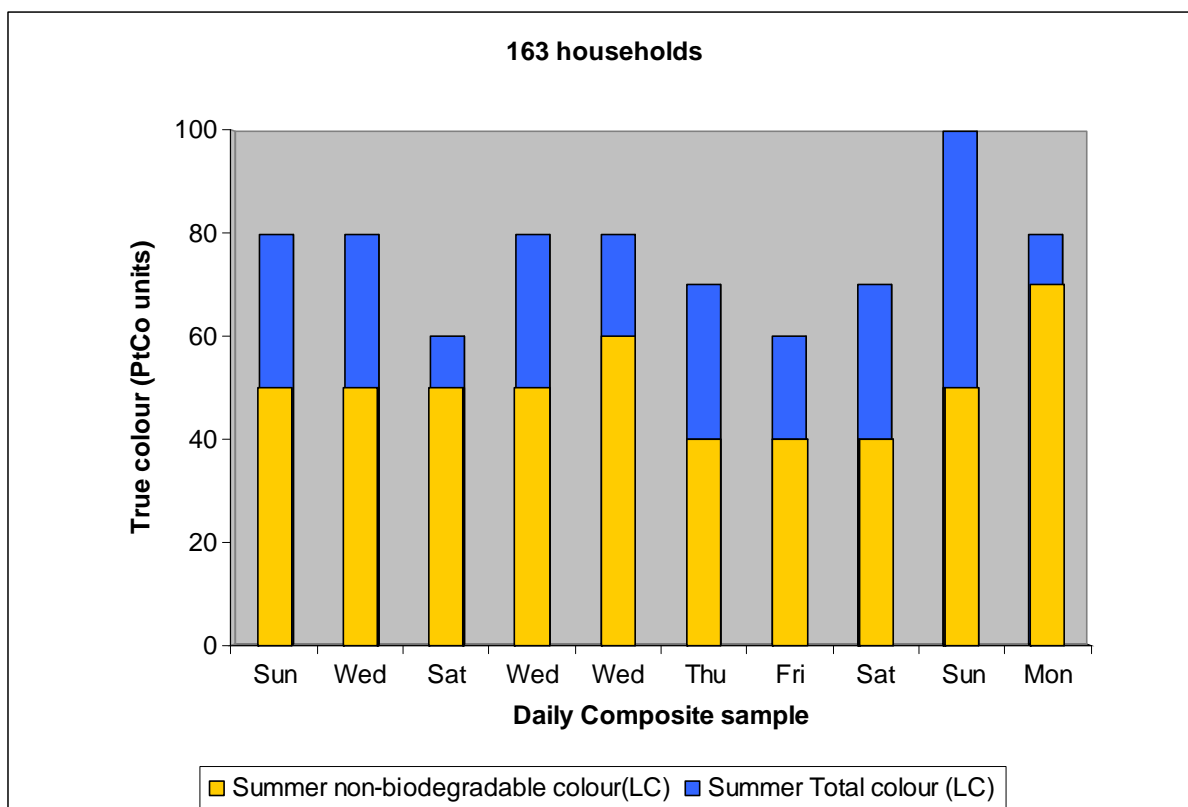


Figure 11: Total and non-biodegradable colour for composite samples from site 2 (163 households).

Table 4: Analysis of colour data for site 2.

	True Colour (PtCo units)			Z-scores		
	Pre-digestion Total (TC)	Post-digestion Non-biodegradable (NBC)	Colour change (NBC-TC). NBC ⁻¹ (%)	Z _{TC}	Z _{NBC}	Z _{change}
Sun 24/02	80	50	-38	0.24	0	-0.22
Wed 27/02	80	50	-38	0.24	0	-0.22
Sat 01/03	60	50	-17	-1.22	0	1.28
Wed 05/03	80	50	-38	0.24	0	-0.22
Wed 12/03	80	60	-25	0.24	-0.79	0.68
Thu 13/03	70	40	-43	-0.49	-0.79	-0.61
Fri 14/03	60	40	-33	-1.22	-0.79	0.08
Sat 15/03	70	40	-43	-0.49	-0.79	-0.61
Sun 16/03	100	50	-50	1.71	0.00	-1.13
Mon 17/03	80	70	-13	1.58	1.58	1.59
Average	77	50	-34			
StDev	13.7	12.6	14			
Upper (90%CL)	99	71	-12			
Lower (90%CL)	54	29	-57			
Correlation factor	0.402					

7.1.2. pH

Tap water in the catchment had a mean pH of 7. The pH of wastewater composites ranged between 5.9 to 9.3 across the 3 sites, with mean pHs of 6.81, 7.02 and 7.04 for each of the sites 1, 2 and 3, respectively, as shown in Table 5.

The variability in the pH measurements is reflected in the standard deviation values shown in Table 5 and further illustrated in Figure 12, which displays the pH variation during a one week period for site 3 (697 households). Figure 12 shows the pH of each 24-hr composite sample, the mean conductivity for the sampling period and the 95% confidence upper (UL) and lower (LL) limits.

The pH varied on a day to day basis for the period of the 11/03 to 27/03. As shown in Figure 12, on the 11/03 and the 13/03 the pH was greater than 7.2. In the week of the 14/03 to the 17/03 the pH varied from 6.6 to 6.8 and was over 7 on the 26/03 and 27/03.

Variance in pH was also observed from one week to another, with equivalent days of the week displaying different pH values, although the readings were still within the 98% confidence limit. For instance, on Tuesdays 11/03 and 18/03 the pH values were 7.22 and 6.78 and on the Thursdays 13/03 and 27/03 they were 7.4 and 7.07. Therefore no specific correlation could be determined between pH and days of the week.

The standard deviation of the samples decreased as catchment size increased. As seen in Table 5, the lowest standard deviation ± 0.26 was recorded for the largest catchment of 697 connections.

Table 5: Summary of Wastewater pH for Feb-Mar 2008.

Number of households	pH					
	Mon-Fri		Weekend		Week	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
7	6.81	0.33	6.75	0.36	6.84	0.33
163	7.02	0.48	6.78	0.27	6.95	0.44
697	7.04	0.22	6.64	0.06	6.93	0.26

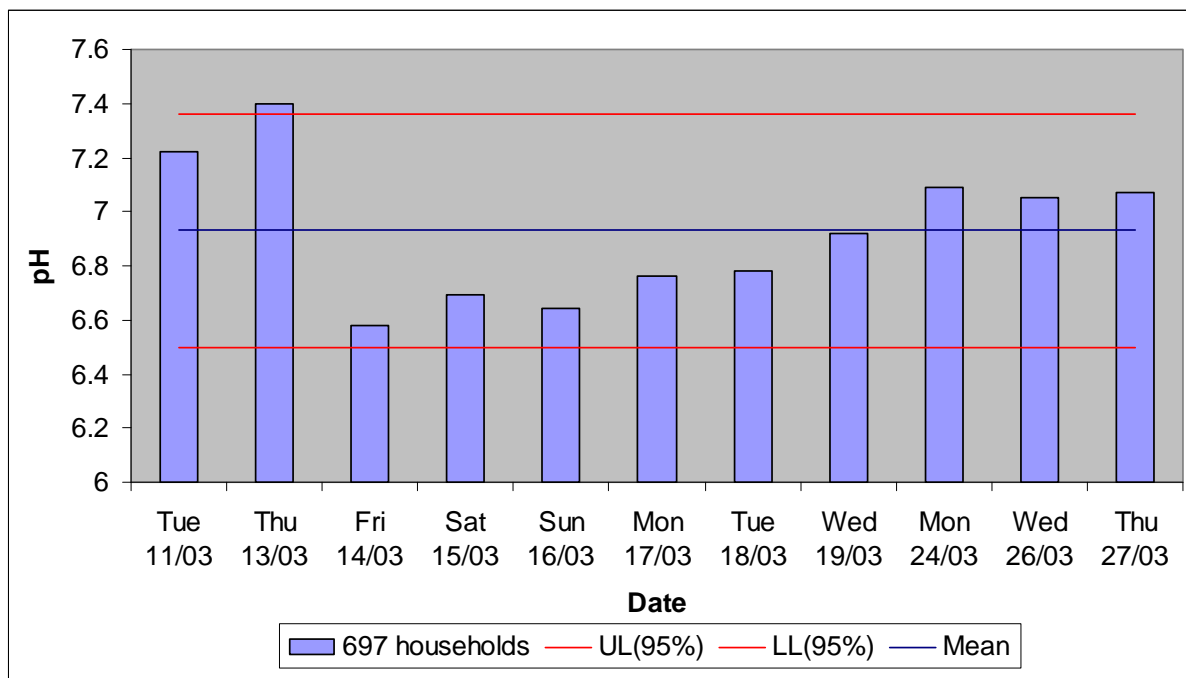


Figure 12: pH for site 3 (697 households)

7.1.3. Electrical conductivity

Tap water in the catchment had a conductivity of $59.9 \pm 4.1 \mu\text{S/cm}$, whilst wastewater displayed a much higher conductivity.

The wastewater conductivity (EC) varied with the time of the day, the days of the week and specific dates. A summary of the data for the catchment is shown in Table 6 and Table 7.

In composite samples, EC ranged from 290 to 1822 $\mu\text{S/cm}$, with mean EC values of 980, 777 and 870 $\mu\text{S/cm}$ for sites 1, 2 and 3 as shown in Table 5.

The changes in EC from one day to another are exemplified in Figure 13 for site 3. It shows the conductivity of each 24-hr composite sample, the mean conductivity for the sampling period and the 95% confidence upper (UL) and lower (LL) limits.

In this case, EC increased from 796 $\mu\text{S/cm}$ on the 11/03 to more than 990 $\mu\text{S/cm}$ in the week of the 24/03.

The highest EC reading for the composites at site 3, 990 $\mu\text{S/cm}$, was recorded on the Easter Monday holiday 24/03. The EC variation between that date and the previous Monday was 2.4 standard deviations. Hence it would seem plausible to assume the higher EC may be caused by additional cleaning/washing following the long weekend and in preparation for the working week.

Overall, considering the standard deviation and the variance in EC readings on the different dates, no trends in EC changes could be established with days of the week, weekends and weekdays.

The variation in conductivity over a 24h period is exemplified in Table 7 and Figure 14. Table 7 displays the summary of EC readings recorded at 5min intervals in the sewer at each of the three sites for the 4 week period. The EC varied from 188 to 2150 μ S/cm, a wider range compared to composite samples as more severe differences would be expected on over a 24h period.

Figure 14 compares the mean conductivity based on time and day of the week for site 3. In general, a higher conductivity reading was observed 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.

Sunday was in general the day when the highest conductivity value was observed in the week.

Table 6: Summary of wastewater conductivity for composites from Feb-Mar 2008

<i>Number of households</i>	<i>EC for diurnal composites (μS/cm)</i>					
	<i>Mon-Fri</i>		<i>Weekend</i>		<i>Week</i>	
	<i>Mean</i>	<i>St.Dev.</i>	<i>Mean</i>	<i>St.Dev.</i>	<i>Mean</i>	<i>St.Dev.</i>
7	993	199.7	943	159	980	191
163	778	216	793	215	777	222
697	878	69	848	13	870	59

Table 7: Summary of sewer conductivity over 24h.

<i>Number of households</i>	<i>EC readings over 24h (μS/cm)</i>			
	<i>Mean</i>	<i>St.Dev.</i>	<i>Median</i>	<i>Range</i>
7	978	192	990	188-1542
163	977	291	940	340-2150
697	782	82	780	530-1300

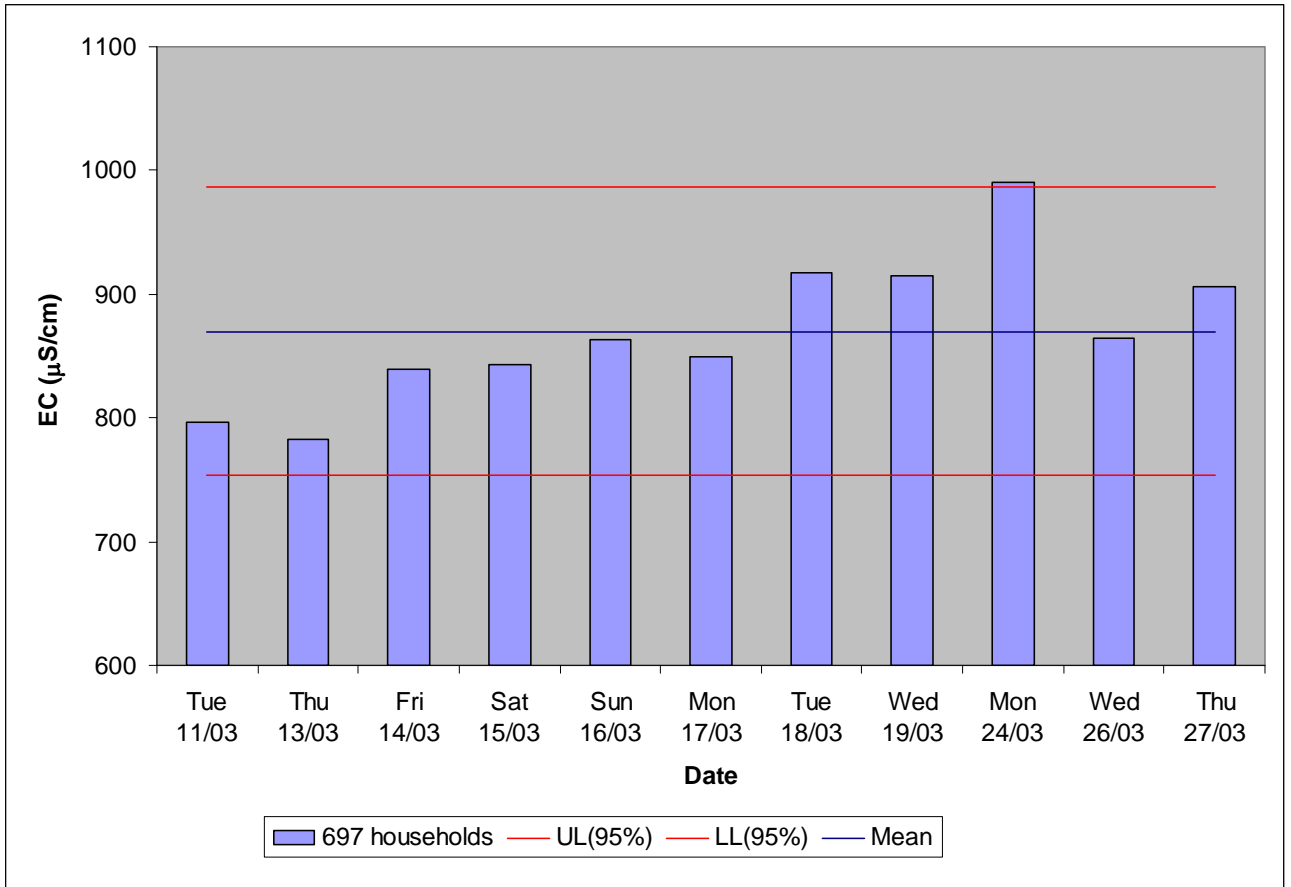


Figure 13: Conductivity at site 3 (697 households)

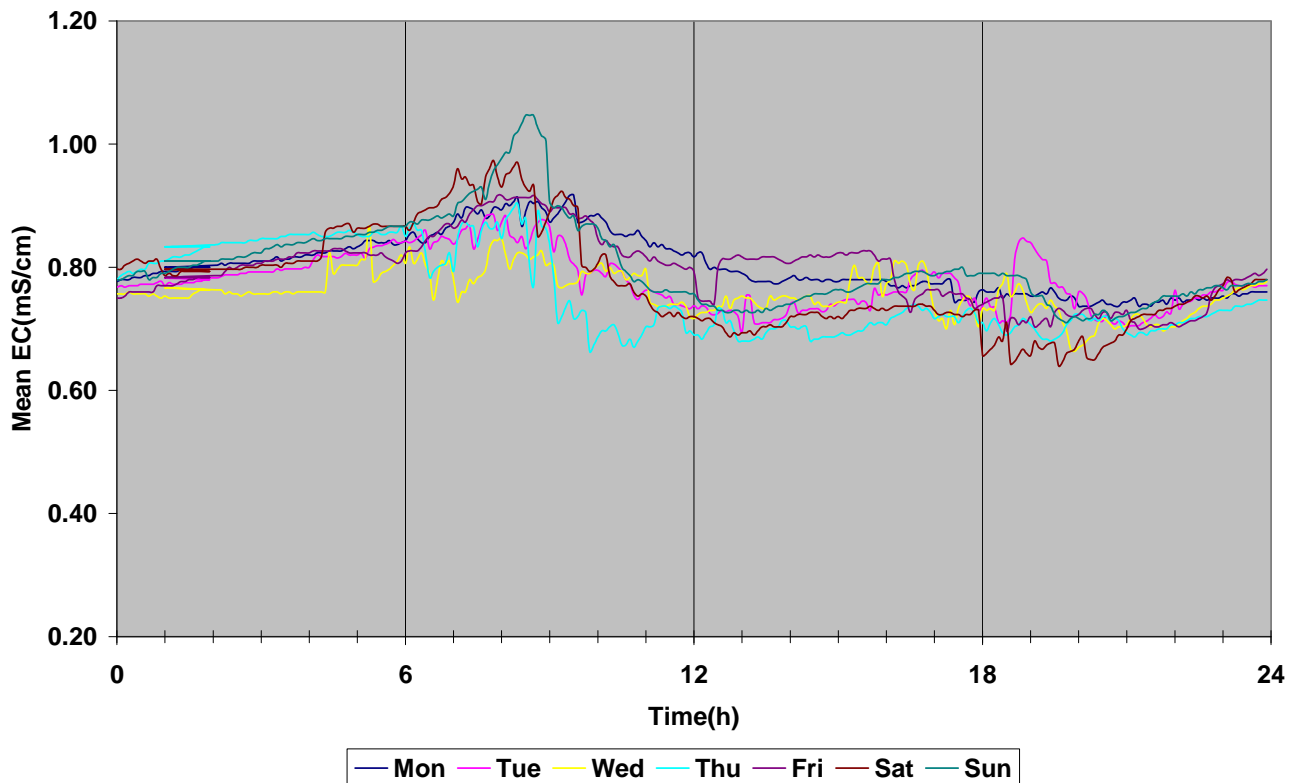


Figure 14: Mean sewage conductivity during 26 Feb to 18 March 2008 for 697 households.

7.1.4. Total Dissolved Solids

Total dissolved solids (TDS) concentrations were determined for composite samples collected over 24h and also for samples collected every hour through a day.

Tap water in the catchment had a TDS concentration of 54.8mg/L \pm 4.8 mg/L, whilst the TDS in wastewater was on average 6 times higher.

Composites

TDS concentrations were evaluated for daily composites of wastewater collected over 6 days from site 2 and 11 days from site 3. Site 1 was excluded from composite analysis and instead analysed on an hourly basis due to the high variability in flow and concentrations from one day to another.

The TDS in wastewater composites was within the range of 287 to 492 mg/L, with a mean TDS of 419.3 \pm 109.4 mg/L. Individual sites had similar TDS means, 420.7 \pm 54.6 mg/L for 163 households (site 2) and 418.6 \pm 47.4mg/L for 697 households (site 3). Hence, the TDS concentration showed little dependency on catchment scale.

A lower standard deviation was observed for composites compared to hourly samples.

In the observed period, the highest TDS concentration was measured on a Wednesday (492mg/L) at site 2 (Figure 15). Whilst at site 3 the highest TDS readings (490 and 492 mg/L) were recorded during the weekend (Figure 16).

Based on such values, the typical household in the catchment would discharge on average 0.16kg TDS/day as shown in Table 8. Loads estimated for individual sites were 0.13kg/day/household for site 2 and 0.17kg/day/household for site 3.

Table 8: Estimated TDS load in the catchment for Feb-Mar. 2008

<i>Number of households</i>	<i>Mean TDS load (kg/hh/d)</i>	<i>St.Dev</i>	<i>LL(95%)</i>	<i>UL(95%)</i>
167	0.13	0.01	0.11	0.15
693	0.17	0.02	0.13	0.21
All readings	0.16	0.03	0.10	0.22

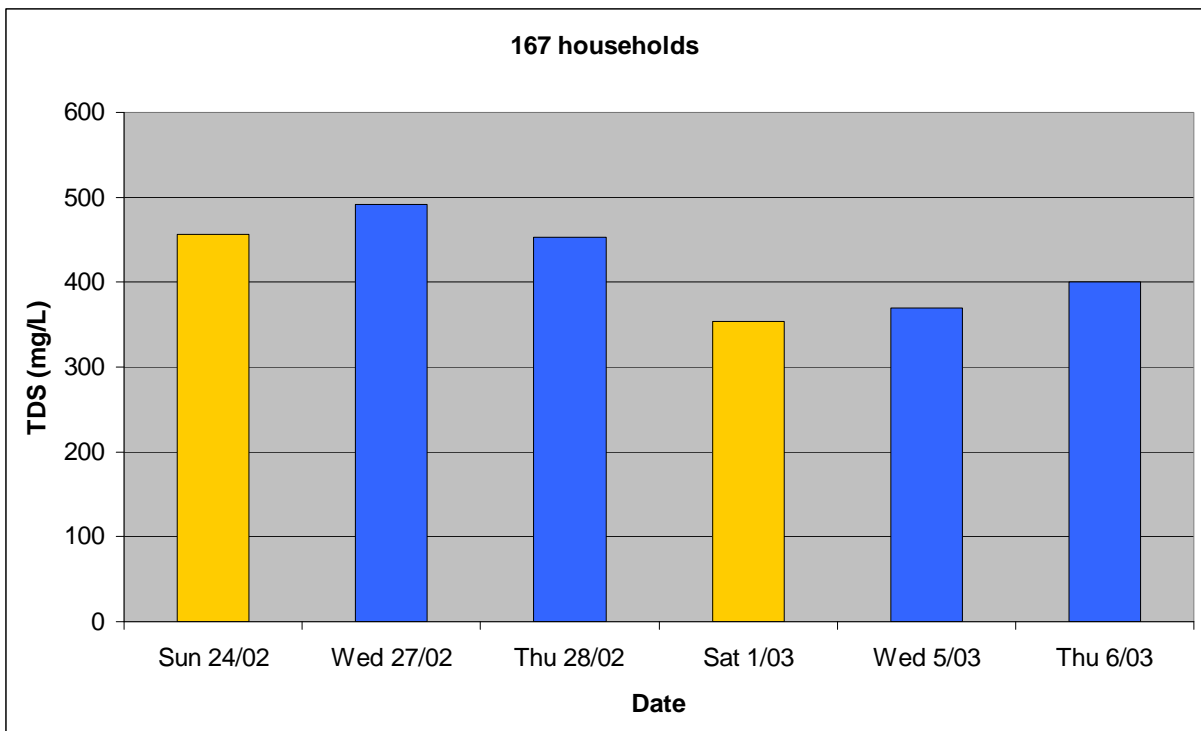


Figure 15: Daily TDS in wastewater from 167 households.

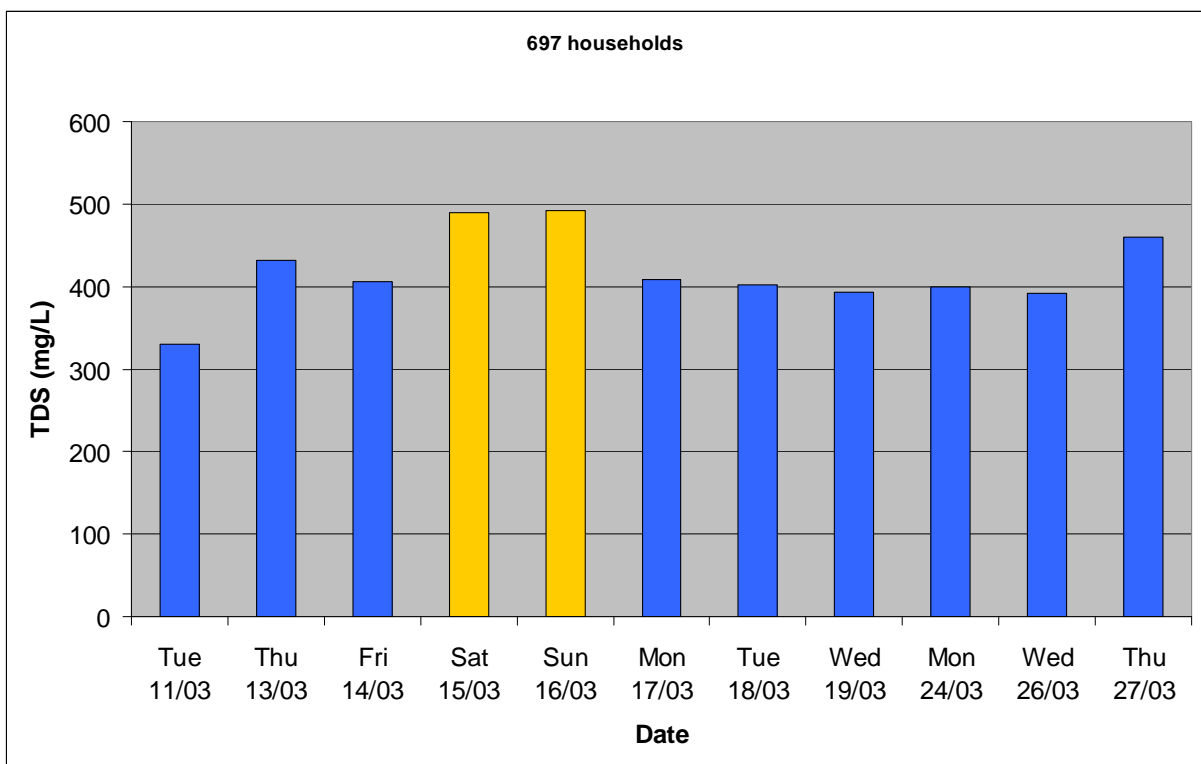


Figure 16: Daily TDS in wastewater from 693 households.

Hourly readings

The TDS concentrations were recorded at each hour at the three sites for a pre-specified number of days over a week. The average of the hourly readings for all the days of the week are shown in Figure 17. As an illustration, the standard deviation of the data for site 3 (697 households) is shown using error bars. The summary of results is shown in Table 9.

Over a 24h period the TDS concentration in wastewater varied between 88mg/L and 1042mg/L, with a mean hourly TDS concentration of 328 mg/L across the 3 sites.

As for most elements, the TDS concentration was at its lowest in the period from midnight to 6am, whilst the highest concentrations were observed during daytime after 6am. However, the time of the peak TDS concentration differed from one catchment to another as seen in Figure 17.

The TDS concentrations were characterized by a high standard deviation ($\pm 39\%$) for the observed period (Table 9). A detailed analysis of the Z-scores is shown in Appendix E.

Peaks were more distinct at site 1 than at the other 2 sites, as less attenuation from multiple connections could affect the readings.

