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Origins of priority contaminants in household wastewater – an experimental assessment

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Executive Summary

Understanding end products of contaminants in domestic wastewater can assist in developing wastewater management strategies that impact effluent recycling and biosolids reuse. Whilst residential wastewater is recognized as a major source of total dissolved solids (TDS) and nutrients reaching the treatment plant, less information is available on its contribution of other priority contaminants or how the loads are generated within households in Australia.

The research outlined in this report aims to increase the knowledge on grey water and black water generated under current Australian settings. In particular, a major objective of the research was to understand the origin of contaminants within a household and the impact that multiple factors (water quality, product use, human interaction and appliance operation) can have on the quality and loads of different wastewater streams generated at household level.

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.

Methodology

To achieve such objectives, a range of common household activities including laundry washing, showering, dishwashing and toilet uses were monitored in a controlled environment at the CSIRO Highett laboratories.

The characteristics of all inputs and outputs into each appliance were recorded:

- The doses of products added to each wash;
- The volume of water used and wastewater discharged;
- The physical-chemical characteristics (pH, electrical conductivity, colour, oxidation reduction potential (ORP);
- The concentration of priority contaminants: antimony, arsenic, boron, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, nitrogen, phosphorus, potassium, selenium, sodium, sulphur, tin and zinc.

The data was used to estimate the contribution of each of the appliances to the total contaminant load discharged from a household and to quantify the contribution that each contaminant source (tap water, products and/or human input) has on the quality and loads of wastewater using a mass balance method.

In addition, because the quality of water supplied to appliances varied during the experimental period, the mass balance was used to recalculate the loads expected under the assumption of a single water supply to all appliances for comparison.

The loads estimated using the mass balance method will tend to be conservative as the measurement of elements from human inputs is constrained by the limits of detection of instrumentation used for the analysis of wastewater.

Physical-chemical characteristics

Physical-chemical characteristics were dominated by either the products added to the wash or the organic matter added through human interaction.

The pH of wastewater ranged from neutral to basic in the field house.

The ORP was within the oxidative range, ranging from +57.93mV to +173mV.

Electrical conductivity and pH were dominated by the human input in streams containing a high content of organic matter, such as for black water, whilst streams with a low organic content were dominated by the products added to the wash, as in the case of the dishwasher and the washing machine.

The major source of colour in the field house was human input. Caution should be exerted, however, in the use of the Platinum Cobalt method for the evaluation of colour in domestic wastewater. The method had originally been designed for the evaluation of natural waters; however the colour in the various wastewater streams within the field house were observed to vary from the yellow hue and in turbidity which could impact colour readings. A typical example was the washing machine discharge after washing coloured clothing and the kitchen sink discharge.

Total dissolved solids

The washing machine and the toilet produced the largest TDS loads in the household, respectively 50% and 27% of the total weekly load. In grey water from the washing machine, dishwasher and vanity unit the main source of TDS were products added to the wash. In black water and in the kitchen sink the major source of TDS was human input (human and food waste).

Element concentrations

There is limited data in the literature on the concentrations and loads of many of the priority contaminants found in residential wastewater streams and even less data on their source attribution. This study has generated additional information on specific streams such as the dishwasher, kitchen sink and vanity unit which should add to the existing knowledge base.

The concentrations for arsenic, antimony, cadmium, cobalt, mercury, manganese, selenium and molybdenum were often at or below the limit of detection and estimated to be either in the parts per billion range or lower in this study and in other Australian and overseas studies.

However, analysis of some of the household products adopted in the field house before dilution indicated that some of the products contained trace amounts of elements such as arsenic, cadmium, chromium and selenium. Whilst overseas literature suggests that heavy metal traces could potentially be encountered in human excreta but the loads would be too small to be detected in wastewater.

Hence, such metals, whilst undetected in the waste streams could potentially still be present. However, differences in water quality, infrastructure, householder lifestyle and product formulation across different countries would have contributed to differences in water quality across countries.

In assessing concentrations, variability was observed for water quality, human inputs, and doses of products and is reflected in the characteristics of the wastewater. In the field house, the wastewater streams which carried the greatest uncertainty were the toilet and the vanity unit. In the case of the toilet this was caused by the variability in use patterns and the difficulty in quantifying inputs due to privacy. In the case of the vanity unit, the estimated elemental loads for iron, potassium, sulphur and aluminium in both the vanity and in black water were in excess of the observed loads.

Load distribution per appliance within the field house

The potential loads for each of the elements of interest were estimated using a mass balance model and were assessed on an appliance basis:

- The washing machine was the main source of the load for aluminium, antimony, arsenic, calcium, copper, fluoride, iron, socium and nickel.
- The shower was the prevalent contributor for boron, cadmium, chromium,and tin; and
- The toilet was the major contributor of chloride (in conjunction with the dishwasher and washing machine), iron, molybdenum, potassium, sulphur, nitrogen, phosphorus and zinc.

- The dishwasher and the toilet were also the potential source of the lead in wastewater.

The loads evaluated for the field house and their point of origin differ from some of the earlier results reported in the literature. Some of these differences may be attributed to differences in water quality, infrastructure, household habits and/or experimental methodology adopted among the different studies.

Origin of contaminants

When the field house loads were decomposed based on sources: tap water, products or human input, it was verified that:

- Products used in the field house were the major potential sources of aluminium, arsenic, boron, cadmium, chromium, lead, sodium, selenium, tin and total dissolved solids;
- Tap water was the major potential source of calcium, copper, fluoride, iron, zinc and magnesium;
- Human input was the most likely source of antimony, chloride, molybdenum, nickel, sulphur, nitrogen and phosphorus.

However, mercury and manganese were below the detection limits in the tap water, in wastewater and in the products used in the household

In the experiments the quality of the water supply was a significant factor influencing the contaminant loads into wastewater particularly in appliances that used large water volumes.

Conclusions and Recommendations

The mass balance model adopted in this study and the loads estimated are likely to be conservative and may tend to under represent some of the loads derived from human inputs, particularly for elements present at concentrations near the limits of detection. In addition the inputs to wastewater can be subject to high variability from one day to another, particularly for human inputs. A more thorough evaluation of the heavy metal input from human excreta would require the evaluation of undiluted samples, which was not within the scope of this study.

The loads estimated did not necessarily match those reported in the literature. The study does however, provide an indication of the role that the different sources have on the loads generated at the household and at each of the individual appliances. In addition, the model can be used for the modelling and investigation of different strategies of source management in the field house.

Understanding the source of contaminants allows the evaluation of strategies for controlling loads at the source. For instance, in the field house (i) reduction in water usage would be effective in decreasing the load of Ca, Cu, F, Mg and Zn discharged to sewer; (ii) product selection could potentially be used to limit the loads of Na, As, B, Cd, Cr and TDS; and (iii) for loads dominated by human sources, control measures would be more complex, but separation of streams such as urine separation could be used to alter the loads entering the sewer.

Future research will aim at evaluating the effectiveness of different source control strategies in reducing the loads of priority contaminants into sewer using the methods developed here.

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Nomenclature

Al	Aluminium
As	Arsenic
B	Boron
Ca	Calcium
Cd	Cadmium
Cl	Chloride
C_p	Concentration of element i measured in product
Cr	Chromium
Co	Cobalt
Cu	Copper
C_{wi}	Concentration of element *i* measured in tap water
C_{wwi}	Concentration of element *i* measured in wastewater
DW	Dishwasher
EC	Electrical conductivity
F	Fluoride
Fe	Iron
Hg	Mercury
ICP-AES	Inductively coupled plasma atomic emission spectroscopy
ICP-MS	Inductively coupled plasma mass spectroscopy
K	Potassium
KS	Kitchen sink
LOD	Limit of detection
m_{dp}	Dose of product used
m_i	Mass of element *i*
Mo	Molybdenum
Mn	Manganese
nd	Not determined
nf	Not filterable
Na	Sodium
Ni	Nickel
ORP	Oxidation-reduction potential
PCU	Platinum-cobalt unit
pe	person
TP	Total Phosphorus
S	Sulphur

SH	Shower
Sb	Antimony
SD	Standard deviation
SD_w	Standard deviation of water
SD_{ww}	Standard deviation of wastewater
SD_p	Standard deviation of product
Se	Selenium
Sn	Tin
TDS	Total dissolved solids
TKN	Total Kjeldahl nitrogen
TO	Toilet
TP	Total phosphorus
V	Volume
VU	Vanity unit
V_{ww}	Volume of wastewater discharged
WW	Wastewater
W	Water
WM	Washing machine
WP	Water + product
Z	Z-score
Zn	Zinc

1 Introduction

Australian cities face the challenge of water service provision under water scarcity and changing rainfall patterns. This is leading to the adoption of alternative water and wastewater management measures, such as demand management and water recycling.

Achieving effective recycling and reuse of biosolids after wastewater treatment is dictated by the quality of wastewater arriving at treatment plants. This is impacted by the quality of domestic, commercial and trade waste inputs.

The concentration of 'priority pollutants' is one of the important determinants of wastewater quality. Priority pollutants are substances that can impact sewage treatment, the environment and/or impact the recycling of effluent and biosolids reuse in agriculture. This group includes parameters such as total dissolved solids (TDS), sodium and chloride, colour, arsenic, boron, copper, cadmium, lead, mercury, nickel, tin, zinc, and nutrients, among others.

Control of TDS is essential for wastewater treatment plants to achieve the Victorian Government's targets of 20% for effluent recycling by 2010 and reduction in water consumption (DSE 2004).

The concentration of salts such as sodium, chloride and boron, in addition to contributing to TDS, can impact crops and soil irrigated with treated effluent when present in excessive concentrations. Colour impacts the aesthetics of the effluent discharged into sea and hence public perception. Metals, such as copper, cadmium, mercury, lead, zinc and arsenic partition into the sludge after wastewater treatment and if present in excessive concentrations can limit the potential for biosolids reuse in agriculture, requiring stockpiling or disposal at landfill.

Understanding the processes that lead to the ingress of contaminants into domestic wastewater can assist in the evaluation of a wider range of integrated wastewater management strategies, such as source management options.

Research on domestic wastewater and its individual components, grey and black water, has traditionally focused on the performance of treatment technologies (with parameters tested usually being biological oxygen demand (BOD), chemical oxygen demand (COD), nitrogen, phosphorus, suspended solids) and pathogen control (Eriksson *et al* 2002). The number of studies that investigated the concentration, range and origins of metal contaminants in grey water and black water is more limited (Almeida *et al*, 1999, Buttler *et al* 1995, Comber and Gunn 1996, Palmquist and Hanæus 2005, Gray and Becker 2002, Christova-Boal *et al* 1996, Jeppesen 1993, Chino *et al* 1991, Lock 1994, Friedler *et al* 2005).

Characterization of specific grey water streams within a household based on concentration has been explored in a number of studies (Hypes 1974, Jeppesen 1993, Hargelius *et al* 1995, Lock 1995, Christova-Boal et al 1996, Gardner and Millar 2003, Tunaley 2004), but evaluation of contaminant loads in Australia and overseas is limited particularly for metals, dissolved solids and colour (Lock 1994, Chino et al 1994, Gray and Becker 2002, Vinneras 2002, Erikkson 2002, Vinneras et al 2006, Comber and Gunn 1996, Gardner 1998).

Differentiation of streams within a household has led to characterisation of individual laundry, bathroom, kitchen, bath, shower and toilet streams. Yet, as mentioned by a number of earlier researchers there is still a lack of reliable information on the composition of grey water and black water and limited data is available on colour of grey water (Eriksson *et al* 2002, Palmquist and Hanaeus 2005).

Discrepancies exist between the results reported in other studies, particularly in regards to the contaminant content in black water and specific grey water streams.The range of conditions and dates of the many studies vary, with the majority on average over 10 years old. In addition the more recent studies have been conducted overseas. Hence the results may not necessarily reflect current Australian conditions due to differences in lifestyle, diet, water use patterns and infrastructure.

Results reported for metals vary depending on the element considered and sampling conditions. Given the complexity of the stream composition, challenges exist in determining the concentration of elements in wastewater, the associated loads, the temporal distribution of loads within the household and their sources in individual streams.

Gray and Becker used literature data to estimate sources of contaminants in the urban residential water system (Gray and Becker, 2002). There were some inconsistencies between calculated values and those measured in residential wastewater. These were explored in a previous report of this series (Tjandraatmadja and Diaper 2007).

Grey water is identified as the major source of contaminants within the household for cadmium, copper, lead, zinc and TDS in a number of studies (Vinneras 2001, Gray and Becker 2002, Lock 1995). In a Japanese study, Chino attributed 70% of the total metals load to sources other than faeces and urine. Infrastructure in the form of metal plumbing, e.g. copper pipes and fittings were also identified as major sources of copper, cadmium, chromium, lead, tin, zinc and other metals (O'Halloran 2002, Icon 2001,Vinneras *et al* 2006) .

For many metals, such as nickel, mercury and cadmium, detection in residential and wastewater is a challenge. This is partly because the concentrations in wastewater are often near detection limits, so identification of their sources is often not conclusive. Furthermore, for other elements a number of potential sources exist in a household and quantifying the specific contribution from each of the major sources is a complex process.

Arsenic, cadmium and mercury concentrations in mixed source grey water are often below the level of detection for the analysis method used in all the studies (Palmquist and Hanaeus 2005).

Among the contaminants of interest in this study a number are detected in significant concentrations in mixed grey water. Sodium concentrations in grey water are generally high, with most detergents and hygiene products containing sodium based compounds (Tjandraatmadja and Diaper 2008).

Copper and lead concentrations up to 0.39 and 0.15 mg/L respectively were observed in septic sullage and grey water but it is not clear if the source was the water supply or products used in the home (Jeppesen 1993, Hargelius *et al* 1995). Lead and nickel concentrations of 0.15 mg/L and 0.027 mg/L respectively have been observed in septic sullage but again the source of these metals was not identified in the study (Jeppesen 1993). Zinc concentrations up to 1.6 mg/L and 0.44 mg/L have been observed in mixed grey water (Hypes 1974) and septic sullage (Jeppesen 1993).

The research outlined in this report was conducted to address some of these challenges and to increase the knowledge on grey water and black water generated under the current Australian conditions. The major aim of the research was to understand the origin of contaminants within a household and the impact that multiple factors (water quality, product use and human inputs) have on the quality and loads of residential wastewater.

The experiments described in this report aimed to:

(a) Measure wastewater physical-chemical characteristics and the concentration of priority contaminants derived from water supply, household products and human activity.

(b) Compare the experimental measurements with predicted concentrations for parameters based on knowledge of product composition.

(c) Evaluate individual loads and compare them with values reported in the literature.

This report is part 4 of the Smart Water Fund project Round 3 – Project 5 *Household sources of priority contaminants in domestic wastewater*. The overall_aim of the project is to identify the sources and contribution of domestic wastewater to the load of specific contaminants in wastewater. The overall project structure is summarised in Figure 1.

This report is part of the household wastewater characterisation process. The knowledge here presented will be used in the development of data for the future evaluation of contaminant reduction strategies.

Other reports in this project series include:

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

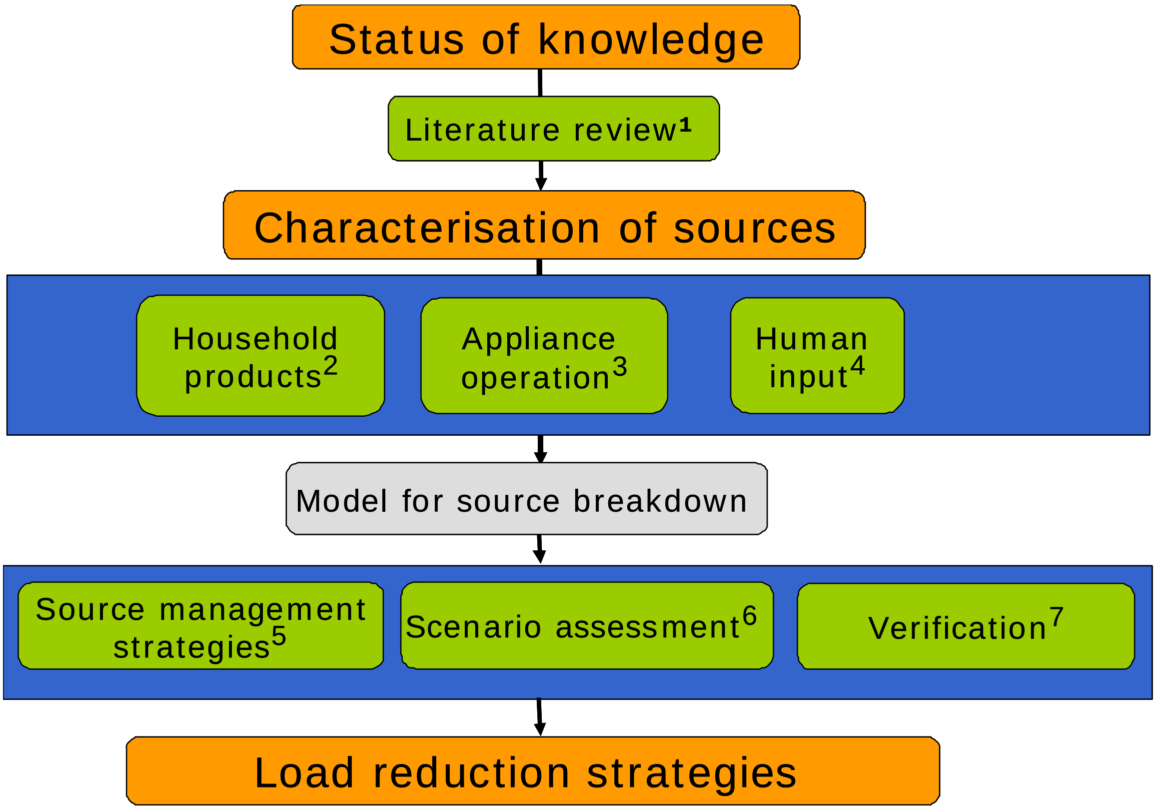


Figure 1: Summary of "Sources of contaminants in domestic wastewater" project

2 Experimentation

2.1 Introduction

Typical household activities which generate grey water were replicated in a laboratory set-up located at the CSIRO Highett site with the aid of volunteers. The volunteers conducted typical household chores such as laundry washing, dishwashing and showering in the mini-house laboratory. The mini-house is a simulated household which contains all major household appliances that produce wastewater. Water and wastewater inputs to the house were monitored during each activity.

Blackwater from toilet use was monitored from male and female toilets located in an office floor at the CSIRO Highett laboratories.

All wastewater generated was analysed for in-situ parameters (pH, conductivity, temperature and oxidation-reduction potential (ORP), colour, total dissolved solids and elemental content. In addition fluoride, chloride, nitrogen and phosphorus were evaluated in selected streams.

This section describes the equipment, experimental set-up, methodology and the analytical procedures adopted in the study.

2.2 Experimental set-up

2.2.1 Grey water installation

Grey water was collected from a laboratory which contains the appliances used in a typical household. The laboratory, a mini-house, is located in the CSIRO Highett laboratories in Victoria. The house is fitted with a laundry, a top loading washing machine, a shower, a dishwasher, a kitchen sink and a vanity unit. All the appliances were brand new and were flushed with tap water at least five times before use. The laboratory set-up is shown in Figure 2.

Hot and cold water were supplied to each appliance via copper pipes. Hot water was provided using a 25 litre Rheem electric hot water service. All water entering the mini house was measured using an inflow meter.

The wastewater collection pipes from each individual appliance were connected to a common outlet pipe, where monitoring equipment was installed. The pipe-work underneath the house was designed to allow easy access for the grey water sampling equipment and is shown in Figure 3.

The wastewater collection network of this household was comprised of PVC pipe with an internal diameter of 50mm.