The mean TDS concentrations for the three sites followed similar trends as shown in Figure 17:

- From midnight to 6am: The TDS concentration was at its lowest. The minimum concentration was registered at 2am for sites 2 and 3 and it was 16mg/L lower than the minimum TDS at site 1. At site 1 the lowest TDS concentration was recorded at 6am.
- From 7am to 1 pm: Rapid increase in TDS concentration with a local maximum observed for site 3 (697 households). TDS increased by 50% from 6am to 7am at site 2 (163 households), this was followed by a slower change in concentration until 12pm. The peak TDS concentration observed for site 1 at 11am was similar in magnitude to that of site 2 at 1pm.
- From 1pm to 5pm: In this period a plateau in TDS concentration was observed at sites 2 and 3. Whilst site 1 was characterized by a drop in TDS from 1pm to 2pm, and followed by increase in TDS up to 5pm.
- From 6pm to midnight: Local peaks in TDS concentration verified at 6pm to 7pm and 8pm to 10pm, with significant data oscillation.

Table 9: Summary of TDS hourly distribution during a 24h period

Site	TDS (mg/L)		
	1	2	3
Number of households	7	163	697
Mean	324	338	323
Minimum	104	88	88
Maximum	732	1042	745
St.dev	122.5 (38% Mean)	133.8 (40% Mean)	126 (39% Mean)
Number of days	6	12	5

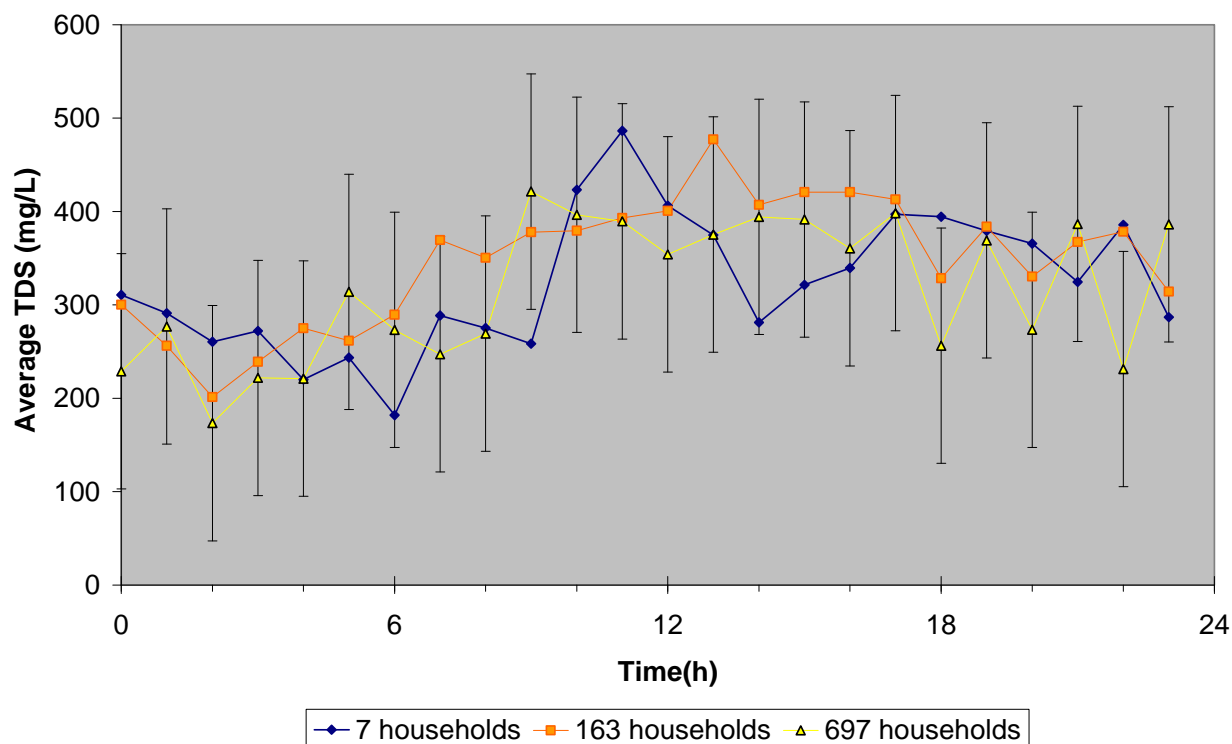


Figure 17: Mean TDS profile for a 24h period.

Analysis of discharges from site 1

The flow profile for site 1 was characterised by a distinct variability in concentration during the day and from one day of the week to the next. This is not surprising, as site 1 received the wastewater produced by an enclave of 7 houses only. As the wastewater volume generated was small, very little load attenuation took place in the sewer and the wastewater was highly sensitive to discharges from individual households.

To gain a greater understanding of the changes in TDS observed at site 1, the TDS concentration profiles were recorded for a period of 7 days. These are compared using box-plots in Figure 18 and Figure 19. The box-plot depicts:

- (a) the mean of a set of data points as red dots,
- (b) the median as the centre-line in the box,
- (c) the lower hinge on the left is the 25th-percentile and the outer hinge on the right is the upper 75th-percentile of the data,
- (d) the left and right arms depict the lowest and highest non-outlier observations; and
- (e) the external squares depict outliers.

Figure 18 shows the distribution of the TDS hourly concentrations on each day of the week. The largest mean TDS concentrations in the week were recorded on Thursday and Saturday (Figure 18). The largest spread in TDS concentration throughout the day was observed on the Saturday, ranging from 104mg/L TDS at 6am to 732mg/L at 11am (Figure 18). This reflects the uncertainty inherent in the range and timing of activities that residents undertake on that day of the week.

The lowest mean TDS was recorded on the Monday. On Fridays, Thursdays, Sundays and Tuesdays there was a strong skew of the TDS data to the right. Whilst on Saturdays and Wednesday the skew was to the left.

TDS recorded at equivalent times of the day on different days of the week were compared to evaluate if any specific trends could be determined regarding the time of TDS release into the sewer (Figure 19). The narrowest distribution of TDS concentrations was recorded in the early hours of the morning (midnight to 5am) and in the evening (6pm to 11pm). However the evening period was also characterised by a number of extreme data outliers.

The first interval (midnight to 5am) is when majority of householders are asleep; hence minimum sewage flow would be expected resulting in the consistency in TDS concentrations during that time period from one day to another.

The largest variation or spread in TDS concentration was verified from 10am to 1pm particularly around 11am, which is shown in Figure 18. Significant variability in TDS concentration was also observed in the afternoon at 1pm and 4pm. This indicates that the quality of wastewater produced by the 7 households and hence the range of activities that householders undertake varied significantly on the different days of the week.

As shown in Figure 19, during a typical 24h period, TDS readings were generally larger from 10am to 11am, decreasing in the afternoon and evening periods (Figure 19).

Overall, over 24 h there was an increase in TDS from 7am to 9am with a local peak at 7am, further increase from 10am to 1pm with the daily peak in TDS at 12 pm (Figure 17). In the afternoon, from 1pm to 4pm, the TDS concentration decreased. This was followed by a TDS increase after 4pm as people started returning home, resulting in a second peak in concentration around 5pm to 7pm. After 7pm the TDS concentration decreased steadily through the night and was generally the lowest between 5am to 6am.

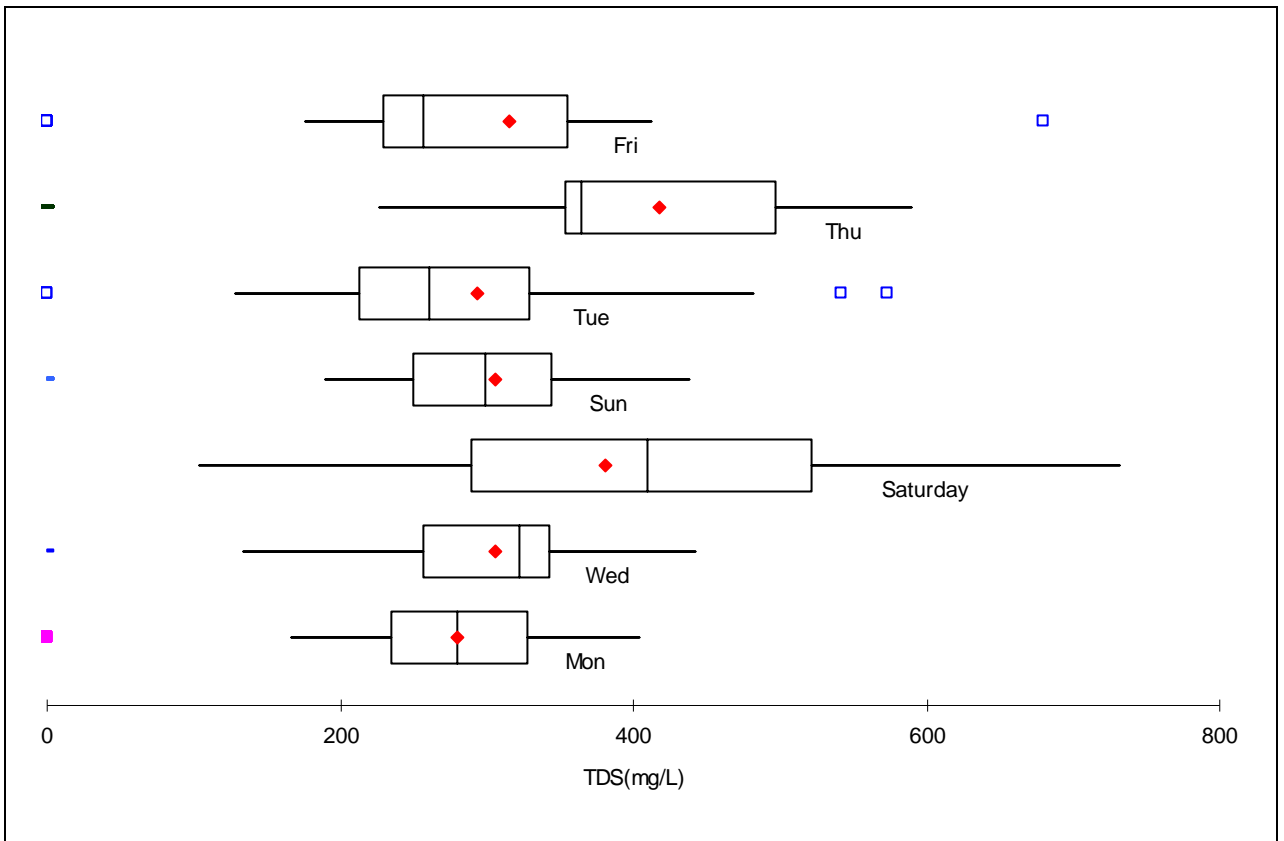


Figure 18: TDS data distribution per day of the week for site 1 (7 households) for a 1-week period.

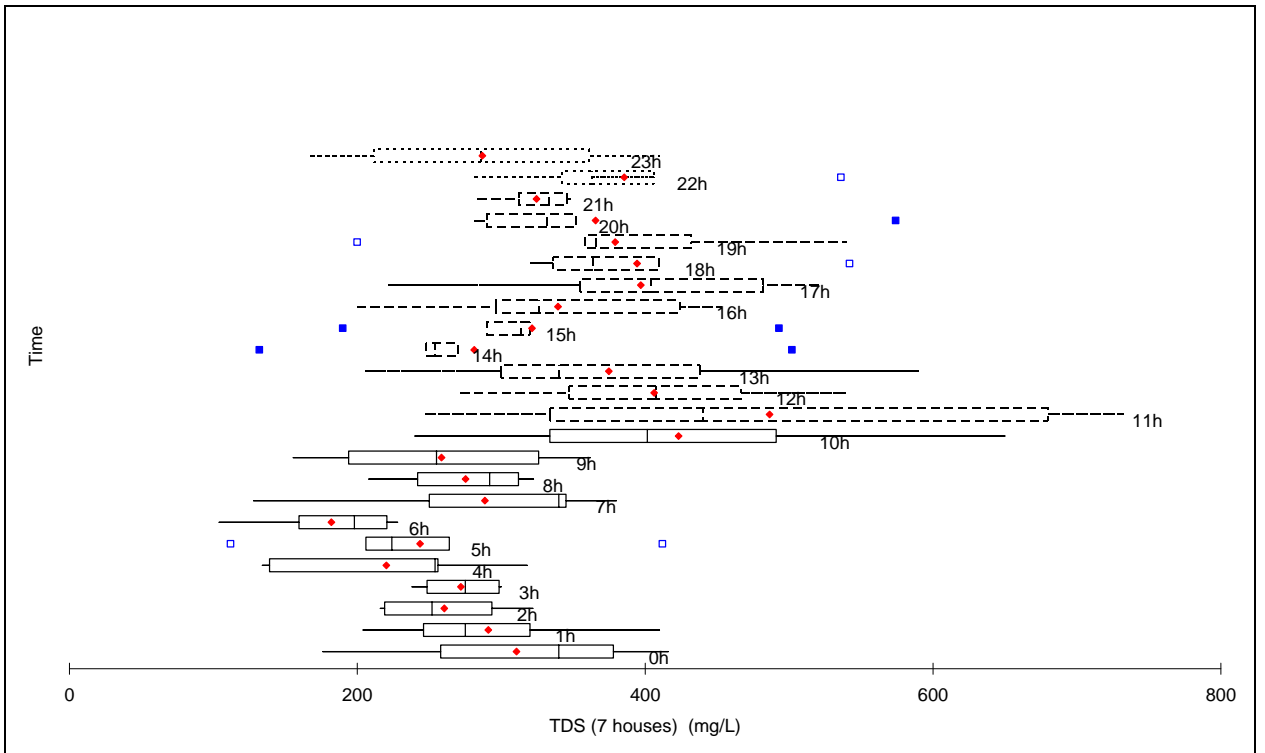


Figure 19: TDS data distribution for site 1 (7 households) for a 1-week period.

7.2. Diurnal profiles

To illustrate the variation in wastewater quality for specific elements over a 24h period, the hourly profile of wastewater for site 2 (163 households) was evaluated on a Sunday, 24th February 2008. Sunday was selected as it is the day of the week with the highest probability of householders being at home.

Hourly samples were analysed for Al, As, B, Ca, Cd, Co, Cr, Fe, Hg, Pb, Mo, Ni, TKN, TP, Se, S, Sn, Na and Zn. This list included priority contaminants and elements whose main origin is the water supply. The last group was selected for comparison purposes and would have been expected to display a constant concentration profile during the day provided their concentration in the water supply was stable and households provided little additional input.

Chloride and fluoride were excluded from the diurnal pattern analysis due to cost restrictions.

An initial scan of elements was conducted to determine what elements in tap water and in wastewater were within the limits of detection during the 24h period. Results of this scan are summarised in Table 10.

A number of the elements were below the detection limits of the analytical instrumentation (ICP-AES). In water samples, these included Sb, As, B, Cd, Cr, Pb, Hg, Mo, Mn, Ni, P, Se and Sn. From this group only P was within the detection limits in wastewater samples.

In the case of As, Hg, Se and Sb the detection limits were in the $\mu\text{g/L}$ range, whilst for the other elements, detection limits were in ppm or mg/L as previously described in section 3.4.4.

Elements detected in wastewater included Al, Ca, Cu, Fe, K, Mg, TKN, Na, S, Si and Zn.

Changes in concentration were assessed by comparing the relative increase in the concentration of an element in wastewater compared to tap water. The average hourly concentration of elements in tap water (C_{tw}), wastewater (C_{ww}) and the ratio of the difference of those concentrations ($(C_{ww}-C_{tw})/C_{tw}$) are shown in Table 10.

The largest change in the concentration from tap water to wastewater was observed for nutrients (TKN and TP), with ratios of wastewater to tap water of 384:1 and 41:1 for TKN and TP. These were followed by K, S, Fe, Al, Na, Zn and Ca with corresponding ratios of 33:1, 7:1, 6:1, 5:1, 3:1 and 2.7:1. Wastewater concentrations for TKN, Na, Ca and K were subject to significant variability, as seen in the respective high standard deviations of 40 mg/L, 17 mg/L, 7.5 mg/L and 6.8mg/L (Table 10).

All other compounds were either at or close to the limit of detection, in the low mg/L range.

Each of the elements detected in Table 10, was further analysed using a 24h concentration profile. The hourly concentration profiles and the corresponding hourly loads are shown in Figure 20 to Figure 37.

Volume and flow rate profiles for the day are also shown in Figure 20 and Figure 21, to provide an indication of the wastewater discharged during the day. The wastewater flow profile on that Sunday was characterised as follows:

- The period of household activity characterised by the highest concentration of elements and flows occurs from 6am to midnight.
- The peak volume discharged to sewer corresponds to the intervals from 7am to 9am and from 5pm to 7pm.
- The peak flow rate occurs around 8:30am-9am.
- Two afternoon flow rate peaks were observed from 5pm to 6:30pm.
- After 8pm the slope of the flow profile decreased and the minimum for the day was reached around 4am to 4:30am (Figure 20).

Table 10: Elements in tap water and wastewater for site 2 on 24.02.08.

	Elements	Units	Tap water concentration	Wastewater concentration			Concentration ratio $[C_{ww}-C_{tw}]/C_{tw}$	
			Average C_{tw}	Average C_{ww}	Std Dev. of C_{ww}	Min		Max
Below detection limit in tap water	Sb	µg/L	<2	<2				
	As	µg/L	<5	<5				
	B	mg/L	<0.02	<0.02				
	Cd	mg/L	<0.01	<0.01				
	Cr	mg/L	<0.01	<0.01				
	Pb	mg/L	<0.1	<0.1				
	Hg	µg/L	<2	<2				
	Mo	mg/L	<0.05	<0.05				
	Mn	mg/L	<0.001	<0.001				
	Ni	mg/L	<0.1	<0.1				
	Se	µg/L	<7	<5				
	Sn	mg/L	<0.05	<0.05				
	P	mg/L	<0.25	10.5	3.6	5	21	40.8
Detected in tap water	Al	mg/L	0.21	1.23	0.78	0.21	2.91	5
	Ca	mg/L	4.83	18.03	7.46	10.6	43.9	2.7
	Cu	mg/L	1.27	0.08	0.04	0.04	0.22	-0.9
	Fe	mg/L	0.11	0.75	0.53	0.20	2.21	5.9
	K	mg/L	0.76	25.88	6.83	15.8	47.1	33.1
	Mg	mg/L	1.44	3.47	0.81	2.1	5.6	1.4
	TKN	mg/L	0.20	77	39.8	37	190	384
	Na	mg/L	14.36	58.18	17.01	32.6	98.2	3.1
	S	mg/L	1.66	13.62	3.80	6.9	22.4	7.2
	Si	mg/L	1.93	1.57	0.32	1.2	2.2	-0.2
	Zn	mg/L	0.12	0.44	0.48	0.16	2.34	2.7

7.2.1. Nitrogen

The concentration and load profiles of TKN are shown in Figure 22 and Figure 23. These provide an indication of the changes in wastewater over a 24h period.

During the day, the mean concentration of TKN was 77 ± 39.7 mg/L, with the highest concentration observed in the morning as shown in Figure 22. The peak concentration in wastewater, 190mg/L, occurred around 7am to 8am, whilst maximum flow for the day was observed one hour later between 8am and 9am. The maximum mass load was discharged from 6am to 10am which corresponds to the start of the day, when residents wake up and prepare themselves for the day ahead (Figure 23).

Urine is estimated to contribute up to 75% of the nitrogen in wastewater (Crites and Tchobanoglous 2003) and the profile for TKN reflects the period of the day when most of the urine discharge occurs. After 10am the concentration of TKN decreased to less than 60mg/L.

Figure 23 shows that 50% of the load of TKN is discharged from 6am to 11am.

7.2.2. Phosphorus

The 24h profile for the concentration of Total phosphorus (TP) is shown in Figure 24. The phosphorus and the TKN concentration profiles had some similarities. Figure 25 shows that the largest load of TP (39%) is discharged in the morning from 6am to 11 am. The mean concentration of TP during the day was $11\text{mg/L} \pm 3.6\text{mg/L}$. The low standard deviation reflects the lower variation in TP during the day compared to nitrogen. The maximum concentration, 21mg/L , occurs at the same time of the day as the nitrogen, 7am to 8am. This is not surprising as urine can contribute with up to 50% of the phosphorus in wastewater. However the presence of localised concentration peaks during the remainder of the day suggests the contribution from household activities other than human excretion.

7.2.3. Iron

Iron, whilst not a priority contaminant, was monitored to verify if it imparted any colour to wastewater. Iron when present in concentrations greater than 5 mg/L can cause discoloration in mains water. The mean concentration of iron in the wastewater collected during a 24h period was $0.75\text{mg/L} \pm 0.53\text{mg/L}$. The maximum concentration, 2.21 mg/L , was recorded between 10am and 11 am and the minimum between 11pm to 12am (Figure 26).

Although, the concentration of iron in the wastewater was higher than in tap water, which had 0.1mg Fe /L , it was not significant to cause any discoloration perceptible to the naked eye.

The second highest peak concentration for the day was observed between midnight and 1am. After 1am, the concentration decreased, reaching 0.4 mg/L by 4am. It increased after 6am as residents resumed their daily routine, with the third highest concentration verified after 3pm.

Approximately 40.5% of the Fe load to sewer was discharged in the morning (6am-12pm), 34% in the afternoon (12pm to 6pm) and 20% in the evening (6pm to midnight) (Figure 27).

7.2.4. Copper

The concentration of copper in wastewater was low, ranging from less than 0.01 to 0.22 mg/L . The highest concentration recorded was 0.22mg/L at midnight. For the remainder of the day it remained below 0.1mg/L with a mean $0.077 \pm 0.04\text{ mg/L}$. At 2pm and after 9pm it was below the detection limit of 0.01mg/L (Figure 28).

The highest copper loads were generated in the morning, with 45% of the daily load discharged from 6am to midday as seen in Figure 29.

Copper is generally attributed to corrosion and leaching from copper water infrastructure (Gray and Becker 2002). Therefore it would have been expected for concentrations to be higher at the start of the day as water is allowed to remain stagnant in the pipes overnight. However, as the houses are continuously occupied, the period of water stagnation might not have been sufficient to cause any significant corrosion.

7.2.5. Sodium

The concentration of sodium, [Na], in tap water was on average 14.4mg/L , whilst in wastewater the [Na] was greater than 33mg/L for the majority of the day and the mean sodium concentration was $58.18 \pm 17.01\text{mg/L}$. this is shown in Figure 30.

The [Na] increased from morning to the afternoon (5pm), with major concentration peaks of 94.4mg/L and 98.2 mg/L observed around 1pm and 4pm. After 4pm a steady reduction in

concentration was observed, reaching 33mg/L by 8pm. This was followed by a rise in concentration up to midnight.

Similarly to the other elements, the early hours of the morning, 12am to 1am, were characterised by a significant sodium concentration, 75 mg/L, but the corresponding load was only 1.8% of the overall daily load.

The largest loads in the sewer occurred from 8am to 12pm and from 3pm to 5pm (Figure 31).

Overall, the load of sodium to sewer was equally distributed during the main periods of the day, i.e. 35% in the morning (6am-12pm), 36% in the afternoon (12pm-6pm) and 22% in the evening (Figure 41).

The sodium concentration profile did not show a strong correlation with the profiles for nutrients, an indication that household activities other than human excretion exert a significant influence on the overall load for the day.

7.2.6. Sulphur

The mean concentration of sulphur, [S], was 7.28 ± 0.05 mg/L in tap water and 13.62 ± 3.8 mg/L in wastewater, i.e. the mean increase from tap water to wastewater was 6.3 mg/L.

The concentration increased from the start of the day to 4pm in the afternoon and decreased through the night. Local peaks were observed in the morning at 1am and 7am, in the afternoon at 4pm and in the evening around 10pm (Figure 32). The highest concentration for the day was 22.4mg/L at 4pm and the minimum was 6.9mg/L around 6 to 7pm.

As with the other samples, the period between midnight to 2am registered a high sulphur concentration of 20.4mg/L, but the equivalent load was only a minor contribution to the total daily load (Figure 33).

The major contribution to the sulphur load in the sewer occurred between 6am to 6pm. Although the largest hourly loads were observed in the afternoon from 12pm to 6pm, the load discharged to sewer in the morning and in the afternoon were equivalent at 36% and 35%, respectively (Figure 41).

7.2.7. Zinc

The mean concentration of zinc, [Zn], in tap water was 0.149 ± 0.026 mg/L. Wastewater had a median [Zn] of 0.285mg/L and a mean of 0.480 ± 0.481 mg/L during the day (Figure 35). The large standard deviation was caused by two concentration spikes, 1.33mg/L between 2pm and 3pm, and 2.34mg/L, between 7pm and 8pm (Figure 35). By excluding those two data points, the mean would have been 0.307 ± 0.147 mg/L. Each hourly load contributed on average to less than 5% to the total load for the day, however the two spikes were equivalent to 38% of the total load for the day (Figure 35).

7.2.8. Potassium

The concentration profile of potassium, [K], followed a similar pattern as the profile for phosphorus (Figure 36) with the largest loads observed from 8 to 10am (Figure 37). Overall [K] in wastewater was much higher than in tap water which had a mean [K] of 0.76 ± 0.34 mg/L. The bulk of the K load (40.5%) was discharged from 6am to 11am.

7.2.9. Aluminium

The concentration profile for aluminium is shown in Figure 38. The concentration was the highest at midnight, decreasing rapidly by 2am and remaining constant for the rest of the early morning. After 6am, it increased steadily through the day until 5pm and then decreased through the evening (Figure 38).

The largest concentrations were observed at midnight (2.9mg/L), 10am (2.6mg/L) and between 4pm to 5pm (2.5mg/L). However, the majority of the load was generated during daytime: 34.6% in the morning (6am to 12pm) and 38.4% in the afternoon (12pm-6pm) (Figure 39).

7.2.10. Discussion

Evaluation of the diurnal wastewater profiles for the Sunday 24th Feb 2008 has shown that the concentrations of nitrogen, phosphorus, potassium, sulphur, iron, aluminium and sodium in wastewater were more than three times the equivalent concentrations observed in tap water.

The remainder of priority contaminants, arsenic, antimony, boron, cadmium, chromium, lead, mercury, molybdenum, nickel, tin and selenium were below the detection limits of the instrumentation used.

The major household behavioural activities that affect wastewater flow profiles during a 24 period include:

(a) Morning start-up: characterised by awakening of householders as the day starts. It typically reflects the use of toilets and showers in the morning. The majority of households prepare to leave for work/school during weekdays, but the pattern is less pronounced during weekends when schedules are subject to greater variability.

(b) Morning/afternoon chores: households with a stay-at-home inhabitant typically undertake daily chores following the morning preparation period. Uncertainty surrounds the timing of tasks and range of tasks conducted, since personal preferences can affect whether dishes are washed after each meal or at the end of the day in the dishwasher, or if laundry washing is conducted.

(c) Lunch: Lunch preparation and clean-up typically occurs in the period between 11am to 2pm.

(d) Afternoon return: typically occurring between 3:30pm to 6pm, this period is characterised by inhabitants returning from school/work/activities. It is typically followed by an increase in the wastewater discharge.

(e) Evening meal: characterised by evening meal preparation and also generally by the washing of dishes, but the time of the activity tends to vary with households.

(f) Rest: ranging anytime from 10pm to 5am as residents go to sleep, this is characterised by the least discharge of wastewater.

The morning start-up period is common to majority of households and hence explains the maximum daily peak in flow verified during that time period. In the afternoon, as there is greater variability in household schedules, the volumetric peaks are less pronounced.

In the analysis of the data we have assumed that the wastewater discharge can be associated with these major behavioural activities. It was therefore assumed that contaminants whose concentration profile followed similar trends as the release of nitrogen, characterised by a maximum during the early morning, were strongly correlated with human excretion.

Inspection of diurnal concentrations and load profiles for the detected elements has shown a strong correlation between the profiles for nitrogen, phosphorus and potassium with morning activity from 6-10am. This was evident in the 50% of TKN, 40% of TP and 39% of K of the daily load discharged to sewer during those hours (Figure 40).

In profiles for other parameters (Al, Fe, Cu, Na, S and Zn) the loads were more evenly distributed throughout the major periods of the day. The concentration profile of sodium, sulphur and aluminium increased from the start of the day to the afternoon, when a maximum concentration was reached.

Copper, iron and zinc had distinct concentration profiles. For iron the concentration increase was characterised by two major peaks, one in the morning and one in the afternoon. For copper a similar trend to iron was observed in that the concentrations were more uniform throughout the day. For zinc the concentration was steady during the morning, but we observed two major spikes mid afternoon and in the early evening.

This suggests that release of those contaminants into wastewater is not associated with human excretion alone, instead being more significantly influenced by other domestic events.

Zinc had a consistent load throughout most of the day, however the larger load from 4pm to 7pm was caused by the two major concentration peaks verified in the afternoon, which significantly increased the load distribution towards the late afternoon (Figure 35). Further investigation would be required to confirm if such peaks were outliers.

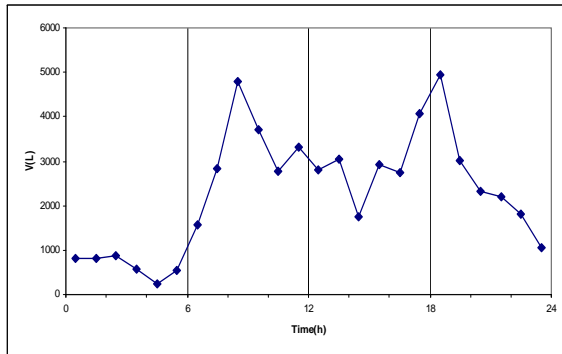


Figure 20: Flow profile for 163 households on 24/02/08.

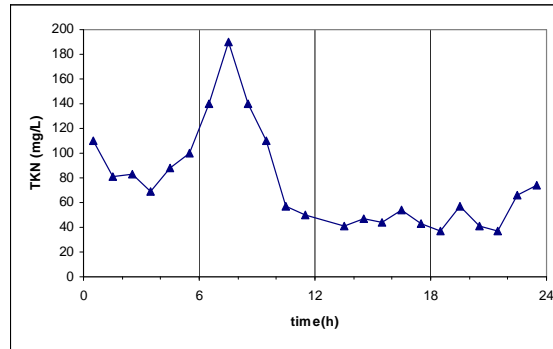


Figure 22: Diurnal concentration profile for Nitrogen (163 households).

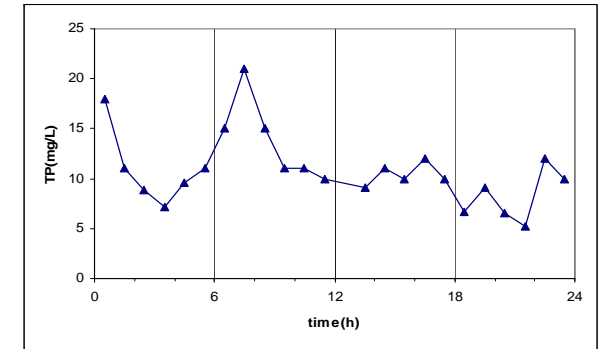


Figure 24: Diurnal concentration profile for Phosphorus (163 households).

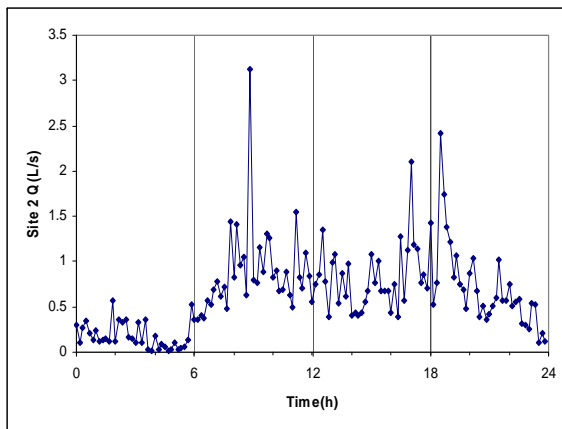


Figure 21: Flow rate profile for 163 households on 24/02/08

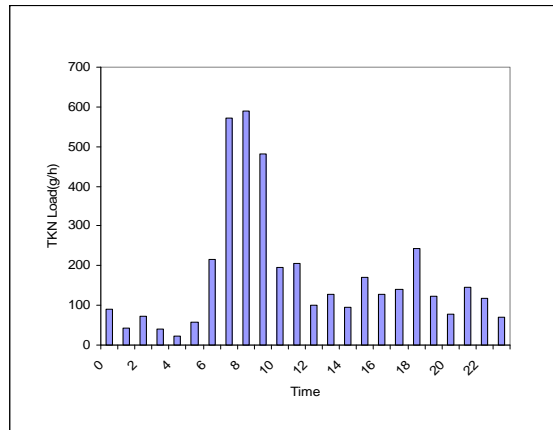


Figure 23: TKN load in wastewater for 163 households on 24 Feb. 2008

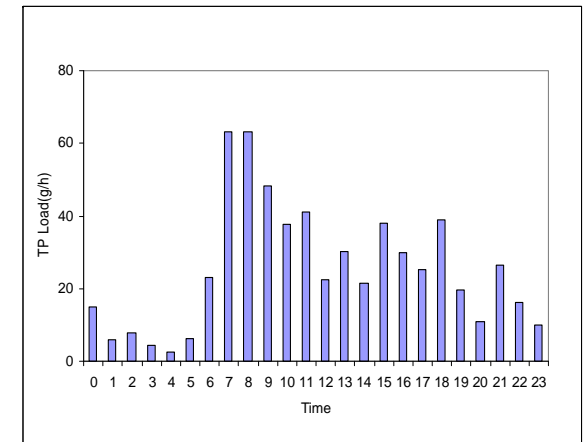


Figure 25: TP in wastewater for 163 households on 24 Feb. 2008

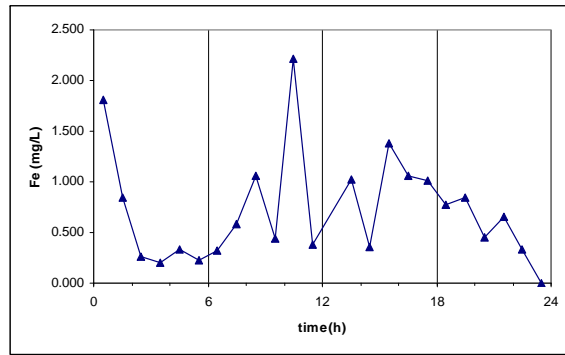


Figure 26: Diurnal concentration profile for Iron (163 households).

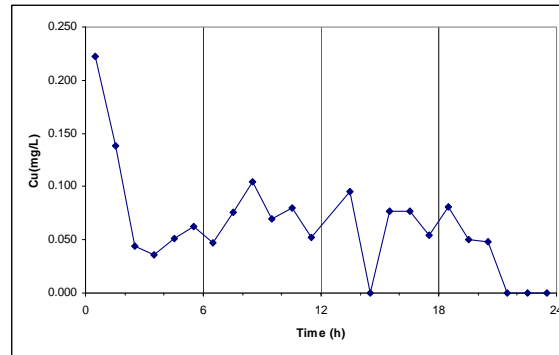


Figure 28: Diurnal concentration profile for Copper (163 households).

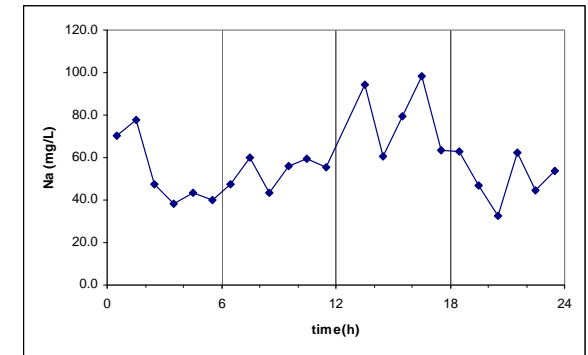


Figure 30: Diurnal concentration profile for sodium (163 households).

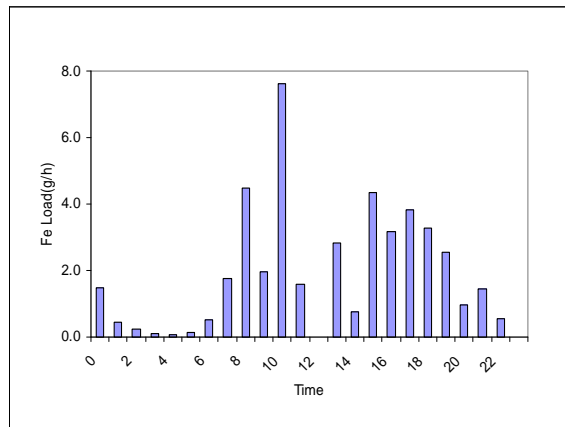


Figure 27: Fe load in wastewater for 163 households

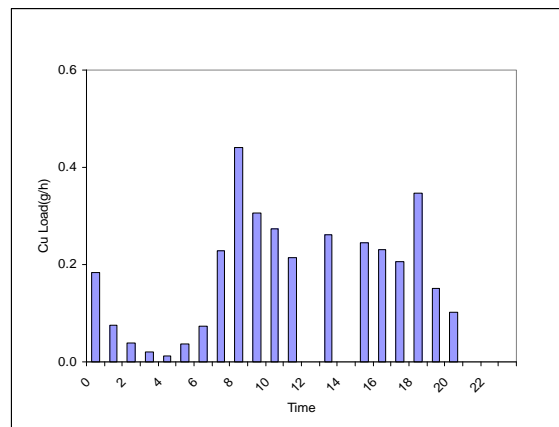


Figure 29: Cu load in wastewater for 163 households

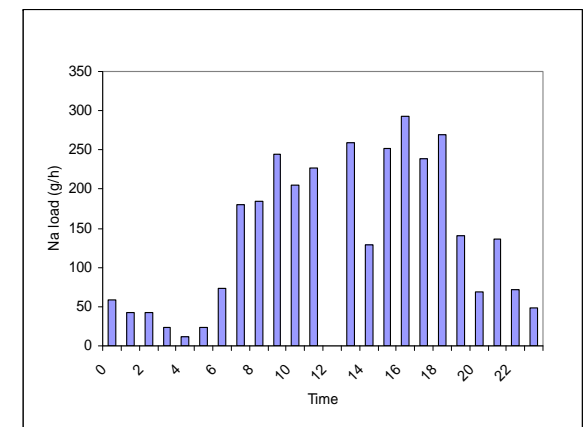


Figure 31: Na load in wastewater for 163 households

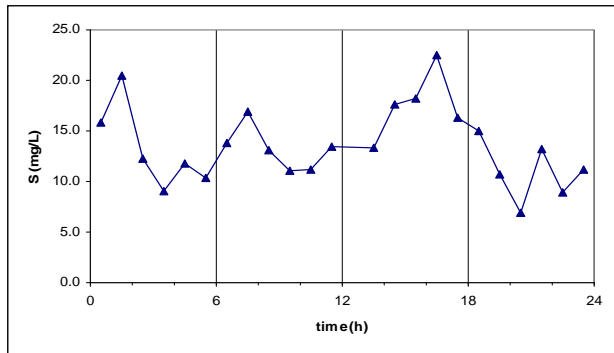


Figure 32: Diurnal concentration profile for Sulphur (163 households).

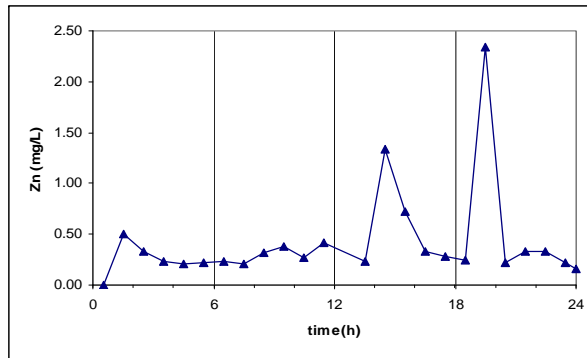


Figure 34: Diurnal concentration profile for Zinc (163 households).

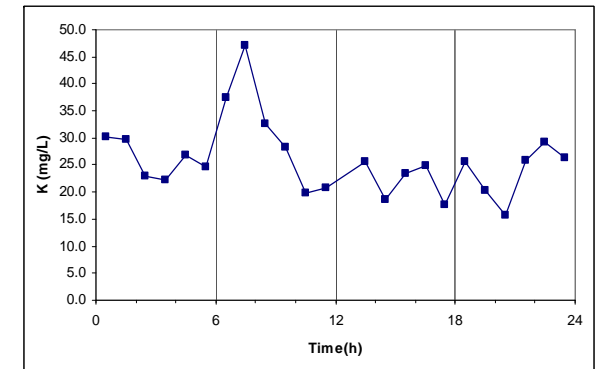


Figure 36: Diurnal concentration profile for potassium (163 households).

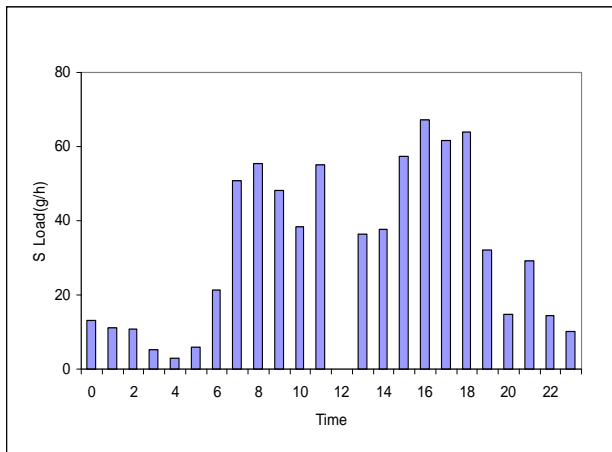


Figure 33: S load in wastewater for 163 households

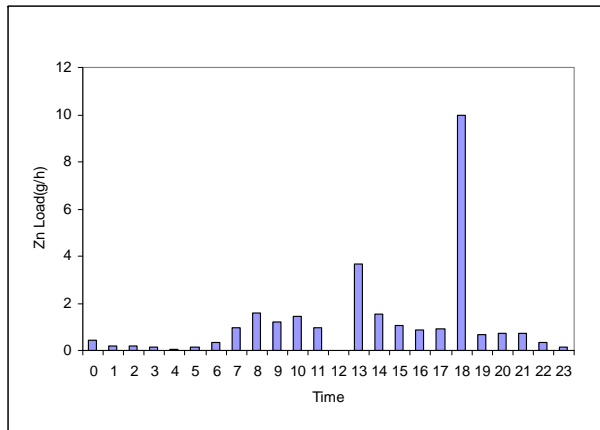


Figure 35: Zn load in wastewater for 163 households

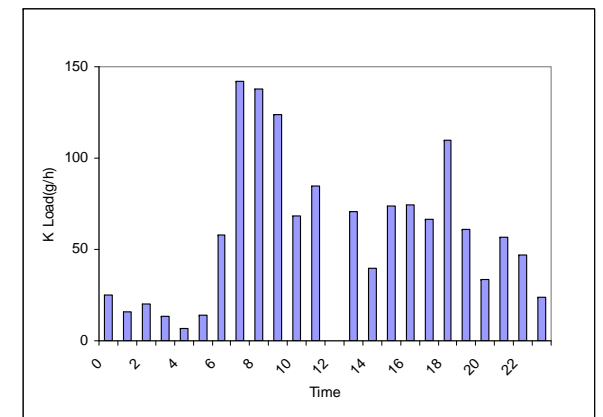


Figure 37: K load in wastewater for 163 household

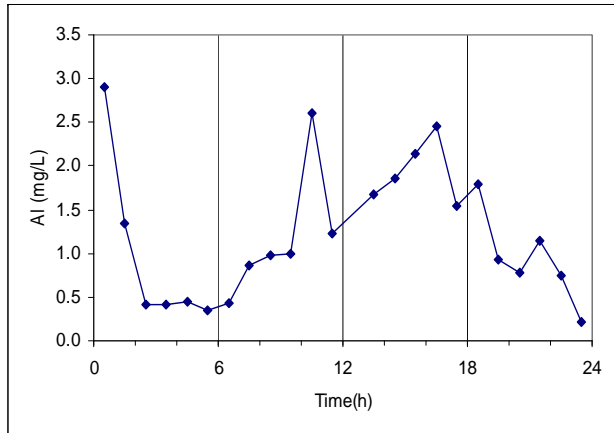


Figure 38: Diurnal concentration profile for aluminium (163 households).

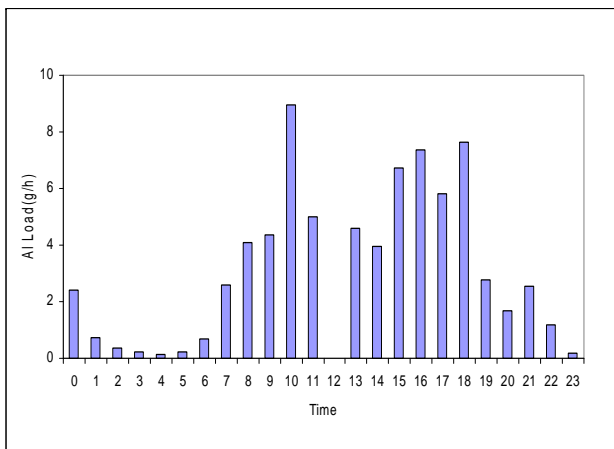


Figure 39: Al load in wastewater for 163 households.

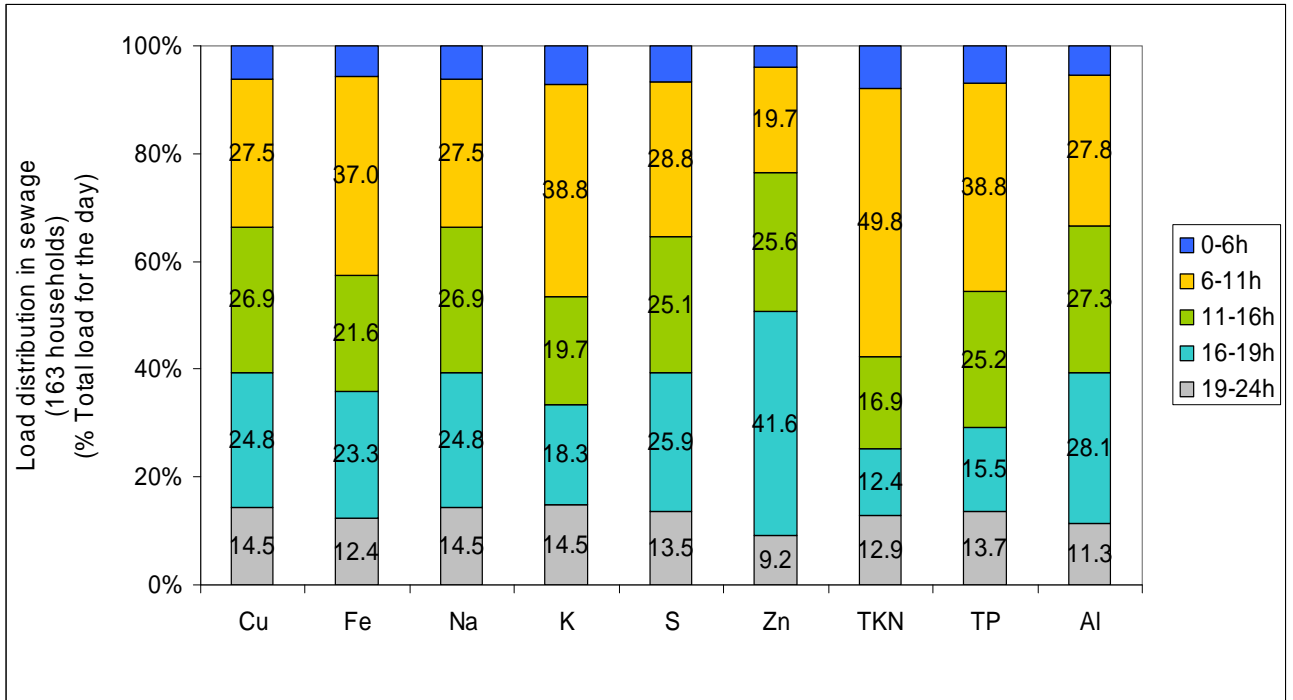


Figure 40: Load distribution for Sunday 24th Feb 2000 based on major household activity periods.

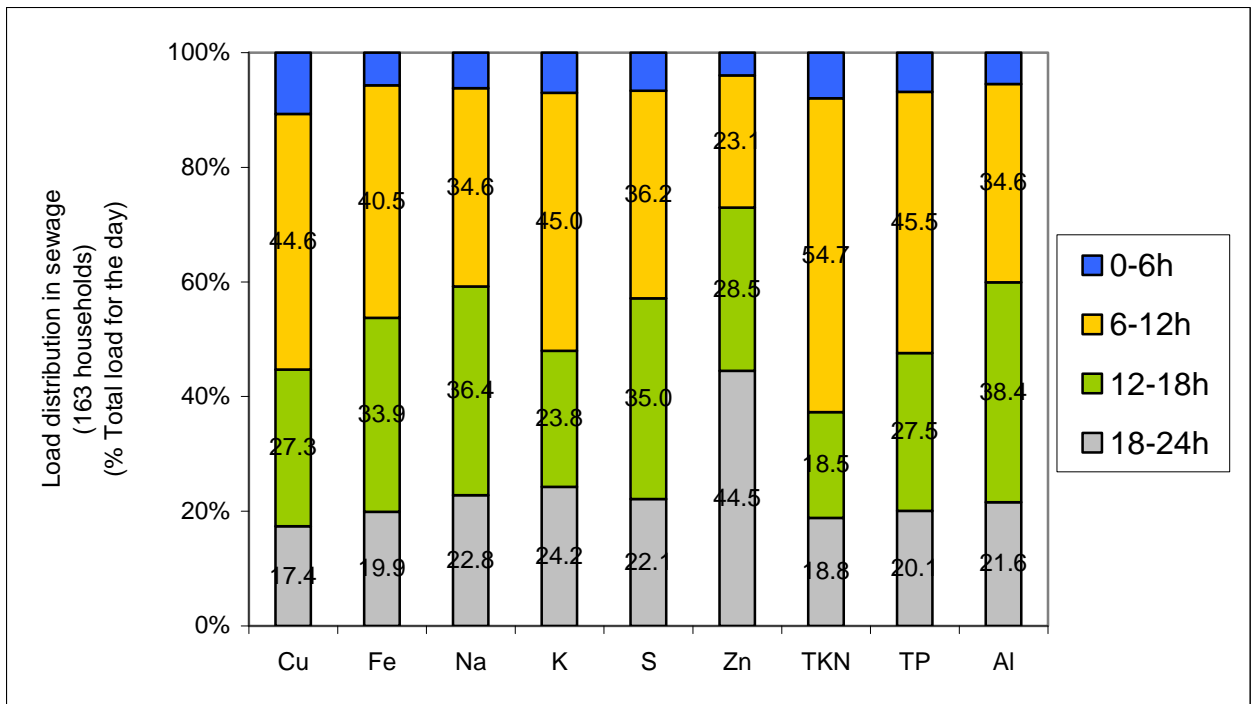


Figure 41: Load distribution for Sunday 24th Feb 2009 based on major periods of the day.

7.3. Weekly profiles

Weekly profiles were evaluated by comparing the characteristics of diurnal composites collected on different dates of the week at each site.

Composite samples were analysed for TKN, TP, Al, As, Sb, B, Cd, Cl, Cr, Cu, F, Fe, Mn, Hg, Pb, Mo, Ni, Na, Se, S, Sn and Zn. A total of 23 samples were analysed for TKN and TP and 17 samples for the other elements.

A number of elements were below the detection limit in wastewater, these included:

- Arsenic – Detection limit [As]<5µg/L;
- Antimony – Detection limit [Sb]< 2 µg/L;
- Cadmium– Detection limit [Cd] < 1µg/L;
- Cobalt – Detection limit [Co]< 0.01mg/L;
- Mercury – Detection limit [Hg] < 2 µg/L;
- Selenium – Detection limit [Se] < 7 µg/L.

The summary of the concentration for sites 2 and 3 are shown in Table 11. Comparison of the concentrations of these elements in the catchment and tap water is illustrated in Figure 46 to Figure 56. Each figure shows how the concentration on each day compares to the average concentration detected in tap water. The detailed comparison for individual readings for sites 2 and 3 can be found in Appendix D

Table 11: Concentration of elements in wastewater composites

Element	Concentration in 24-h composite samples (mg/L)					
	Site 2		Site 3		Overall	
	Mean	StDev	Mean	StDev	Mean	StDev
Al	0.85	0.493	0.98	0.212	0.93	0.328
As	<0.005		<0.005		<0.005	
Sb (µg/L)	<2		<2		<2	
B	0.108	0.050	0.096	0.034	0.089	0.039
Ca	11.1	1.578	12.2	0.974	0.09	1.293
Cd	<0.001		<0.001		<0.001	
Cl ⁻¹	48	4.1	51.8	15.6	51	1
Co	<0.01		<0.01		<0.01	
Cr (µg/L)	22.3	2.160	25.0	3.847	24.1	3.526
Cu (µg/L)	80.8	25.17	89.5	15.56	86.5	19.18
F	0.97	0.02	1.04	0.08	1.00	0.07
Fe	0.294	0.188	0.543	0.138	0.477	0.185
Pb (µg/L)	3.67	3.14	4.2	2.86	4.0	1.48
Mg	2.45	0.362	3.10	0.177	2.97	0.403
Mn	<0.001		0.033	0.004	0.033	0.004
Hg (µg/L)	<2		<2		<2	
Mo	<0.05		<0.05		<0.05	
Ni (µg/L)	21.17	3.55	22.1	1.81	21.76	2.49
N (as TKN)	79	15.7	67.9	4.1	73.7	12.79
K	15.8	2.009	9.5	0.625	11.7	3.34
P (as TP)	13.3	3.1	11.7	0.8	12.5	2.37
Se	<0.007		<0.007		<0.007	
Na	56.4	3.213	11.7	0.98	27.5	22.08
S	10.6	1.307	12.5	1.068	11.8	1.48
Sn	≤0.015	0.036	<0.05		≤0.088	
Zn	0.34	0.386	0.172	0.03	0.231	0.23

7.3.1. Nutrients

Tap water had on average 0.2 mg/L TKN and <0.5mg/L TP, which is minimal in comparison to the concentrations found in wastewater shown in Table 12.