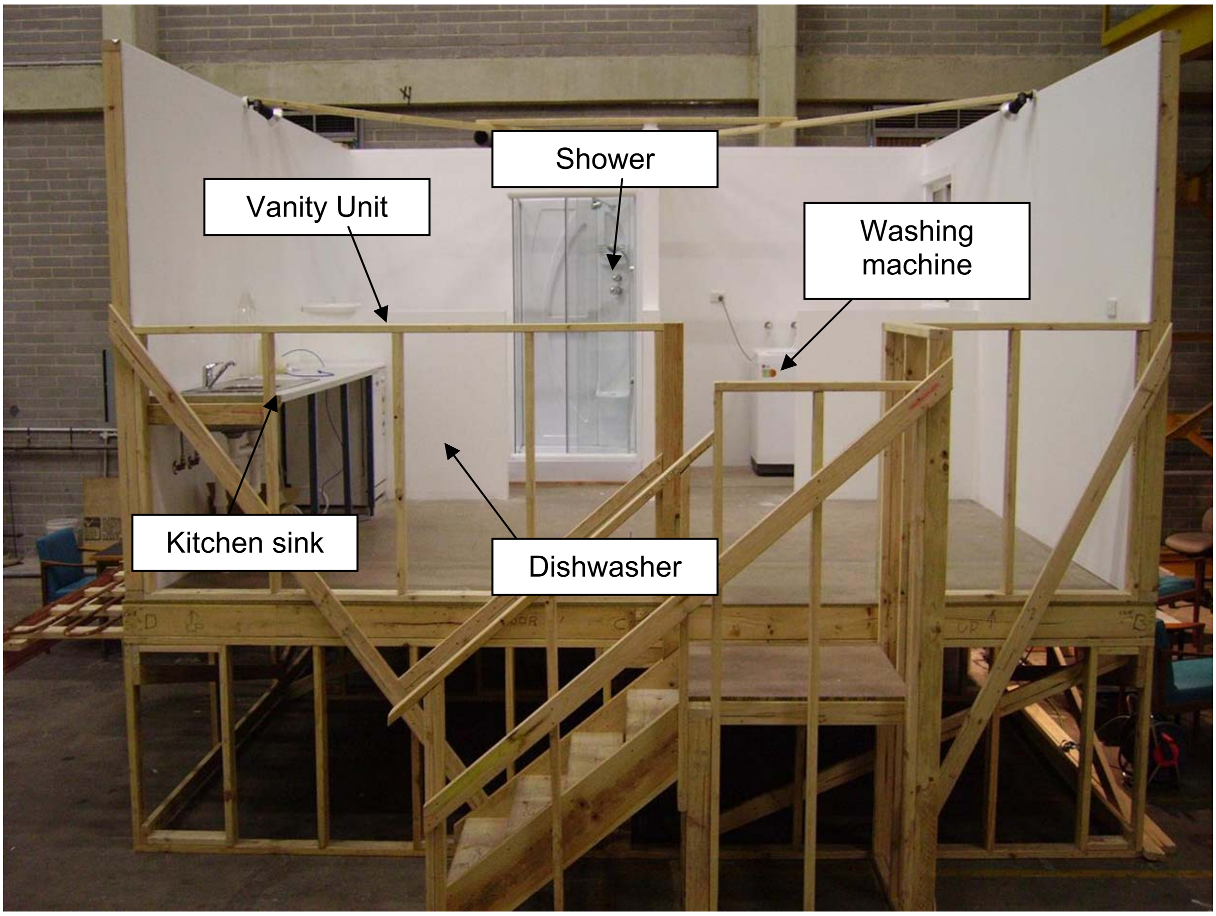


Figure 2: Mini-house set-up

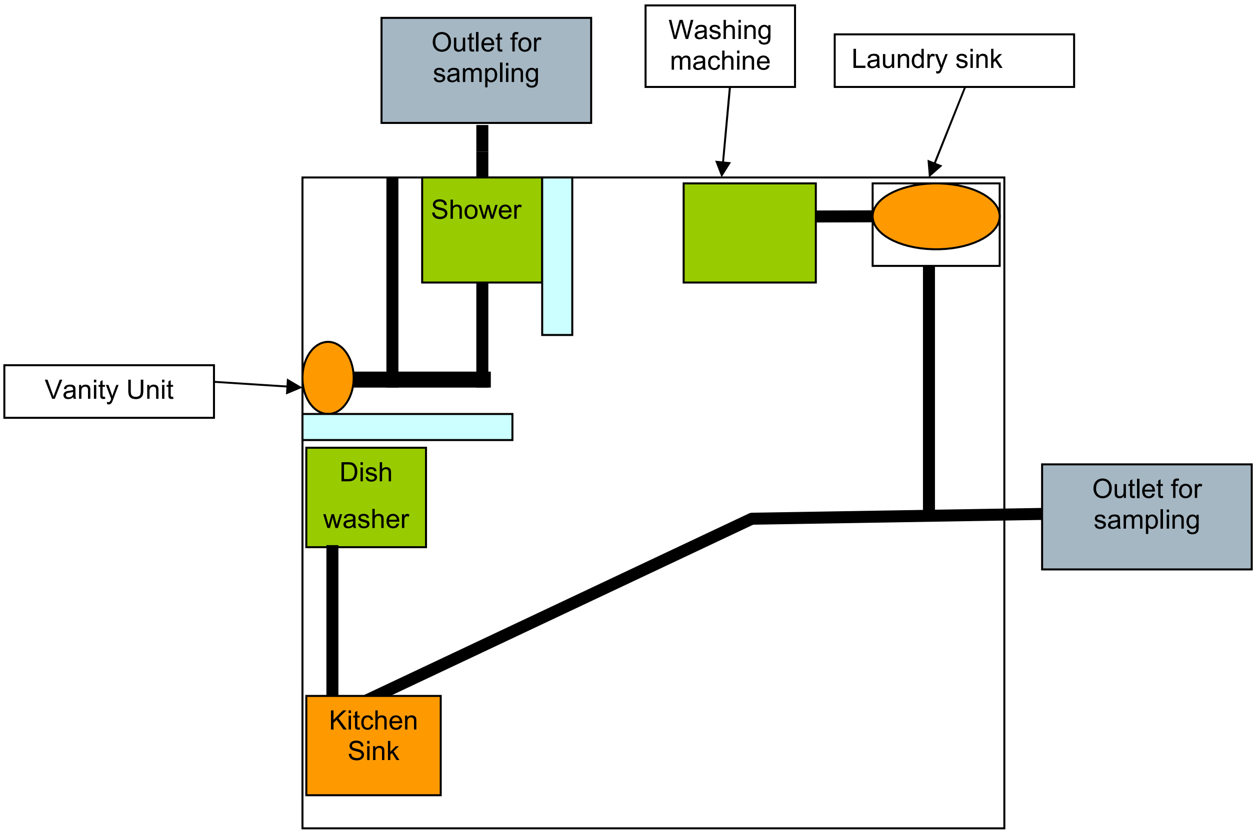


Figure 3: Mini-house outlet pipe network

2.2.2 Black water installation

Black water was sampled from an office building located at the CSIRO Highett site in Victoria.

A sampling rig was designed to collect and analyse black water. The rig collected the wastewater from a toilet block located in an office building which was separate from the mini house laboratory. The toilet block included two toilets, one male and one female. The female toilet contained a toilet bowl and a wash basin and the male toilet contained the same appliances plus one urinal. Characteristics of the toilet bowls and urinals are outlined in Table 1.

The black water rig collected the entire daily discharge from the toilet block. The rig and its schematic diagram are shown in Figure 4 and Figure 5 respectively.

The rig was constructed with two 44-gallon plastic drums and a network of PVC piping to allow the wastewater to be gravity fed into a receiving drum (1). The wastewater was pumped from a receiving drum (1) using a macerating pump into a second drum (2) while passing through a flow meter to measure the entire volume of wastewater being discharged. The second drum was used for sample collection and analysis. At the end of each day the wastewater was disposed into the sewer and the rig was flushed.

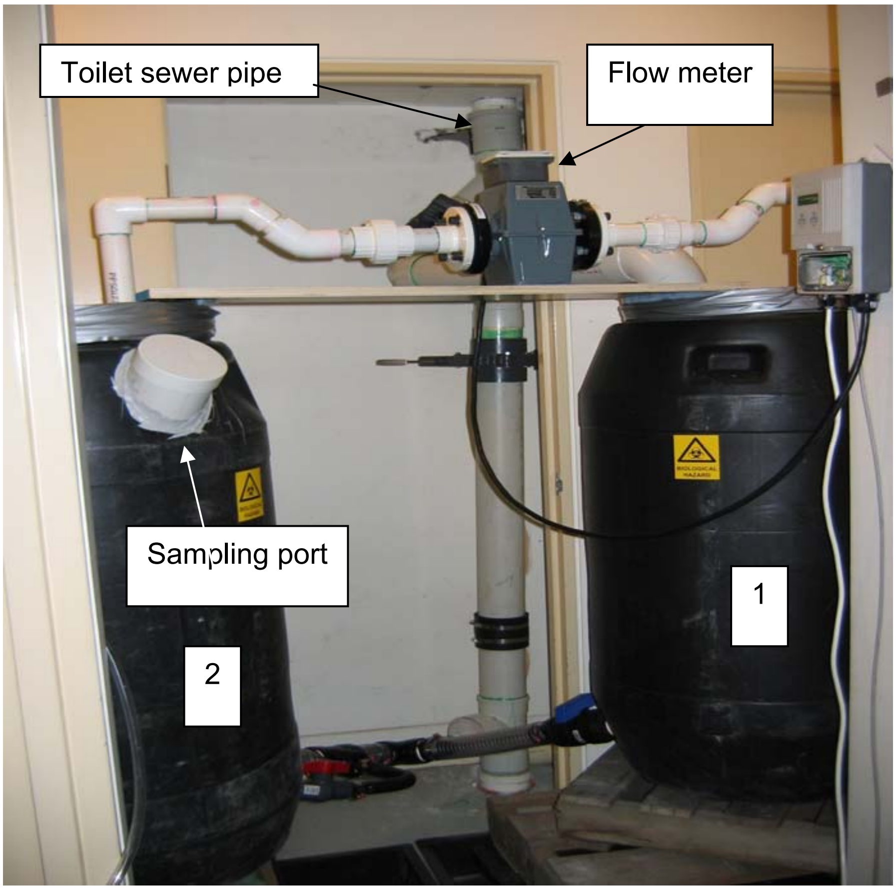


Figure 4: Black water monitoring rig

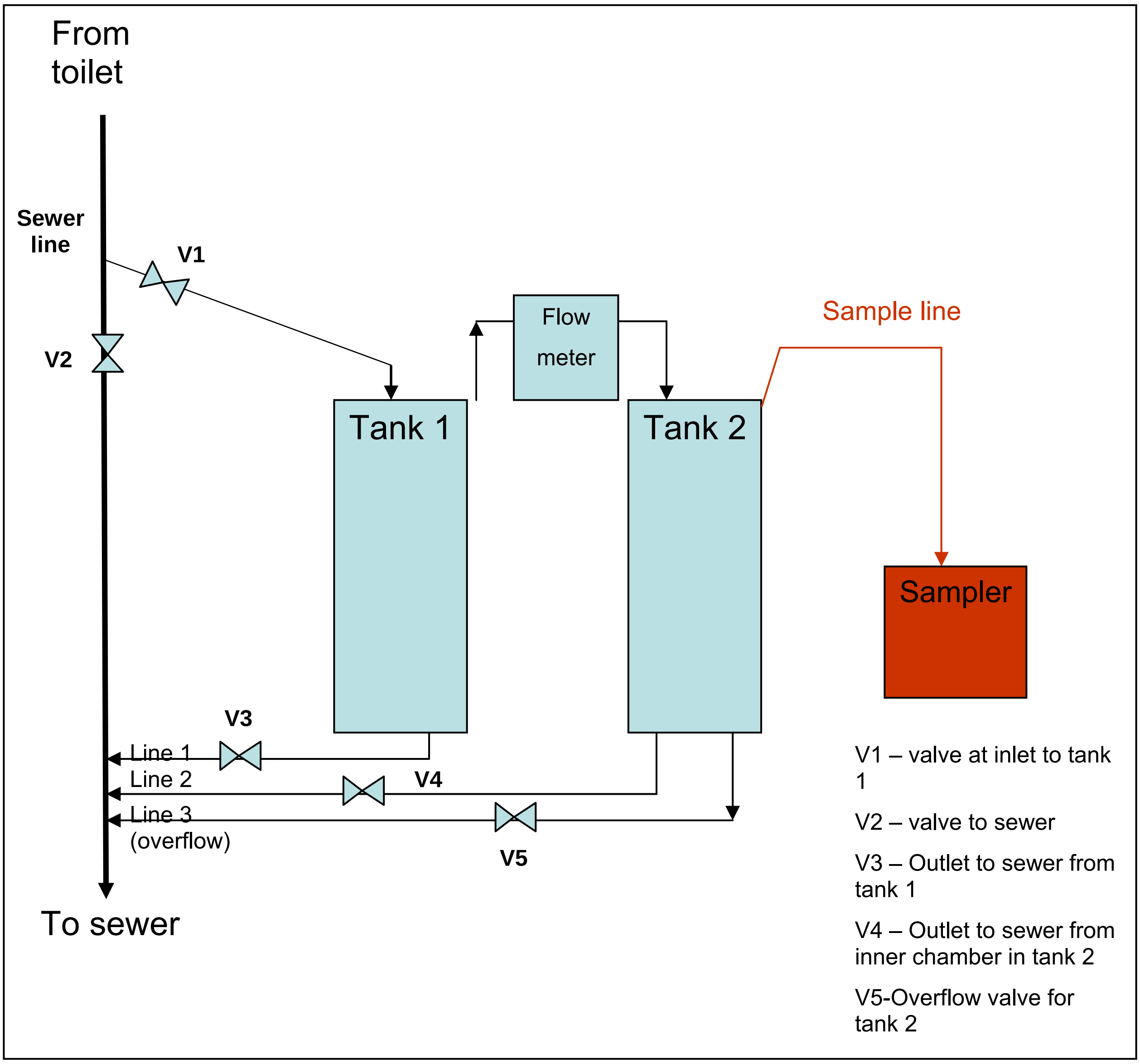


Figure 5: Schematic diagram of black water monitoring rig

2.3 Equipment

2.3.1 Flow meters

Water flows into the mini-house and through the black water rig were monitored using an ABB Magmaster flow meter with an internal bore of 40mm. The apparatus consisted of a PVC barrel and electromagnetic radiation was used to measure the flow moving through this barrel. The flow meter was built into a waterproof housing and connected to a wall mounted LCD display that displayed forward (+) or reverse (-) flow as L/s, percentage of total flow and/or total net volume.

In the mini-house this was used to cross check the water volume used for appliances as recorded by the automatic sampling equipment installed at the outlet of individual appliances.

Grey water outflow from the washing machine and the shower were automatically recorded using the ABB Magmaster flow meter. These appliances were sampled throughout the wastewater discharge. Samples were collected at a designated time or volume intervals.

Grey water outflows from the kitchen sink, vanity unit and dishwasher were collected manually as flows were too low for accurate analysis using the flow meters. The entire discharge was collected and analysed.

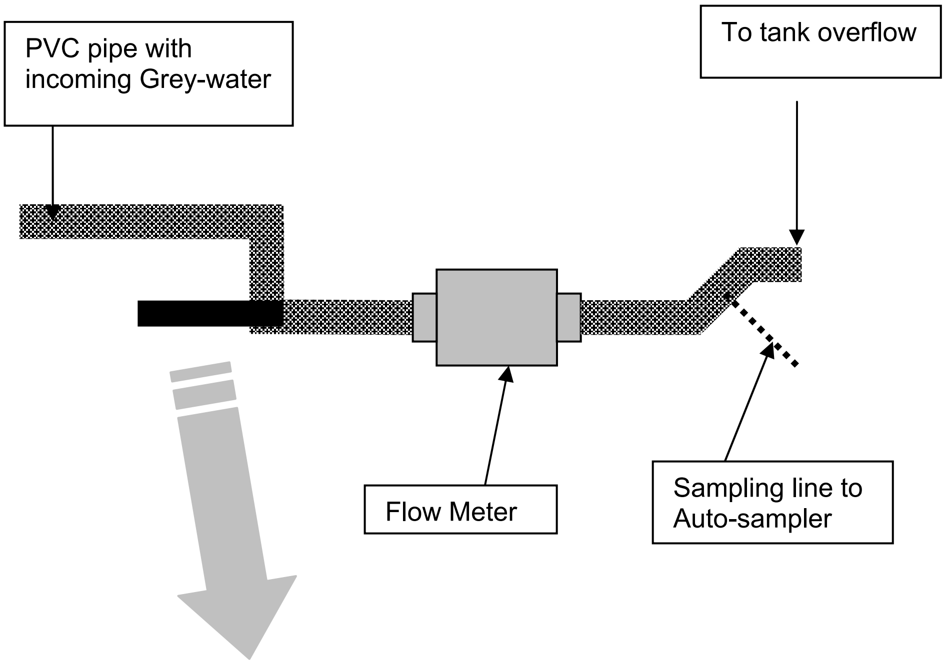
Detailed analysis of the flow profiles for the different appliances can be found in the Smart Water Fund report "Contaminant loads from household appliances" (Diaper *et al* 2008)**.**

2.3.2 Sonde

Analysis of pH, electrical conductivity (EC), oxidation reduction potential (ORP) and temperature was conducted using a YSI multiparameter sonde. The sonde is a multi probe in-line monitoring apparatus designed to take measurements in direct flows of water and wastewater. It can be used in either wastewater piping using a special housing or directly in a body of water.

The sonde was used to monitor black water collected in the black water rig and grey water flowing through the PVC pipe-work, to measure all parameters at 1 minute intervals.

A PVC manifold was designed to accommodate the sonde, flow meter and sampling port in the mini-house (Figure 6). The sonde was mounted in the pipe-work within a small section of PVC tube sealed with a rubber mounting cover which was inserted into the open PVC pipe in the manifold and sealed with hose clamps. Both the sonde and flow meter were connected electronically to an auto sampler and the manifold sampling line was physically connected to the auto-sampler inlet. Conductivity and flow readings were used to trigger start-up of the auto-sampler.



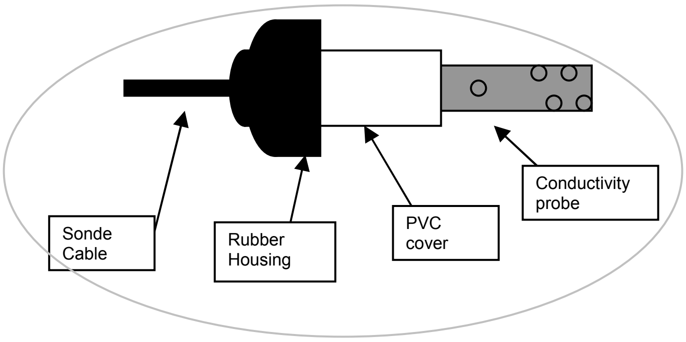


Figure 6: Sonde and autosampler set-up

2.3.3 Autosampler

An ISCO model 6712 automated sampling device was used to sample wastewater. The activation mechanisms we utilised in this project were flow and time based. The auto sampler carries 24 polyethylene bottles, each with a 1000 mL volume capacity.

In automatic sampling of the washing machine and shower, samples where obtained sequentially through time or flow based pacing, once the flow was above a selected trigger value.

Each of the major equipment items adopted is shown in Figure 7.

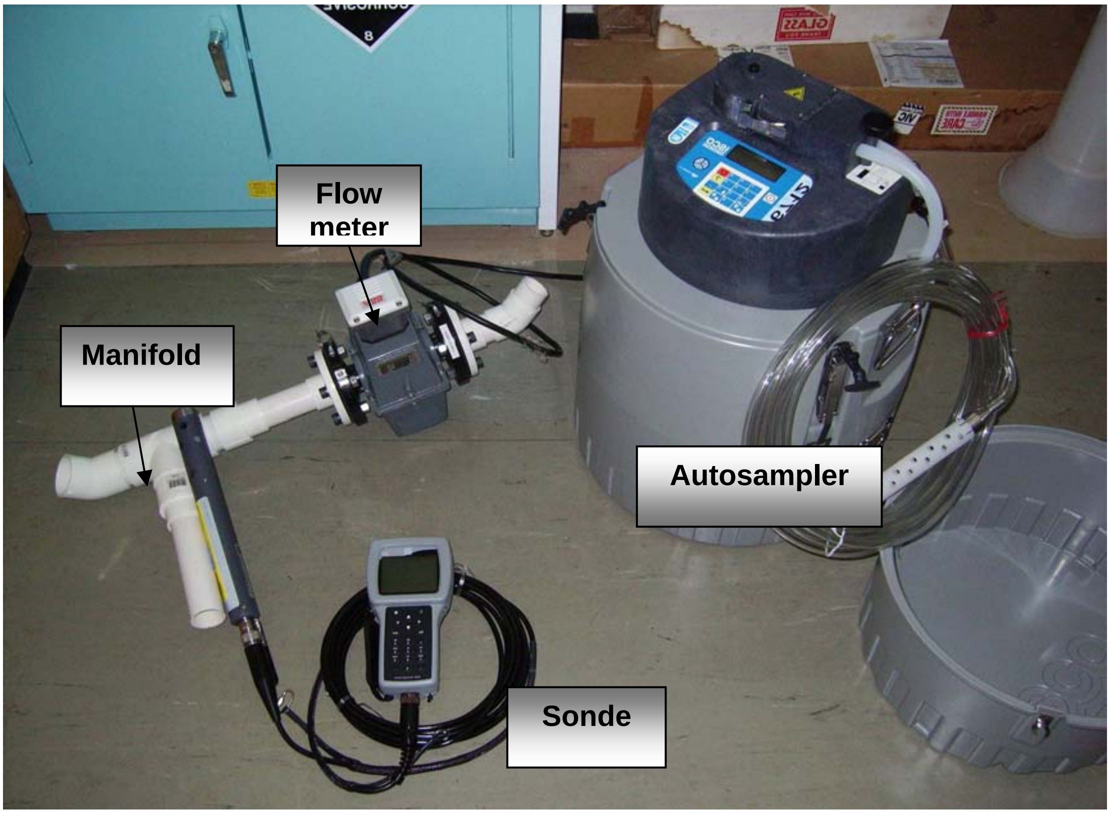


Figure 7: Manifold, flowmeter, sonde and autosampler

2.3.4 Calibration Procedures

The Sonde and the other meters were calibrated on a regular basis. The calibrations utilized a set of standard solutions to reference the probes. The parameters calibrated and calibration procedures were:

- pH: A two point calibration using pH 6.88 and 10 buffers;
- EC: A single point 1412 μS/cm conductivity standard;
- ORP: A single point standard 240 mV solution;
- Flow: A three point calibration.

With calibration of the sonde to specifications the accuracies of the probe are as follows:

- pH: ±0.2 units with an operating range of 1 to 14 pH units
- ORP: ±20mV with an operating range of -999 mV to +999 mV
- Temperature: ±0.15 °C with an operating range of -5 to 50°C
- Conductivity: ±0.5% of reading +0.001mS/cm with a range of 0 to 100 mS/cm
- Flow: ±10 %, operating range of 0.0167 L/s to 0.99999 L/s.

2.4 Methodology for household simulation

Major household chores were conducted in the mini-house replicating the settings, products and behaviour adopted by volunteers in their households. The characteristics of appliances used in the experiments are shown in Table 1. Typical discharge profiles for the appliances, except the toilet and urinal, have been published in Diaper *et al* (2008). The household activities evaluated are summarised in Table 3.

Table 1: Major appliances, brands and water usage

Appliance type	*Location*	*Brand*	*Average volume*	*Water consumption rating*
Washing Machine – Top Loader	Field house	LG – Turbo Drum 5.5kg Capacity	63.3 L/wash (normal cycle)	1 star energy efficiency 4 star water rating
Dishwasher	Field house	Conia - model CDW1211	15.7 L/wash (normal cycle)	2 ½ stars energy rating 2 ½ stars water rating.
Shower	Field house	na	10L/min	Water efficient (WELS 2.0 star rating)
Kitchen sink	Field house	na	8L (full)	na
Bathroom sink	Field house	na	2L (full)	na
Toilet	Office building	Caroma Pedigree	9L single flush	na
Urinal	Office building	Caroma Torres B1	2L flush	na

Note: na – not applicable.

2.4.1 Clothes washing

The wash settings for each wash are detailed in Table 2. These conditions replicate the typical washing set-up used by our volunteer. Six washes where performed in a LG top loader washing machine using dirty clothes from a volunteer family. The laundry loads were typical of a family of 2 adults and 2 children. The amount of detergent used by the volunteer was replicated in the lab study, with an average dose of 54g per wash. The product used for the analysis was identical to the product used in the volunteer's household and was an "environmentally friendly" powder concentrate detergent.

The wash settings for each wash are detailed in Table 2. These conditions replicate the typical washing set up used by our volunteer. The product used for the analysis was identical to the product used in the volunteer's household. Clothes used in the washing cycles were the clothes of the volunteer family. A blank run was conducted with clean sheets and using the same brand of laundry detergent used by the family.