For wastewater samples the composite concentrations were on average:

- TKN: 67.9mg/L and 79 mg/L for sites 2 and 3 respectively; and
- TP: 11.7 mg/L and 13.3 mg/L and for sites 2 and 3 respectively.

Concentrations could vary significantly over a 24h period, for instance for site 3 on a Sunday the TP ranged from 8 to 18mg/L and the TKN from 38 to 120mg/L.

TKN concentrations were 3.5% and 9.6% larger on weekdays compared to weekends for each of the two sites. Whilst, TP concentrations differed by -1.9% and 3.4% from weekdays to weekends for the two respective sites (Table 12).

The concentration of nutrients in the catchment with 167 households experienced a larger variability during weekdays, as observed in the standard deviations and the data range in Table 12:

- TKN concentration range: 57 - 120 mg/L (163 households) and 63 – 76 mg/L (697 households).
- TP concentration range: 10 - 21 mg/L (163 households) and 11 – 13 mg/L (697 households).

The nutrient readings for the weekend were among the top 80th percentile of all readings. The variability in concentrations during the week did not feature any distinct trends (Figure 42 to Figure 45).

Table 12: Concentration of TKN and TP in wastewater composite samples

		<i>Concentration (mg/L)</i>							
		<i>Monday to Sunday</i>				<i>Weekday</i>		<i>Weekend</i>	
TKN	Catchment	Average	Stdev	Max	Min	Average	Count	Average	Count
	163 houses	79.0	15.7	120.0	57.0	81.4	8	74.3	2
	697 houses	67.9	4.1	76.0	63.0	68.3	9	66	4
	Tap water	0.2	0.0	0.2	0.2				
TP	Catchment	Average	StDev	Max	Min	Weekday	Count	Weekend	Count
	163 houses	13.3	3.1	21.0	10.0	13.1	8	13.2	2
	697 houses	11.7	0.8	13.0	11.0	11.8	9	11.5	4
	Tap water	<0.5	0	0.5	<0.5				

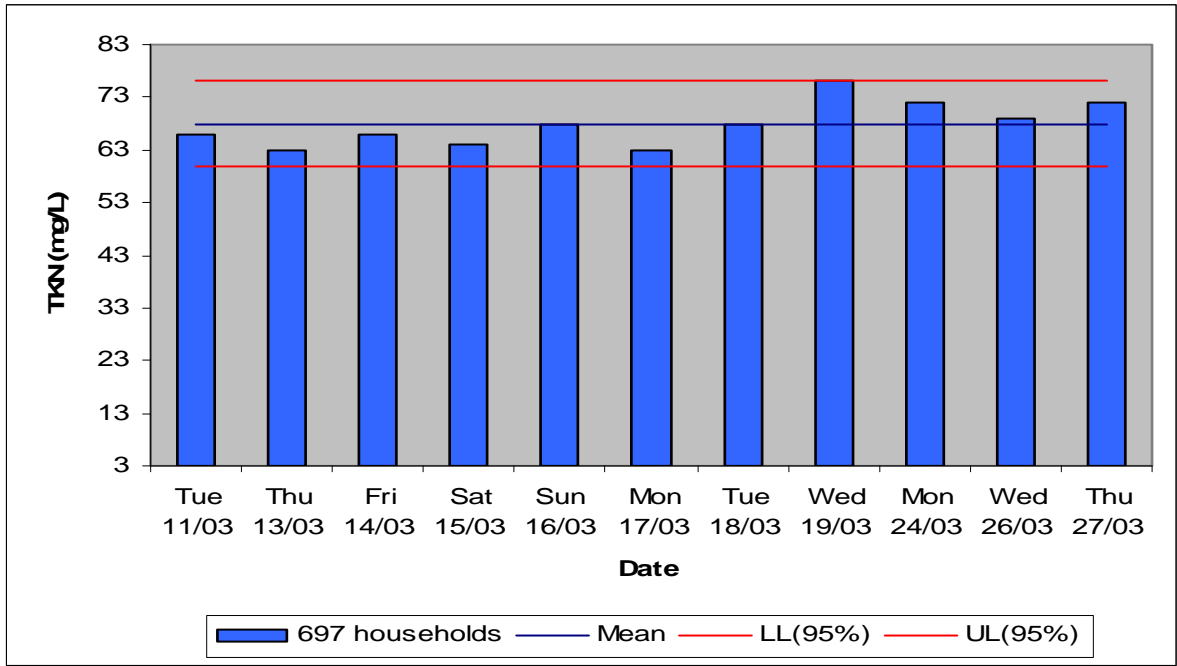


Figure 42: TKN concentration for wastewater from 697 households.

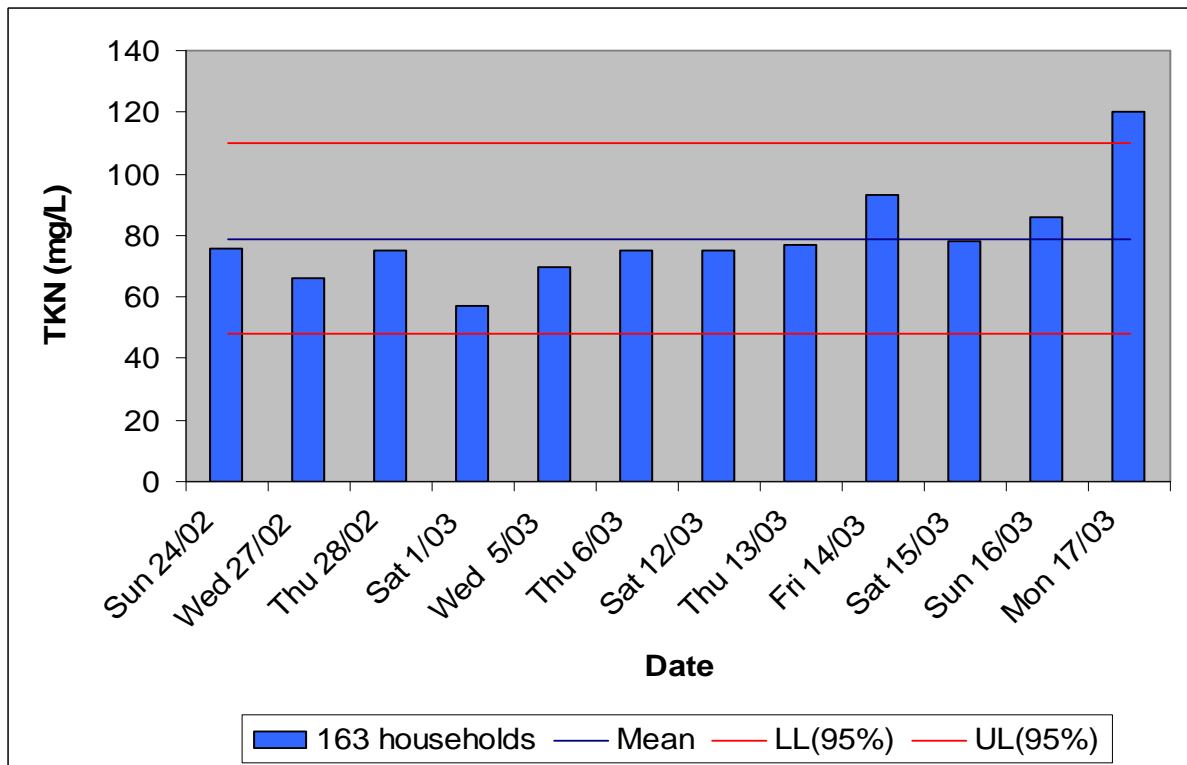


Figure 43: TKN for composites for wastewater from 163 households.

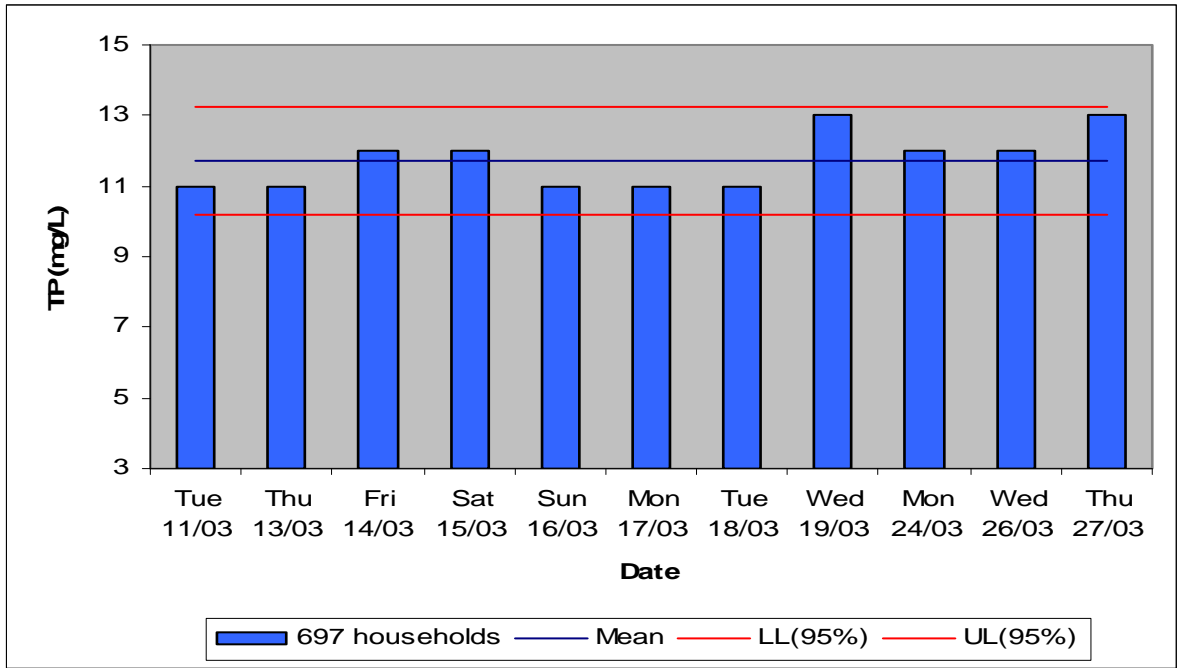


Figure 44: TP for composites from 697 households

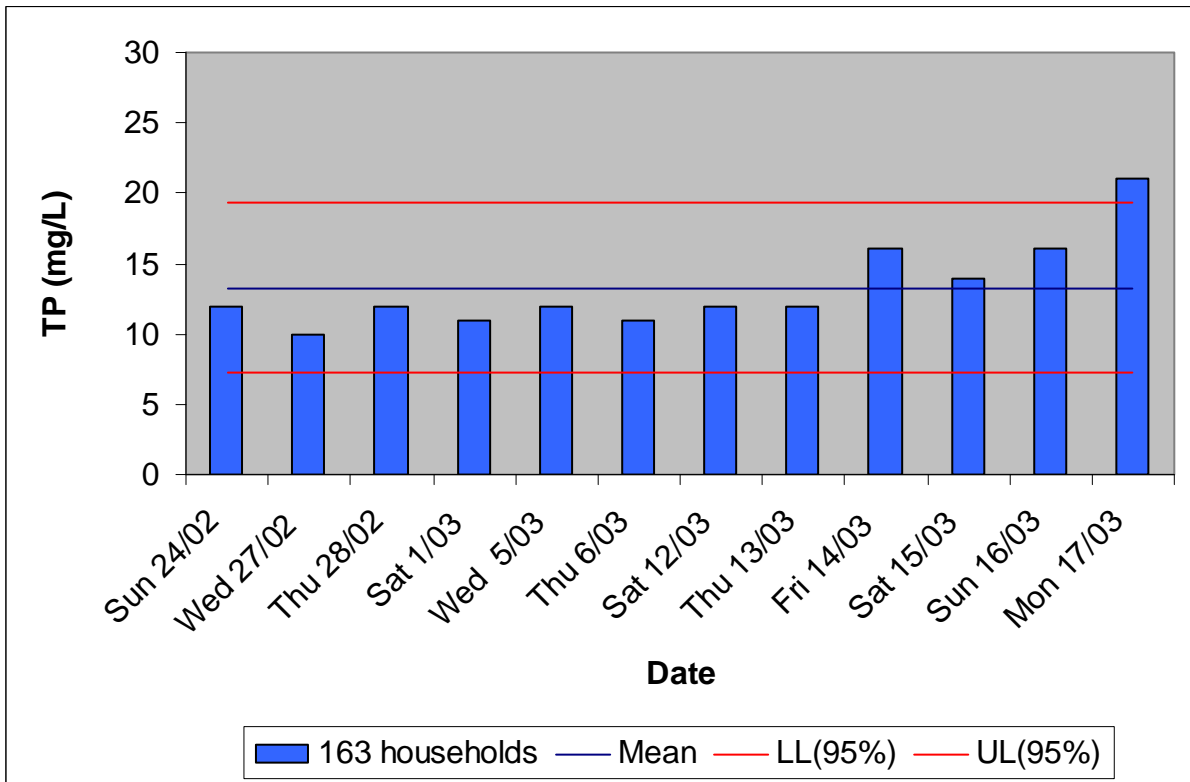


Figure 45: TP for composites from 163 households.

7.3.2. Aluminium

The concentration of aluminium in the tap water of the catchment was lower than the typical average concentration in wastewater, the mean values being respectively 0.183 mg/L (St.Dev. \pm 0.083mg/L) and 0.931 mg/L (St.Dev. \pm 0.328 mg/L). These are shown in Figure 63 and Figure 64 in appendix D.

The range of concentrations in wastewater varied between 0.037 mg/L to 1.491mg/L. At individual sites 2 and 3, the mean concentrations were 0.849 ± 0.493 mg/L and 0.975 ± 0.211 mg/L respectively.

7.3.3. Antimony

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

7.3.4. Arsenic

Arsenic was below the detection limit of 5 μ g/L in all water and wastewater samples analysed.

7.3.5. Boron

The concentration of Boron in the catchment is shown in Figure 46. Data for site 2 are shown in blue and for site 3 in orange in Figure 46.

The concentration of Boron in tap water was below the detection limit of 0.02 mg/L. In the overall catchment, the concentration in wastewater ranged from 0.04 to 0.19mg/L, with a mean of 0.101mg/L (St.Dev. \pm 0.039mg./L).

At individual sites the mean concentrations were 0.108 ± 0.050 mg/L and 0.096 ± 0.034 mg/L for sites 2 and 3 respectively.

Results indicates that the tap water in the catchment was an unlikely source of Boron, but instead households were a major source of boron in the wastewater.

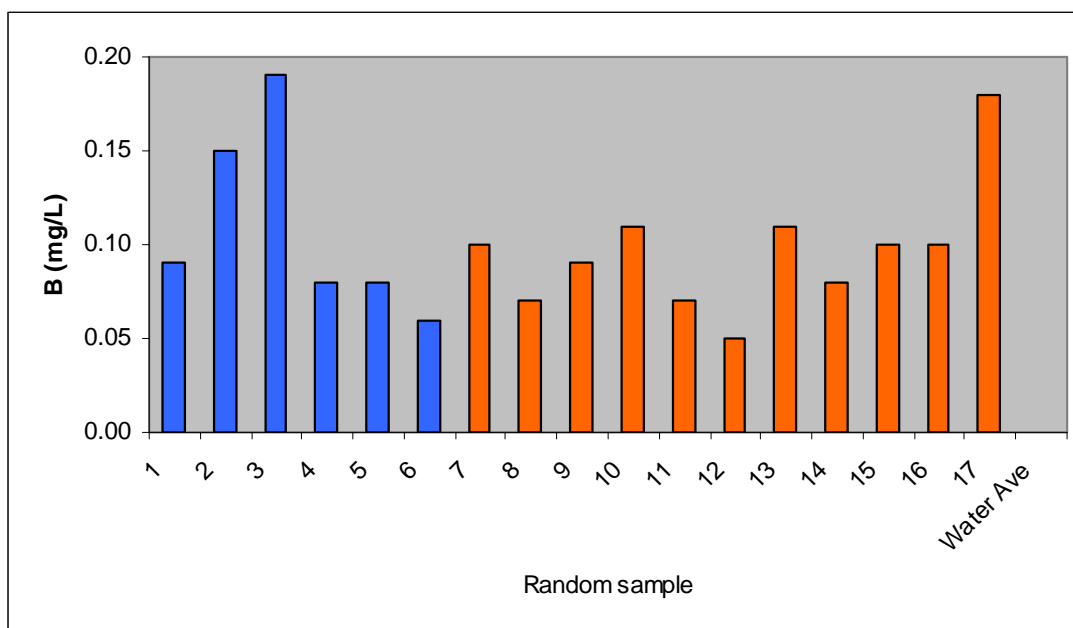


Figure 46: Boron concentration for random samples from Frankston North

7.3.6. Cadmium

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

7.3.7. Chloride

Households made a significant contribution to the load of chloride discharged into wastewater. Chloride in tap water was on average 8 ± 1 mg/L. Whilst in wastewater concentrations were six times larger, as seen by the mean of 51 ± 1 mg/L.

Mean chloride concentrations of 48 ± 4.1 mg/L and 51.8 ± 15.6 mg/L were observed for sites 2 and 3 respectively. The larger catchment, 697 households, had a larger data spread (St.Dev. ± 15.6 mg/L) compared to the catchment of 167 households (St.Dev. ± 4.1 mg/L). The respective data ranges were 48 to 73 mg/l and 42 to 59 mg/L for each of the two sites. The concentrations at site 3 were up to 16% higher than at site 2 (Figure 47).

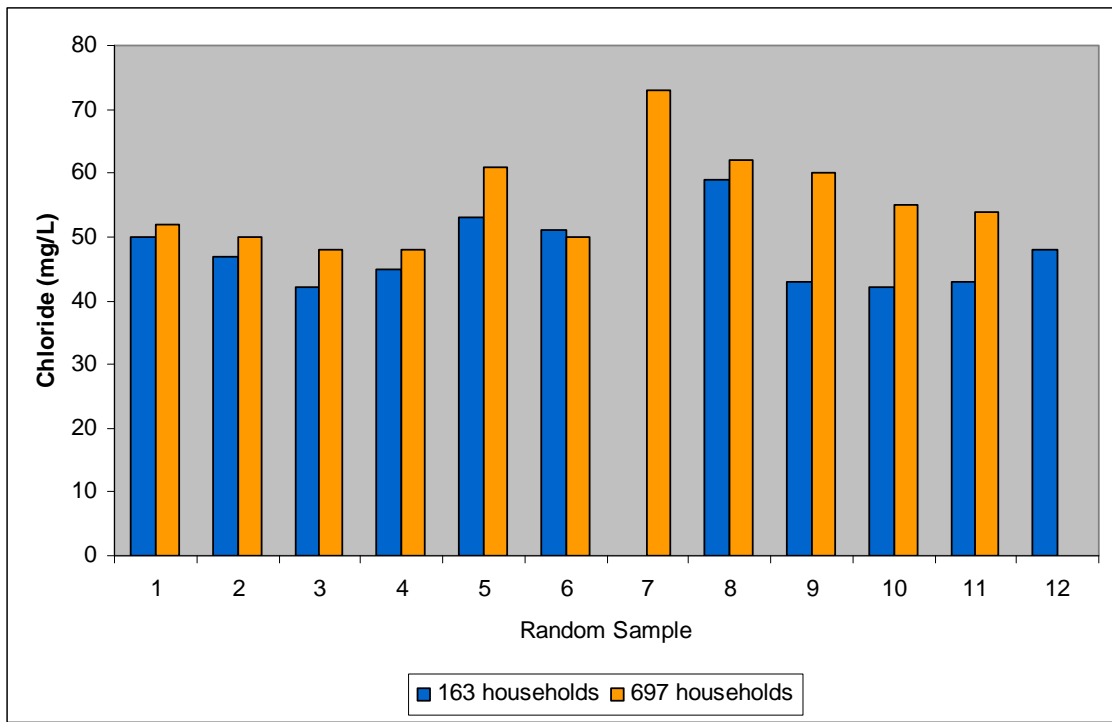


Figure 47: Chloride concentration for random samples at Frankston north.

7.3.8. Copper

The concentration of copper in wastewater was not significant compared to the concentration of copper observed in the tap water (mean concentration 2.301 ± 2.163 mg/L). Taps used for collection of water samples were garden taps which had been allowed to run for 5 minutes before sample collection to flush the line. Despite of the flushing, leaching of copper from the pipe infrastructure seems to have contributed to the high copper readings in the tap water collected from the garden.

Copper concentrations in wastewater ranged between 0.055 and 0.113 mg/L for the composites analysed, with an average concentration of 0.090 ± 0.016 mg/L (Figure 48). Mean copper concentrations at individual sites were 0.081 ± 0.025 mg/L and 0.0895 ± 0.0156 mg/L for sites 2 and 3 respectively (Figure 71 and Figure 72).

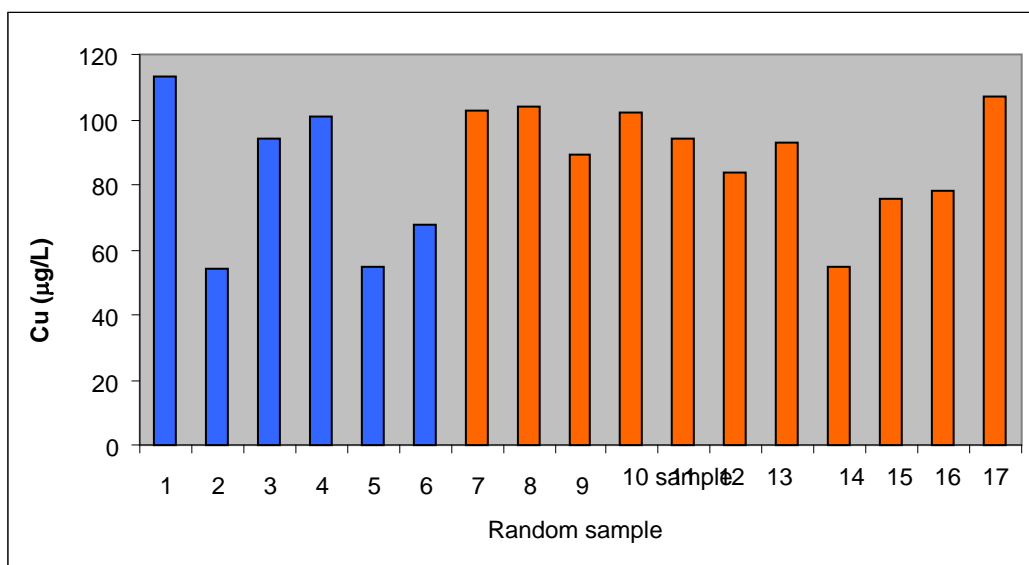


Figure 48: Copper concentration for random samples from Frankston North

7.3.9. Chromium

The mean concentration of chromium in wastewater was marginally higher than in tap water, $24.1 \pm 3.5 \mu\text{g/L}$ (range 19 – 35 $\mu\text{g/L}$) compared to a tap water mean concentration of $18.6 \pm 0.5 \mu\text{g/L}$ (Figure 49) . On average a difference of less than 30% was observed between the two means. Mean copper concentrations at individual sites were $22.3 \mu\text{g/L} \pm 2.2\mu\text{g/L}$ and $25.0 \pm 3.8\mu\text{g/L}$ for sites 2 and 3 respectively (Figure 70 and Figure 69).

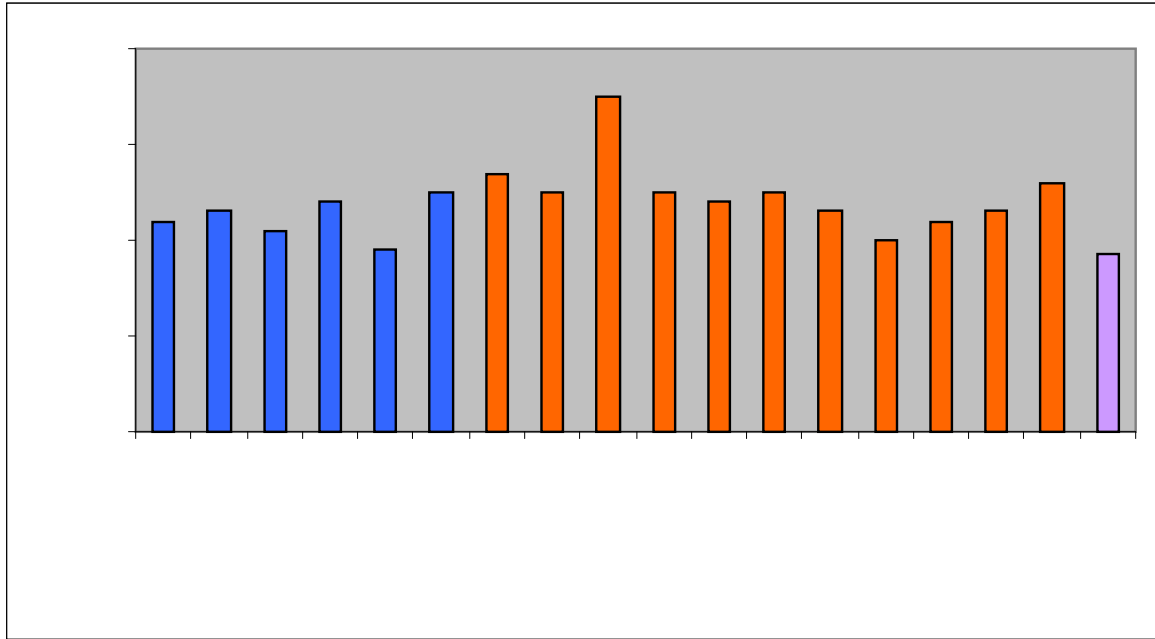


Figure 49: Chromium concentration for random samples from Frankston North

7.3.10. Fluoride

The mean fluoride concentration in tap water from the catchment was $0.91 \pm 0.09\text{mg/L}$. In wastewater the mean fluoride concentration was $1 \pm 0.07 \text{ mg/L}$ (Figure 50). The variability in concentration was within the expected normal distribution for the data. During the sampling period, rainfall was recorded on the 28/02, but this was less than 3mm and hence unlikely to have had a significant impact on the wastewater characteristics.

Comparison of the fluoride concentration in random samples for sites 2 (163 households) and 3 (697 households) indicated that whilst samples for the larger catchment (site 3) displayed slightly higher Fluoride concentrations (mean $1.04 \pm 0.08 \text{ mg/L}$) than site 2 (mean $0.97\pm 0.02 \text{ mg/L}$) (Figure 50), these were again within the normal variability range.

Overall, the contribution of households to the fluoride concentration in wastewater was equivalent to an increase of only up to 10% of the fluoride already present in tap water.

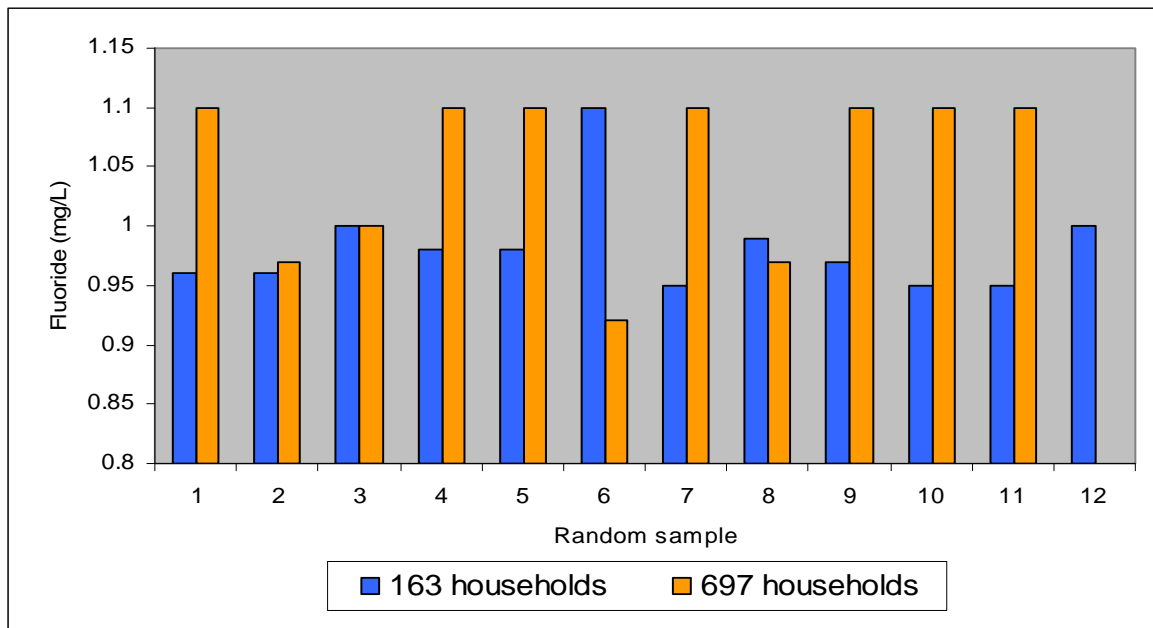


Figure 50: Fluoride concentration for random samples from Frankston North.

7.3.11. Iron

Iron was present in wastewater samples at significantly higher concentrations than in tap water. Tap water contained 0.095 ± 0.024 mg/L of iron, whilst the concentration range was 0.077 to 0.743 mg/L in wastewater, with a mean concentration of 0.421 ± 0.234 mg/L (Figure 51). The concentrations at individual sites were 0.294 ± 0.188 mg/L and 0.543 ± 0.138 mg/L for sites 2 and 3 respectively.

At site 3, the concentration decreased from the 11/03 to the 19/03 as the week progressed and increased in the week that followed, from the 4/03 to 27/03.

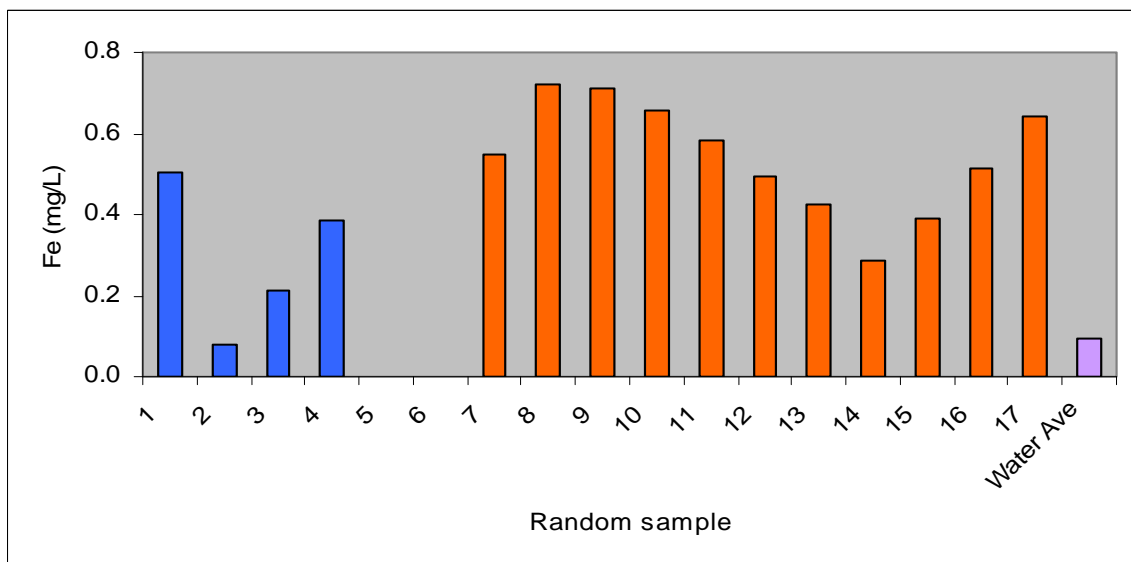


Figure 51: Iron concentration for random samples from Frankston North

7.3.12. Lead

Lead in tap water from the catchment was below the detection limit of $5 \mu\text{g/L}$. In wastewater, it was detected in 76% of the wastewater samples analysed (Figure 52). The lead

concentrations were close to the detection limit, ranging from $< 5\mu\text{g/L}$ to $8\mu\text{g/L}$, and with a mean of $4.0 \pm 2.8\mu\text{g/L}$ (Figure 52). Mean concentrations at sites 2 and 3 were $3.7\mu\text{g/L} \pm 3.1\mu\text{g/L}$ and $4.2\mu\text{g/L} \pm 2.86\mu\text{g/L}$, respectively.

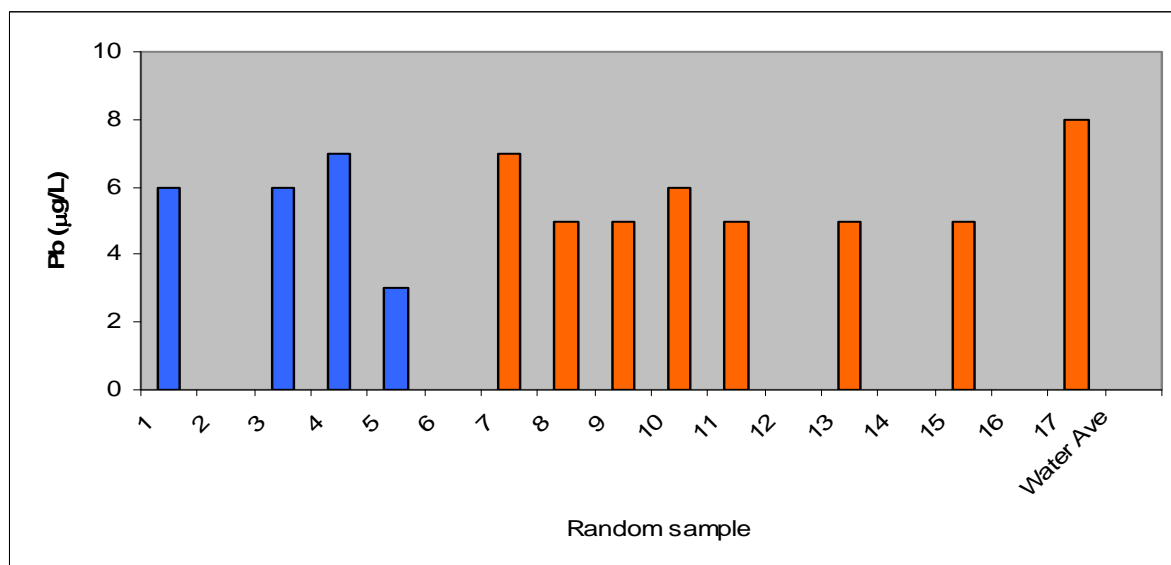


Figure 52: Lead concentration for random samples from Frankston North

7.3.13. Manganese

Only 29.4% of the samples had manganese within measurable concentrations, in all the remaining samples manganese was below the detection limit. At site 2, in particular, none of the samples were within the minimum limits of detection.

Overall, the concentration of manganese in the catchment's wastewater was low, ranging from less than 0.001mg/L to 0.36mg/L . The mean concentration was $0.010\text{mg/L} \pm 0.004\text{mg/L}$. Such concentrations were too low to have any significant impact on colour.

7.3.14. Mercury

Mercury was below the detection limit of $2\mu\text{g/L}$ in all water and wastewater samples analysed.

7.3.15. Molybdenum

Molybdenum was below the detection limit of $50\mu\text{g/L}$ in all water and wastewater samples analysed.

7.3.16. Nickel

The concentration of nickel in the tap water of the catchment was $0.015 \pm 0.001\text{mg/L}$. In wastewater samples, the nickel concentration ranged from 0.016 to 0.025mg/L , with an average value of $0.022 \pm 0.002\text{mg/L}$ (Figure 53). Concentrations at individual sites were $0.021 \pm 0.0035\text{mg/L}$ and $0.022 \pm 0.0018\text{mg/L}$ for sites 2 and 3 respectively. These are shown in Figure 77 and Figure 80 in Appendix D.

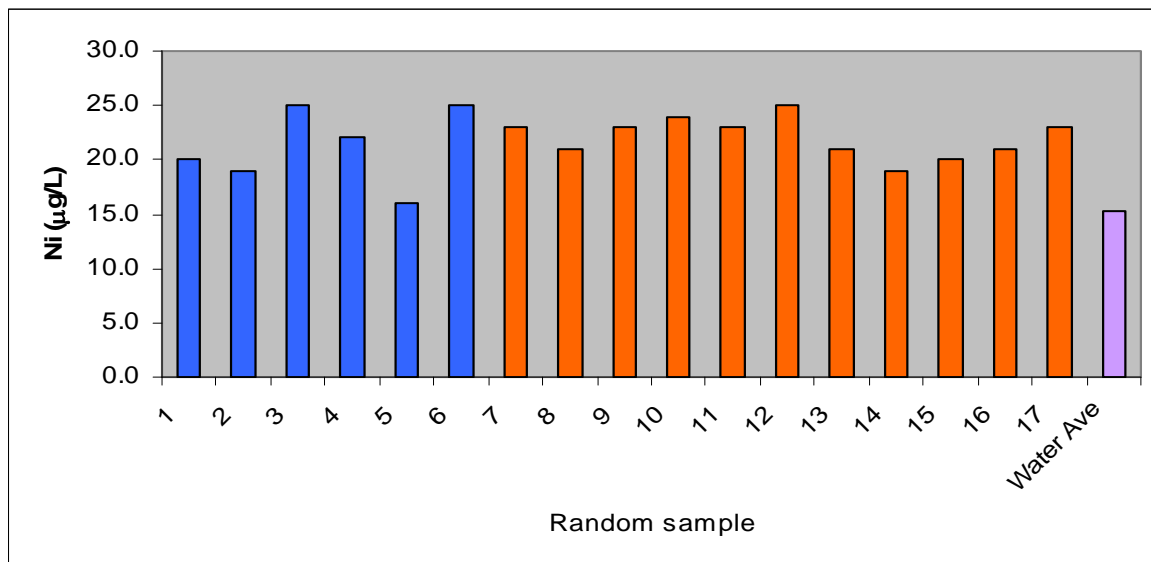


Figure 53: Nickel concentration for random samples from Frankston North

7.3.17. Selenium

Selenium was below the detection limit of 7µg/L in all samples analysed.

7.3.18. Sodium

The sodium concentration in wastewater was equivalent to 2 to 3 times the concentration detected in tap water, which was 8.99± 6.2 mg/L (Figure 54).

The sodium concentration ranged between 10 and 66 mg/L over the whole catchment and the overall mean for the catchment was 27.5 ± 22.1 mg/L.

There was however significant variability between the readings at sites 2 and 3. The concentrations at site 3 (mean 11.7 ± 1 mg/L) were lower and similar to those found in tap water, whilst site 2 had a mean concentration of 56.4 ± 3.2 mg/L.

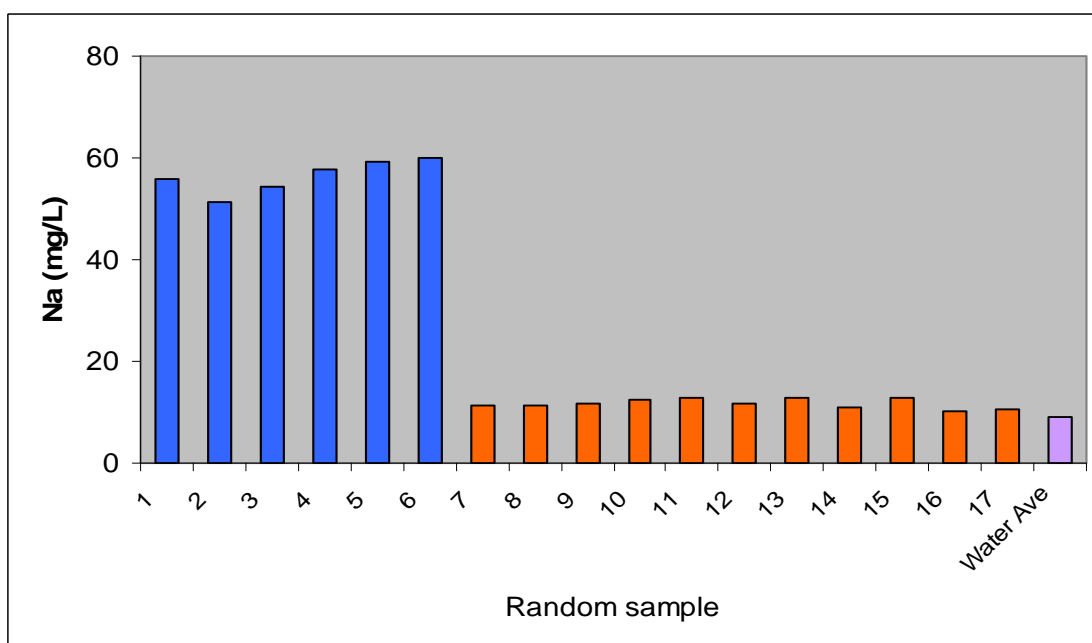


Figure 54: Sodium concentration for random samples from Frankston North

7.3.19. Sulphur

The concentration of sulphur in wastewater was higher than the concentration in tap water by a factor of 8. In tap water the mean sulphur concentration was 1.5 mg/L, and in wastewater it was 11.85 ± 1.48 mg/L (Figure 55). Earlier reports in the series had verified a significant concentration of sulphur in the greywater streams from households (Diaper et al 2008).

Results showed consistency in the mean sulphur concentrations at the two individual sites, 10.57 ± 1.31 mg/L for site 2 and 12.55 ± 1.07 mg/L for site 3.

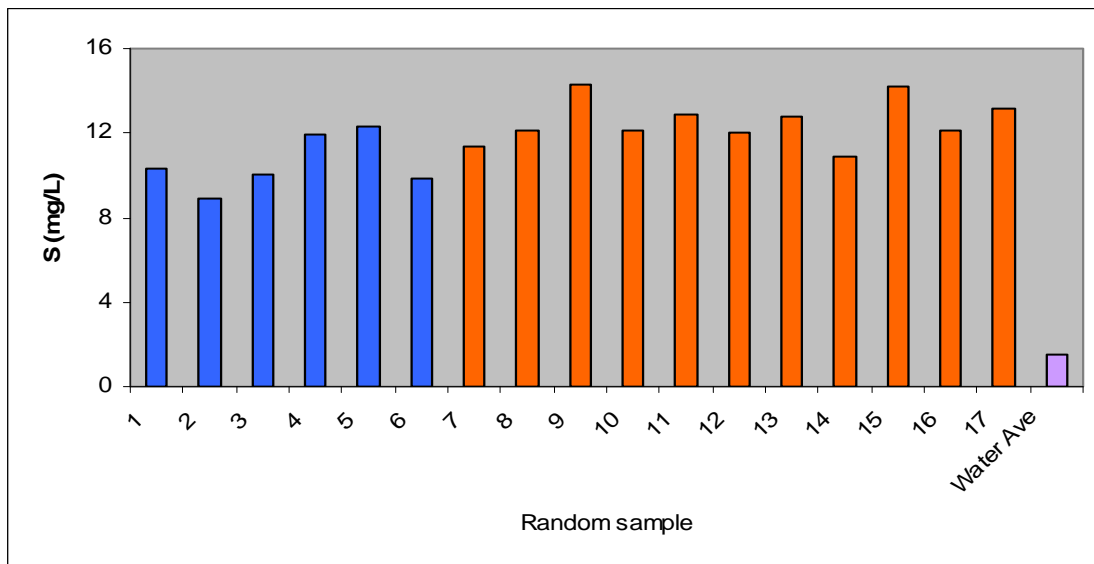


Figure 55: Sulphur concentration for random samples from Frankston North

7.3.20. Tin

Tin was detected in only one sample from the catchment at 0.088mg/L. In all other samples tin was below the detection limit of 0.050mg/L.

7.3.21. Zinc

The concentration of zinc in tap water, 0.106 ± 0.031 mg/L, was comparable to that from wastewater, which had a mean of 0.231 ± 0.232 mg/L and ranged from 0.060 to 1.105 mg/L. These are shown in Figure 56.

The mean concentration for site 2, 0.34 ± 0.39 mg/L, was 97.6% larger than the mean at site 3, 0.172 mg/L ± 0.031 , and it was also subject to a higher standard deviation. This was caused by a high concentration reading of 1.105 mg/L observed on a Saturday.

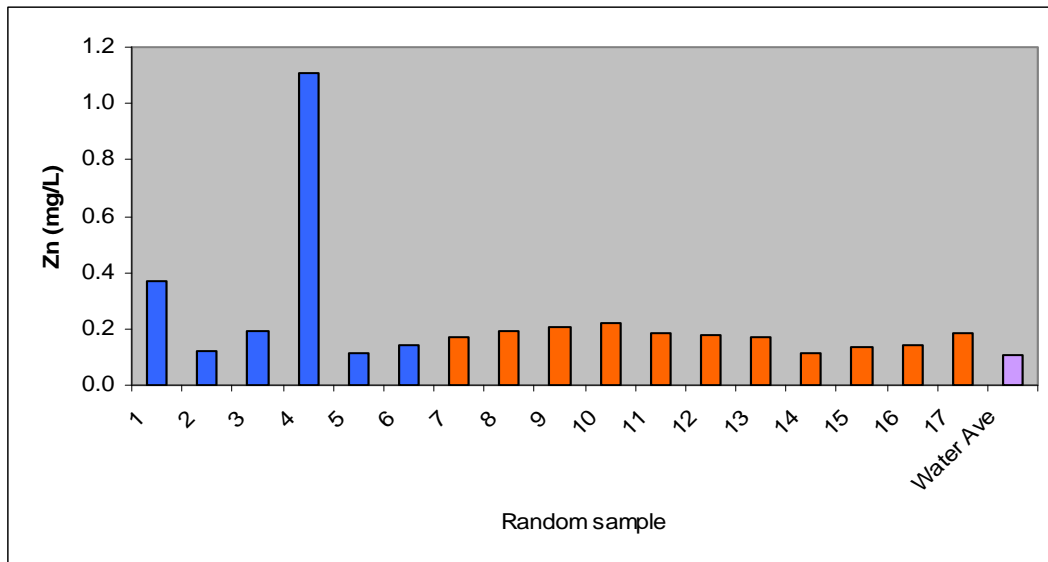


Figure 56: Zinc concentration for random samples from Frankston North

8. COMPARISON WITH OTHER STUDIES

The data collected in this study was compared with three other Australian studies. The three studies were:

- (a) Lock(1994) evaluated the wastewater from wet wells in four major catchments in Adelaide in 1992, servicing 97, 191, 1500 and 3390 people ;
- (b) Connor and Wilkie (1995) evaluated the wastewater from a number of residential and mixed catchments located across Melbourne in 1994;
- (c) City West Water (2007) evaluated the wastewater from a new residential catchment located in the west of Melbourne for a period of 2 weeks in 2006 and 2 weeks in 2007. The catchment received wastewater from 9651 connections (99.4% residential and 0.6% commercial)

Details of each of the four study areas are outlined in Table 13 and a summary of the major results is shown in Table 14.

Table 13: Selected studies on Australian wastewater quality

<i>Year</i>	<i>Location</i>	<i>Catchment type</i>	<i>Catchment size</i>	<i>Reference</i>
1992	Adelaide	Domestic with minimal interference of trade waste	97, 191, 1500 and 3390 people	Lock 1994
1995	Melbourne	Mixed	Various	Connor and Wilkie 1995
2007 and 2007	Melbourne west	Domestic and commercial	9651 connections in 2006 and 2007	City West Water 2007
2008	Melbourne south-east	Domestic only	697 connections	This study

Physical parameters

The two latest studies, City West (2007) and this study are expected to reflect the influence of water restrictions on wastewater quality. The mean pH in wastewater for the last two studies was within a similar range, 6.9 to 7.4, as was the mean conductivity, EC, at 852±39 µS/cm. By comparison the EC of the wastewater in the Adelaide study was much higher (> 1000 µS/cm). This could potentially be attributed to differences in tap water quality and/or groundwater infiltration in Adelaide.

TDS

When comparing the Melbourne studies only, the TDS concentration was 12 to 72.2% higher in 2006-2008 than in 1994 (TDS of 375mg/L) (Connor and Wilkie, 1995).

The TDS in this study , 421±54.6mg/L, was 35% lower than that recorded in the West, 646 ± 15 mg/L (CWW 2007) and only 12% higher than the mean recorded by Connor and Wilkie in 1994 (Connor and Wilkie, 1995).

As with the EC, the TDS concentrations in the two most recent studies were 50% lower than the values verified in the Adelaide study (Lock 1994).

Aluminium

Significant variability was observed in aluminium concentrations. This was reflected in the data from the four south Australian catchments with mean concentrations ranging from 0.293 to 1.387mg/L. In the three Melbourne studies, the concentration of aluminium was consistent at 0.85 ± 0.5 mg/L. This may be attributed in part to differences in the quality of mains water in each of the two cities.

Arsenic

Low concentrations of arsenic were prevalent in the residential sewage analysed. These are either at or close to the detection limits. Arsenic was less than 0.005mg/L in all the Melbourne studies, being detected at 0.002mg/L in Connor and Wilkie (1995) and CWW(2007), and being below the limit of detection of 0.005mg/L in this study.

Boron

The concentration of boron in residential wastewater has decreased since the 1990s. Concentrations were one order of magnitude higher, 0.263 to 0.808mg/L in the 1990's studies (Lock 1994 and Connor and Wilkie 1995), whilst in 2007-2008 they were less than 0.101mg/L.

Calcium

The concentration of Ca was similar in all the Melbourne studies at 10mg/L.

Cadmium

Less than 0.002mg/L of Cd was detected in all studies, including Adelaide where the concentration of Cd was 0.001mg/L (Lock 1994).

Chloride

The concentration of chloride in wastewater was within the same range in the west and the south east of the city, i.e. between 45 to 55mg/L. However, it had not been evaluated in the earlier studies.

Chromium

The concentration of Cr was higher in this study at 0.024mg/L than in the other Melbourne studies, 0.006mg/L in CWW(2007) and 0.003mg/L in Connor and Wilkie (1995).

Cobalt

The concentration of cobalt in wastewater was below the detection limit in all 4 studies.

Iron

The concentration of iron, [Fe], ranged from 0.2 to 0.3mg/L, and was the lowest in this study by 18 to 60% compared to the other studies.

Fluoride

The concentration of fluoride in wastewater was higher in this study, at 0.99mg/l, than in the CWW study, 0.62 mg/L (CWW 2007).

Lead

In 1994, the concentration of lead in Adelaide ranged from 0.009 to 0.059mg/L, whilst in Melbourne it was on average 0.013mg/L (Lock 1994, Connor and Wilkie 1994). However

lower concentrations were prevalent in the more recent Melbourne studies: 0.003mg/L in CWW (2007) and either at or below the detection limit of 0.005mg/L in this study.

Magnesium

Wastewater in the three Melbourne studies showed similar concentrations of magnesium, 3.95 ± 0.66 mg/L.

Manganese

Wastewater in the three Melbourne studies displayed similar concentrations of manganese, 0.039 ± 0.007 mg/L.

Mercury

Mercury in wastewater was below the detection limit of 0.002mg/L in all 4 studies.

Molybdenum

Molybdenum in wastewater was below the detection limit in all 4 studies.

Nickel

The concentration of nickel in this study, 0.022mg/L, was comparable to values recorded in Adelaide and was three times larger than the results from the other 2 Melbourne studies.

Nitrogen

TKN concentrations were similar across all the Melbourne studies, approximately 62 ± 11 mg/L. In this study, the concentration of nitrogen was slightly higher but still within the normal data distribution.

Phosphorus

A phosphorus concentration of approximately 24 mg/L ± 1.5 had been detected in all the earlier studies, but in the current study the values were 48% lower.

Potassium

The concentration of potassium in all Melbourne studies was similar, being on average 15.5 ± 3.5 mg/L.

Selenium

Selenium in wastewater was either at or below the detection limit of 0.007mg/L.

Sodium

Similar concentrations of sodium were detected in Connor and Wilkie (1995) and City West Water (2007) at approximately 80mg/l, whilst in this study they were 30% lower at less than 56mg/L.

Zinc

The mean concentration of zinc in the 3 Melbourne studies was equivalent at 0.116 ± 0.06 mg/L. However, in this study individual sites 2 and 3 showed that significant variability can be detected within a catchment, as seen in the respective concentrations of $0.34 \pm$

0.386 mg/L and 0.172 ± 0.031 mg/L. By comparison the concentration for the Adelaide study was much higher at 0.553 ± 0.24 mg/L.