Table 2: Operational parameters for washing machine

Run	*Program used*	*Load size*	*Temperature*
1	Wash 15min, Two rinses 4min, Spin 1 min	XL	Warm 30-35°C
2	Wash 15min Two rinses 4min Spin 1 min	L	Warm 30-35°C
3	Wash 15min Two rinses 4min Spin 1 min	L	Warm 30-35°C
4	Wash 15min, Two rinses 4min, Spin 1 min	XL	Warm 30-35°C
5	Wash 15min, Two rinses 4min, Spin 1 min	XL	Warm 30-35°C
6	Wash 15min Two rinses 4min Spin 1 min	L	Warm 30-35°C
Top Loader Blank	Wash 15min Two rinses 4min Spin 1 min	L	Warm 30-35°C

The auto-sampler was set to take samples every minute when the flow was over 0.25 $L.s^{-1}$. For the top loader this allowed approximately three samples for each of the phases within the total wash. After collection in the auto-sampler, samples were then transferred to bottles for storage and used for further analysis as necessary.

In addition, an unpreserved, a nitric acid preserved and a sulphuric acid preserved composite sample were taken from the total water collected for each program.

The parameters analysed for all samples were as follows;

- On-line - DO, Conductivity, ORP pH, Temperature, TDS.
- Composite - TDS, salts and metals.

2.4.2 Shower

Grey water generated from the showers of one male and one female volunteer were sampled and analysed. Each volunteer took a total of five showers in the mini-house. The female volunteer used a range of random products that she brought herself. The male volunteer used market leading brands of shampoo, conditioner, body wash and deodorant.

The brand and mass of personal care products used by the male volunteer were determined before and after each shower and used to evaluate the load contribution from household products and from human activity. He also undertook showers of 4min duration and consumed the products in sequence at specific times to obtain comparable data.

A blank without human input was obtained by dissolving equivalent amounts of the products used by the male volunteer using gloved hands.

The auto-sampler was set to activate when the flow was over 0.001 Ls^{-1} and to take samples every 0.005m^3.On line monitoring analysed pH conductivity, DO, ORP temperature, and samples where also analysed for TDS and metals. Samples of the composite water collected from each shower were taken as an unpreserved, a nitric preserved and a sulphuric preserved sample.

2.4.3 Dishwashing

Dirty dishes were washed in a dishwasher and manually in the kitchen sink. Dirty dishes from the CSIRO canteen were utilised to replicate the typical household wastewater produced by an average family of 2 adults and 2 children. The washing loads where chosen to simulate our volunteers' household usage and were comprised of various loads of plates, cups, glasses, bowls and cutlery.

Grey water samples were collected from the kitchen sink and from each cycle of the dishwasher run for analysis.

2.4.3.1 Dishwasher

The dishwasher was a Conia CDW1211 that utilized 15.7 L per wash on normal program and 319 kWh when using water from a cold tap. The dishwasher had five different modes of operation. In this study, the normal mode was adopted to reflect the volunteers' dishwashing machine usage. The normal mode includes a pre-wash, a wash and two rinses.

The dishwasher product chosen was the product used by the CSIRO volunteer at home, at a dose rate which also reflects the amount used, which was ~10 g per wash.

Overall five washes and one blank were run for the dishwasher. Due to the low flows observed from the dishwasher programs, samples of the individual cycles and the total discharge were taken manually. The grey water from each stage was analysed for pH, DO, conductivity, ORP, temperature and TDS. The composite was analysed for metals.

2.4.3.2 Manual dishwashing in a kitchen sink

Manual dishwashing was conducted with a sink full of water to which liquid detergent was added.

Washing of dirty dishes in the kitchen sink was conducted on five occasions and each run was sampled individually, with an unpreserved sample, sulphuric acid and nitric acid preserved samples

2.4.4 Vanity Unit

A volunteer washed hands, brushed teeth and rinsed with mouthwash to represent the typical consumption of bathroom products relative to a single person. All the grey water generated was collected and a composite prepared. This was performed on five separate occasions and the wastewater was collected for analysis unpreserved, and preserved with sulphuric and nitric acids.

A blank run was conducted by running tap water into the sink and dissolving the same products in the water but without the human input.

2.4.5 Toilet

The output from a toilet block at a CSIRO building which included two toilets, one urinal and two hand basins, was collected during working hours from 9am to 5pm. The number of toilet and urinal flushes was recorded each day using a log sheet. On six of the sampling dates the amount of toilet paper used during the day was also recorded. The toilet pipework and the rig were flushed by running water through the system for 20 minutes each morning before the beginning of sampling and each evening after sample collection.

Table 3: Summary of major activities in field house: appliance and operation mode

Activity	*Description*	*Control*	*Number of runs*	*Cleaning product used*
Laundry washing	Laundry from a family was washed in a top loading washing machine	Clean sheets	6	Low phosphorus concentrated laundry powder detergent
Dishwasher	Washing of dishes for 4 people after lunch	Clean dishes	6	A private brand dishwashing detergent
Kitchen sink	Washing of dishes for 4 people in a sink full of water after lunch	Washing of clean dishes for 4 people in a sink full of water.	5	Liquid detergent
Shower	Male and female volunteers showered using a number of personal care products.	Shower run for same amount of time as male volunteer's with dissolution of products using gloved hands.	5	Shampoo, conditioner, body gel, deodorant.
Vanity Unit	A male volunteer brushed his teeth and washed his hands in the vanity unit	The same products used by the volunteer were dissolved in the vanity unit filled with an equivalent amount of water as generated by the volunteer	5	Hand wash, toothpaste and mouthwash.
Toilet use and hand washing	The total volume of wastewater generated by male and female toilets in an office block was collected.	None. Tap water from the toilet was analysed.	12	Toilet paper and hand wash.

2.5 Frequency of appliance use

The weekly mass loads of contaminants discharged by the various appliances were used to compare the various household wastewater streams. Mass loads were estimated assuming frequencies of appliance use derived from the 2005 Melbourne study by Roberts (2005) for a one person household for the dishwasher, washing machine, shower, kitchen sink and toilet and estimates for the vanity sink. The frequencies adopted were:

- 5.32 showers per person per week;
- Laundry washing 3 times per week;
- Dishwasher use 1.8 times per week;
- Kitchen sink 10.5 loads of dirty dishes per week;
- Vanity unit 14 times per week; and
- Toilet 29.4 flushes per week (equivalent to 25.26L/pe per day)

2.6 Analytical methodology

All samples where analysed for physical parameters including pH, electrical conductivity (EC), oxidation-reduction potential (ORP), total dissolved solids (TDS), colour, metals, total Kjeldahl Nitrogen (TKN), total phosphorus (TP), fluoride and chloride using the methods described in the following sections.

2.6.1 Physical-chemical parameters

Physical parameters (pH, EC, ORP, DO and temperature) of samples were measured in-situ using the YSI sonde and by use of other probes.

For the washing machine and the shower, the sampler and sonde data collection were initiated during preparation of the appliance for testing, hence results for those appliances also show the initial values for tap water which was utilised to flush the appliances between runs.

2.6.2 TDS analysis

Samples collected by the auto-sampler and composite samples were analysed for TDS according to APHA standard method 2504c at the CSIRO Highett laboratories (APHA/AWWA 2008).

2.6.3 Colour

Samples that were collected for TDS and metal analysis were also used for colour determination in CSIRO laboratories.

A HACH DR/2000 spectrophotometer was used to analyse the true colour in Platinum Cobalt units (PCU) according to the standard method as per HACH spectrophotometer handbook (1989). Samples were filtered before analysis using a 0.45 µm filter in order to remove any solids or particulates that cause interference in the spectrophotometer readings. Once filtered, the sample was transferred to a quartz cell for analysis. The instrument colour measurement range was between 15 and 500 PCU. Calibration of the spectrophotometer was performed using standard APHA Method 2120B (APHA/AWWA 2008)

2.6.4 Nitrogen

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

2.6.5 Phosphorus

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

2.6.6 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 2008).

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 metal such as 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 4.

Table 4: Detection limits for elemental analysis

Metal	***Limit of detection (LOD) ICP-AES (mg/L)***	***Limit of detection (LOD) ICP-MS (μg/L)***
Aluminium	0. 01	0. 01
Antimony	-	2
Arsenic*	-	5
Boron	0.02	-
Cadmium	0.002	0.5
Calcium	-	-
Chromium	0.005	2
Cobalt	0.005	0.5
Copper	0.01	5
Iron	0.05	-
Lead	0.04	0.5
Magnesium	-	-
Manganese	0.001	-
Mercury*	-	2
Molybdenum	0.02	-
Nickel	0.1	30
Phosphorus	0.05	-
Potassium	0.01	-
Selenium*	-	5
Sodium	-	-
Sulphur	-	-
Tin	0.01	-
Zinc	0.001	-

*Note: Analysis by ICP-MS.

3 Evaluation of wastewater from the field house - Results

In this report, the term “field house” designates typical household activities carried out by volunteers in the mini-house laboratory as they would at home. “Field house” activities such as clothes washing, showering and dish washing consisted of volunteers washing dirty laundry or dishes, etc as they would at home.

Household activities were also conducted using the same set-up by scientists without human waste, i.e. dish washing was conducted with clean dishes, clothes washing with clean clothes and showering with the release of household products without a human subject. These activities were designed to measure the input from products and water alone, without human waste.

Results are presented in two major sections:

(a) Stream characteristics of wastewater: evaluates the physical-chemical characteristics of wastewater produced by each of the major appliances with and without human input. This includes the typical profiles for physical-chemical parameters such as pH, EC, colour and ORP generated by typical household activities and compares it to wastewater generated by operation of the same appliances without human input.

(b) Contaminant loads in wastewater: evaluates the concentrations and mass loads of priority contaminants generated by each appliance. The elemental loads are characterised based on their point of discharge within the field house and a source assessment is made using the individual contributions from tap water, human inputs and household products to the overall load in wastewater.

3.1 Characteristics of wastewater from household appliances

The volume and stream characteristics of the wastewater generated by each appliance in our “field house” study were impacted by the quality of the tap water from each of the test sites, the characteristics of each appliance, its operation by the volunteers and by the lifestyle attributes from each volunteer. This includes, for instance, how many times the volunteer wears an outfit before washing it, if a volunteer wipes dishes before placing them in a dishwasher, and if a volunteer undertakes vigorous physical activity before a shower, e.g. after playing footy, or simply showers after waking up in the morning.

To minimise the variance in results caused by different test subjects, all runs of an individual appliance were conducted by a single volunteer, using his/her customary household products, dosages and settings. The only exception was the toilet block which was used by a varying number of individuals on a day to day basis.

3.2 Volume of wastewater

Figure 8 shows the typical amount of water consumed and the wastewater generated by each appliance and the daily volume of black water discharged in the toilet block. The standard deviation of the data is represented by the error bars. The washing machine (WM) produced the largest volume of wastewater, an average of 158 litres per wash, with a standard deviation of 33.1L taking into consideration the variability of water volume from different washing styles.

Blackwater was the second largest volume recorded, with an average of 155 litres produced in a day. The standard deviation of the readings was ± 26.3L. This represents the average daily volume of wastewater generated in the specific office building, and as such it is not typical of the volume of wastewater generated by the daily appliance use in a household as the population in the building varied from 5 to 18 people during the study period.

The toilets used in our experiment were each a 9L single flush toilet and the urinal had a 2L flush. The corresponding volume discharged by such appliances based on the typical use by one individual was estimated to be 22.7L/pe/day (TO*). In comparison, the average volume of water used in toilet flushing was estimated to range from 31L/pe/d to 42L/pe/day, subject to a standard deviation of ±20L, depending on the type of toilet, either a 6/3 dual flush or an 10-11L single flush toilet according to a Melbourne study conducted in 2004 (Roberts 2005).

The shower (SH) generated the third largest volume of wastewater with an average of 34 litres per use and a standard deviation of ± 2.9L.

The other appliances (dishwasher (DW), vanity unit (VU) and kitchen sink (KS)) produced the equivalent of less than 10% of the volume that the washing machine produced, with the respective volumes of wastewater being 15.9 L/wash, 2.0 L/wash and 8.2L/wash.

Significant variation was observed in the volume of water used in the washing machine, as seen in the standard deviation. The variation in the washing machine was caused by the different cycles in the machine and the size of the washing load which varied from run to run.

The black water setup, exhibited the second largest standard deviation, caused by different numbers of people using the toilets on a daily basis.

The other runs showed greater reproducibility in volume from one run to another.

The appliances that produced the most wastewater per single use descend in this fashion;

WM> SH> DW> TO*>KS>VU

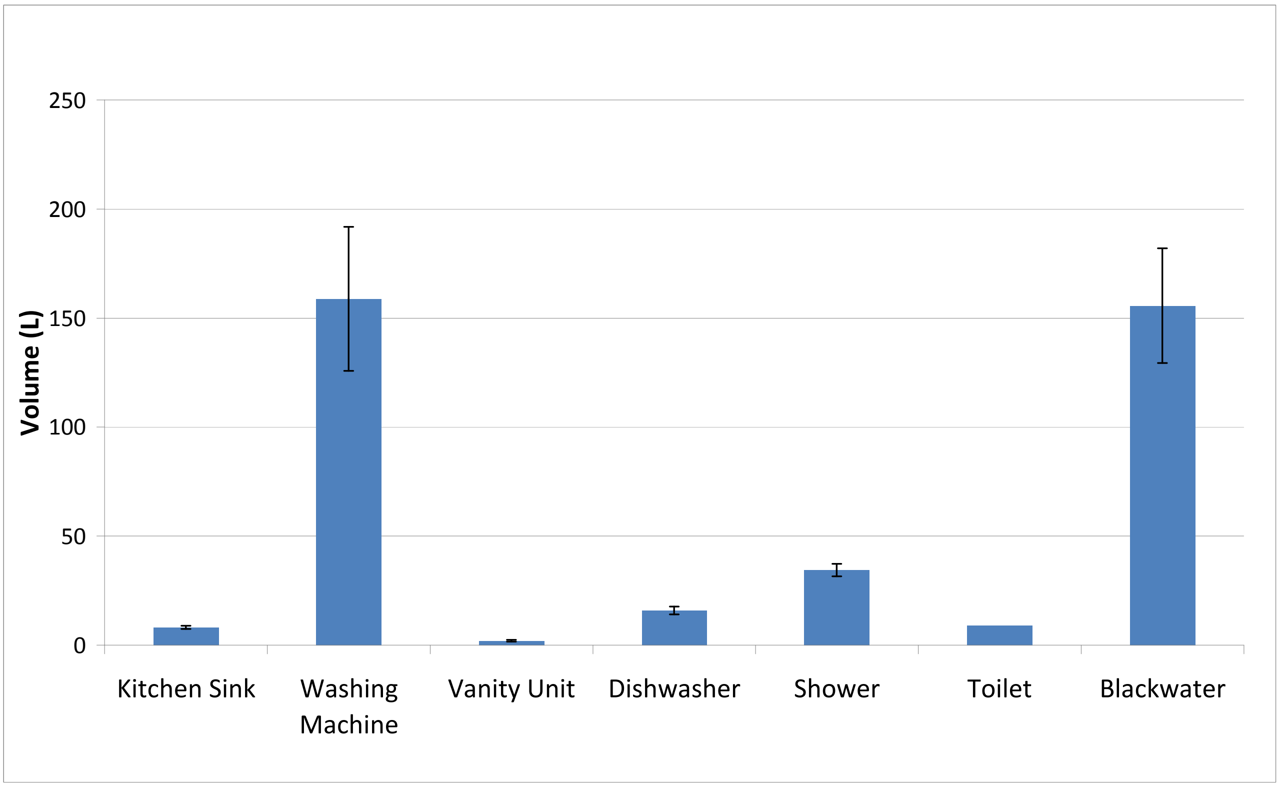


Figure 8: Typical volume of wastewater generated by each appliance in the field house. Black water is the average daily volume of blackwater from a toilet block for multiple users.

Appliances such as the washing machine, the dishwasher and the shower which have a characteristic discharge profile were also monitored during operation.

3.2.1 Washing machine

The top loader washing machine generated the highest volume of wastewater of all the appliances. It was used on two different settings, large and extra large. The differences between the two settings are based on volume of water consumed for washing purposes. The large setting used between 131 and 134 litres per wash giving an average of 132.6 L per wash and the extra large setting used between 169 and 179 L per wash giving an average of 172 litres per wash.

The typical wash cycle was characterised by one wash and two rinse cycles. In the first run the clothes became entangled and the machine performed an additional wash stage using more water than normal. For this reason the data from this run has not been included in the results, as the entangled clothes affected the discharge time and volume.

3.2.2 Dishwasher

The dishwasher used a minimum of 15 and maximum of 17 litres per normal wash. The program cycle used on average 16.14 litres per complete wash. The program used in the dishwasher was comprised of a pre-rinse, a wash and 2 rinses thereafter.

3.2.3 Shower

The amount of wastewater generated in the shower by the volunteer varied from 31 to 39 litres with an average of 34.4 litres discharged per shower.

3.3 Wastewater pH

The pH of wastewater generated by the different field house appliances ranged from 4.6 to 10.6 units. The mean pH values for each appliance are compared in Figure 9. The pH readings were determined from composite wastewater samples for most of the appliances, except for the washing machine and dishwasher, for which averages of the respective process cycles were taken.

Table 5 shows the pH of tap water, of the blank run (wastewater which contains the same household products, but no human input) and of wastewater for comparison. The high pH in the tap water in the field house was attributed to leaching from the cement lined water main that carries water into that specific building.

The wastewater streams generally had a basic pH of 8 or higher, with the exception of the kitchen sink whose pH was 7.08. The washing machine had the highest reading with a pH of 10.05.

The mean pH in wastewater increased from lowest to highest in this manner:

KS<VU<TO<SH<DW<WM

The high overall readings for sources other than the toilet block were strongly influenced by the pH of the tap water. The tap water in the building which housed the major household appliances (washing machine, dishwasher, shower, kitchen sink and vanity unit) had a pH of 9.24 and a standard deviation of ± 0.203, whilst tap water in the toilet block building had a pH of 7.14 and a standard deviation of ± 0.219.

The largest variance in pH results was verified in the discharges from the dishwasher and the kitchen sink. The respective ranges were 4.6 to 10.5 and 5.99 to 8.22 pH units. Wastewater from the toilet showed the least variance ranging from 8.41 to 8.76.

A possible reason for the pH reduction in the kitchen sink would be food scraps. These are usually high in food acids, decreasing the pH. The type of food waste left on dirty dishes would also be likely to vary significantly from one day to another. This effect would be less pronounced in the dishwasher due to the higher amount of dishwashing powder used and its strongly basic pH.

The washing machine powder also increased the pH resulting in a pH reading of 10.05.

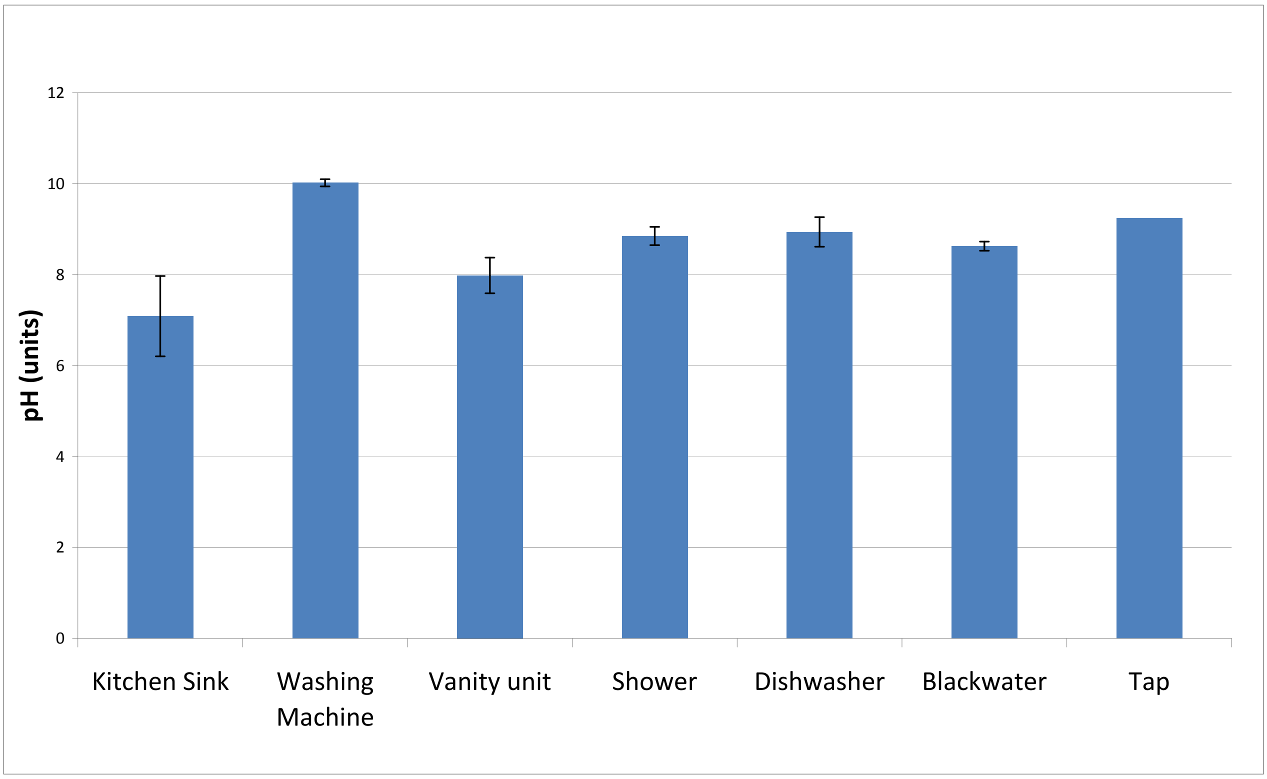


Figure 9: pH of wastewater generated by individual appliances.

The effect of adding household products and human inputs to wastewater is shown in the pH of wastewater streams with and without human inputs (dirty dishes, dirty laundry, etc) in Table 5. These were evaluated for most appliances with the exception of the toilet.

When compared to the original pH of tap water, the addition of household products changed the pH by -0.49, +0.02, -0.93, +0.22, +0.66 units for the kitchen sink, shower, vanity unit, dishwasher and washing machine respectively.

Human inputs, as either dirty clothes, dirty dishes or human residues, caused further change of pH: -1.67, -0.41, -0.33, -0.52 and +0.15 units for the kitchen sink, shower, vanity unit, dishwasher and washing machine streams.

The pH of the blank (water + product) was higher than that of wastewater for both kitchen and vanity sinks suggesting some buffering of the mix occurs with human input.

In the shower, personal care products were responsible for approximately 100% of the pH increase.

In the washing machine laundry powder and human input were responsible for 81% and 19% of the increase in pH.

In the vanity unit, personal care products (handwash, toothpaste, mouthwash) and human residues were responsible for 74% and 26% of the decrease in pH.

On the other hand, food waste had a marked effect on pH. In the kitchen sink, the addition of liquid detergent and food waste were responsible for 23% and 77% of the pH reduction seen in wastewater. Likewise in the dishwasher, pH increased due to the powder detergent, but decreased due to food residues. Food residues had the largest effect, as the change caused by the detergent was equivalent to only 42% of the change caused by food residues.