Table 14: Summary of wastewater quality data for selected domestic catchments In Australia

Reference	Lock				Connor and Wilkie	CWW				This study				
Year	1994				1994	Nov-Dec 2006	May 2007			Feb-Mar 2008				
Location	SA				Vic	Vic				Vic				
	Hillbank	Kidman Park	Eden Hills	Coromandel Valley	Melbourne	Melbourne West				South-East Melbourne				
Size	97pe	191pe	1500pe	3390pe			9651 connections				697 connections		183 connections	
Type	Domestic	Domestic	Domestic	Domestic	Mixed		Domestic		Domestic		Domestic		Domestic	
Conc (mg/L)	Mean	Mean	Mean	Mean	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Al	0.543	0.293	1.387	0.741	0.745	0.352	1.116	0.33	0.499	0.381	0.975	0.212	0.849	0.493
As					0.002	0.001			0.002	0	<0.005		<0.005	
B	0.331	0.808	0.363	0.431	0.263	0.206	0.174	0.13	0.094	0.049	0.096	0.034	0.084	0.0401
Ca	nd	nd	nd	nd	9.261	2.45	12	0.926	10.99	1.498	12.2	0.974	11.09	1.5781
Cd	0.001	0.001	0.001	0.001	0.0005		<0.002		<0.002		<0.01		<0.001	
Cl					nd		45.553	14.379	43.1	8.33	55.7	7.656	45.33	3.08
Cr	0.003	0.009	0.195	0.01	0.003	0.002	0.006	0.001			0.024	0.004	0.023	0.0026
Cu	0.112	0.182	0.521	0.25	0.062	0.015	0.1	0.1	0.136	0.163	0.11	0.023	0.081	0.025
Co	nd	nd	nd	nd	0.001		<5		<5		<0.01		<0.01	
F					Nd		0.62	0.11			1.1	0.07	0.99	0.056
Fe	0.507	0.329	1.099	0.788	0.728	0.373	0.613	0.012	0.358	0.305	0.204	0.138	0.294	0.188
Pb	0.016	0.009	0.059	0.011	0.013				0.003	0.001	≤0.0056	0.001	0.005	0.001
Mg	nd	nd	nd	nd	4.925	1.655	3.7		4.081	0.465	3.096	0.177	2.448	0.362
Mn	0.107	0.03	0.089	0.168	0.048	0.013	0.043	0.006	0.032	0.005	0.033	0.004	<0.001	
Hg				0.0001	<0.0005		<0.001		<0.001		<0.002		<0.002	
Mo	nd	nd	nd	nd	<0.001						<0.050		<0.050	
Ni	0.025	0.025	0.026	0.037	0.004	0.002	0.006	0.001			0.022	0.002	0.021	0.003
N (asTKN)					57.23	21.66	51	27.41	56	5.151	67.9	11.7	79	13.25
P	24.18	18.31	17.89	29.87	22.4	11.3	26.1		24.357	8.177	11.7	0.786	13.25	3.079

K					16.785	7.285	17.6	1.121	18.214	0.893	9.458	0.625	15.77	2.009
Se	nd	nd	nd	nd	<0.01		0.008	0.001			<0.007		<0.007	
Na	nd	nd	nd	nd	87.28	28.52	76	6.234	80.036	7.936	11.723	0.976	56.371	3.213
Zn	0.838	0.169	0.577	0.628	0.169	0.076	0.145	0.027	0.095	0.029	0.172	0.031	0.34	0.386
TDS	870	940	1000	950	375.4	93.74	657.33	301.9	635	86.1	418	47	421	54.6
EC(μ S/cm)			1820	1010	nd		878		806.8	76.2	870	59	777	222
pH			8.3	6.4	nd		7.407		7.14	0.195	6.9	0.26	6.95	0.44

9. DISCUSSION

A residential catchment of 697 households located in the south-east of Melbourne was monitored for the quality of wastewater during February to March 2008. During the monitoring period rainfall was insignificant, hence the results are not subject to inflow and infiltration and the flow can be assumed as equivalent to the dry weather flow, i.e. originating mainly from wastewater discharged by households.

The catchment was comprised of residential stand-alone properties. The typical population in the area was representative of the Melbourne population comprised of 39.3% couples, 36.4% families with children, 22.4% one parent families and 1.7% other families, and the average income of households ranges between \$1148 and \$ 1416 per week.

The sewerage infrastructure of the catchment was in good condition. Assets had a condition grading 1 and were subject to low infiltration based on a 2006 study (SEWL 2006). They were comprised mainly of a vitrified clay gravity system with one rising main. Other materials used in the network included cast iron, ductile iron and small sections of polymeric materials.

Wastewater monitoring was conducted at 3 manholes in the catchment which encompassed sewage generated by 7, 163 and 697 connections.

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

The height of the peak flow to the diurnal flow measured in 2008 was lower by 2.5 to 4% compared to the Frankston historic flow average. The change, from 12% to less than 8%, may be a reflection of demand management measures introduced through water restrictions.

Priority contaminants

The major characteristics of the wastewater in the catchment are summarised in Table 15. These values were compared to other studies conducted in Adelaide (Lock 1994), and in other parts of Melbourne (Connor and Wilkie 1995 and City West Water 2007).

Wastewater is subject to significant variability in quality and quantity. In this catchment, the most abundant priority parameters detected in wastewater were TDS, phosphorus, nitrogen, chloride, sodium and zinc. The concentration of elements such as antimony, arsenic, cadmium, cobalt, mercury, selenium, tin and molybdenum were below the detection limits, which is in agreement with earlier results reported in the literature for Melbourne. Lead was present either at or close to the limit of detection.

Fluoride was present in wastewater, but concentrations were on average only 10% higher than in tap water. Hence, household activities during the sampling period resulted in a small increase to the concentration of fluoride in the catchment.

It had initially been hypothesized that with lower water use the concentration of contaminants would have been expected to increase, particularly for those contaminants associated with household chores, e.g. sodium and boron. However, this was not necessarily observed.

TDS at this catchment was very similar to the average TDS recorded for Melbourne in 1995. On the other hand, the increase verified for the West side of the city was 72% larger (City West Water 2007). The TDS in this catchment was 35% lower than that recorded in the City West Water study.

A lower concentration of boron was also observed in this study compared to 1995 data.

Wastewater quality data collected in Adelaide from 1992, in particular, had significantly higher values for parameters such as TDS and boron compared to the Melbourne studies, which could be a reflection of the much harder water quality found in Adelaide and/or of

groundwater infiltration, but may also result from changes in household practices and household product development in the last 15 years.

Conductivity, chloride and calcium concentrations were comparable to those recorded in the 1995, 2006 and 2007 Melbourne studies. Concentrations of calcium and potassium in this study were lower by at least 27% and 50%, respectively compared to those earlier studies. On the other hand, the concentration of sodium reported in the 1995 study was similar to that recorded in this study (only 12% higher), but it was also 60% lower than the TDS reported in the 2006-07 Melbourne West study. Hence other species besides sodium are affecting the TDS concentration in the West.

The phosphorus concentration observed in this catchment was also lower by 40% to 50% compared to the previous studies, whether this is a reflection of different household habits or changes in the formulation of detergents and other household products would need to be confirmed.

The concentration of TKN, which is mainly attributed to anthropogenic activity, was similar in concentration to 1995 values. It can be hypothesized that as its origin is mainly from human urine, blackwater discharges would not have changed that significantly over time.

Practices such as diversion of washing machine grey water to garden, could contribute to reduction of salts in wastewater, but at this stage it is not possible to confirm if such practices were adopted by householders in the catchment.

Colour in wastewater was 77 ± 14 Pt-Co units during Summer, with on average 34% removable through aerobic digestion. This implies that the current aerobic treatment at the Eastern treatment plant would partly remove the colour from the effluent and that additional treatment would be required to achieve further removal. The variability in colour for each day of the week and also in the removal rates observed after aerobic degradation indicate the presence of multiple compounds responsible for colour and that these vary from day to day in concentration and origin.

Scale effects

The catchment was monitored at a range of scales based on the number of connections. Majority of parameters were present in similar concentrations along the catchment as verified in 24h wastewater composites, but there were exceptions such as for Na and Zn – the concentration for these last two elements varied significantly at different points within the catchment.

For parameters such as Al, As, Sb, B, Ca, Cd, Cl, Cu, F, TDS, TKN, Mg, Mn, K, Pb, Se, Hg, P and Mo, similar concentrations were verified between sites 2 and 3 within the catchment.

As expected, the size of the catchment affects the standard deviation of the data – in general as the catchment size and number of connections increased from sites 1 to 3, less influence from individual dischargers was observed, resulting in the narrowing of the data spread and consequently in a lower standard deviation for the sample population. However, a few exceptions were verified, such as for sodium, highlighting the influence that particular discharge events can have in a catchment.

In the smaller catchment, a wider range of concentrations was verified during the day compared to the larger catchment, partly because less dilution would occur.

Table 15: Major characteristics of wastewater at the selected catchment in Feb-March 2008

<i>Parameter</i>	<i>Mean \pm St.Dev.</i>	<i>Comment</i>
pH	7.04 ± 0.22	
EC	$870 \pm 59 \mu\text{S/cm}$	

<i>Parameter</i>	<i>Mean ± St.Dev.</i>	<i>Comment</i>
Colour	Total: 77 PCU ± 14 Non biodegradable: 50 PCU ± 13	Colour in the samples was comprised mainly of non-biodegradable colour (on average 66% of the total colour was non-biodegradable).
Arsenic	< 5µg/L	
Antimony	< 2µg/L	
Boron	0.02 + 0.19 mg/L	Concentration was much higher than tap water (<0.02mg/L) but showed a reduction in concentration compared to historical values.
Chloride	51.8 ± 15.6mg/L	
Copper	0.089 ± 0.015 mg/L	Range 0.054-0.113mg/L. Tap water collected from the sites had a higher concentration than wastewater most likely due to contamination from infrastructure at time of collection.
Chromium	24.1 ± 3.5µg/L,	A marginal increase from the concentration in tap water at 18.6 µg/L, but higher values than earlier 2006-07 studies.
Fluoride	1± 0.07mg/L	Concentration was 10% higher compared to other Melbourne studies.
Iron	0.477± 0.185 mg/L	Concentration is higher than 0.095mg/l in tap water. But in the same range as other studies in Melbourne and too low to cause any discoloration in the wastewater.
Lead	≤ 5.7 ± 1.3 µg/L	Concentration very similar to tap water (<5 µg/L).
Mercury:	< 2µg/L	
Molybdenum	<0.05 mg/L	
Nickel	0.022 ± 0.002 mg/L	Concentration is 4 times larger than earlier Melbourne studies, but only slightly higher than tap water (0.015±0.001mg/L).
Nitrogen as TKN	67.9± 4.1 mg/L	
Phosphorus as TP	11.7 ± 0.8 mg/L	
Selenium	< 2 µg/L	
Sodium	11.7 ± 1mg/L	Concentration varied significantly between sites (mean of 56.4mg/L for site 2).
Sulphur	11.8 ± 1.5mg/L	Concentration was significantly higher than in tap water (1.5mg/L)
TDS	418 ± 47.4 mg/L;	

<i>Parameter</i>	<i>Mean ± St.Dev.</i>	<i>Comment</i>
Tin	≤0.005mg/L	
Zinc	0.231 ± 0.232mg/L	Concentration similar to water at 0.106mg/L and also similar to other studies.

Load distribution over time

A number of studies in the literature had reported significant changes in the concentrations of selected contaminants on certain days of the week. For instance, Rule et al (2006) verified an increase in chromium, lead and nickel on a Friday in wastewater from 1960 housing estates in the UK, whilst Pantsar-Kallio et al (1999) had verified higher metal concentrations during weekdays and higher nitrogen and phosphorus during weekends.

In this study trends over the week were not ascertained based on the results from the composite samples. The wastewater showed significant variability in concentration over the monitoring period from week to week and day to day, displaying maxima and minima concentrations on different days of the week over different weeks. Monitoring over a longer time period could be recommended if further investigation into any trends is desired.

The concentration of contaminants changed during the day driven by the range of activities undertaken by householders. Contaminants which displayed the highest concentrations in wastewater, TKN, TP, Na, S, Cu, Fe and Zn were characterised hourly over a 24h period on a Sunday. Over 70% of the daily load of these elements were discharged between 6am to 7pm. Discharge of TKN, which is associated with anthropogenic waste, occurred mainly from 6 to 11am. However, elements, such as Na, Cu and S, were more equally distributed during the day. For Na and S majority of the load was discharged in the afternoon – an indication that household activities may have an important role in their generation. In the case of Zn, the largest load of the day was observed from 4 to 7pm, but this was partly due to 2 major spikes in concentration that occurred at those times on that specific day.

In summary, results indicate that caution is required when comparing data from studies conducted in different catchments, particularly where the infrastructure of the catchment and the quality of mains water differ, as in the case of Adelaide and Melbourne.

A slight reduction in water consumption patterns was verified from earlier studies, however, concentrations found in the sewer were not necessarily higher than those observed in previous studies prior to the implementation of water restrictions, except for TDS.

The concentration of some elements can differ significantly between catchments, and this was observed within this study at different scales within a same catchment and between different catchments. For example, when comparing data from the east and west of Melbourne, particularly for parameters such as TDS and the sodium concentration.

Monitoring of the smallest catchment, 7 connections, was useful to provide an indication of the range of concentrations that are generated by households before significant dilution and mixing with other wastewater streams occurs. But such monitoring also carries greater complexity due to the strong dependency on householder behaviour from day to day. In such regard, comparison with data from the mini-house studies carried in this research program would assist in gaining a greater understanding of the events responsible for wastewater quality.

This study was carried during the period from February to March 2008. This was a dry weather period, hence it was assumed to incur minimal inflow or infiltration from stormwater. In addition it was also assumed that this period was the most likely time of the year for residents to be diverting greywater to the garden, given that 3a water restrictions were in place at the time.

Suggestions to increase the validity of future studies include extending the sampling period adopted given the data variability.

Future evaluation of this catchment will also be undertaken in the Winter period to determine if any seasonal variation can be detected.

10. 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.

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

- Concentration of priority contaminants in wastewater and in tap water;
- Daily changes in contaminant concentration, by examining wastewater quality on different days of the week;
- Hourly variability of priority contaminants, by examining the concentration of selected contaminants during a 24 period; and
- The impact of catchment scale on wastewater.

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

- pH: 7.04 ± 0.22
- EC: $870 \pm 59 \mu\text{S/cm}$
- Colour: Total: 77 ± 14 PtCo units and non biodegradable: 50 Pt Co units ± 13
- Arsenic: $< 5\mu\text{g/L}$
- Antimony: $< 2\mu\text{g/L}$
- Boron: 0.101 ± 0.039 mg/L
- Chloride: 51.8 ± 15.6 mg/L
- Copper: 0.062 ± 0.015 mg/L
- Chromium: $24.1 \pm 3.5\mu\text{g/L}$,
- Fluoride: 1 ± 0.07 mg/L
- Iron: 0.421 ± 0.234 mg/L
- Lead: $\leq 5.7 \pm 1.3 \mu\text{g/L}$
- Mercury: $< 2\mu\text{g/L}$
- Molybdenum: < 0.05 mg/L
- Nickel: 0.022 ± 0.002 mg/L
- Nitrogen as TKN: 67.9 ± 4.1 mg/L
- Phosphorus as TP: 11.7 ± 0.8 mg/L
- Selenium: $< 2 \mu\text{g/L}$
- Sodium: 27.5 ± 22.1 mg/L
- Sulphur: 11.8 ± 1.5 mg/L
- TDS: 418 ± 47.4 mg/L
- Tin ≤ 0.005 mg/L
- Zinc 0.231 ± 0.232 mg/L

Wastewater flows

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

The height of the relative peak flow to the overall diurnal flow was lower by 2.5% to 4% compared to the historic flow average for the region, which may be reflection of demand management measures introduced through water restrictions.

Detection of priority contaminants

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

Colour in the wastewater was 77 ± 14 PtCo units during summer, with on average 34% removable through aerobic digestion. Elements such as iron and manganese were present in concentrations too low to contribute to any of the discoloration. Significant variability was observed from one day to another.

The elements present at the highest concentrations in wastewater were TDS, nitrogen, phosphorus, potassium, sulphur, aluminium and sodium - equivalent to more than 3 times the initial concentration observed in tap water.

A number of priority contaminants, including arsenic, antimony, cadmium, cobalt, mercury, selenium, tin and molybdenum were below the limits of detection, which is similar to results reported in the literature for earlier Melbourne studies.

Lead was detected on specific days only, either at or close to the limit of detection.

Fluoride was also present in wastewater; the concentration verified was on average only 10% higher than that in tap water.

TDS was higher by over 12% compared to 1995 Melbourne data, but lower by 30% compared to wastewater collected in the west of Melbourne in 2006-07. It was hypothesized that greywater diversion to garden or less groundwater infiltration could be some of the causes for this variation, but this is still to be confirmed.

The conductivity, chloride, aluminium and calcium concentrations were comparable to those recorded in 1995, 2006 and 2007 Melbourne studies. Whilst concentrations of sodium and potassium in this study were lower by at least 12% and 50%, respectively. On the other hand, the concentration of sodium reported in the 1995 study was similar to that recorded in Melbourne West in 2006-07, whilst the TDS at the time was 60% lower. Given the large number of TDS sources and the complexity of the data no attempt was made to correlate the concentration of ionic species to TDS.

The phosphorus concentration observed in this catchment was 40% to 50% lower compared to previous studies; whether this is a reflection of different household habits or less phosphorus in household products would need to be confirmed in the future.

The concentration of TKN, which is mainly attributed to anthropogenic activity, was in agreement with values reported in the literature.

The concentration of copper in wastewater was lower than in tap water collected in the catchment, hence it was concluded that contamination from the pipe work at the time of tap water collection had occurred.

The concentration of nickel in tap water and wastewater was similar within the catchment. Concentrations in this catchment were higher than those reported in the literature. This discrepancy could be attributed to differences in water infrastructure.

Weekly patterns

The sewage flow rate was generally higher during weekends than in weekdays. But the day of the week had no significant effect on concentration, which differs from earlier observations (Wilkie et al 1996 and Rule et al 2006).

Wastewater displayed significant variability in concentration over the monitoring period from week to week and day to day.

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 less variability 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 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 Al, As, Sb, B, Ca, Cd, Cl, Cu, F, TDS, TKN, Mg, Mn, K, Pb, Se, Hg and Mo, similar concentrations were verified between sites 2 and 3, corresponding to 163 and 697 connections. But significant differences were evident for Na and Zn between the 2 sites.

Diurnal distribution

The concentration of contaminants varied during the day due to the range of activities undertaken by householders. Contaminants which displayed the highest concentrations in wastewater, TKN, TP, Na, S, Cu, Fe and Zn were characterised hourly over a 24h period on a Sunday and integrated in respect to flow rate.

For nutrients, such as nitrogen and phosphorus approximately 70% of the daily mass load was discharged in the morning.

Nitrogen and phosphorus, which have a strong correlation with anthropogenic discharges, had 50% and 39% of their respective total loads for the day discharged from 6am to 11am.

The loads for other parameters (Al, Fe, Cu, Na, S and Zn) had a more even spread throughout the day. This suggests that release of those contaminants into wastewater is not associated with human excretion alone, and that household activities may have an important role in their generation.

For Zn, the largest load of the day was observed from 4pm to 7pm. However, this caused by 2 major spikes in concentration and hence further investigation is recommended to confirm the diurnal distribution.

General remarks

In summary, results indicate that caution is required when comparing data from studies conducted in different catchments, particularly where the infrastructure of the catchment and the quality of mains water differ.

A slight reduction in water consumption patterns was verified from earlier studies; however, concentrations found in the sewer were not necessarily higher than those observed in previous studies prior to the implementation of water restrictions, but for TDS.

The concentration of some elements was determined to differ significantly between catchments. This was observed within this study and when comparing data from the east and west of Melbourne, particularly for parameters such as TDS and sodium.

The causes of such variations are unknown at this stage, but a range of factors affect them, such as diversion of machine greywater to garden, changes in household product formulation, etc.

In addition, it also needs to be verified whether the results here verified were not an anomaly or peculiarity of this catchment and sampling period. Future evaluation of this catchment will be undertaken in the winter period to determine if any seasonal variation can be detected.

Suggestions to increase the validity of future studies include extending the sampling period adopted, as longer time periods would allow for evaluation of long term trends despite of the high data variability.

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APPENDIX A – DETAILS OF SITE INSTALLATION

A1. Summary

CSIRO installed 3 autosamplers in Frankston North for collection of wastewater samples. The autosamplers were installed at Whistlestop Reserve (site 1), Lanena Court Pump Station (Site 2) and Toolomba Court (site 3). Each autosampler was housed in a security enclosure of dimensions 800mm (H) x 750 mm (W) x 550mm (D) for protection against vandalism. A buried conduit or pipe was used as a channel to connect the autosampler to the interior of the manhole and the wastewater. A sampling tube was installed through the conduit to the sampling point at the bottom of the manhole. At each site a flow meter and a conductivity meter were also installed for monitoring. This document outlines the details of the site and installation.

A2. Site set-up

Details of each location for surface installation area as follow:

(1) Site 1 : Whistlestop Reserve

Sampling was conducted from manhole (FGL 57) over a sewer made of VC 375 and 3.2 m deep. The equipment was located on public land and installed 1 m away from the manhole and away 3m from a neighbouring residence.

(2) Site 2: Lanena Ct

Sampling was conducted from manhole (SPS 378-1) over a sewer made of VC 255 and 3.5m deep. The manhole was located prior to entry to a pump station at Lanena Ct. The station was located at the entrance of the pump station beside a private property. The driveway in the front of the pump station was shared with the residence (Figure 57).

The autosampler was placed in front of the pump station and pipe or conduit installed from the back of the pump station to the autosampler housing unit.

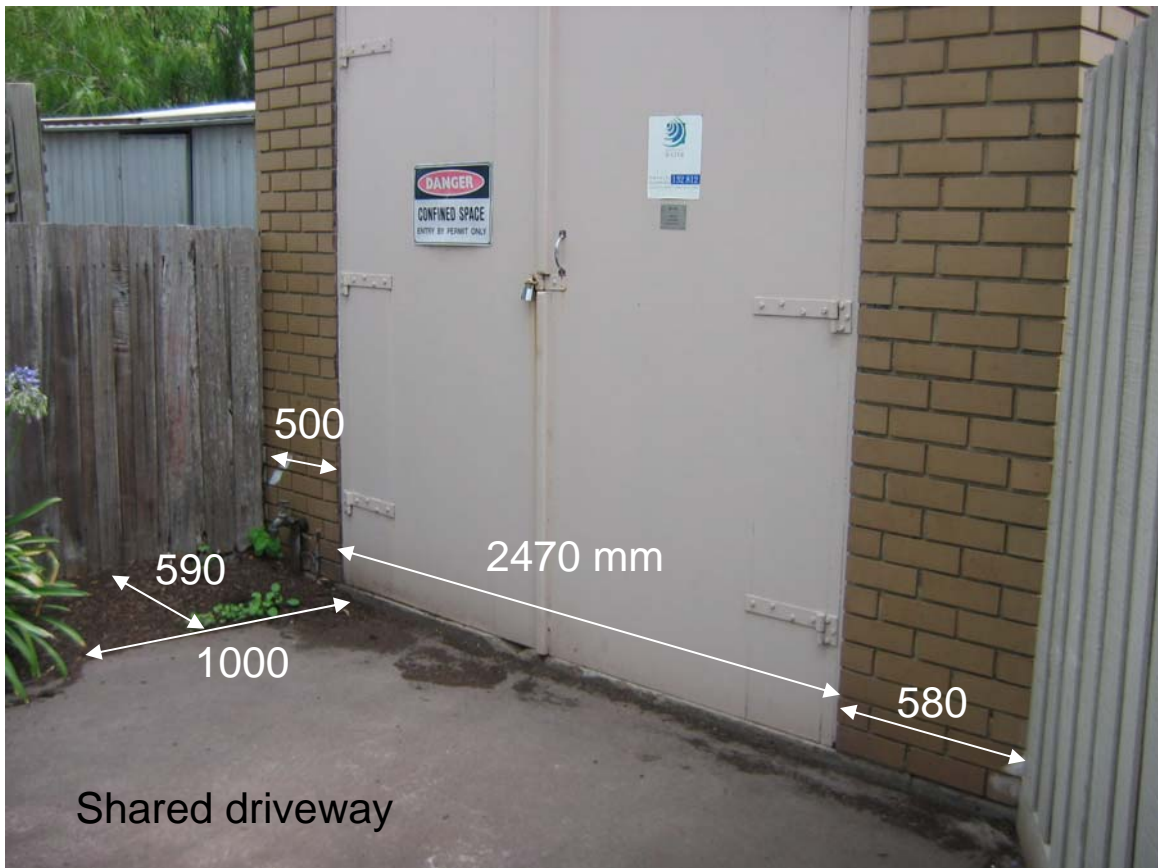


Figure 57: Pump station entry at Lanena Ct.

(3) Site 3: Toolomba Ct

The manhole (FGL 59) was over a VC150 sewer and 1.8m deep. It was located at Toolomba Ct on the nature strip and at the boundary of two properties. The housing unit was placed 60cm from the manhole facing towards the street (Figure 58 and Figure 59).

Details of the housing used for autosamplers at site 1 and 2 are shown in Figure 60



Figure 58: Manhole at site 3 (7 households)



Figure 59: Manhole at Site 3

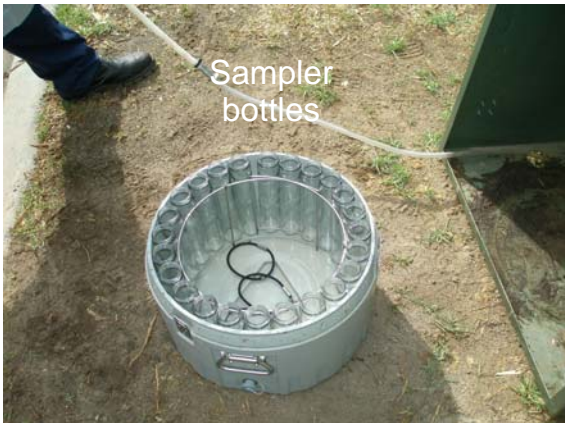


Figure 60: Installation for autosamplers.

APPENDIX B - DAILY WEATHER OBSERVATIONS FOR FRANKSTON

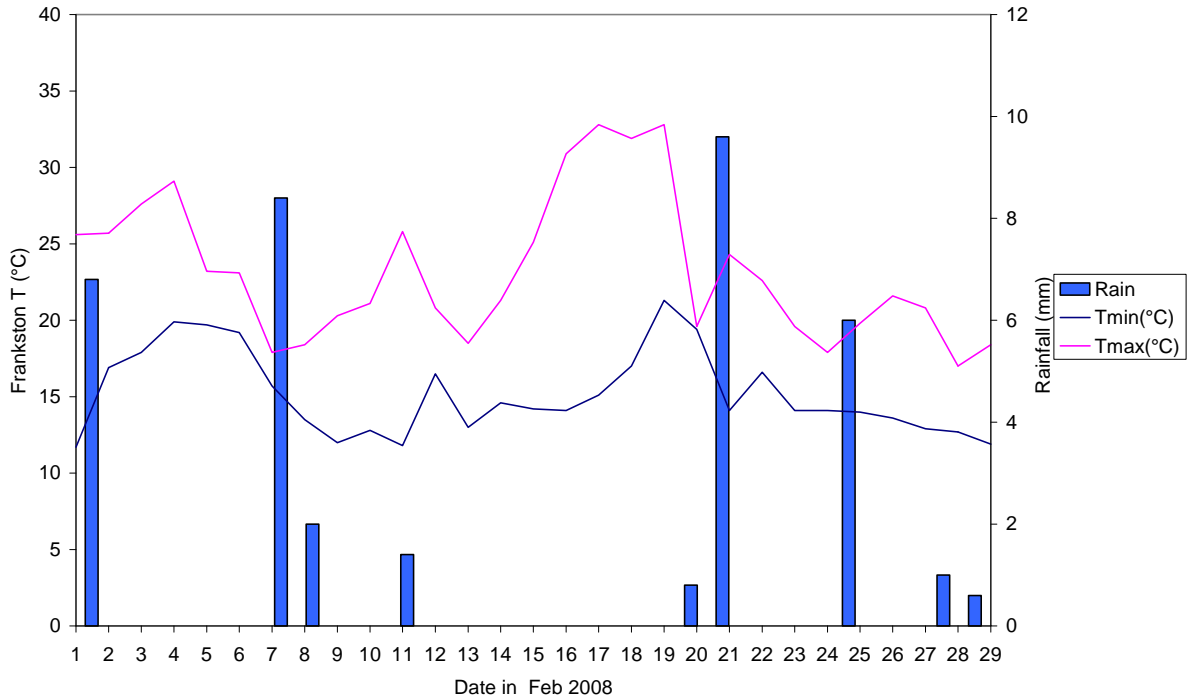


Figure 61: Daily weather observations for Frankston in February 2008 (adapted from Bureau of meteorology 2008)

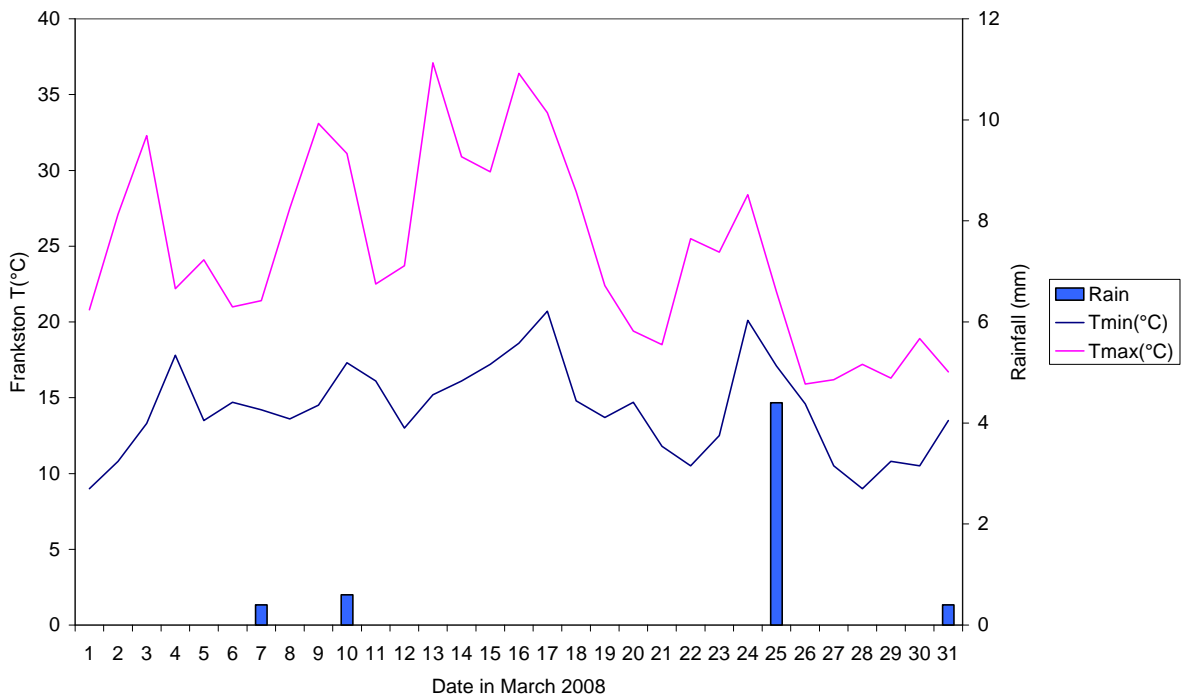
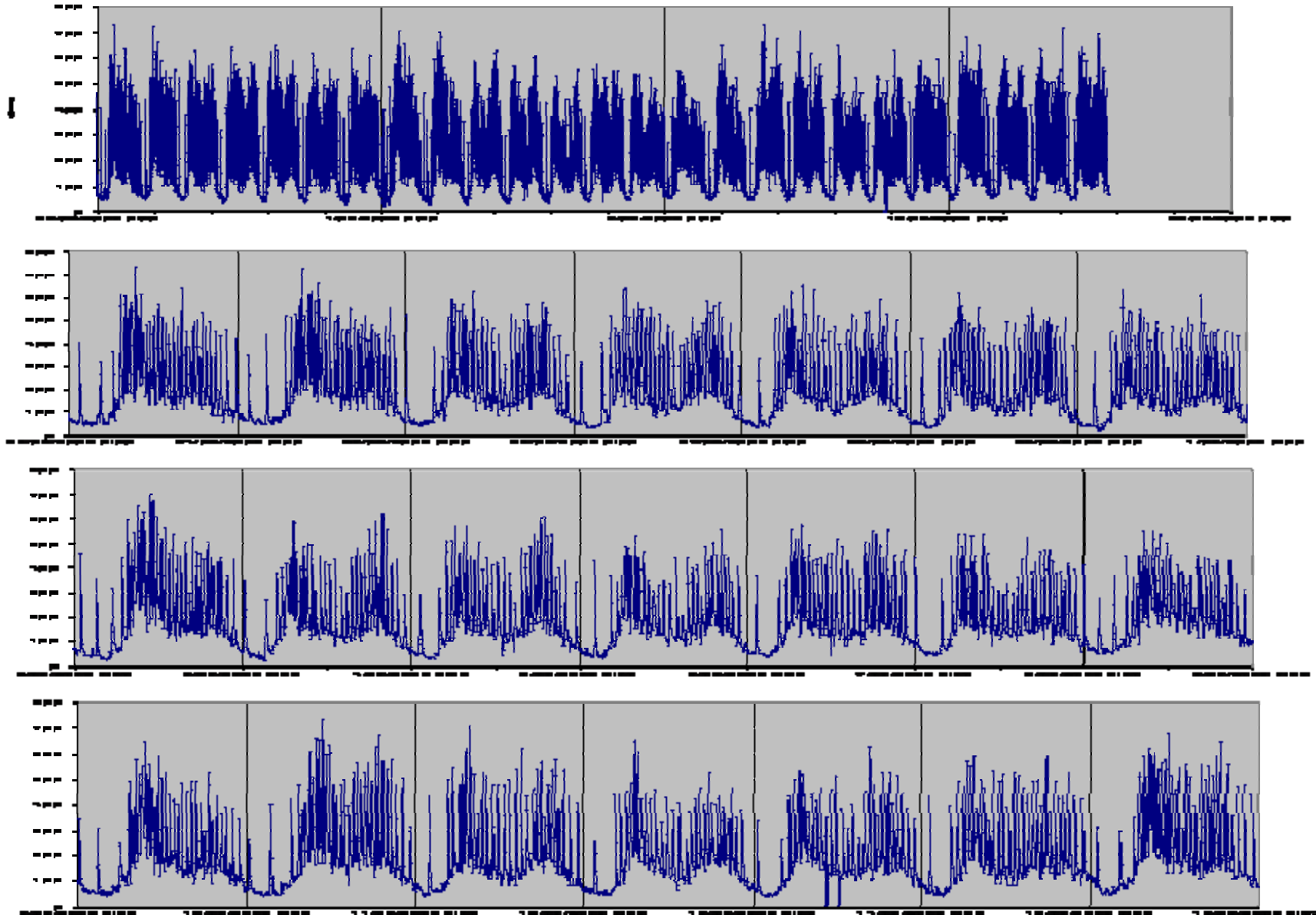


Figure 62: Daily weather observations for Frankston in March 2008(adapted from Bureau of meteorology 2008)

APPENDIX C – FLOW PROFILES FOR SAMPLING SITE 3



APPENDIX D – COMPARISON OF ELEMENTAL ANALYSIS FOR SITES 2 AND 3

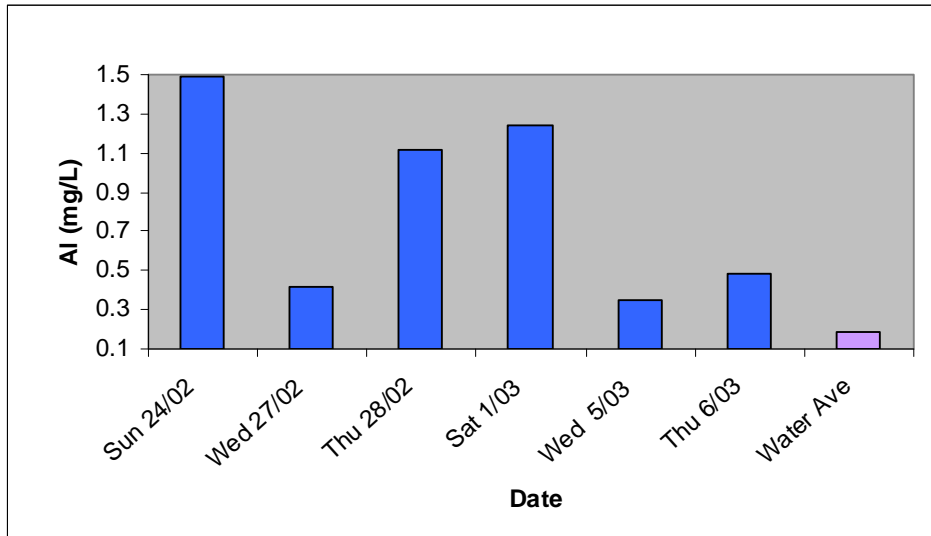


Figure 63: Concentration of aluminium in wastewater from 163 households

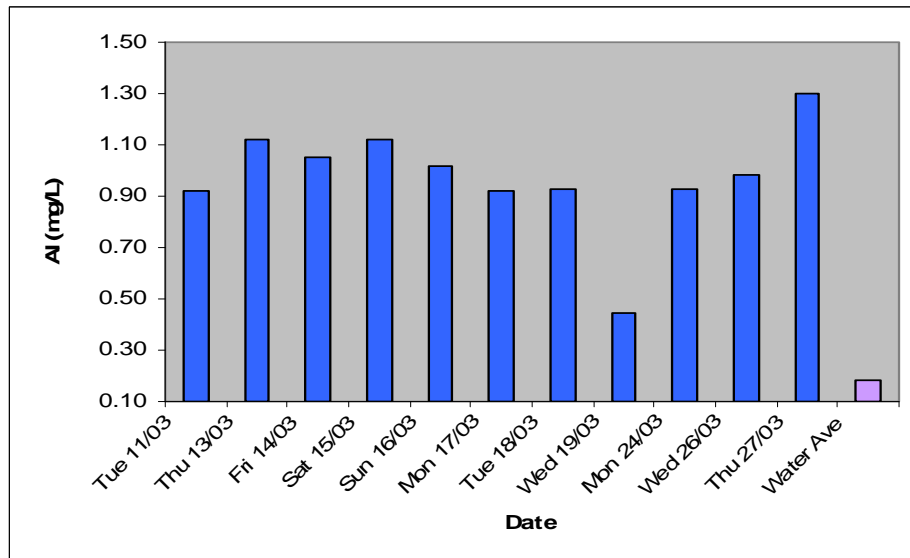


Figure 64: Concentration of aluminium in wastewater from 697 households.

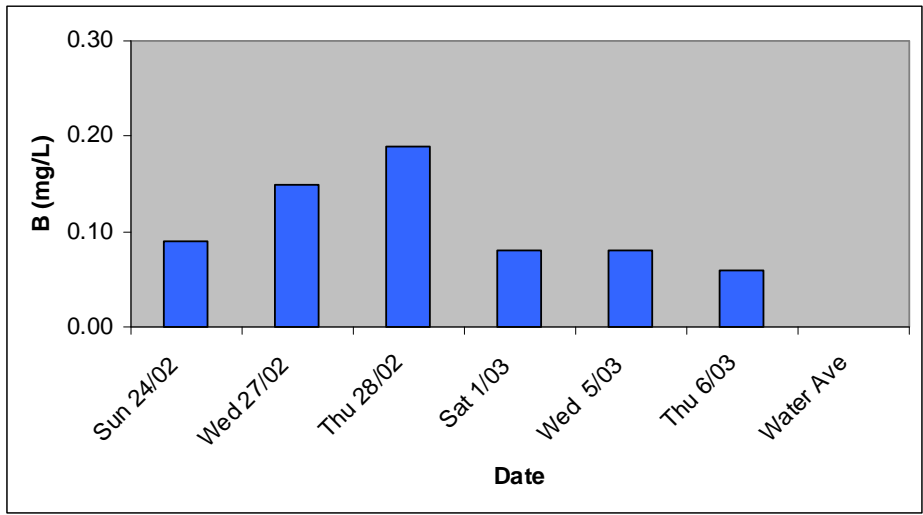


Figure 65: Concentration of boron in wastewater from 163 households

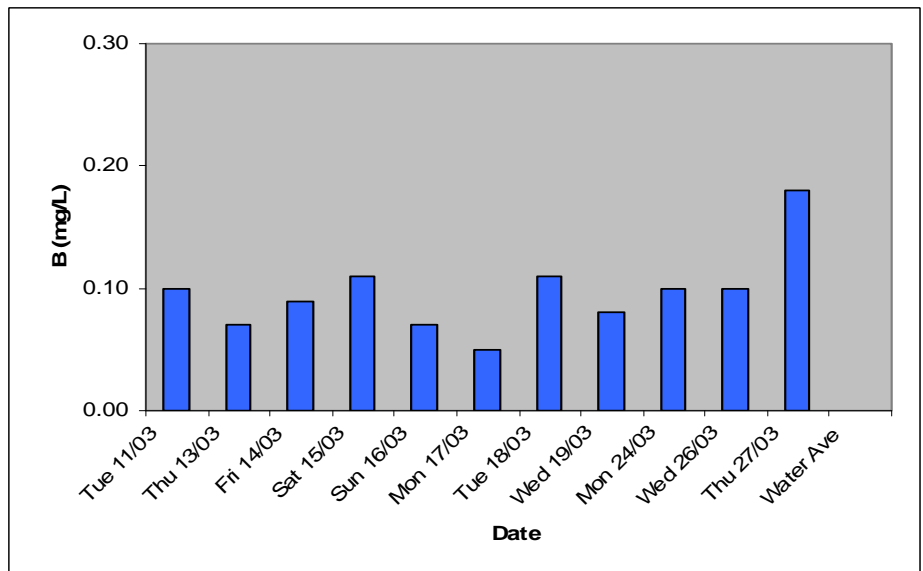


Figure 66: Concentration of boron in wastewater from 697 households.

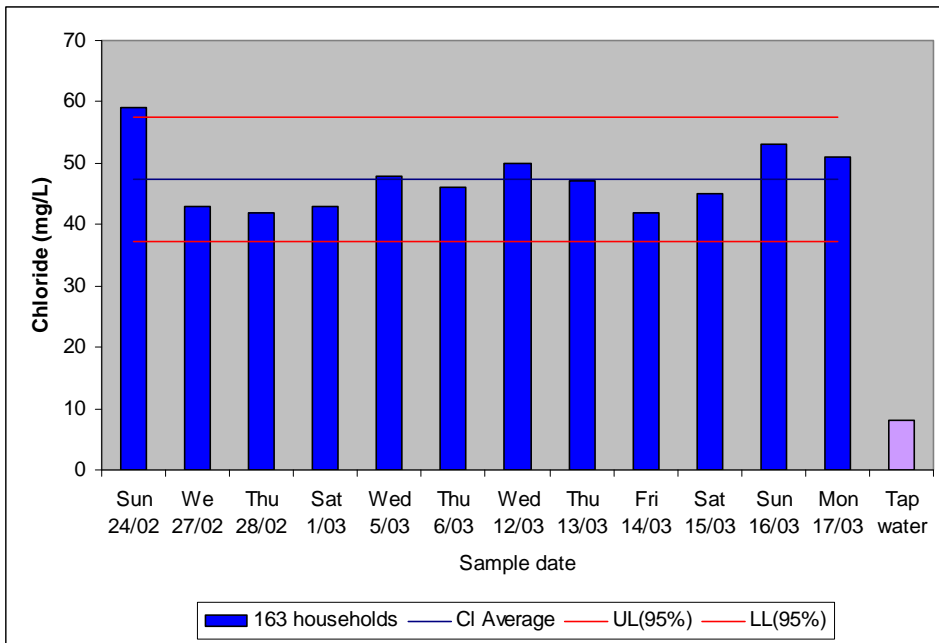


Figure 67: Chloride concentration of composite samples for 167 households.

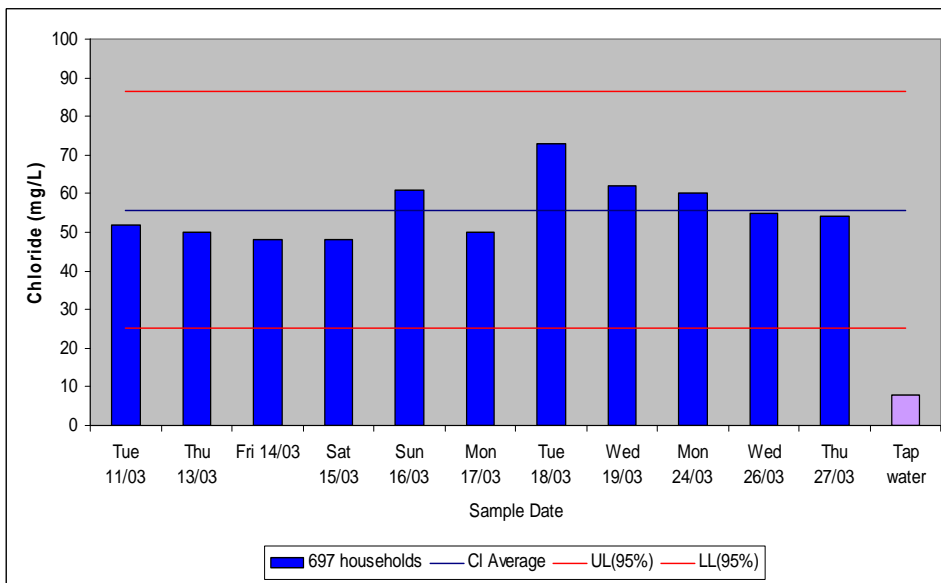


Figure 68: Chloride concentration of composite samples for 697 households.

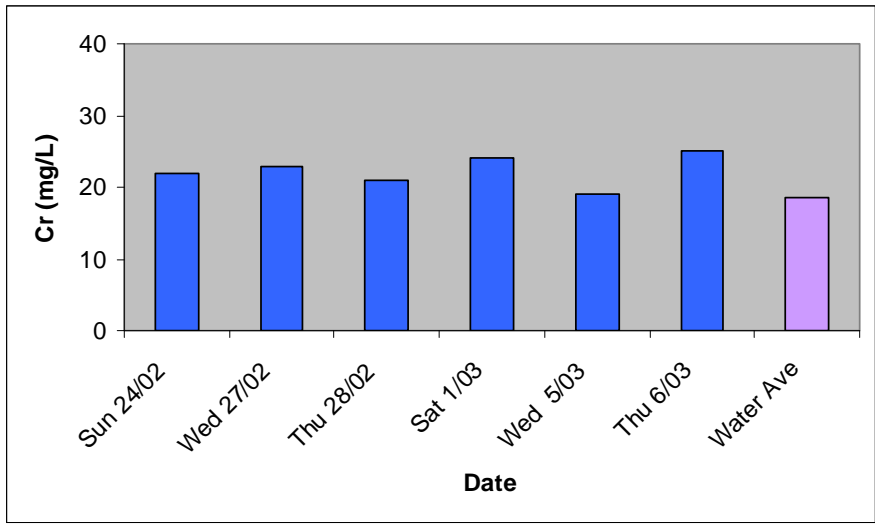


Figure 69: Concentration of chromium in wastewater from 163 households

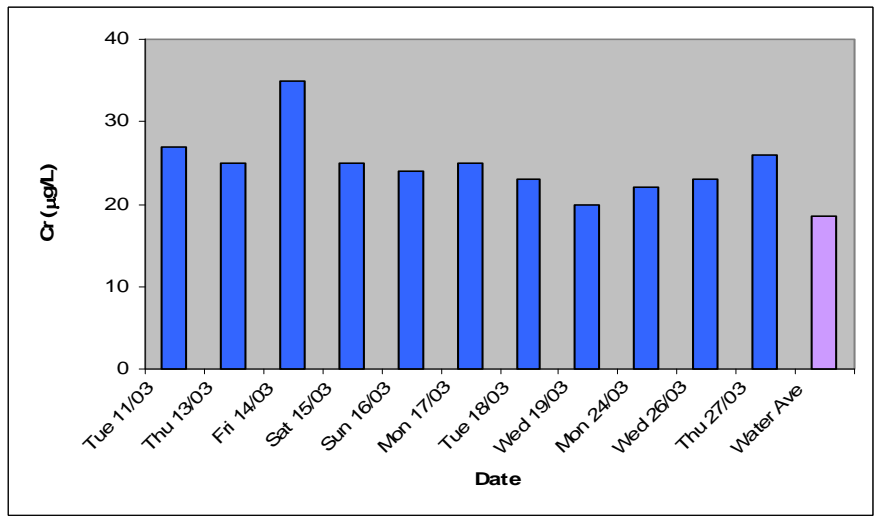


Figure 70: Concentration of chromium in wastewater from 697 households.

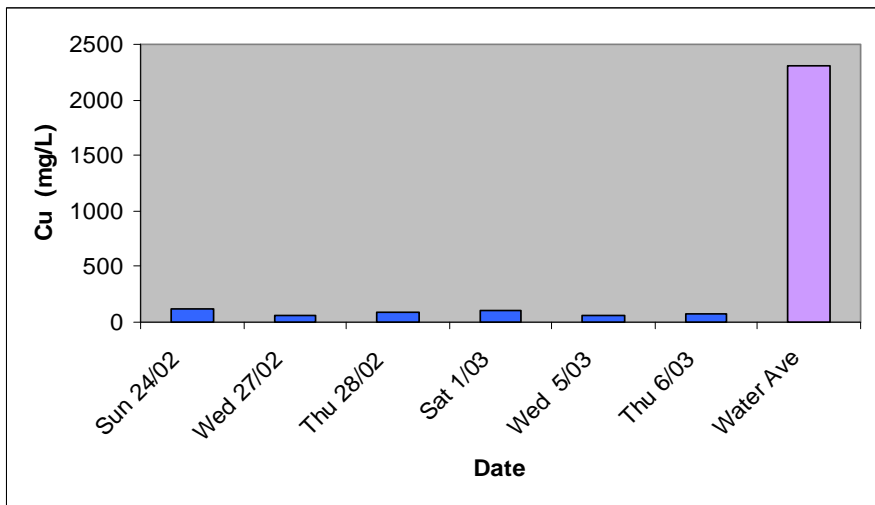


Figure 71: Concentration of copper in wastewater from 163 households

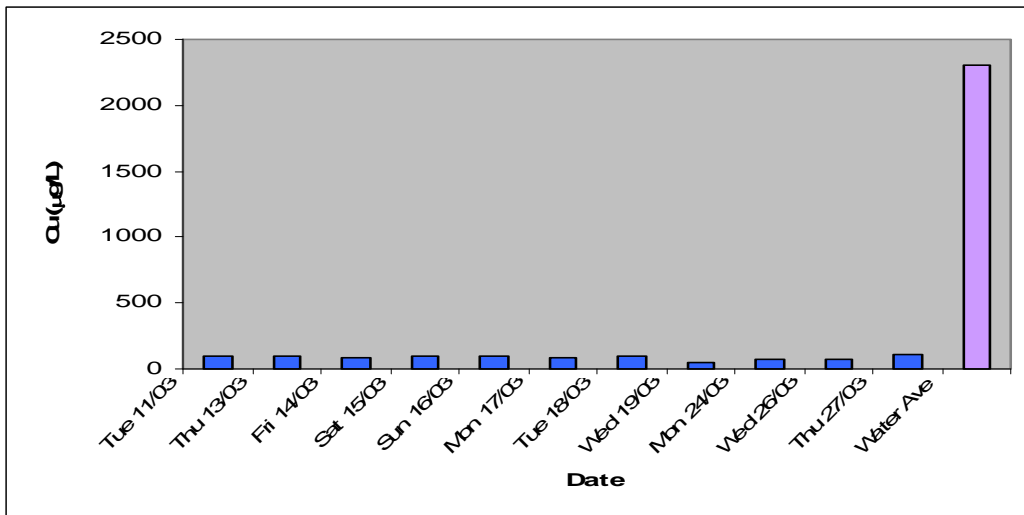


Figure 72: Concentration of copper in wastewater from 697 households.

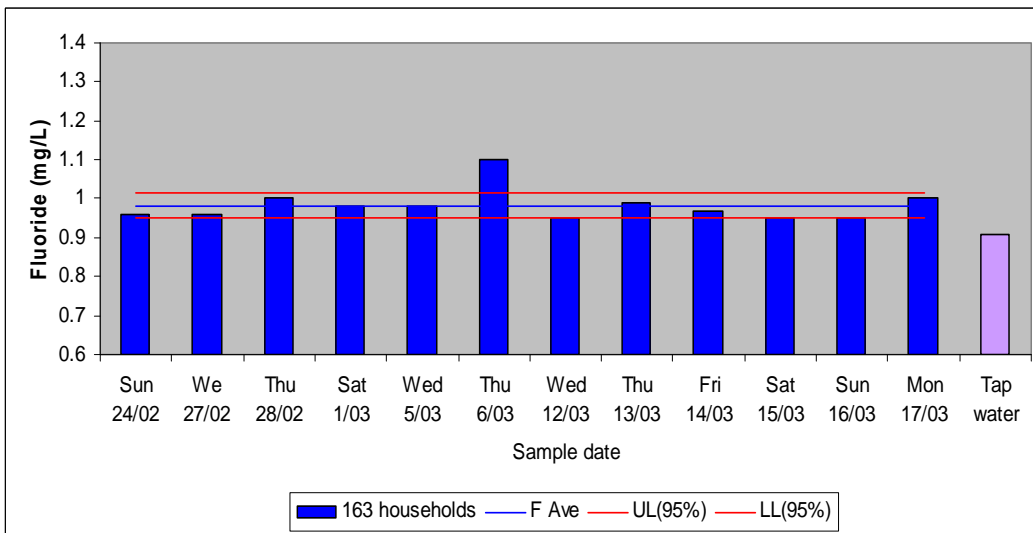


Figure 73: Fluoride concentration in composite samples for 163 households

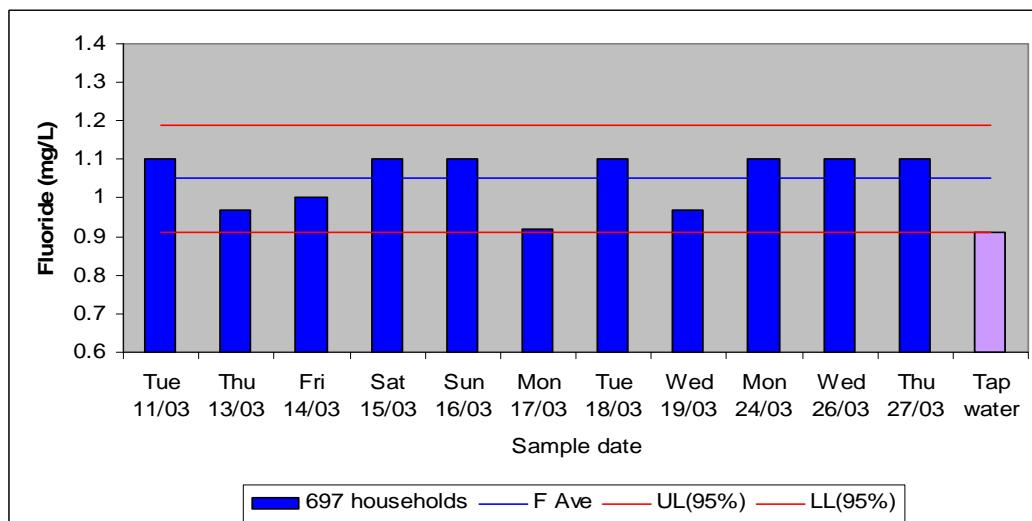


Figure 74: Fluoride concentration in composite samples for 697 households.