In summary, the major influence on pH in wastewater streams with a high amount of organic residues, such as the kitchen streams and black water was the human input. For appliances with a low amount of organic residues, such as the washing machine, vanity unity and shower, the pH was determined mainly by the household products used in the appliances.

Table 5: Summary of pH characteristics in wastewater

Mean pH							
Source	***Water (W)***	***Water + product (P)***	***Wastewater (WW)***	***SD (WW)***	***Min***	***Max***	***pH Ratio (P-W). $(WW-P)^{-1}$***
Kitchen sink	9.24	8.75	7.08	0.882	5.9	8.22	0.29
Washing machine	9.24	9.90	10.05	0.378	9.4	10.6	4.29
Vanity Unit	9.24	8.31	7.98	0.393	7.61	8.63	2.82
Dishwasher	9.24	9.46	8.94	1.936	4.63	10.52	-0.42
Shower	9.24	9.26	8.85	0.407	8.1	9.7	-196
Toilet block	7.14	na	8.63	0.10	8.41	8.76	NA

Note: NA – not applicable.

The pH variations for the wash machine, the dishwasher and the shower were also monitored during operation.

3.3.1 Washing machine

The initial pH of tap water ranged from 8.9 to 9.6. The pH of wastewater generated during the different washing machine cycles was very similar. The wash had the highest pH (average 10.44), followed closely by rinse 1 and rinse 2 at 9.88 and 9.15 respectively.

In the wash stage, the pH increased to between 10.4 and 10.7. During the subsequent rinse stages the pH was progressively reduced to the pH of tap water as the detergent was removed.

There were only minor changes in pH for wastewater with and without human input.

There was no apparent difference in pH between each wash despite the different size of the wash loads.

Extra large wash pH ≈ large wash pH

Table 6: pH during washing machine operation

Washing machine pH	***Water***	***Water + Product***	***Wastewater***	
			Mean	**SD**
Wash	9.24	10.66	10.44	0.11
Rinse 1	9.24	9.88	10.12	0.1
Rinse 2	9.24	9.15	9.59	0.14

3.3.2 Dishwasher

The pH profile for the dishwasher operation is shown in Table 7.

The pH of wastewater had the highest acidity during the pre-rinse stage, 5.87pH units. In the wash stage, the pH increased to 10 with the addition of detergent. It decreased to the pH value of tap water during the rinse stages as seen in Table 7. The variation compared to the absence of human input was marked during the pre-rinse, but less significant for the wash and rinse stages.

It is apparent that the food scraps in the pre-rinse water reduce the initial pH of the water, in the next cycle of the wash, the pH increases well above that of tap water as detergent is introduced, and it decreases in subsequent rinses.

Table 7: pH during dishwasher operation

Dishwasher pH	***Water mean***	***Water + Product mean***	***Wastewater***	
			Mean	**SD**
Pre-rinse	9.24	8.4	5.87	1.26
Wash	9.24	10.06	10.4	0.08
Rinse 1	9.24	9.93	10.06	0.07
Rinse 2	9.24	9.44	9.41	0.11

3.3.3 Shower

The typical shower lasted on average 4 minutes for both the male and female volunteers. The overall change in pH was small, less than 0.84 pH units, with the largest change verified 2 to 3 minutes into the shower during application of hair and body wash products. The variation compared to the absence of human input was not significant (<2.5 SD). There was no significant variation in pH between the two volunteers either.

Table 8: Wastewater pH during shower

Shower pH	***Water mean***	***Water + product (male) mean***	***Wastewater***			
Time(min)			***Female mean***	***Female SD***	***Male mean***	***Male SD***
0	9.24	9.32	9.12	0.84	9.2	0.33
1	9.24	8.84	8.90	0.55	8.38	0.25
2	9.24	9.28	8.58	0.68	8.52	0.27
3	9.24	9.42	9.16	0.66	9.04	0.19
4	9.24	9.46	8.80	0.65	9.1	0.12

3.4 Electrical conductivity

The electrical conductivity (EC) of wastewater generated by different appliances in the house is shown in Figure 10.

EC was determined from composite samples for the toilet block, the shower, the vanity unit and the kitchen sink. For the washing machine and the dishwasher, the EC values are the averages of the three and four discharges that make a full wash cycle. In the case of the washing machine this is comprised of wash, rinse one and rinse two and for the dishwasher this is comprised of pre-rinse, wash, rinse one and rinse two. The EC of the appliance outputs depended on the volume of water and amount of product used.

The mean conductivity of the appliances descended in this manner;

BW>DW>WM>KS>VU>SH>TAP

The highest EC readings were from wastewater from the toilet, dishwasher and washing machine at 1354, 1243 and 682 µS/cm, respectively. With both the washing machine and the dishwasher, the reason the conductivity was that high was predominantly due to the products used, and not any influence from human input.

The standard deviation was highest in the black water; which is explained by differences in composition of black water on a daily basis, i.e. dependant on how many people used the toilet and the ratio of urine to faecal matter.

The kitchen sink, vanity unit and the shower had mean ECs of 326, 207 and 114 µS/cm.

In the kitchen sink and the vanity unit, the variation in EC in the composite samples is attributed to products and human inputs (such as saliva when brushing teeth, food residues when dishwashing).

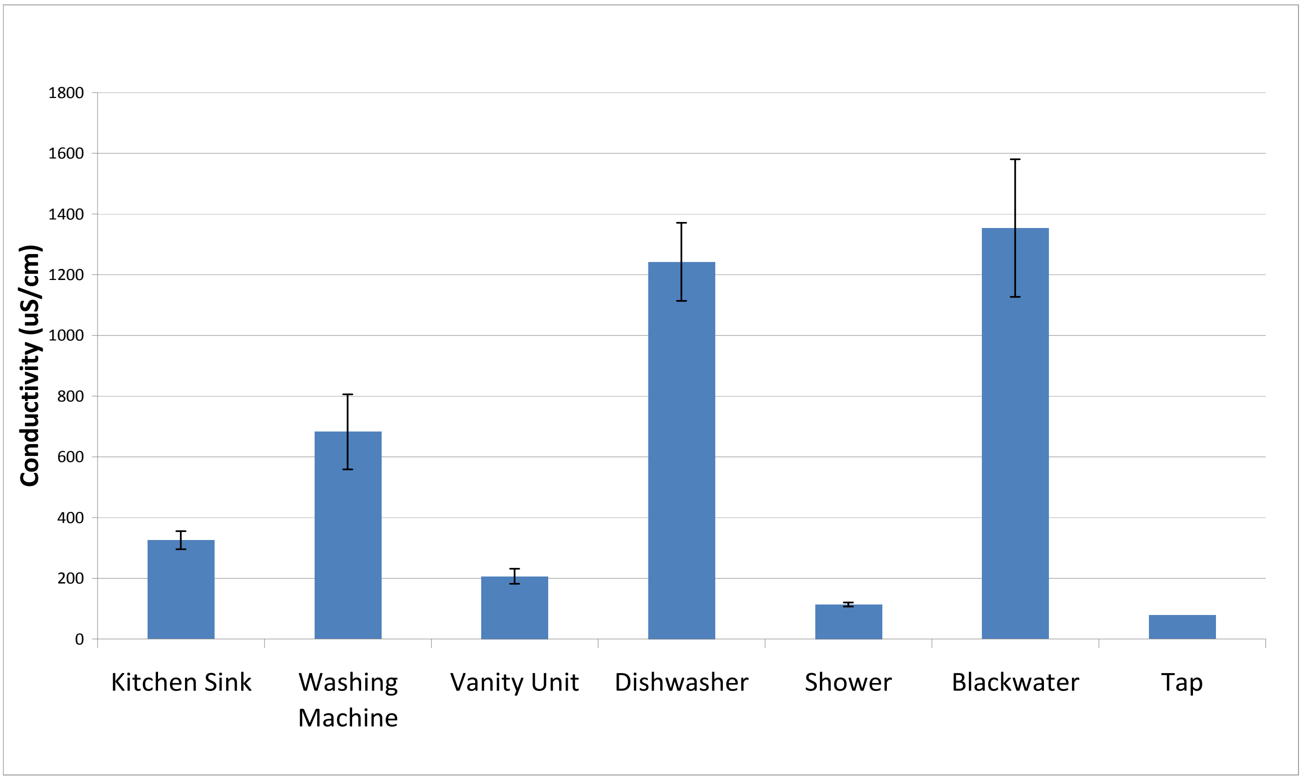


Figure 10: Mean EC of wastewater streams

Table 9: Summary of EC characteristics in wastewater

Source	***EC (µS/cm)***						
	Water	***Water + product***	***Wastewater***				
			Mean	***SD***	***Min***	***Max***	***EC ratio (WP-W) /(WW-WP)***
Kitchen sink	78.5	129.0	325.6	29.4	279.0	354.0	0.25
Washing machine	78.5	574.1	682.0	123.5	618.7	826.8	4.59
Vanity Unit	78.5	198.3	206.8	24.8	180.0	354.0	14.09
Dishwasher	78.5	1243.8	1,242.6	128.3	1,005.6	1,379.8	-971
Shower	78.5	92.2	114.1	27.9	89.6	151.6	0.62
Toilet block	78.5	na	1353.8	226.8	985.0	1,638.0	na

Note: na – not available

3.4.1 Washing machine

Table 10 shows the five washes and the conductivity of the grey water produced within each wash.

The difference in EC between the “large” and “extra large” loads was only 13%, 42% and 15.7% greater for the “large” load in conductivity in each of the stages in a cycle, and less than 1 standard deviation from the overall mean.

Hence, conductivity was not dependant on the clothes put into the wash, but given a fixed amount of detergent, volume of water consumed within the wash was the major influencing factor.

Table 10: EC during washing machine operation

Washing machine cycle	***EC (µS/cm)***					
	Water	***Water + Product***	***Wastewater***			
	Mean	***Mean***	***Mean (XL)***	***Mean (L)***	***Mean***	***SD***
Wash	78.5	1,349.8	1,551.9	1,756.2	1,654.1	207.0
Rinse 1	78.5	257.7	286.2	407.3	346.7	107.1
Rinse 2	78.5	114.7	107. 9	124.8	116.4	25.2

3.4.2 Dishwasher

Table 11 shows the conductivity of the dishwasher cycles in the field house.

In the pre-rinse stage food scraps contributed to the conductivity, with all the pre-rinse values exceeding 500 µS/cm. The EC of tap water alone was in the range of 70-90 µS/cm. Following the dishwashing powder addition, the conductivity rose to more than 3500 µS/cm, representing the largest increase during operation.

Hence the dishwashing powder caused the major EC change in the grey water.

Table 11: EC during dishwasher cycles

Dishwasher cycle	***EC (μS/cm)***			
	Water Mean	***Water + Product Mean***	***Wastewater***	
			Average	***SD***
Pre-rinse	78.5	108.8	580.2	154.52
Wash	78.5	3,778.0	3,600.0	318.41
Rinse 1	78.5	817.8	586.3	60.54
Rinse 2	78.5	270.5	203.9	33.68

3.4.3 Shower

Changes in EC during the shower are shown in Table 12. The EC increased during the first 2 minutes of the shower when personal care products were discharged into the wastewater. The variance in the EC data was also larger during the first few minutes for the male as evidenced in the standard deviation values. Whilst the standard deviation for the female was larger at 1 and 3 min into the shower.

There was no difference in EC for grey water generated by the male and female volunteers.

Table 12: Wastewater electrical conductivity during shower

ShowerTime (min)	***EC (μS/cm)***					
	Water mean	***Water + Product Mean***	***Wastewater***			
			Female mean	***SD***	***Male mean***	***SD***
0	78.5	103.2	106.0	10.58	151.6	19.36
1	78.5	52.0	120.8	23.48	136	17.66
2	78.5	92.0	97.6	10.04	100.8	4.15
3	78.5	106.8	109.2	27.70	92.4	4.98
4	78.5	106.8	106.0	10.58	89.6	4.33

3.5 ORP

ORP is a measurement of the activity of oxidisers and reducers and serves as an indicator of the biological reactions that can occur in wastewater. For instance, nitrification typically occurs in the ORP range of +100 to +350mV, whilst odours due to formation of hydrogen sulphide and methane typically occur at negative ORP values.

The ORP in the wastewater generated by each major appliance (washing machine, kitchen sink, dishwasher, vanity unit, shower and toilet block) was evaluated.

Figure 11 and Table 13 show the mean ORP values and the respective standard deviations of the sample population. The mean ORP readings were measured from composite wastewater samples for most of the appliances, except for the washing machine and dishwasher, for which an average of the respective process cycles was taken.

All the ORP readings from the wastewater streams were positive, hence the field house wastewater was in the oxidising range. The ORP value in wastewater decreased in the following order:

VU>KS>TAP>BW>DW>SH>WM

The vanity unit exhibited the highest average ORP of +173.4mV compared to all the other appliances. Close behind was the kitchen sink with a reading of +142.6 mV, which is comparable to that of tap water, +139.8 mV.

The appliances that reduced the ORP reading the most were the washing machine and the shower, with readings of +57.9 and +68.0 mV. This reduction was caused mainly by the product and not the human input as seen in Table 13.

The highest standard deviations were recorded for the kitchen sink (±40.86 mV) and the shower (±36.93 mV). The higher temperature of those wastewater streams may have influenced the ORP readings, as the ORP probe is sensitive to temperature, which can shift baseline readings. Furthermore, food scraps in the kitchen sink can vary considerably from wash to wash contributing to the high variance.

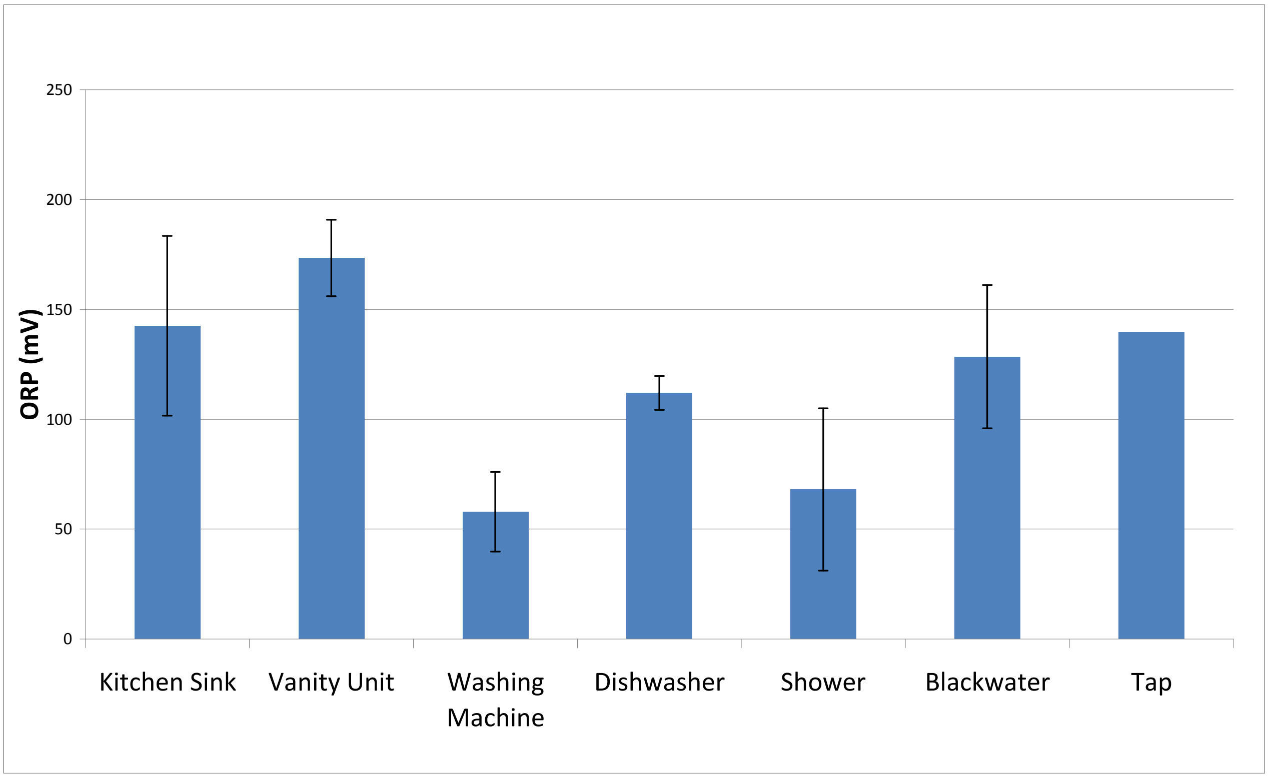


Figure 11: Mean ORP values of wastewater streams in field house

Table 13: Summary of ORP in wastewater from field house

Source	***ORP (mV)***					
	Water mean	***Water + Product mean***	***Wastewater***			
			Mean	***SD***	***Min***	***Max***
Kitchen sink	+139.8	+89.3	+142.6	40.86	+104.3	+206.0
Washing machine	+139.8	+87.3	+57.9	33.48	+31.2	+83.5
Vanity Unit	+139.8	+118.7	+173.4	17.41	+149.4	+190.0
Dishwasher	+139.8	+114.4	+112.0	66.69	+45.7	+260.6
Shower	+139.8	-33.0	+68.0	36.93	+13.5	+114.5
Toilet block	+139.8	na	+128.5	32.57	+75.2	+156.3

3.5.1 Washing machine

The ORP recorded for wash run one is shown in Table 14. The washing machine typically performs one wash cycle and two rinse cycles. During wash one the laundry became entangled during the final spin of rinse two disrupting the cycle, which resulted in an additional rinse cycle. As the washing machine was filled with water, the ORP in the third rinse was higher than in the two previous rinses, but not as high as the original ORP of tap water. This suggests that even after the second rinse, some detergent residue remained in the washing machine.

Dirty laundry and detergent have a larger impact on ORP during the early stages of the wash. The dirty laundry and detergent reduced the ORP of tap water by approximately 82% in the wash cycle to 25.2mV. The ORP decreased further by almost 88mV in rinse one and in rinse two the ORP decreased by 49.5mV. The ORP decreased by 82%, 63% and 35.4% from the wash to the subsequent rinse cycles compared to tap water.

The comparison between the product in water and field house data shows that laundry detergent and dirty laundry contribute differently to the final ORP in wastewater.

During each of the cycles, the wash, rinse one and rinse two, the detergent was responsible for 74.6%, 66.4% and 26.8% of the change in ORP from tap water, whilst the remainder was due to the dirty laundry.

The ORP in tap water ranged from 86.6 to 128.9 mV and the lowest values recorded during the wash were between -3.2 and 40.0 mV. As detergent was removed with each subsequent rinse cycle, the ORP increases through each wash.

The strongest effect on ORP was caused by the detergent.

Table 14: ORP during washing machine operation

Washing machine cycle	***ORP (mV)***									
	Water mean	***Water + Product mean***	***Wastewater***							
			Wash 1	***Wash 2***	***Wash 3***	***Wash 4***	***Wash 5***	***Wash 6***	***Mean***	***SD***
Wash	+139.8	+54.3	+27.8	+20.2	+30.2	+38.9	+18.6	+15.3	+25.2	+8.78
Rinse 1	+139.8	+80.9	+67.8	+56.7	+51.5	+67.8	20.6	+42.4	+51.2	+17.84
Rinse 2	+139.8	+126.5	+111.6	+104.9	+83.1	+103.8	54.5	+83.8	+90.3	+21.11
Rinse 3	+139.8	na	+126.5	na	na	na	na	na	na	na

3.5.2 Dishwasher

The ORP of the grey water generated during the different stages of the operating cycle are shown in Table 15. The ORP was the highest in the pre-rinse stage, it decreased following the introduction of the detergent in the wash stage and rinse stages. The corresponding ORP changes relative to tap water in each stage were 56%, -61%, -43% and -31% respectively, i.e. the major changes in ORP were caused by food residues and detergent introduction.

The ORP clearly shows that in the pre-rinse, the ORP undergoes a 55% increase due to the introduction of food matter. However, the latter wash shows a decrease of 61% in ORP value compared to tap water, due to the introduction of the dishwashing powder.

In the absence of food, rinsing of clean dishes results in a change in ORP of 35mV. This was equivalent to one standard deviation of the pre-rinse cycle, and to a 36%, 25% and 37% reduction in ORP during the wash and subsequent rinse stages.

Food residues were the main cause of ORP variation in the dishwasher.

Table 15: ORP during dishwasher operation

Dishwasher cycle	***ORP (mV)***						
	Water mean	***Water +Product mean***	***Wastewater***				
			Mean	***SD***	***Min***	***Max***
Pre-rinse	+139.8	+175.0	+217.7	+36.52	+164.3	+260.58
Wash	+139.8	+89.4	+54.4	+7.86	+45.7	+65.48
Rinse 1	+139.8	+105.4	+79.8	+7.37	+72.2	+87.66
Rinse 2	+139.8	+88.0	+96.2	+8.06	+87.7	+107.60

3.5.3 Shower

Human input in the shower caused a reduction in ORP in wastewater as shown in Table 16. The ORP readings for the shower were very erratic and to obtain correlating data proved difficult due to the ORP probe sensitivity to water temperature. This is partly because in warmer water the ORP values can change the baseline significantly.

Comparison of the ORP for tap water with products (with personal care products, but without human input) and for wastewater indicates that personal care products reduced the ORP to negative values. However, the ORP reduction was less severe with the human input.

Similar trends were observed for both the kitchen and bathroom sinks, with products alone reducing the ORP by -50.5 mV and -21.1 mV (Table 13). The ORP increase for the respective sinks with human input were +53 and +55mV compared to product alone (Table 13).

Change in ORP throughout each wash, measured continuously as the wastewater was discharged showed poor reproducibility due to the changing dilutions and range of products used in the shower.

Table 16: ORP during shower

Shower ORP (mV)									
			Wastewater (male)						
Time(min)	***Water mean***	***Water + product mean***	***Wash 1***	***Wash 2***	***Wash 3***	***Wash 4***	***Wash 5***	***Mean***	***SD***
0	+139.8	-27.1	+11.2	+54.6	+82.7	+127.7	+96.1	+74.5	44.07
1	+139.8	+1.8	+20.6	+64.6	+91.3	+128.6	+91.8	+79.4	39.98
2	+139.8	-13.2	+21.8	+57.1	+76.6	+123.7	+85.4	+72.9	37.45
3	+139.8	-45.5	+4.9	+49.9	+58.6	+100.7	+67.0	+56.2	34.55
4	+139.8	-50.4	+9.2	+58.9	+60.4	+91.7	+65.8	+57.2	29.92

3.6 Colour

The colour of the wastewater discharged by each appliance was measured for all appliances. For the dishwasher, the washing machine and the shower colour was measured for each stage of the appliance's operation. For the kitchen sink and the vanity unity colour was determined using composite samples. And for the toilet block the colour of the composite from the total daily wastewater discharged was evaluated.

Colour in tap water was 6.33 PCU, whilst wastewater streams displayed a much stronger colour.

3.6.1 Washing machine

Figure 12 shows the colour results for a single wash in the washing machine. The dirty laundry increased the colour to 240 PCU in the wash, 180 PCU in rinse one, 67 PCU in rinse two and 32 PCU in rinse three. The colour of the composite sample for the wash was 130 PCU.

In comparison, the blank which had detergent alone resulted in maximum colour of 28 PCU in the wash stage, and 13, 11 and 15 PCU in the rinse stages. The blank was comprised of white clean sheets, whilst the field house washing loads contained washing of all colours, contributing to bleeding of colour, lint and other dirt residues removed during the wash.

The wastewater also exhibited a higher standard deviation in the colour readings, which are shown as error bars in the graph.

As seen in Figure 12, dirty and coloured clothing was the major contributor to colour in the washing machine grey water. Tap water and detergent alone had a minimal impact on colour formation by comparison.

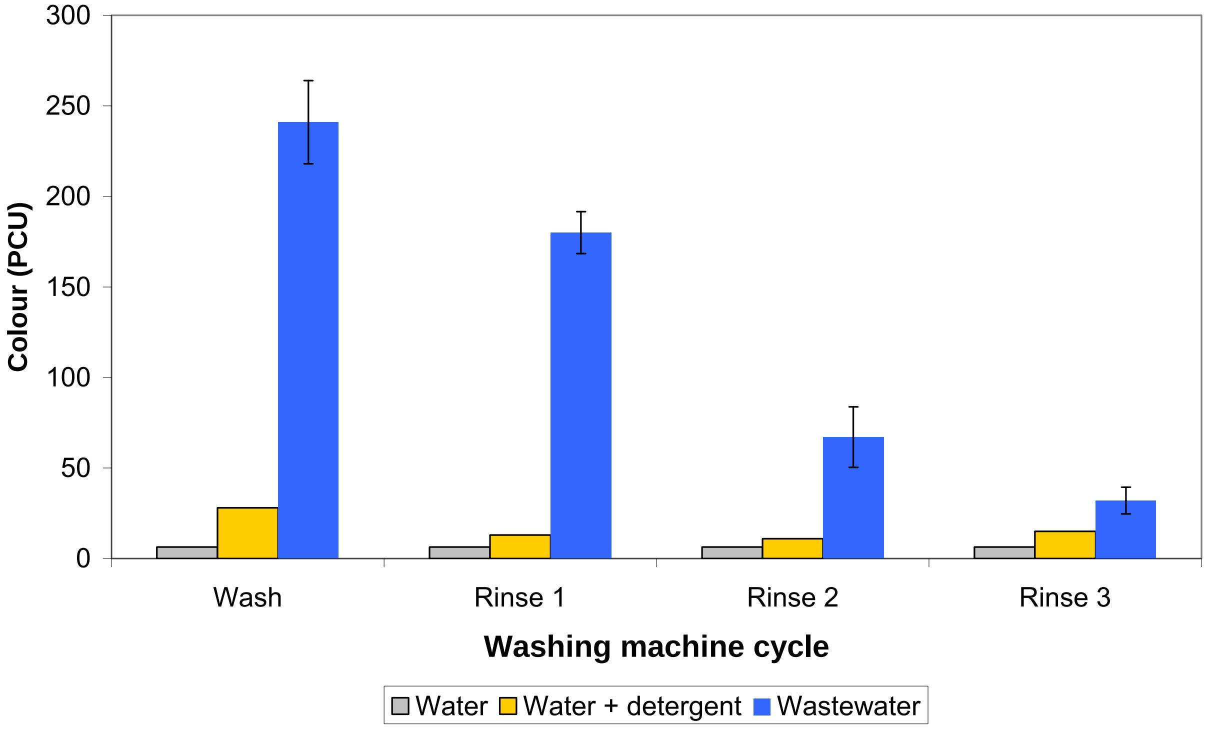


Figure 12: Colour development during washing machine operation

3.6.2 Dishwasher

The evolution of colour in wastewater released by the dishwasher is shown in Figure 13.

Table 17 shows the colour measurements from five separate washes. Some of the samples could not be analysed as they could not be filtered using a 0.45μm membrane due to clogging and blockage of the filter, these are marked “nf” in the table.

Colour was more intense in the wash stage, followed by the pre-rinse, rinse one and rinse two. The mean colour intensity for these respective stages was 45 PCU, 24 PCU, 17 PCU and 8 PCU. The variability expressed as the standard deviation and shown as error bars was also larger during the wash stage, as seen in the high standard deviation of 35.4 PCU attributed to when the food residues and detergent were washed away.

Both food scraps and detergent contributed to the colour change observed. In the absence of food scraps, detergent produced a colour increase of 7 PCU, 13.4 PCU, 10.7 PCU and 7.4 PCU to tap water in each of the dishwasher cycles and the composite. Whilst with the addition of food, the additional increase in colour was approximately 10 PCU and 25 PCU in the pre-rinse and wash stages over the water and detergent mix, but no significant change was seen in the rinse stages.

The composite samples from the two dishwashing cycles with food had colour readings of 20 PCU and 30 PCU. Whilst in the absence of food and with detergent only colour was 17 PCU.

This shows that dilution can have a marked effect on the final colour in wastewater.

The presence of solids and the range of food residues that remain in the dishes have a major impact on turbidity and colour of the wastewater and can change significantly form one day to another. For instance, the food residues from a salad and residues from spaghetti Bolognese impact wastewater colour differently.

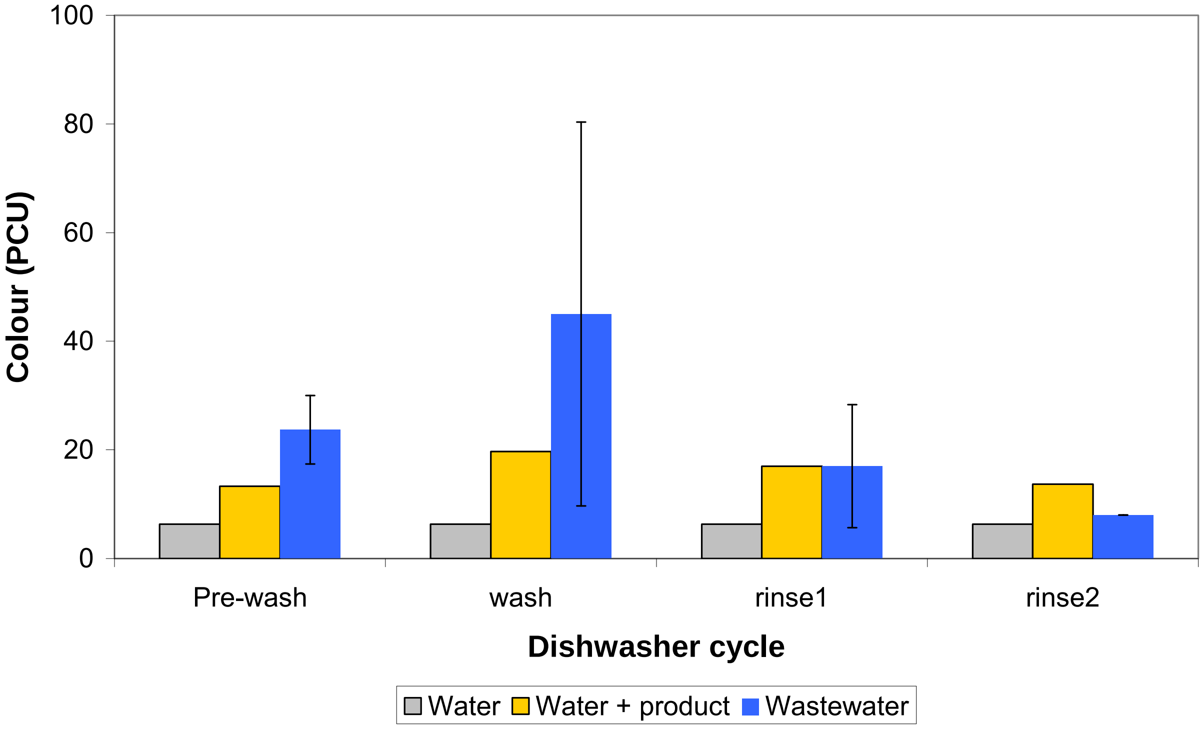


Figure 13: Colour development during dishwasher operation

Table 17: Results from 5 separate washes.

	Colour (PCU)								
			Wastewater						
Dishwasher cycle	**Water mean**	**Water + Product mean**	**Wash 1**	**Wash 2**	**Wash 3**	**Wash 4**	**Wash 5**	**Mean**	**SD**
Prerinse	6.33	13.3	25	30	25	nf	15	23.7	6.30
Wash	6.33	19.7	20	70	nf	nf	nf	45	35.35
Rinse 1	6.33	17	9	25	nf	nf	nf	17	11.31
Rinse 2	6.33	13.7	nf	8	nf	nf	8	8	0
Composite	6.33	17.3	30	nf	nf	20	nf	nf	

Note: nf – sample could not be filtered.

3.6.3 Shower

The second strongest colour and the greatest variability observed in the study were in wastewater from the shower. The colour results are shown in Table 18. During the shower colour ranged from 6 to 404 PCU. In addition the standard deviation varied from 14 to 137 PCU.

Colour development during the shower of a male volunteer is shown in Figure 14. The shower lasted on average 4-5 minutes, but the sampling period was longer as wastewater left in the shower cubicle funnelled into drain and continued to run through the sewer pipe.

Colour was more intense 2 to 3 minutes into the shower after application of shampoo and conditioner and decreased as the volunteer rinsed off.

The volunteer used body wash, shampoo and conditioner in that sequence during his shower. Each of these products produces lather and foam.

The wastewater composite for the shower run had a mean colouration of 199.6 PCU, but a high standard deviation of ±104 PCU. In comparison an earlier Melbourne study had reported 60 to 100 PCU for bathroom wastewater (Christova-Boal *et al* 1996)

Colour generated when a volunteer was using the shower and when products were only dissolved in the shower by a scientist produced some differences in the timing of residues discharged into wastewater and hence it was not used for comparison on a time series basis.

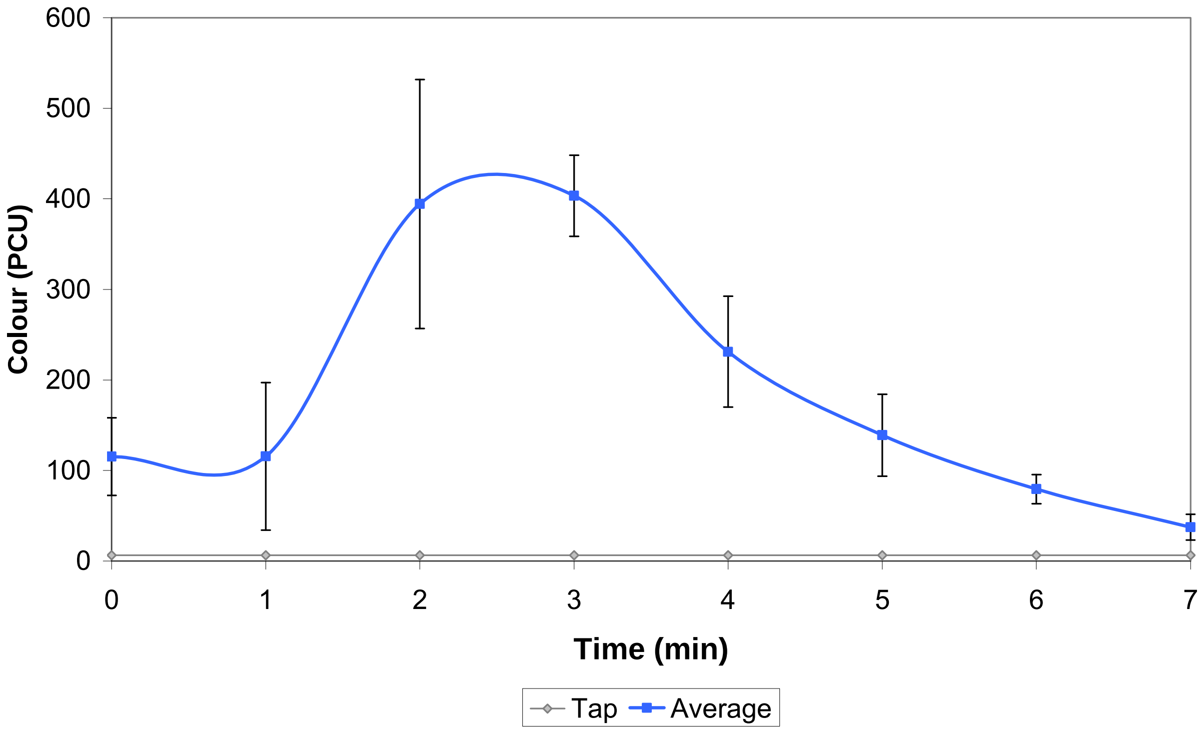


Figure 14: Colour development during shower

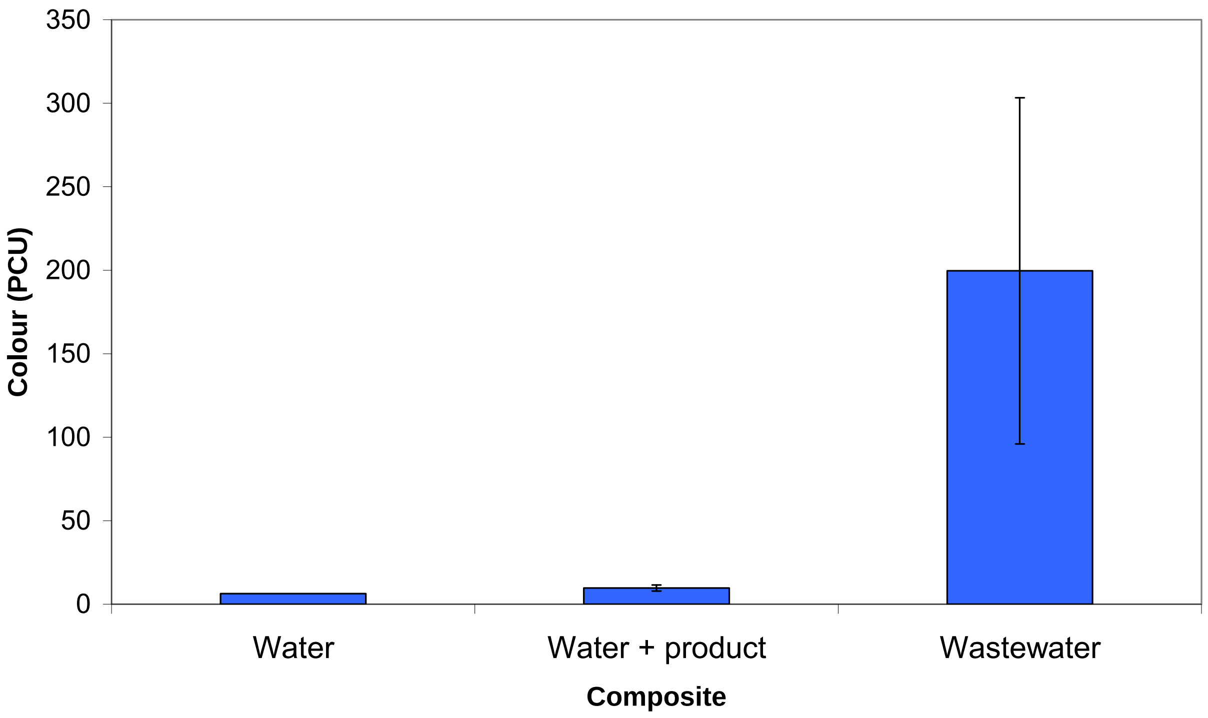


Figure 15: Colour in composite samples from the shower.

Table 18: Colour development during shower for male volunteer

Shower(PCU)	***Water***	***Wastewater***	
Time (min)	**Mean**	**Mean**	**SD**
0	6.3	115.2	42.9
1	6.3	115.6	81.5
2	6.3	394.4	137.5
3	6.3	403.5	44.8
4	6.3	231.2	61.3
5	6.3	138.9	45.2
6	6.3	79.4	16.1
7	6.3	37.2	14.2
Composite	6.3	199.6	103.7

3.6.4 Kitchen sink

Water and detergent alone increased the colour of the wastewater to 18 PCU, which is equivalent to 3.7 times the original colour of tap water. Furthermore, with the addition of food residues from the dirty dishes the final colour was equivalent to 115 times the original water colour.

As shown in Table 19, the grey water from the kitchen sink ranged in colour from 349 to 1110 PCU. The mean for five washes was 727 PCU, however the readings were subject to high variance given the standard deviation of ± 319 PCU. This was equivalent to 44% of the mean reading. The high variance can be attributed to variability in the amount and composition of the food residues left on the dirty dishes from one day to another. This was also evidenced in the tint of the wastewater which ranged from yellow, red to grey on different days. In addition, food residues also increased the turbidity of the wastewater which can affect the colour reading.

The increase in colour from tap water to grey water was +12 PCU with the addition of product alone, and +720.7 PCU with the addition of product and dirty dishes to tap water (Table 19).

Thus food residues were the main contributor to colour in wastewater from the kitchen sink.

3.6.5 Vanity unit

Colour changes in wastewater from the vanity unit were also evaluated for five washes. The grey water collected as a composite ranged from 103 to 291 PCU in colour, with a mean of 158 PCU. The standard deviation was also high at 76PCU it was equivalent to 48.3% of the mean value. It was verified that a significant amount of foam and turbidity was generated in the grey water after the volunteer had brushed his teeth and gargled into the vanity unit.

Dissolution of the products in the tap water alone had only increased the colour to 19 PCU.

Overall, human influence produced the largest change in colour in the vanity unit – the grey water showed an increase of +139 PCU in the vanity unit, but data was also subject to high variance (46 % of the mean).

Table 19: Colour in grey water from the kitchen sink and vanity unity

Colour (PCU)	***Water mean***	***Water + product mean***	***Wastewater***			
			Mean	**SD**	**Min**	**Max**
Kitchen Sink	6.3	18.3	727	319	349	1110
Vanity Unit	6.3	19	158	76	103	291

3.6.6 Toilet block

Wastewater from the toilet block was monitored for 12 days. The colour ranged from 122 to 310 PCU. The mean was 192.5 PCU and the standard deviation ± 62.7 PCU. The variability in the data is shown in Figure 16. The wastewater generally had a yellow tint.

In comparison, the colour of tap water in the building was 6.3 PCU.

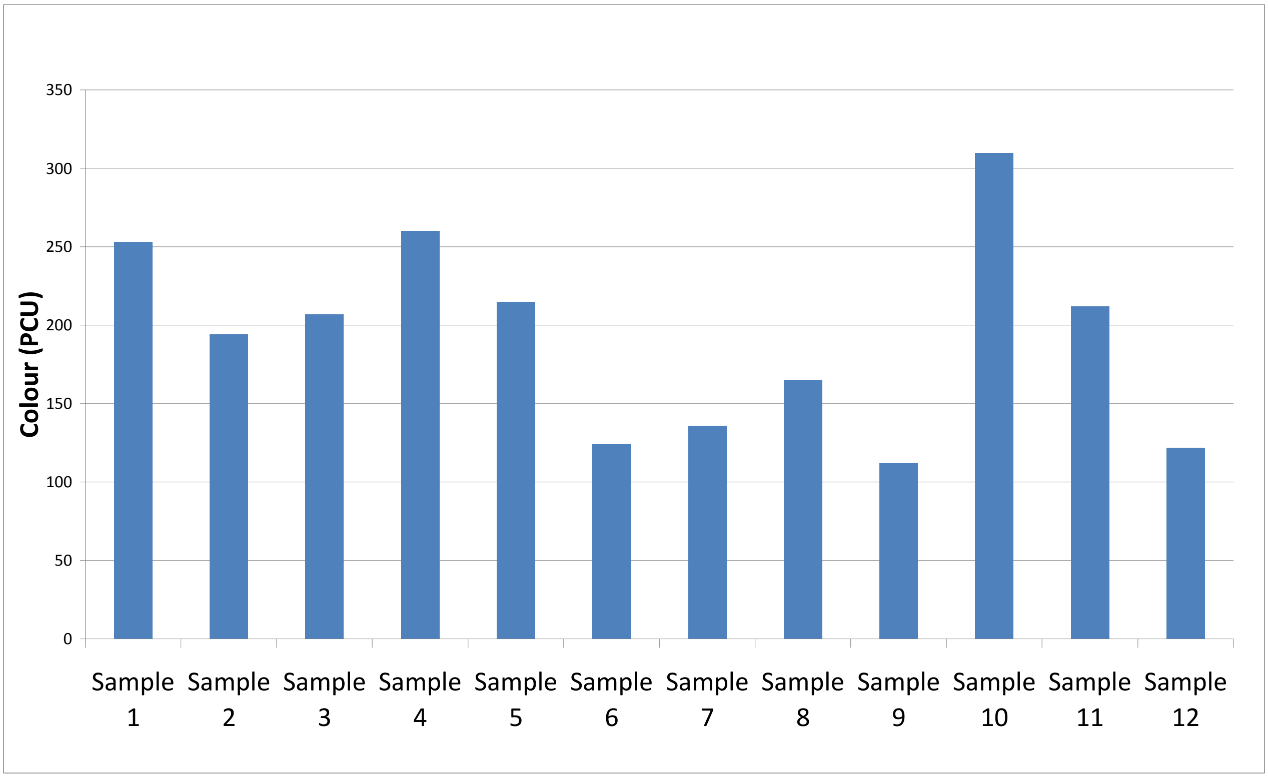


Figure 16: Colour in wastewater from a toilet block recorded during December 2008.

3.6.7 Discussion

The colour of wastewater in the field house varied across the different appliances. Appliances which operate in cycles such as the washing machine and the dishwasher were characterised by a stronger colouration in one of the initial cycles, followed by colour attenuation as the dirt and products residues were dissolved and removed in subsequent cycles.

The shower which operates continuously was more difficult to monitor and was also subject to the highest variance in regards to colour. This was partly caused by the unpredictability in volunteer behaviour during the shower.

Previous analysis of a range of household products at their typical dilution had established that the colour generated by household products could vary significantly with the type and brand of household product adopted (Tjandraatmadja *et al* 2008). For example, colour from certain dishwashing products and shower products could result in wastewater with up to 200 PCU and 500 PCU respectively.