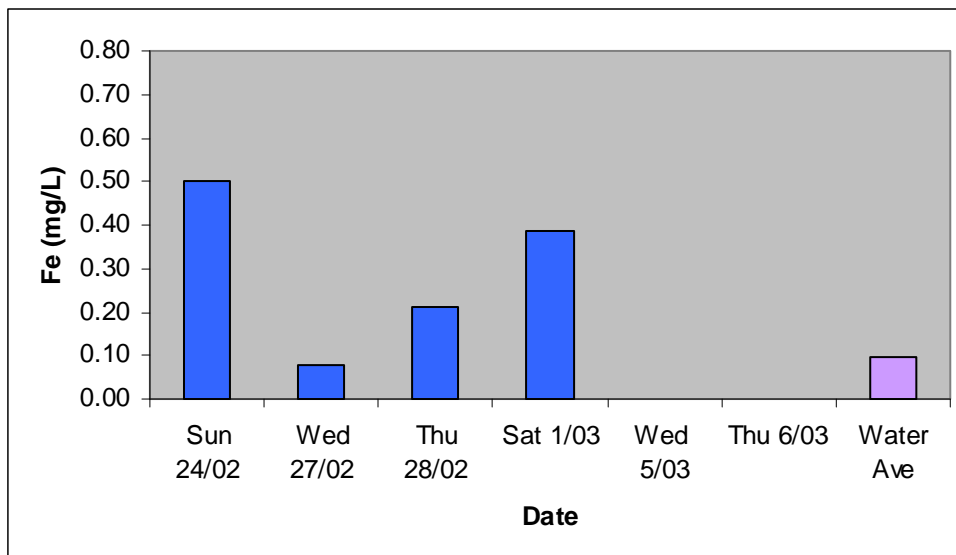


Figure 75: Concentration of iron in wastewater from 163 households

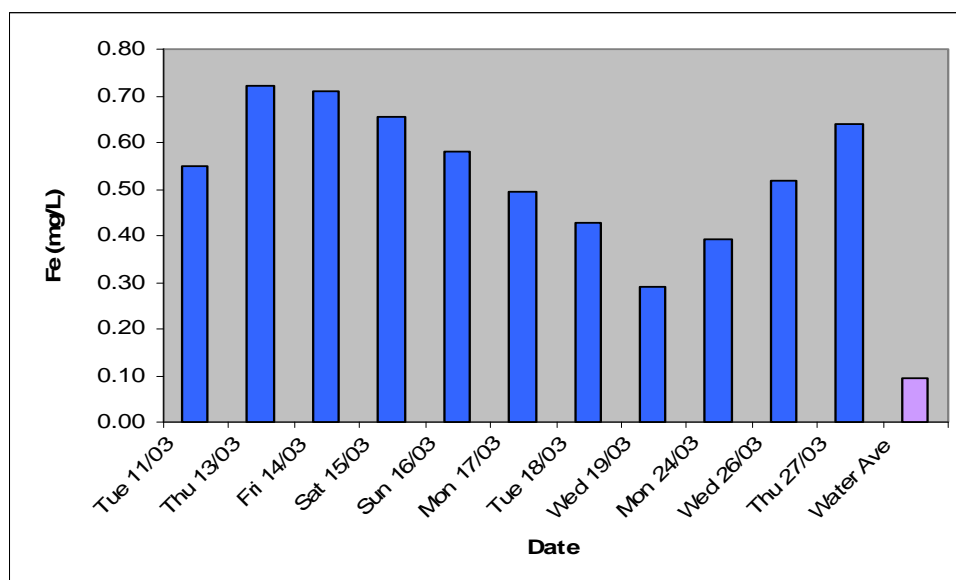


Figure 76: Concentration of iron in wastewater from 697 households.

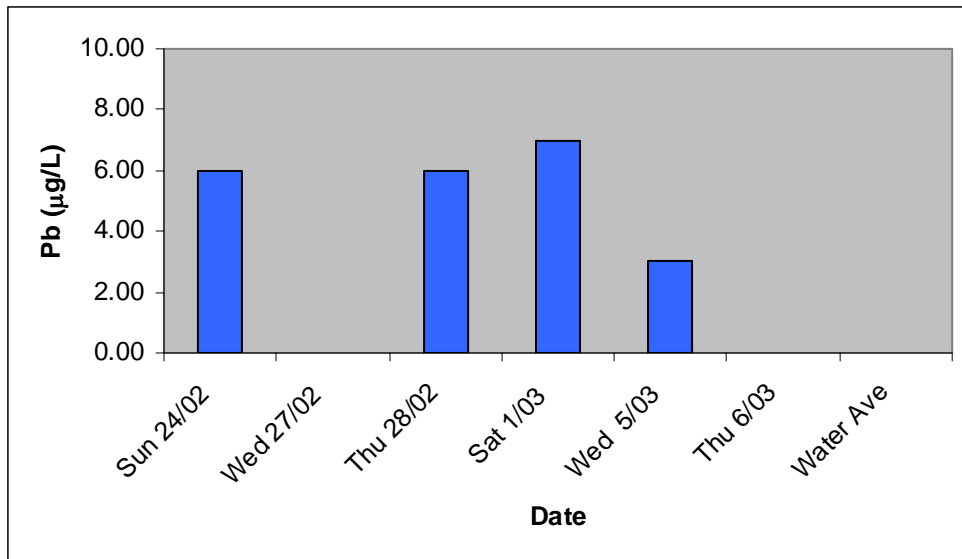


Figure 77: Concentration of lead in wastewater from 163 households

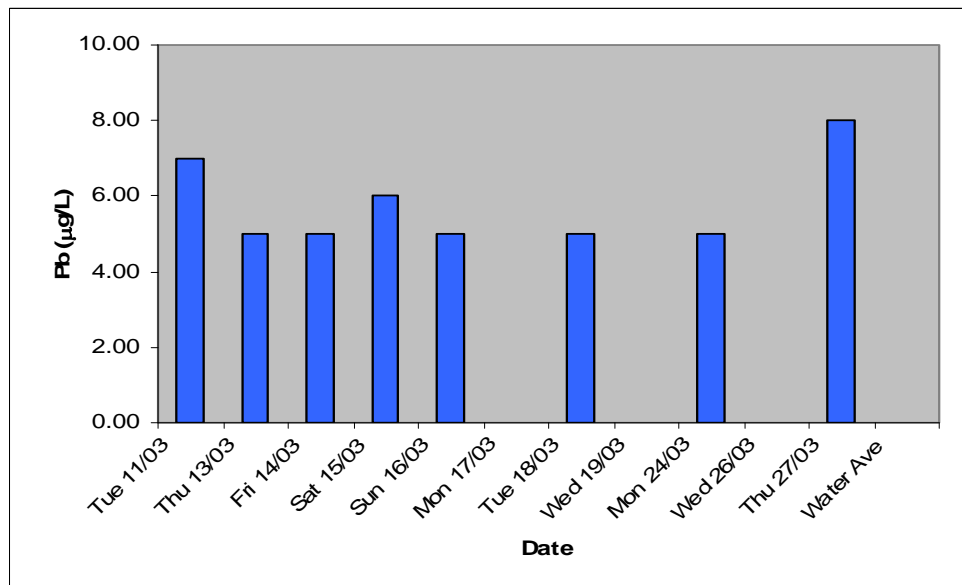


Figure 78: Concentration of lead in wastewater from 697 households.

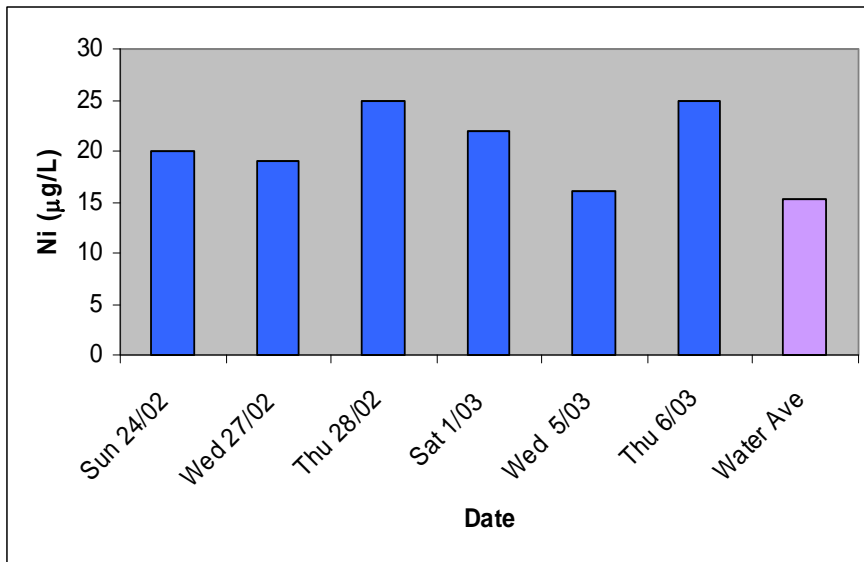


Figure 79: Concentration of nickel in wastewater from 163 households

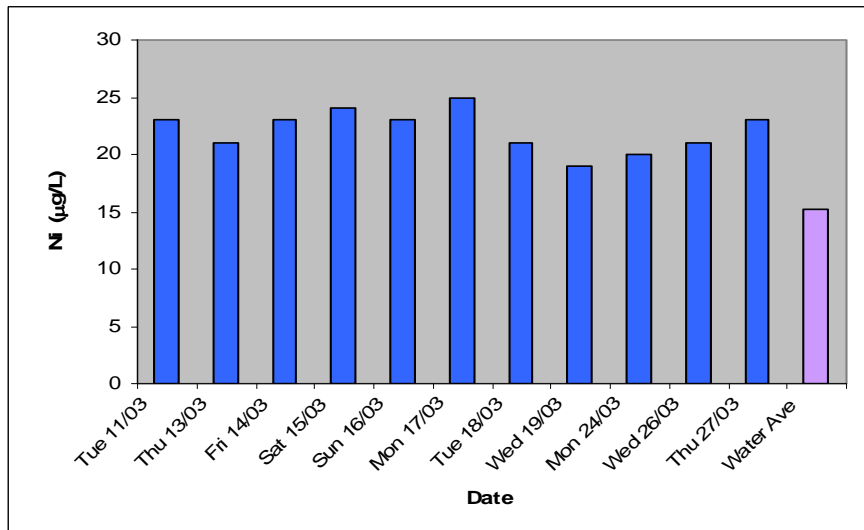


Figure 80: Concentration of Nickel in wastewater from 697 households

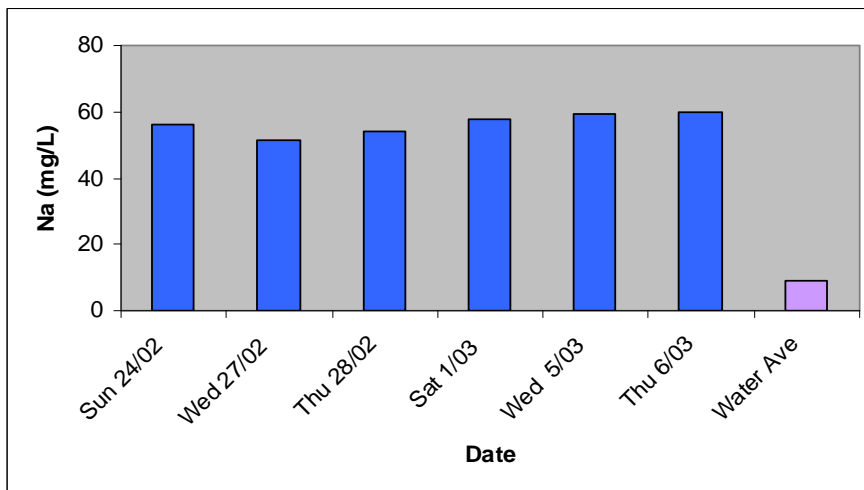


Figure 81: Concentration of sodium in wastewater from 163 households

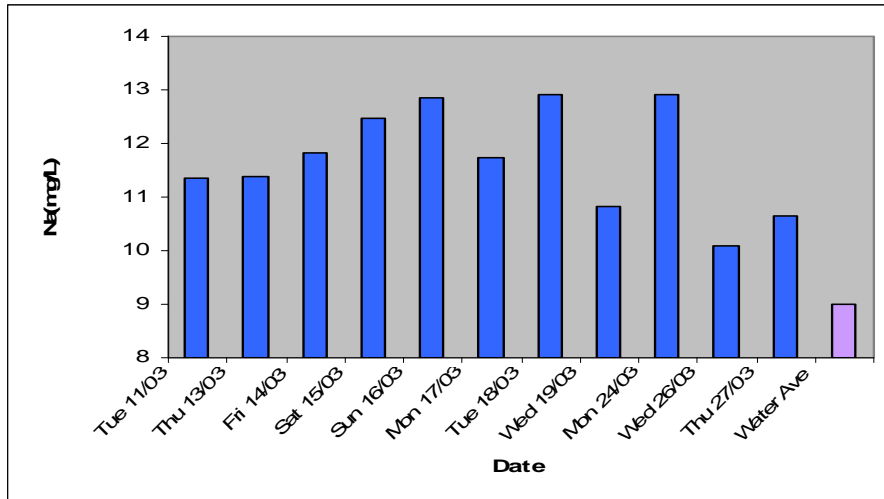


Figure 82: Concentration of sodium in wastewater from 697 households.

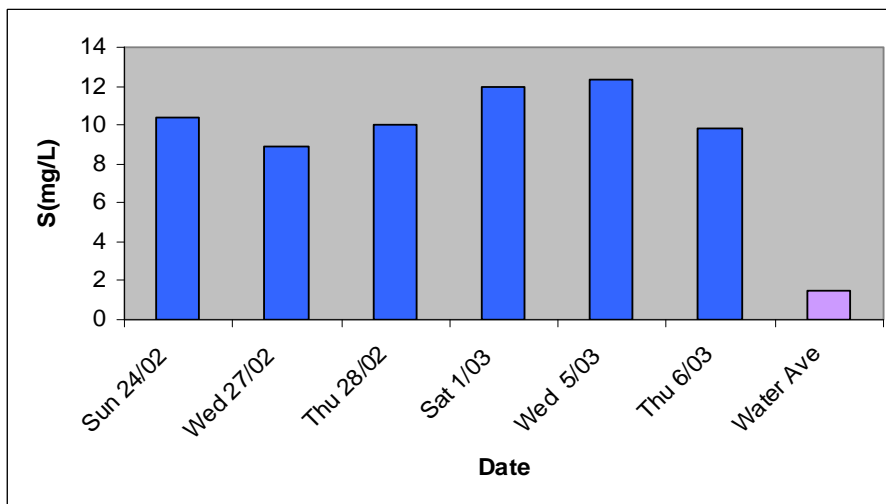


Figure 83: Concentration of sulphur in wastewater from 163 households

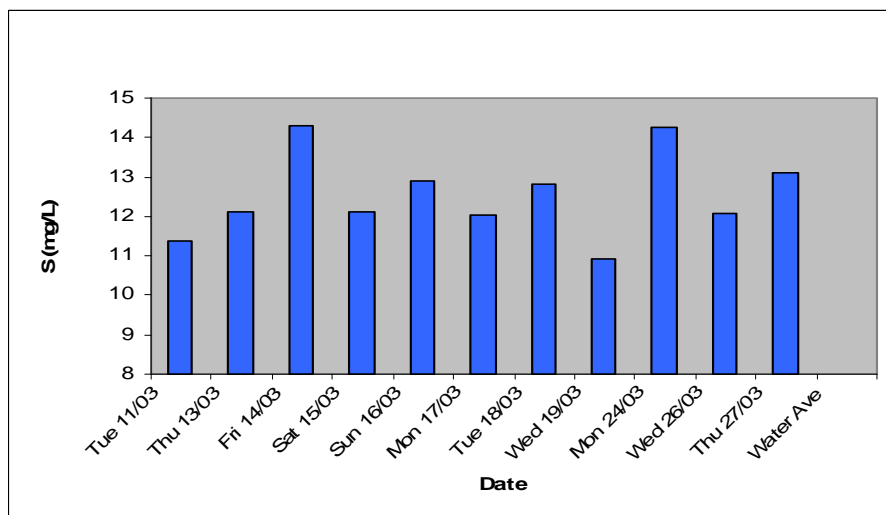


Figure 84: Concentration of sulphur in wastewater from 697 households.

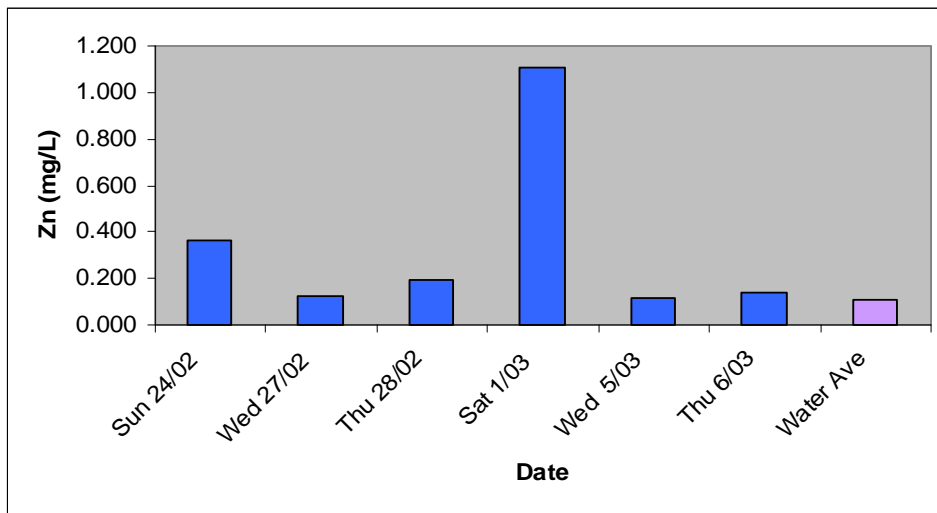


Figure 85: Concentration of zinc in wastewater from 163 households

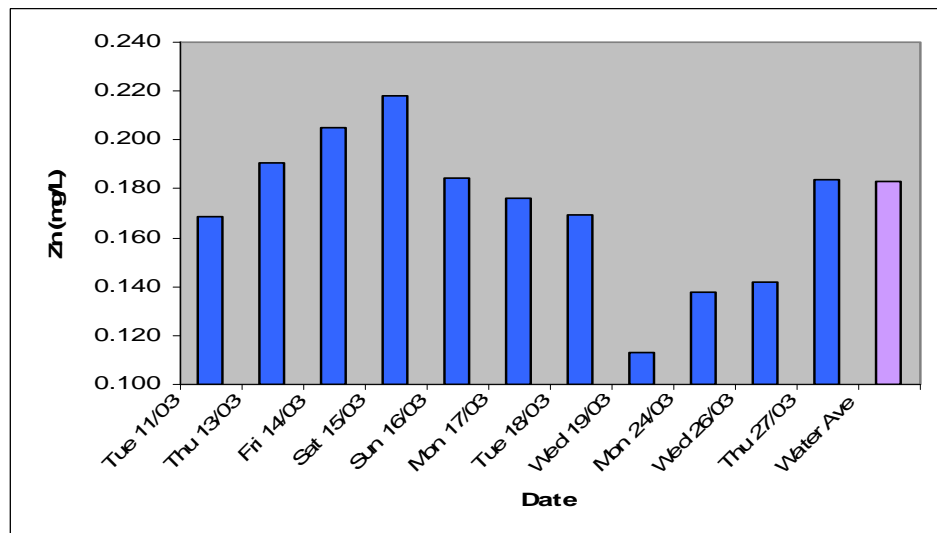


Figure 86: Concentration of zinc in wastewater from 697 households.

APPENDIX E – ANALYSIS OF STANDARD DEVIATION OF TDS IN HOURLY SAMPLES

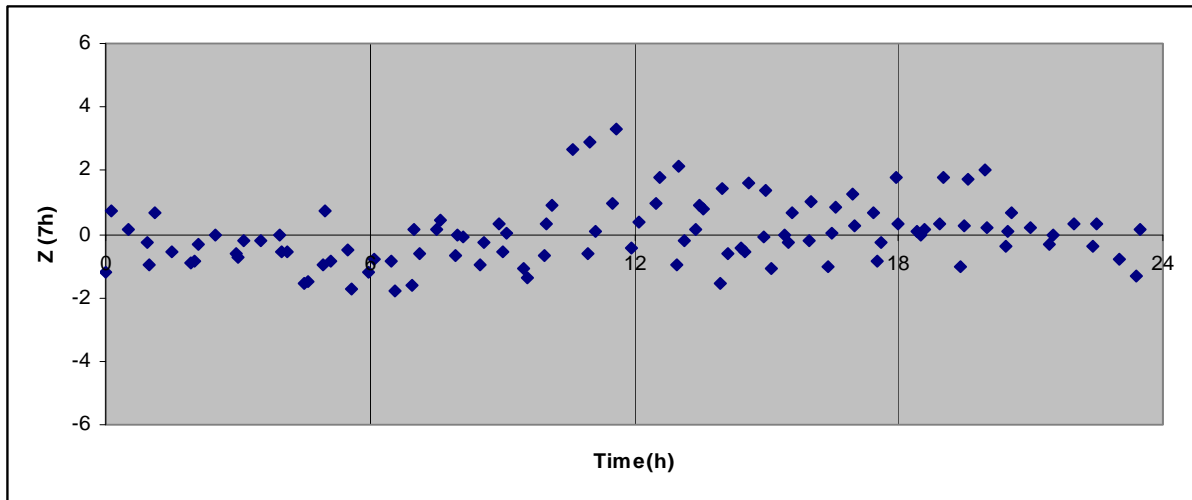


Figure 87 : Z-scores of TDS for catchment of 7 households.

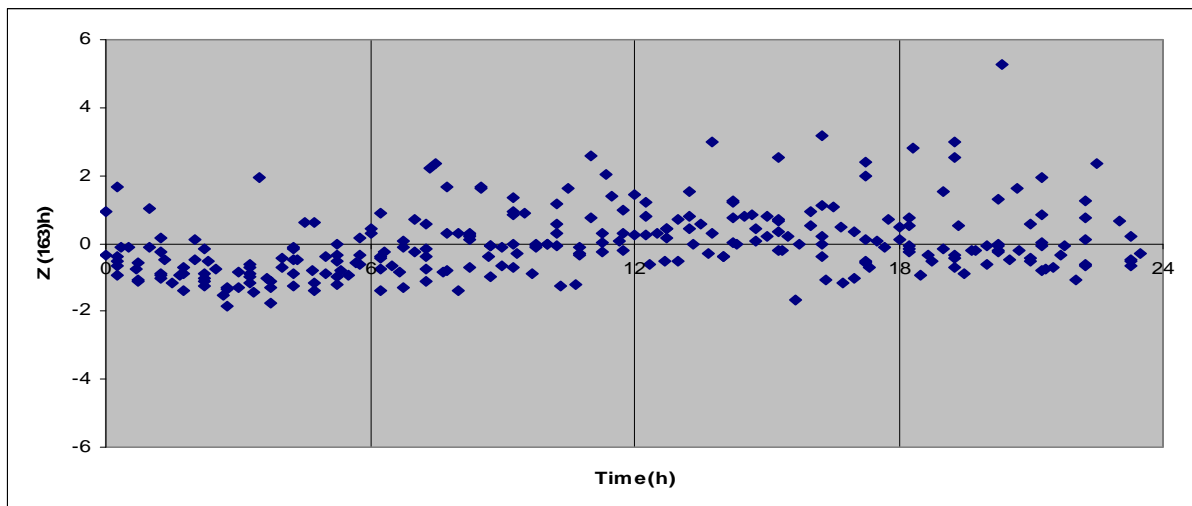


Figure 88: Z-scores of TDS for catchment of 163 households.

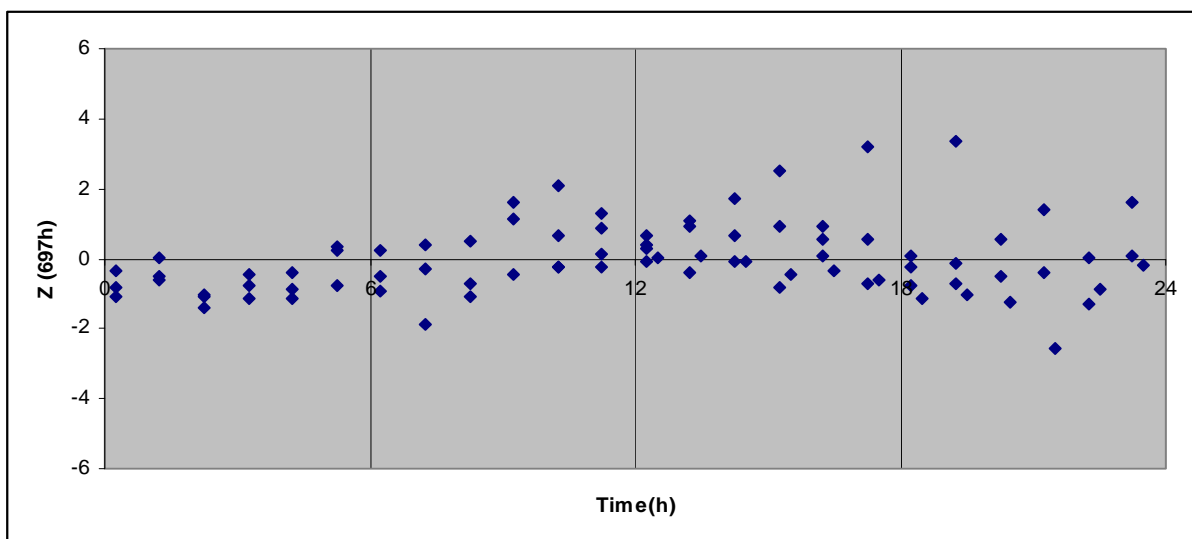


Figure 89: Z-scores of TDS for catchment of 697 households.



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