However, for the majority of the appliances in the field house, the strongest contribution to colour in wastewater was caused by human input. This was observed for example in the colour from the washing machine, the kitchen waste streams, the toilet and the vanity.

Human intervention was evidenced not only in the addition of food, dirt and human residues to wastewater as in the case of the kitchen sink, toilet and the laundry, but it also altered the timing of the grey water discharged as in the case of the shower through lathering of the shower products.

The presence of food residues and other particulate matter also exerts significant influence on the results obtained using the standard Platinum cobalt test. This standard test method is based on the measurement of light transmission and comparison with a yellow standard. It was originally designed to evaluate the colour of natural waters. Samples with residues or compounds that display a strong coloration of a different hue than yellow, for instance, some detergents, shampoo and hair conditioners, would still be analysed based on the yellow standards. However, the method does not as effectively capture colour variation of a different hue.

Turbidity also affects the readings. Filtration is typically used to reduce turbidity and eliminate the interference of particulate matter, but the high solids content of some of the kitchen wastewater samples complicated the analysis, as in the case of the dishwasher. In addition, some of the samples still showed signs of turbidity after the filtration, for instance the washing machine samples. The presence of turbidity increases the absorption of the sample. This would explain the high readings colour observed for the shower, laundry and kitchen wastewater streams.

3.7 TDS

The total dissolved solids (TDS) concentration in wastewater discharged by each of the appliances was determined. The summary of results is shown in Figure 17 and in Table 20. The graph shows the concentration of TDS in tap water, in water mixed with product and in wastewater for most appliances. The TDS in black water was determined for the combined stream only and not evaluated in the absence of human waste.

The concentration of TDS in the field house can be ranked as follows:

DW>VU>BW>WM>KS>SH

The lowest TDS concentration, 73 mg/L, was in the wastewater from the shower, which was only 16.7% higher than the TDS of tap water. The dishwasher, the vanity unit, the toilet wastewater and the washing machine had the four highest TDS concentrations at 998 mg/L, 734 mg/L, 597 mg/L and 406 mg/L.

The standard deviation, shown as error bars in the graph, was the largest for the vanity unit at ±192mg/L. Such high variability is attributed to variation in the amount and the combination of products used by the volunteer on each wash.

The ranking of appliances based on TDS concentration differs from the ranking based on EC. The EC ranking was BW>DW>WM>KS>VU>SH, as described in section 3.4. Thus, this reinforces that although EC is often used for the estimation of TDS, a number of the compounds that contribute to TDS are not major contributors to EC. A typical example is the vanity unit, the grey water from which contains residues from toothpaste, mouthwash and soap. Toothpaste residues include a range of inorganic compounds which contribute to TDS but not to EC.

Figure 17 shows a marked increase in the TDS concentration for the washing machine, the dishwasher and the vanity unit waste streams with the addition of products to the wash. This indicates that products are the main source of TDS in the wastewater generated by the washing machine, dishwasher and vanity unit.

On the other hand, human inputs were the dominant source of TDS in the toilet and the kitchen sink. In the shower addition of products and human input had a negligible impact on TDS, instead for this appliance the water supply was the dominant source of TDS (Figure 19).

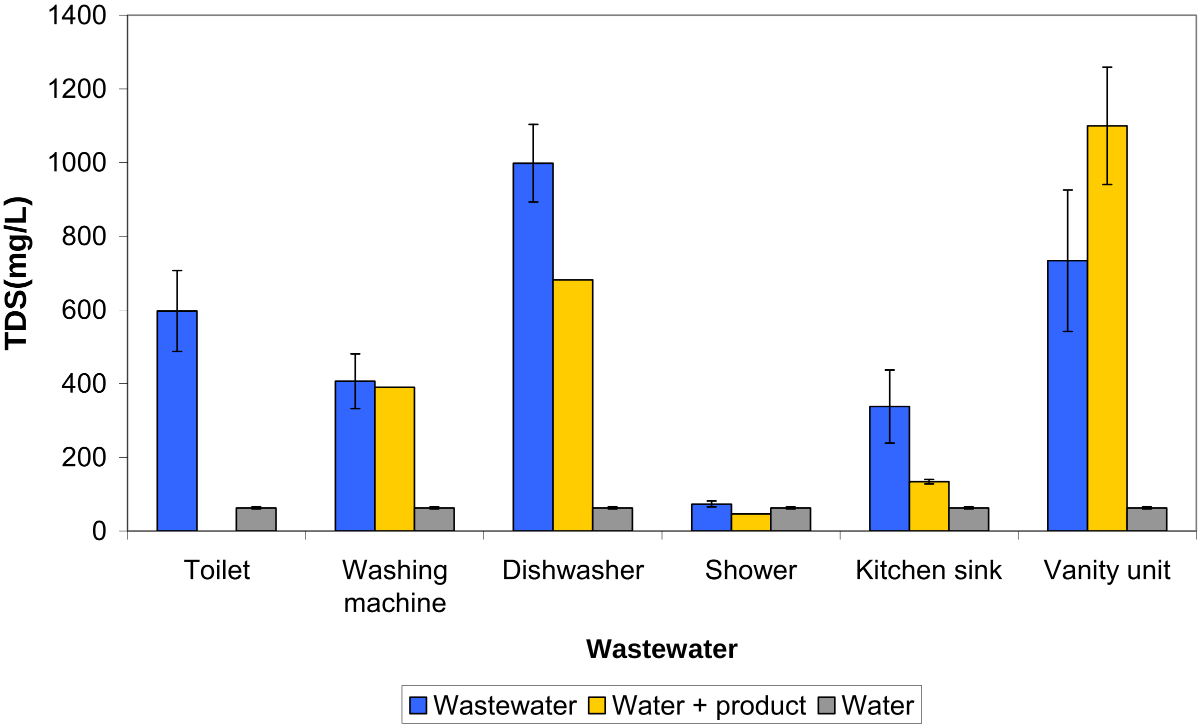


Figure 17: TDS of wastewater streams in field house.

Table 20: Summary of TDS in wastewater from field house

Source	***TDS (mg/L)***						
	Water mean	***Water + product mean***	***Wastewater***				
			Mean	***SD***	***Max***	***Min***	***Mean weekly load (% total load)***
Kitchen sink	62.9	134	338	99	470	140	7.43
Washing machine	62.9	390	406	71	520	330	49.57
Vanity Unit	62.9	1100	734	192	1000	550	5.34
Dishwasher	62.9	682	998	105	1200	910	7.31
Shower	62.9	46	73	8	87	67	3.44
Toilet block	67.0	na	597	110	758	403	26.91
SD (water)	9.8						

The estimated weekly mass loads for each appliance are shown in Figure 18. The figure shows the incremental mean loads as products and human input are added to the water streams. The 95% upper and lower confidence limits for each of the wastewater streams are shown as error bars. As indicated by the bars there is significant variance in the weekly wastewater loads.

The contribution from each appliance to the weekly mass load is ranked as:

WM>TO>KS≈DW>VU>SH

As shown in Figure 18, the washing machine was the main TDS contributor to the field house, generating 49.6 % of the weekly TDS load. The toilet was the second largest source contributing 26.9 %.

The kitchen sink and the dishwasher provide similar contributions of approximately 7.4 % of the weekly load each.

The bathroom, represented by the vanity unit and the shower had the least impact on the TDS load with each of he last two appliances contributing only to 5.3 % and 3.4 % respectively.

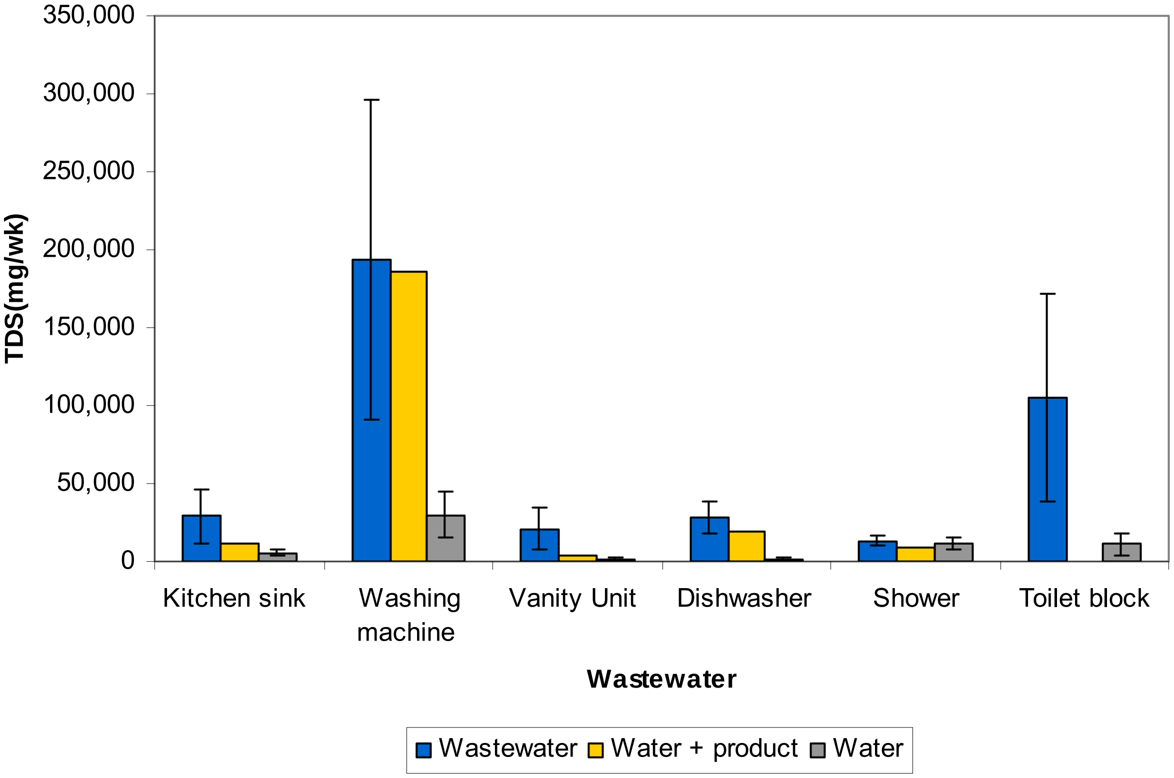


Figure 18: TDS loads in field house wastewater streams.

Overall, tap water was a minor source of TDS to the field house as it contributed to only 15.8 % of the total weekly load of field house load as shown in Figure 19. The remainder 84.2 % was caused by the combination of products and human input, but products were the dominant source as shown in Figure 20.

In the black water stream, the combined input of products and human excreta contributed to 23.1% of the total TDS load. Whilst, in the grey water stream, products and human input discharged accounted for 46.7 % and 14.5 % of the TDS load, respectively. Hence, significant reduction of TDS can be achieved by controlling the products used in a household.

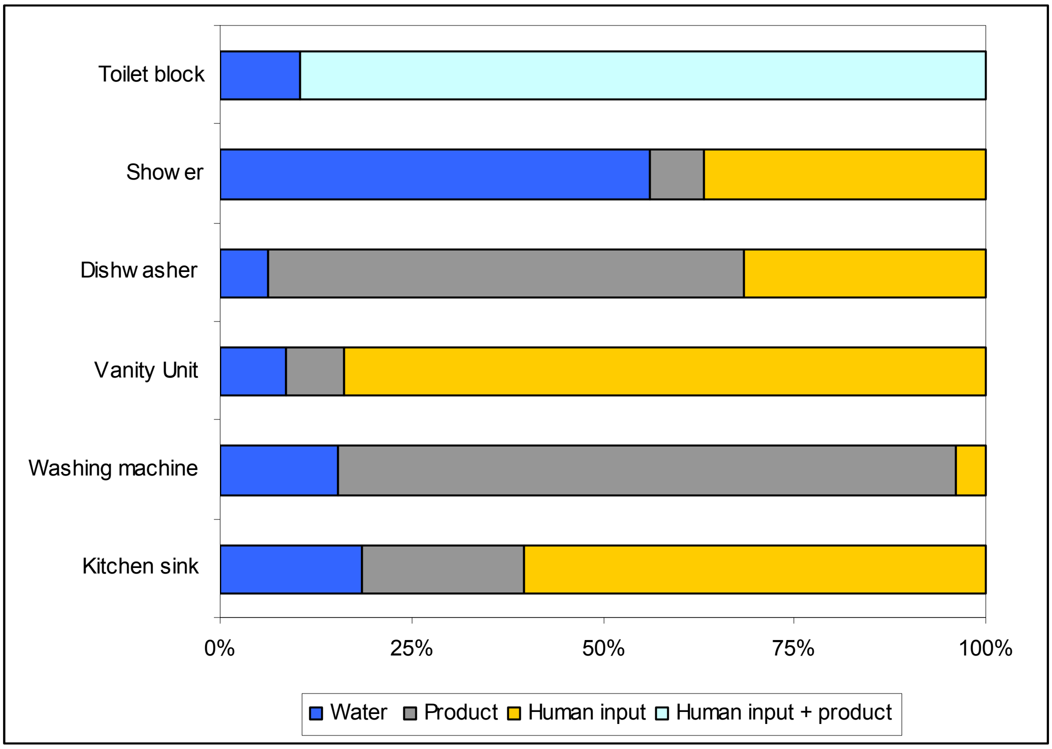


Figure 19: TDS contribution per source for each appliance.

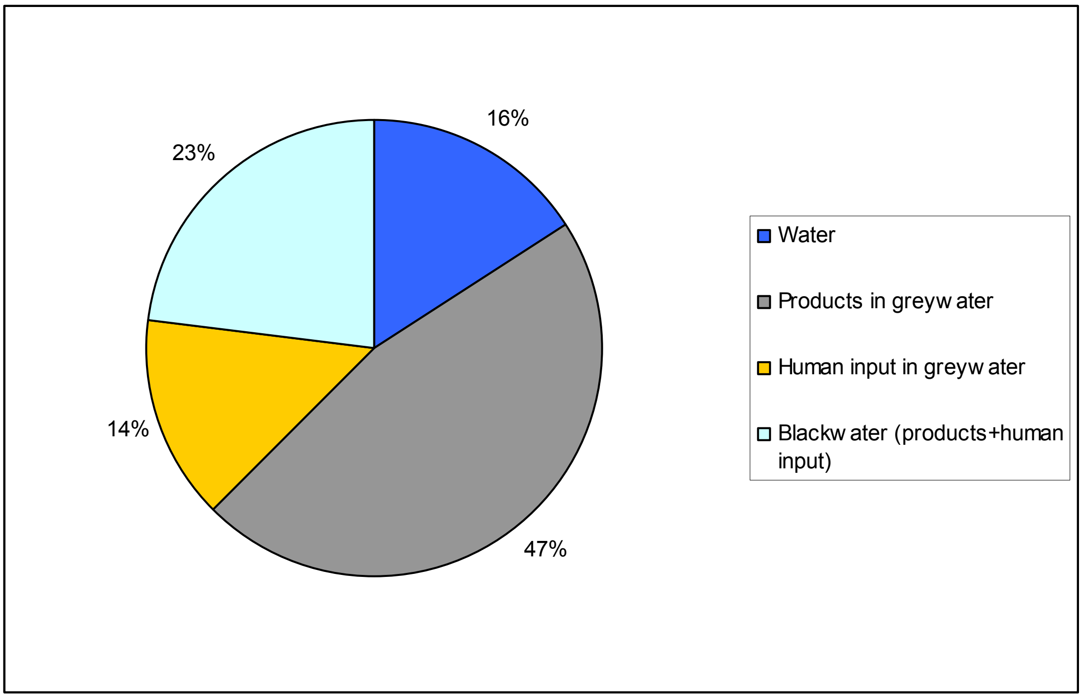


Figure 20: Sources of TDS in the field house.

3.8 Contaminant loads in wastewater

3.8.1 Tap water

The elemental characteristics of tap water supplied to the field house experiments in this study were analysed and are shown in Table 21.

Variation in water quality from building 42 which houses the toilet block and building 26 which houses the field house at the CSIRO site was observed. Testing of two groups of appliances: (i) dishwasher and washing machine, and (ii) shower, vanity unit and kitchen, was conducted during different time periods in the year. Although the field house appliances were supplied by a same water main in the same building, the elemental composition of the tap water supplied to the field house varied during the experimental period. This is attributed to the combined effect of infrastructure, residence time within the site and variability in water mains supply.

The water supply was designated as:

(a) Tap 1: the water supplied to the dishwasher and washing machine located in the mini-house;

(b) Tap 2 : the water supplied to the shower, kitchen sink and vanity unit located in the mini-house; and

(c) Tap 3: the water supplied to the toilet which was located in a different building from the mini-house.

Before each run at the mini-house and at the toilet, the water mains and toilet cistern were flushed with running water to remove any residues which may have accumulated in the pipes overnight.

Tap 1 and Tap 2 refer to the water quality characteristic of the time periods in which of testing of the washing machine and the dishwasher and of the remainder appliances (shower, vanity unit and sinks) were conducted.

The major differences in concentrations observed were:

(a) Al was present at a higher concentration in Tap 1. The expected concentration range based on 95 % confidence limits was 0.11 to 0.39 mg/L, which was higher than the range for Tap 2 and 3. The standard deviation for Tap 1 was also the highest among the three.

(b) Sb was below the limit of detection in Taps 2 and 3 and at the limit of detection in Tap 1;

(c) Ca was lowest in Tap 3;

(d) Cl was around 7 mg/L for Tap 1 and 2, but lower at Tap 3 at 4.5 mg/L;

(e) Cu was consistent across the sites given the standard deviation of the data;

(f) F was below the limit of detection in Tap 3;

(g) K differed markedly across the three sources;

(h) Mg was significantly higher at Tap 2 (t-test = -8.9);

(i) Na was significantly lower at Tap 3 (4.75±0.28mg/L) and within a similar range for Tap 1 and 2 (≈ 9 mg/L);

(j) Pb was markedly higher at 0.5 mg/L at Tap 1, below detection at Tap 2 and at Tap 3 it was either at or below the detection limit. The higher concentration in Tap 1 was also reflected in the quality of wastewater discharged by the washing machine and the dishwasher.

(k) S: was the highest at Tap 1 (1.3mg/L), Tap 2 and 3 had a concentration of approximately 0.83mg/L.

(l) Zn: high variability was observed in the standard deviation values.

(m) TKN was consistent across the site, being either at or below the limit of detection.

(n) TP was either at or below the limit of detection.

(o) TDS was consistent across the site with a mean of 66.3mg/L.

Table 21: Mains water quality during experiments

		Concentration in water			***Standard Deviation***		
Element	***Units***	***Tap 1***	***Tap 2***	***Tap 3***	***Tap 1***	***Tap 2***	***Tap 3***
Al	mg/L	0.25	0.04	0.01	0.0706	0.0085	0.0350
As	μg/L	<5	<5	<4	na	na	na
B	mg/L	<0.02	<0.02	0.03	na	na	0.0184
Ca	mg/L	7.65	7.07	5.03	0.8919	0.3702	0.3974
Cd	mg/L	<0.001	<0.001	<0.0001	na	na	na
Co	mg/L	<0.005	<0.005	<0.01	na	na	na
Cr	mg/L	<0.005	<0.005	<0.002	na	na	na
Cu	mg/L	0.22	0.11	0.11	0.0714	0.1051	0.0321
Fe	mg/L	0.06	0.11	0.10	0.0209	0.0736	0.0000
Hg	μg/L	<2	<2	<2	na	na	na
K	mg/L	3.15	<0.01	0.77	0.0131	0.0000	0.1889
Mg	mg/L	1.09	2.64	1.39	0.0757	0.6802	0.0568
Mn	mg/L	<0.0002	<0.0002	<0.1	na	na	na
Mo	mg/L	<0.005	<0.005	<0.001	na	na	na
Na	mg/L	8.34	9.25	4.75	0.5524	0.0828	0.2759
Ni	mg/L	<0.01	<0.003	<0.003	na	na	na
Pb	mg/L	0.50	<0.01	0.002	0.0052	0.0000	0.0015
S	mg/L	1.34	0.79	0.84	0.1836	0.0373	0.0516
Sb	μg/L	2.50	<2	<0.5	1.3663	na	na
Se	μg/L	<5	<5	<4	na	na	na
Sn	mg/L	<0.01	<0.01	<0.2	0	0	0
Zn	mg/L	0.066	0.002	0.013	0.0963	0.0063	0.0048
F	mg/L	0.817	0.817	<0.1	0.0354	0.00	0
Cl	mg/L	7	7	4.5	na	0.0354	0.5477
TKN	mg/L	0.01	0.01	0.01	na	na	na
TDS	mg/L	62.8	69	67	9.8	8.5	na
TP	mg/L	<0.05	<0.05	0.05	0	0	0.1080
Number of samples		6	9	10			

3.9 Concentration of priority contaminants in wastewater streams

The concentrations of priority contaminants were measured in the wastewater from the field house for the washing machine (WM), dishwasher(DW), shower (SH), kitchen sink (KS), vanity unit (VU) and toilet block (TO).

The elements analysed included aluminium, antimony, arsenic, boron, calcium, cadmium, chloride, cobalt, chromium, copper, iron, fluoride, lead, mercury, potassium, magnesium, manganese, molybdenum, nitrogen (as TKN), sodium, nickel, phosphorus, sulphur, selenium, tin and zinc.

The mean concentrations of priority elements in the wastewater streams from the field house are compared in sections 3.9.1 to 3.9.26 to values reported in the literature. Given the scarcity of data on individual streams in the literature, the values reported in this study and the literature may not necessarily refer to the same source appliance but instead refer to the same location within a household. The conditions of sample collection for the literature studies are not evaluated in this section.

The quality of tap water corresponding to the time of sample collection is also included as a reference in the tables to indicate the baseline for each reading of the field house. Tap 1, Tap 2 and Tap 3 are respectively the tap water used for the washing machine and dishwasher; shower, kitchen sink and vanity unit; and the toilet. The standard deviations of tap 1, 2 and 3 are shown in Table 54 in the Appendix.

3.9.1 Aluminium

The mean concentration of Al in the wastewater streams from each of the appliances from the field house is compared in Table 22 to values reported in the literature.

Within the household the concentration decreased in the following order:

WM>SH>DW=VU>KS>TO

The washing machine had a much higher concentration, 1.91±0.40 mg/L, than the other streams. This was equivalent to 5.1 times the second highest concentration, the shower's at 0.37± 0.07mg/L.

The concentrations from the washing machine and the shower are within the same ranges detected by Christova-Boal *et al* in their 1996 Melbourne study (Christova- Boal *et al* 1996). Swedish studies (Palmquist and Hanaeus 2005 and Hargelius *et al* 1995) reported much higher values for kitchen wastewater and black water.

Mains water supplied to the toilet block had the lowest Al concentration.

Table 22: Concentration of Al in field house wastewater

Reference	**Units**	***Concentration in wastewater (SD)***						
		Washing Machine	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	1.91 (0.40)	0.27 (0.05)	0.37 (0.07)	0.09 (0.017)	0.27 (0.11)	0.08 (0.019)	0.25 (1) 0.039 (2) 0.01(3)
Palmquist and Hanaeus 2005	mg/L						0.54	
Christova Boal *et al 1996*	mg/L	Laundry <1 - 21		Bathroom <1				
Hargelius *et al* 1995	mg/L				Kitchen 0.67- 1.8			

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink , shower and vanity unit, and Tap(3) supplied the toilet block.

3.9.2 Antimony

The mean concentration of Sb in the wastewater streams from each of the appliances in the field house is compared in Table 23 to the literature (Palmquist and Hanaeus 2005). The concentrations in the waste streams were near to or below the detection limit both in this study and in the literature.

Within the household the concentration decreased in the following order:

WM>DW>SH (VU=KS=TO<LOD)

The washing machine and the dishwasher had the highest concentrations, 3.40±1.72 μg/L and 3.0 ± 1.2 μg/L, respectively. Although this corresponds to an increase of 0.5 to 0.9 μg/L given the initial Sb concentration of the tap water, the variability in the data from one day to another was statistically significant.

The concentration of Sb for all other streams was below the detection limit. The only other reported Sb data was from a Swedish study which reported means of 0.26 μg/L (range 0.22 to 0.33 μg/L) in black water and the range of 0.28 to 0.68 μg/L for grey water (Palmquist and Hanaeus 2005).

Hence, the data shows that the Sb concentration is near the LOD in domestic wastewater.

Table 23: Concentration of Sb in field house wastewater

		Concentration in wastewater (SD)						
Reference	***Sb Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	μg/L	3.40 (1.72)	3 (1.21)	<2	<2 (0.11)	<2	<2	2.5(1) <2(2) <0.5 (3)
Palmquist and Hanaeus 2005	μg/L						0.26	

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink , shower and vanity unit, and Tap(3) supplied the toilet block.

3.9.3 Arsenic

The mean concentration of As in the wastewater streams from each of the appliances from the field house is compared in Table 22 to values reported in the literature.

The As concentration was below the limit of detection (<5 μg/L) in wastewater and tap water from the field house.

Other studies reported similar concentration ranges, with a maximum of 2.14 μg/L As for black water in a Swedish study (Palmquist and Hanaeus 2005) and within 1 to 7 μg/L As for laundry and bathroom grey water in the Melbourne study by Christova-Boal *et al* (1996).

These results also support the initial results from Lock (1994) and Hargelius *et al* (1995) for kitchen wastewater.

Table 24: Concentration of As in field house wastewater

	As	Concentration in wastewater (SD)						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	µg/L	<5	<5	<5	<5	<5	<4	<5 (1,2) <4 (3)
Palmquist and Hanaeus 2005	µg/L						2 range 1.83-2.14	
Hargelius *et al* 1995	µg/L		<38	<38 bath	Kitchen <38			
Lock 1994	mg/L			<1 bath room	<1 kitchen			
Christova Boal *et al* 2005	mg/L	0.001-0.007 laundry		0.001 bath room				

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink , shower and vanity unit, and Tap(3) supplied the toilet block.

3.9.4 Boron

The mean concentration of B in the wastewater streams from each of the appliances from the field house is compared in Table 25 to values reported in the literature for a 1996 Melbourne study (Christova-Boal *et al* 1996), which reported B concentrations ranging from less than 0.1 mg/L and 0.7 mg/L for bath and laundry grey water (Christova Boal *et al* 1996).

In this study, a lower detection limit was used and within the household, the concentration decreased in the following order:

TO>WM=DW=SH=VU=KS

The mean concentration in black water was 0.09± 0.08 mg/L B, whilst the concentrations for the other streams were below the limit of detection, 0.02 mg/L. B had also been detected in tap water from the toilet (Tap 3) at 0.03 mg/L during the monitoring period.

Table 25: Concentration of B in field house wastewater

	B	Concentration in wastewater (SD)						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	0.09 (0.08)	<0.02 (1, 2) 0.03 (3)
Christova-Boal *et al* 1996	mg/L	<0.1- <0.7 laundry		<0.1 bath				

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink , shower and vanity unit, and Tap(3) supplied the toilet block.

3.9.5 Calcium

The mean concentration of Ca in the wastewater streams from each of the appliances from the field house is compared to the literature in Table 26.

Within the household the concentration of Ca decreased in the following order:

VU>TO>DW>KS>SH=WM=TAP

The vanity unit had a much higher concentration, 83.6 ± 19.7 mg/L, than the other streams. This was equivalent to seven times the second highest concentration, the dishwasher's, 11.7 ± 3.6 mg/L. Most other wastewater streams had concentrations much more similar to tap water, whose means ranged from 5.03 ± 0.39 to 7.65 ± 0.89 mg/L. This was attributed to the toothpaste, which contains calcium compounds in its formulation.

The concentrations from the washing machine and the shower are within similar ranges detected by Christova-Boal and co-workers in their 1996 Melbourne study, respectively 3.9 to 12 mg/L and 3.5 to 7.9 mg/L for laundry and bathroom grey water (Christova-Boal *et al 1996*). The Ca concentrations for the kitchen sink and the black water are comparatively lower than those reported in the Swedish studies, (Palmquist and Hanaeus 2005 and Hargelius *et al* 1995).

Table 26: Concentration of Ca in field house wastewater

	Ca	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	7.17 (1.00)	11.73 (3.61)	7.68 (0.19)	8.73 (0.78)	83.59 (19.66)	15.46 (2.34)	7.65 $^{(1)}$ 7.07 $^{(2)}$ 5.03 $^{(3)}$
Palmquist and Hanaeus 2005	mg/L						68.6	
Christova Boal *et al 1996*	mg/L	Laundry 3.9-12		Bath room 3.5-7.9				
Hargelius *et al* 1995	mg/L				Kitchen 13-30			

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink , shower and vanity unit, and Tap(3) supplied the toilet block.

3.9.6 Cadmium

The mean concentration of Cd in the wastewater streams from each of the appliances in the field house and from tap water was below the limit of detection, 0.001 mg/L. These concentrations are in agreement with values reported in the literature in Table 27.

Earlier studies had suggested that Cd concentrations in household wastewater were likely to be less than 0.010 mg/L for kitchen (Siegrist *et al* 1976), bath/bathroom (Hargelius *et al.* 1995, Christova-Boal *et al.* 1996) and laundry grey water (Hargelius *et al.* 1995)

Some studies had also reported concentrations of less than 1μg/LCd. For example, concentrations of 0.63, 0.54 and 0.40 μg/L for laundry, bathroom appliances and black water had been previously reported (Christova-Boal *et al.* 1996, Surendran and Wheatley 1998, Palmquist and Hanaeus 2005).

The concentration of Cd in the field house wastewater has been confirmed to be less than 1μg/L.

Table 27: Concentration of Cd in field house wastewater

	Cd	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<1	<0.001 $^{(1, 2)}$ <1 $^{(3)}$
Hargelius *et al.* 1995	mg/L		<0.006	<0.006 bath	Kitchen <0.007			
Palmquist and Hanaeus 2005	mg/L						0.0004	
Siegrist *et al* 1976	mg/L	<0.01						
Christova Boal *et al.* 1996	mg/L	0.00063 laundry		<0.01 bath room				
Surendran and Wheatley 1998	mg/L			Shower/ bath 0.00054		0.00054		

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink , shower and vanity unit, and Tap(3) supplied the toilet block.

3.9.7 Chloride

The mean concentration of Cl in the wastewater streams from each of the appliances in the field house are compared in Table 28 to values reported in the literature.

Within the household the concentration decreased in the following order:

DW>TO>KS>VU>WM>SH>TAP

All streams had a higher Cl concentration than tap water.

The dishwasher had the highest concentration, 265 ± 10.5mg/L. This was equivalent to almost three times the second highest concentration, the toilet's, at 90 mg/L. However Cl in toilet wastewater varies markedly from day to day as seen in the standard deviation ±94.5 mg/L.

The washing machine and the shower were the appliances with the lowest Cl concentrations at 12 .7± 3.5 mg/L and 12.4 ± 1.5 mg/L.

The concentrations from the washing machine and the shower were within the range reported for laundry and bathroom grey water by Christova-Boal *et al* (1996).

Table 28: Concentration of Cl in field house wastewater

	Cl	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	12.7 (3.5)	265 (10.5)	12.4 (1.5)	65.4 (19.6)	18.6 (2.6)	90.3 (94.5)	7 $^{(1,2)}$ 4.5 $^{(3)}$
Christova Boal *et al.* 1996	mg/L	Laundry 9.0-88		Bath room 9-18				

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink , shower and vanity unit, and Tap(3) supplied the toilet block.

3.9.8 Cobalt

The mean concentration of Co in the wastewater streams and in tap water from the field house was below 5μg/L.In black water the concentration was 1.08±1.3 μg/L. These values are compared in Table 29 to values reported in the literature.

In Swedish studies, less than 0.9 μg/L and less than 13 μg/L had been reported for black water and kitchen wastewater (Palmquist and Hanaeus 2005 and Hargelius *et al* 1995).

Table 29: Concentration of Co in field house wastewater

	Co	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	μg/L	<5	<5	<5	<5	<5	1.08 (1.32)	<5(1, 2) 0.2 (3)
Palmquist and Hanaeus 2005	μg/L						0.86	
Hargelius *et al* 1995	μg/L				Kitchen <13			

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink , shower and vanity unit, and Tap(3) supplied the toilet block.

3.9.9 Chromium

The mean concentration of Cr in the wastewater streams and in tap water from the field house are compared in Table 30 to values reported in the literature.

Hargelius and co-workers had detected up to 0.13 mg/L Cr in kitchen grey water in Sweden (Hargelius *et al* 1995). Concentrations of 3 μg/L had been verified in tap water in Melbourne and in black water in Sweden (Wilkie *et al* 1997, Palmquist and Hanaeus 2005). But within the field house the concentrations were below the detection limit of 5 μg/L and 2 μg/L for grey water and black water respectively.

Table 30: Concentration of Cr in field house wastewater

	Cr	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	μg/L	<5	<5	<5	<5	<5	<2	<5 (1,2) <2 (3)
Wilkie *et al* 1997	μg/L							3.2
Palmquist and Hanaeus 2005	μg/L						3.09	
Hargelius *et al* 1995	μg/L				Kitchen <25-130			

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.10 Copper

The mean concentration of Cu in the wastewater streams from each of the appliances from the field house is compared in Table 31 to values reported in the literature.

Within the household the concentration decreased in the following order:

VU>DW>TO>KS>WM≈TAP≈SH

The vanity had the highest mean concentration, 1.39 ± 0.99 mg/L.. This was followed by the dishwasher, the toilet and the kitchen sink at 0.811 ± 0.19 mg/L, 0.471 ± 0.079 mg/L and 0.268 ± 0.110 mg/L, respectively.

The concentrations from the two appliances that consumed the most water, i.e. the washing machine and the shower, showed the least deviation from tap water. The mean concentrations in tap water varied from 0.1±0.1 mg/L to 0.22 ± 0.07 mg/L.

The concentrations reported for the field house were one order of magnitude higher than those reported in Swedish studies for the laundry and the dishwasher (Hargelius *et al* 1995), but for black water the field house concentration was four times higher (Palmquist and Hanaeus 2005).

Laundry and bathroom concentrations were also within the range reported in Melbourne by Christova-Boal and colleagues (Christova-Boal *et al.* 1996).

Table 31: Concentration of Cu in field house wastewater

	Cu	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	0.17 (0.087)	0.811 (0.19)	0.121 (0.18)	0.268 (0.110)	1.39 (0.99)	0.471 (0.079)	$0.22^{(1)}$ $0.109^{(2)}$ $0.105^{(3)}$
Palmquist and Hanaeus 2005	mg/L						0.126	
Hargelius *et al* 1995	mg/L	0.058 laundy	0.056 bath & dishwasher		Kitchen 0.068-0.26			
Christova Boal *et al.* 1996	mg/L	<0.05-0.27 laundry		Bath room 0.06-0.12				
Surendran and Wheatley 1998	mg/L	0.322 laundry		Shower/ bath wash 0.111				

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.11 Iron

The mean concentration of Fe in the wastewater streams from each of the appliances from the field house is compared in Table 32 to values reported in the literature.

Within the household the concentration decreased in the following order:

TO>VU>KS>DW>SH>WM

The toilet had a much higher concentration, 0.546 ± 0.117 mg/L, than the other streams. The other streams had concentrations much more similar to tap water. Yet the concentrations at the field house were all lower than those reported previously in the literature for laundry, bathroom, kitchen and black water (Christova-Boal *et al* 1996, Palmquist and Hanaeus 2005, Hargelius *et al* 1995). Concentrations in wastewater were also subject to significant variance as seen in the standard deviation values.

The concentration of Fe was too low overall to cause any discoloration in the wastewater.

Table 32: Concentration of Fe in field house wastewater

	Fe	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	0.09 (0.097)	0.121 (0.072)	0.110 (0.021)	0.146 (0.021)	0.19 (0.078)	0.546 (0.117)	0.060(1) 0.115(2) 0.1(3)
Christova-Boal *et al* 1996	mg/L	Laundry 80th percentile 1.2-4.2		Bath room 0.05-1.4				
Palmquist and Hanaeus 2005	mg/L						1.28	
Hargelius *et al* 1995	mg/L				Kitchen 0.6-1.2			

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.12 Fluoride

The mean concentration of F in the wastewater streams from each of the appliances from the field house is compared in Table 33 to the literature. Scarce data on F in grey water was found in the literature, the only reference was a range of 0.7 to 0.95mg/L for mixed grey water (Hypes 1974).

Within the field house the concentration decreased in the following order:

VU>WM≈DW>KS>SH>TO

The vanity unit had the highest mean concentration, 1.4 ± 0.2mg/L. This is most likely due to the use of toothpaste which contains fluoride. For the other streams, besides the increase in the washing machine and the dishwasher, the concentrations in the wastewater were very similar to tap water. For black water and its source tap water, the mean concentration of F was below the detection limit of 0.1mg/L.

Table 33: Concentration of F in field house wastewater

	F	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	0.995 (0.005)	0.992 (0.010)	0.76 (0.05)	0.844 (0.042)	1.4 (0.20)	<0.1 (0.08)	0.817(1,2) <0.1 (3)
Christova-Boal *et al* 1996	mg/L	Laundry 80th percentile 1.2-4.2		Bath room 0.05-1.4				

Hypes (1974)	mg/L	Grey water no garbage 0.7-0.95					1.28	

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.13 Lead

The mean concentration of Pb in the wastewater streams from each of the appliances from the field house is compared in Table 34 to values reported in the literature.

Within the household the concentration decreased in the following order:

DW>WM (Tap 1)

VU≈KS≈TAP≈SH≈TO (Tap 2 and 3)

The Pb concentration in the washing machine and the dishwasher was caused mainly by the Pb in tap water supplied to those two appliances (0.50±0.005mg/L). Whilst Pb in tap water used in the other appliances was less than 0.002±0.002 mg/L Pb.

Compared to the tap water, the mean concentration was only +0.06 mg/L higher for the dishwasher and +3.09 μg/L for black water. The mean Pb concentrations in grey water from the kitchen and the shower were at or below the detection limit of 0.01mg/L and the remainder wastewater streams showed concentration increases of +0.06mg/L, +0.02mg/L, +0mg/L for dishwasher, vanity unity and washing machine. However, as shown in the standard deviation there was significant variance in the readings for the waste streams and for tap water.

The concentrations from the washing machine and the shower are within the same ranges detected by Christova Boal *et al* (1996). Swedish studies (Palmquist and Hanaeus 2005 and Hargelius *et al* 1995) reported much higher values for kitchen wastewater and black water.

These results are comparable to those reported in the literature.

Table 34: Concentration of Pb in field house wastewater

	Pb	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	0.50 (0.008)	0.56 (0.037)	<0.01 (0)	0 (0.009)	0.03 (0.014)	0.0046 (0.8165)	0.50(1) <0.01(2) 0.0017(3)
Hargelius *et al* 1995	mg/L		<0.063 bath and dishwasher		Kitchen <0.062-0.14			
Christova-Boal 1996	mg/L	Laundry 70% readings <0.05		Bath room 75% <0.05				
Surendran and Wheatley 1998	mg/L	Laundry 0.033				0.003		
Palmquist and Hanaeus 2005	mg/L					0.00226		

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.14 Mercury

The concentration of Hg in the wastewater streams from each of the appliances from the field house and tap water were below the detection limit of 2 μg/L as seen in Table 35.

Overseas literature for household streams reported a similar magnitude of results, i.e. less than 0.3 μg/L and 0.7 μg/L for grey water and for black water, respectively (Hargelius *et al* 1995, Palmquist and Hanæus 2005).

Table 35: Concentration of Hg in field house wastewater

	Hg	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	μg/L	<2	<2	<2	<2	<2	<2	<2
Hargelius *et al* 1995	μg/L		Grey water <0.3		Kitchen <0.3			
Palmquist and Hanaeus 2005	μg/L						0.70	

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.15 Potassium

The mean concentration of K in the wastewater streams from each of the appliances from the field house is compared in

Table **36** to values reported in the literature.

Within the household the concentration decreased in the following order:

TO>DW>KS>WM>VU>SH>Tap

The toilet had a much higher mean concentration, 92.08 + 17.43 mg/L, than the other streams. This can be attributed to the potassium content in urine. The kitchen, through the dishwasher and kitchen sink, was the second largest source, followed by the vanity unit. Whilst K in the shower was below the limit of detection of 0.01mg/L.

Earlier grey water data had concentrations of similar order of magnitude for black water, laundry and kitchen grey water, but values reported in the literature for the bathroom stream were two orders of magnitude higher than those found in the field house.

Table 36: Concentration of K in field house wastewater

	K	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	5.80 (1.93)	13.23 (5.27)	<0.01 (0)	11.8 (7.96)	5.4 (2.92)	92.08 (17.43)	3.15 (1) <0.01 (2) 0.77 (3)
Palmquist and Hanaeus 2005	mg/L						75	
Christova-Boal 1996	mg/L	Laundry 1.1-1.7		Bath room 1.5-5.2				
Hargelius *et*	mg/L				Kitchen			

al 1995					19-59			

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.16 Magnesium

The mean concentration of Mg in the wastewater streams in each of the appliances from the field house is compared in Table 37 to values reported in the literature.

Within the household the concentration decreased in the following order:

TO>KS≈VU≈SH≈DW≈WM≈TAP

The toilet had a much higher mean concentration, 5.58±0.65 mg/L, than the other streams. This was equivalent to three times the concentration in tap water, 1.39±0.06mg/L. The grey water streams were very similar in concentration to tap water.

The grey water concentrations for the laundry, bathroom and kitchen were within the ranges reported in the literature in Melbourne and Swedish studies (Christova Boal *et al 1996,* Hargelius *et al* 1995). Whilst the concentration in black water was equivalent to 33% of that reported by Palmquist and Hanaeus (2005).

Table 37: Concentration of Mg in field house wastewater

	Mg	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	1.47 (0.25)	1.628 (0.246)	2.132 (0.060)	2.631 (0.408)	2.4 (0.4)	5.58 (0.65)	1.09 $^{(1)}$ 2.64 $^{(2)}$ 1.39$^{(3)}$
Palmquist and Hanaeus 2005	mg/L						17.0	
Christova-Boal 1996	mg/L	Laundry 1.1-2.9		Bath room 1.4-2.3				
Hargelius *et al* 1995	mg/L				Kitchen 3.3-7.3			

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.17 Manganese

The mean concentration of Mn in the wastewater streams from each of the appliances from the field house is compared in Table 38 to values reported in the literature. In the field house the concentration of Mn in all tap and wastewater streams did not exceed the detection limit of 0.0002mg/L and 0.1mg/L for the black water and Tap 3.

Similarly, Mn had been below the limit of detection of 0.02 mg/L in laundry grey water in an earlier Melbourne study (Christova-Boal *et al* 1996), although overseas studies had reported Mn concentrations in kitchen grey and black water of less than 0.075 mg/L an 0.130 mg/L respectively (Hargelius *et al* 1995 and Palmquist and Hanaeus 2005).

Overall, the Mn concentration in Melbourne was below the limit of detection compared to other localities. Hence it will not be explored any further in this study.

Table 38: Concentration of Mn in field house wastewater

	Mn	*Concentration in wastewater (SD)*						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.1	<0.0002 (1,2) <0.1(3)
Christova-Boal *et al* 1996	mg/L	<0.02						
Palmquist and Hanaeus 2005	mg/L						0.130	
Hargelius *et al* 1995	mg/L				Kitchen 0.031-0.075			

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.18 Molybdenum

The mean concentration of Mo in the wastewater streams from each of the appliances from the field house is shown in Table 39. No values for individual household streams have been found in the literature.

Within the field house the Mo concentration was below the limit of detection for all tap wastewater samples, with the exception of black water which had a concentration of 2.61±0.96 µg/L.

Table 39: Concentration of Mo in field house wastewater

	Mo	*Concentration in wastewater (SD)*						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block (µg/L)***	***Tap***
Field house	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	2.61 (0.96)	<0.005(1,2) <0.001(3)

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.19 Nitrogen (as TKN)

The mean concentration of TKN in the wastewater streams from each of the appliances from the field house is compared in Table 40 to values reported in the literature.

Tap water had on average 0.1mg/L TKN. The concentration of TKN in wastewater was much higher. Within the household the concentration decreased in the following order:

TO>DW>VU>KS>WM≈SH>Tap

The black water had the highest mean concentration, 276.7± 52.4mg/L. This was equivalent to approximately seventeen times the concentration from the dishwasher, 16.7±8.1mg/L and other appliances. Such results are expected given that urine is the major source of nitrogen in wastewater. The following largest concentrations were in wastewater from kitchen appliances, the dishwasher and kitchen sink, which contained food scraps.

The concentrations from the washing machine and the shower are within the order of magnitude detected by Christova-Boal *et al* (1996) for the laundry and the bathroom. The concentration in black water was 84% higher than reported in a Swedish study (Palmquist and Hanaeus 2005)

Table 40: Concentration of TKN in field house wastewater

	N	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	5.45 (2.06)	16.7 (8.14)	5.02 (1.17)	10.9 (6.2)	13.34 (2.79)	276.7 (52.4)	0.01$^{(1, 2, 3)}$
Palmquist and Hanaeus 2005	mg/L	Grey water 9.68					150 (130-180)	
Christova Boal *et al.* (1996	mg/L	Laundry <0.1-1.9		Bath room 4.6-20				

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.20 Sodium

The mean concentration of Na in the wastewater streams from each of the appliances from the field house is compared in Table 41 to values reported in the literature. The mean Na concentration in tap water ranged from 4.75± 0.27 to 9.25± 0.08mg/L, but in wastewater the concentration was much higher.

Within the household the concentration decreased in the following order:

DW>WM>TO>KS>VU>SH>tap

The values found in the field house are within the same range reported for grey and black water in the literature (Christova Boal *et al 1996,* Howard *et al* 2005*,* Palmquist and Hanaeus 2005), except for the dishwasher which had a Na concentration one order of magnitude higher than reported by Hargelius *et al* (1995).

The dishwasher, washing machine and toilet had mean concentrations of 261±8 mg/L, 117±23 mg/L and 87±20 mg/L. Concentrations for the kitchen sink, the vanity unit and the shower were 40±8 mg/L, 26±4 mg/L and 13.5±1 mg/L respectively.

Table 41: Concentration of Na in field house wastewater

	Na	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	116.6 (23.3)	260.6 (17.9)	13.47 (0.95)	40.10 (8.31)	26 (4.32)	87.23 (20.19)	8.34 $^{(1)}$ 9.25$^{(2)}$ 4.75$^{(3)}$
Hargelius *et al* 1995	mg/L		21	Bath and dish washer 21	Kitchen 29-180		150 (130-180)	
Christova Boal *et al.*	mg/L	49 – 480		Bath room				

1996				7.4 – 18				
Howard *et al* 2005	mg/L	178						
Palmquist and Hanaeus 2005	mg/L						97.7	

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.21 Nickel

The mean concentration of Ni in the wastewater streams from each of the appliances from the field house is compared in Table 42 to values reported in the literature.

Within the household the concentration decreased in the following order:

DW>WM

The dishwasher had a much higher concentration, 0.016 mg/L, than the other streams. The majority of the wastewater streams were below the limit of detection (0.003mg/L), except for the washing machine which had 0.0016 ± 0.0134 mg/L Ni.

The concentrations from the washing machine and the shower are within the same ranges detected in the Melbourne study by Christova-Boal *et al* (1996). Swedish studies (Palmquist and Hanaeus 2005 and Hargelius *et al* 1995) reported much higher values for black water.

Table 42: Concentration of Ni in field house wastewater

	Ni	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	0.0016 (0.0134)	0.032 (0.023)	<0.003 (0)	<0.003 (0)	<0.003 (0)	<0.003 (0)	<0.01 $^{(1)}$ <0.003 $^{(2, 3)}$
Christova Boal *et al*. 1996	mg/L	<0.02 Bathroom & laundry						
Hargelius *et al* 1995	mg/L	Laundry <0.028mg			Kitchen <0.025			
Palmquist and Hanaeus 2005	mg/L						0.0092	

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.22 Phosphorus

The mean concentration of TP in the wastewater streams from each of the appliances from the field house is compared in Table 43 to values reported in the literature.

Within the household the concentration decreased in the following order:

VU>TO>DW>KS>SH≈WM>Tap

The highest TP concentrations were for the vanity unit, toilet, dishwasher and kitchen sink at 64 ± 18.4 mg/L, 50.1± 2.2 mg/L, 12.2± 4.2 mg/L and 2.2±1.5 mg/L. The washing machine and the shower wastewater had on average less than 0.3 mg/L TP.

TP in the vanity unit is most likely due to toothpaste, which contained monofluorophosphate. In backwater phosphorus is excreted via urine and faeces. The washing machine which had the lowest concentrations of TP also used the largest volume of water among the appliances.

In the literature, TP concentrations in overseas grey water were reported to be higher; 21mg/L in the laundry in a UK study (Almeida *et al* 1999), 32 mg/L for the dishwasher (Siegrist *et al* 1976) and 15 to 26mg/L for the kitchen sink (Almeida *et al* 1999, Surendran & Wheatley 1998, Siegrist *et al*. 1976). A reduction of TP concentration in more recent detergent formulations could explain the difference, but confirmation would require further investigation.

However a similar range, 21 to 58mg/L, was observed for black water (Palmquist and Hanaeus 2005) and for the vanity unit Almeida had recorded only 13.3mg/L (Almeida *et al* 1999).

The concentration detected for the shower in the field house was within the bathroom range reported in a previous Melbourne study (Christova-Boal *et al* 1996 and Nolde 1999).

Table 43: Concentration of TP in field house wastewater

		Concentration in wastewater (SD)						
Reference	***P Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	0.22 (0.12)	12.18 (4.22)	0.26 (0.07)	2.2 (1.48)	64 (18.4)	50.06 (2.19)	<0.05 (1,2) 0.25(3)
Palmquist and Hanaeus 2005	mg/L	Grey water 7.5					42.7 (21-58)	
Almeida *et al* 1999	mg/L	21		19.2	26.0	13.3		
Christova Boal *et al*. 1996	mg/L			Bath room 0.11-5.8				
Nolde 1999	mg/L			Bath & shower 0.2-0.6				
Siegrist *et al*. 1976	mg/L		32	Shower/ bath 2	31			
Surendran & Wheatley 1998	mg/L				15.6			
Almeida and Buttler 1999	mg/L	23-200		1-2	10-74	49-50		

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.23 Sulphur

The mean concentration of S in the wastewater streams from each of the appliances from the field house is compared in Table 44 to values reported in the literature. Wastewater had a higher concentration of S than tap water. Tap water had less than 1.34mg/L S.

Within the household the mean concentration decreased in the following order;

TO≥VU≈KS≈SH≈WM≈DW

The toilet and the vanity unit had the two highest concentrations, 18.5± 3.5 mg/L and 14± 4.07 mg/L, respectively.

Previous studies had reported 35mg/L S, a higher concentration, in black water in Sweden; and also between 9.5 to 40mg/L and 1.2 to 3.3mg/L in laundry and bathroom grey water in Melbourne (Palmquist and Hanæus 2005, Christova-Boal *et al* 1996).

Table 44: Concentration of S in field house wastewater

	P	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	3.53 (0.49)	2.363 (0.31)	6.79 (1.17)	8.83 (2.56)	14 (4.07)	18.54 (3.54)	1.34$^{(1)}$ 0.79$^{(2)}$ 0.84$^{(3)}$
Palmquist and Hanaeus 2005	mg/L						35.2	
Christova Boal *et al*. 1996	mg/L	Laundry 9.5-40		Bath room 1.2-3.3				

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.24 Selenium

The mean concentration of Se in the wastewater streams from each of the appliances from the field house were below the detection limit of 0.005 mg/L in this study and in the literature as seen in Table 45.

Table 45: Concentration of Se in field house wastewater

	Se	***Concentration in wastewater (SD)***						
Reference	***Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.002	<0.005$^{(1,2)}$ <0.004$^{(3)}$
Christova Boal *et al*. 1996	mg/L	Laundry <0.001		Bath room <0.0001				

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.25 Tin

The mean concentration of Sn in the water and wastewater streams from each of the appliances from the field house were below the detection limit of 0.01mg/L. Blackwater had less than 0.2mg/L Sn. As shown in Table 46, black water had a concentration 0.021mg/L in a Swedish study (Palmquist and Hanaeus 2005).

Table 46: Concentration of Sn in field house wastewater

		Concentration in wastewater (SD)						
Reference	***Sn Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.2	<0.01(1,2) <0.2(3)
Palmquist and Hanæus 2005	mg/L						0.0213	

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.26 Zinc

The mean concentration of Zn in the wastewater streams from each of the appliances from the field house is compared in Table 47 to values reported in the literature.

Within the household the concentration decreased in the following order;

DW≈TO>VU>WM>SH≈KS

The dishwasher, toilet and vanity unit had the highest concentrations, greater than 0.1 mg/L. whilst in tap water it was 0.013 ± 0.0048 mg/L. The washing machine had 0.04 mg/L. and the concentration in the shower was below the limit of detection. However, the standard deviation of the readings was also large for those appliances (Table 47).

The concentrations reported in the literature for the laundry, bathroom and toilet were higher than those observed in this study (Christova Boal *et al.*1996, Palmquist and Hanaeus 2005, Hargelius *et al* 1995). Whilst for the vanity unit the concentration reported by Surendran and Wheatley (1998) was lower, 0.059mg/L.

Table 47: Concentration of Zn in field house wastewater

		Concentration in wastewater (SD)						
Reference	***Zn Units***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity unit***	***Toilet block***	***Tap***
Field house	mg/L	0.013 (0.025)	0.22 (0.27)	<0.001 (0)	<0.003 (0.006)	0.15 (0.16)	0.26 (0.087)	0.07(1) 0.002(2) 0.013 (3)
Christova Boal *et al.* 1996	mg/L	Laundry 0.09 – 0.32		Bath room 0.2 - 6.3				
Surendran and Wheatley 1998	mg/L	0.00031				0.00006		
Hargelius *et al.* 1995	mg/L	0.44			Kitchen 0.12-1.8			
Palmquist and Hanæus 2005	mg/L						0.525	

Note: Tap (1) supplied the washing machine and dishwasher, Tap (2) supplied the kitchen sink, shower and vanity unit, and Tap (3) supplied the toilet block.

3.9.27 Summary

Wastewater streams in the field house were analysed. The concentrations of elements in wastewater were compared to experimental values reported in the literature (Almeida *et al* 1999, Almeida and Buttler 1999, Boyle 1976, Christova Boal *et al.* 1996, Hargelius *et al.* 1995, Nolde 1999, Palmquist and Hanæus 2005, Siegrist *et al*. 1976 and Surendran and Wheatley 1998).

Unfortunately not all household streams nor elements could be matched to literature data, with limited data reported for dishwasher wastewater. In addition, whilst the field house study focused on appliances, some of the values reported in the literature refer to the discharge from specific rooms in a house, for example bathroom versus vanity unit and shower. In such case the concentrations observed may differ due to the source type.

A number of elements in the field house were below the limit of detection of the instrumentation in all wastewater streams. These included As, Cd, Cr, Hg, Mn, Se and Sn.

Overall, the ranges reported in the literature did not always match the ranges reported in the field house study, particularly for the overseas studies. However, a number of streams within the field house were within the wastewater ranges reported in an earlier Melbourne study (Christova-Boal *et al* 1996).

Concentrations can be significantly impacted by the original concentration in tap water. This was shown to vary within the field house and would also have differed in the literature studies. The concentrations in wastewater measured in this study were also subject to significant variance between readings, which reflects the high variability in wastewater characteristics even when obtained from a single appliance operated by the same person.

3.10 Source allocation

The evaluation of contaminants on a load basis was used to compare multiple streams within the field house. This aimed to assist in the quantification of the major discharges within the field house, the identification of their origins based on appliances and on major household input factors.

The task of allocating the priority contaminants to their true source is complex, given the natural variability in water quality, household habits, cleaning regimens and human behaviour.

This section describes an attempt of conducting such an analysis. Using the field house data, wastewater streams from each appliance were evaluated according to the three major sources: tap water, products and human related waste.

The assessment, whilst not comprehensive, is intended to provide an initial indication of the potential contribution of the individual sources to the overall load.

3.10.1 Mass balance method

To identify the origins of the contaminants and to be able to understand the contribution that different sources have on the loads, it is paramount to decompose each wastewater stream into its major contributing sources. These are shown in Figure 21 .

Contaminants in household wastewater stream are derived from three principal sources:

(a) Tap water, which includes mains water and any contaminants derived from the water supply network and household pipe infrastructure,

(b) Products purposely used in cleaning or washing, such as cleaning products or personal care products;

(c) Human related waste, which is exemplified by food scraps on dirty dishes, dirt in laundry, skin and other surface residues in the shower and human excretion in black water.

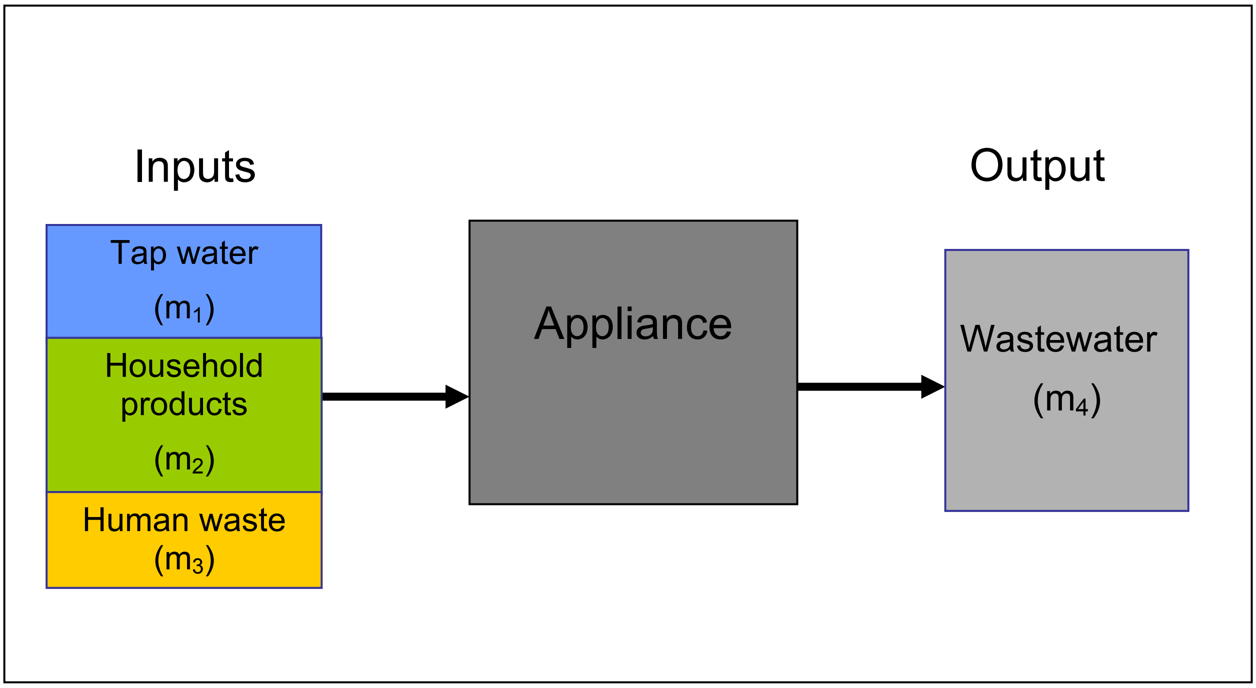


Figure 21: Mass balance for each household appliance.

Each appliance is characterised by a conservative mass balance describing the metal and inorganic input into and output from each appliance:

$$m_1 + m_2 + m_3 = m_4 \qquad \text{Equation (1)}$$

Where: m_1: mass load of element *i* derived from tap water

m_2 : mass load of element *i* derived from household products

m_3 : mass load of element *i* derived human related waste (food scraps, dirt, etc)

m_4: mass load of element *i* derived from wastewater

Each of the parameters were defined as:

$$m_1 = C_{wi} * V \qquad \text{Equation (2)}$$

$$m_2 = m_d * Cp \qquad \text{Equation (3)}$$

$$m_4 = C_{wwi} * V_{ww} \qquad \text{Equation (4)}$$

Where: C_{wi} : Concentration of element *i* measured in tap water

V : Volume of water used

m_{dp} : Dose of product used

Cp : Concentration of element *i* measured in product

C_{wwi} : Concentration of element *i* measured in wastewater

V_{ww} : Volume of wastewater discharged

The contribution of each source, tap water, products and human input, was expressed in mg/week or as a percentage of the total weekly field house load.

The mean concentrations evaluated experimentally were used to determine the corresponding overall loads (m_4) for each of the contaminants based on the volume of wastewater discharged per appliance use.

The same approach was used to determine the mean mass load contribution from tap water (m_1) using the volumes and concentrations measured in tap water from the field house.

The load derived from household products (m_2) was determined by measuring the amount of product used in each application (m_{dp}) and multiplying it by the elemental composition of each product (Cp).

The human input (m_3) was determined through the mass balance method for the inputs and outputs for each appliance stream. Details of the calculations can be found in Appendix 2.

For black water a similar procedure was adopted, but calculations were based on the total daily load instead of the load generated for a single appliance use. The assumptions and the procedure for determination of the individual loads were as follows:

(a) The total volume and load of black water differed from that typically collected for a single appliance use on an individual basis.

(b) The ratio between the volume of water used in the toilet and the amount of waste released per flush was assumed to be constant on an individual basis and the black water concentration was assumed to be independent of the total number of users.

(c) The total volume of wastewater generated by the multiple toilet users and the total number of flushes each day was recorded. The daily amount of toilet paper consumed was also monitored for a period of 6 days.

(d) The contribution to the total elemental load by the hand wash and the human input into the hand basin were assumed to be negligible.

(e) The contribution of each source (tap water, toilet paper and human input) was estimated as a percentage of the total mass load per day.

To determine the loads generated by 1 person per day, the following assumptions were made:

(f) A ratio between half and full flushes of 43:57 was used to determine the typical water discharge based on a half flush of 2 L and a full flush of 9L as per the toilet cistern in the building.

(g) A frequency of appliance use of 3.8 flushes per person per day (Roberts 2005) was assumed to estimate the load generated by a 1 person household on a daily basis. This resulted in a volume of 25.16L per person per day as the typical discharge for a 1 person household for the field house.

(h) Based on the volume discharged by an individual and the contribution of each source as a percentage of the total load, the loads for a single person household were determined.

Further details on the evaluation method, including the discussion of results and validation are shown in Appendix 2.

Total mass loads were initially estimated using the measured wastewater concentrations and the volume of wastewater discharged and compared to the mass balance method. For the majority of the appliances there was good agreement between the elemental loads estimated using the mass balance and by estimating loads based on volume and concentration alone. In some cases, a larger load was estimated using the mass balance method. This was discussed in detail in Appendix 2 using Table 57 to Table 61.

In summary, the discrepancies between the two methods fell into three major categories:

- A number of elements were present in trace amounts (ppb or lower), mostly in the products, and were not detected experimentally given the dilution volume and detection limits of the analytical instrumentation. Their loads could be captured using the mass balance method. Examples included Sb, B, Cd, Pb, Ni and Mo.
- Normal variance in measurements ($Z \leq 2.5$): volume, mass, composition, etc. Majority of error between the mass loads estimates was explained by a normal data variance, i.e. the error was less than 2.5 SD of wastewater, SD_{ww}.
- Significant discrepancies ($Z>2.5$): these were characterised by large deviations. This was observed in the vanity unit for Al, Fe, K and S which had an error larger than 3 SD_{ww} and which could also not be attributed to the normal variance in the data. The respective Z-values for those elements were 3.08, 37, 3.2 and 3.8. For those elements the mass load for the product and distribution per sources were re-evaluated based on the experimental load.

The mass balance method tends to be conservative and because of the order of evaluation used in the method it prioritises the loads attributed to tap water and household products, but could underestimate the contribution from human inputs, which are difficult to measure.

Potentially another source of error could be the removal of contaminants from the process. For example in the washing machine, the wet clothes may remove some of the contaminants generated in the process, but removal was assumed to be negligible in our estimations.

Overall in the estimation of loads the largest discrepancies between the theoretical and the experimental values were reported for the vanity unit and for specific elements in the black water. In the majority of examples, these were within the expected standard deviation of the data.

3.10.2 Estimation of weekly contaminant loads

The load generated per appliance use or per day (for the toilet) was estimated using the mass balance method. Using those values, the average weekly mass load of contaminants generated by each appliance in the field house was determined by assuming an average frequency of appliance use for a one person household. As previously explained in section 2.5, use frequencies were derived from data collected in Melbourne for the washing machine, dishwasher, shower and toilet during 2005 (Roberts 2005) and estimates for the kitchen sink and vanity unit. These were:

- 5.32 showers per week (average volume of 34L per shower) ;
- Laundry washing 3 times per week (average volume of 158L per wash);
- Dishwasher use 1.8 times per week (average volume of 15.9L per wash);
- Kitchen sink 10.5 loads of dirty dishes per week (average volume of 8.2L per wash);
- Vanity unit 14 times per week (average volume of 2L per wash); and
- Toilet 29.4 flushes per week (equivalent to 25.26L per person per day)

The weekly loads were used to evaluate the contribution that individual appliances have to the total load generated by the household.

It was also assumed that the householder only operated the washing machine and the dishwasher with a full load of dishes.

In section 3.8.1, it had been verified that the quality of water supplied to specific appliances changed during the evaluation process (Tap 1, 2 and 3). Therefore, we decided to evaluate the loads and the sources assuming a common water supply (Tap 2) to all the appliances to provide a common baseline for comparison. As a result, the load evaluation and breakdown was conducted twice.

Table 48 shows the weekly loads generated in the field house using the mass balance method and assuming supply of tap water 2 to all appliances. The associated standard deviations are listed in Appendix 3.

The corresponding contribution by each appliance to the total load from the field house is shown in Figure 22, as a percentage of the total load, and in Figure 23, as mass loads. The elemental contributions from each major source (tap water, products and human input) to the load generated by each major appliance are shown in Figure 24 to Figure 29.

Estimates of the weekly loads, the load contribution per appliance and per source using the original data from the field house are not shown here but are available in Appendix 4 in Table 68 and in Appendix 5 in Figure 38 to Figure 44.

The results show that in the field-house:

- Wastewater from the toilet and the washing machine contributed to the majority of the elements of interest as shown in Figure 22.
- Based on the original wastewater concentrations using the original source water, the washing machine was the major source of Al, Pb, Ni, Na, F and Ca (Figure 38 in Appendix 5). However, the Pb detected in the washing machine wastewater was caused mainly by the Pb in tap water (Tap 1). Hence, when all appliances were supplied with Tap water 2 and loads estimated using the mass balance method, the washing machine remained the major source of Al, As, Ca, F, Mg, Ni, Na and TDS, but not of Pb (Figure 22).
- Based on the original wastewater concentrations, the toilet was the major source of B, Mo, TKN, K, TP, Cl, Fe, Mg, S and Zn (Figure 38 in appendix 2). Again, this was influenced by water supply and when supplied with tap water 2 the toilet would remain the major source of Co, Cl, Cu, Fe, Mo, K, S, TKN and TP.
- The shower and the dishwasher were also important sources of a number of elements including Cl, F, S, Pb and Zn.
- Elements such as As, Cd, Cr, Sb and Se had concentrations below the limit of detection in the monitored wastewater streams. However, the mass balance indicated that potentially trace amounts could be present in a number of the individual wastewater streams which would impact the loads discharged by each appliance (Figure 22) resulting in the washing machine as a major source of As, the shower as an important source of Sb, Cd and Cr and the vanity unit as a major source of Se.

Table 48: Mass loads of elements in field house wastewater streams

		Mass load (mg/week)						
Element	***Tap water***	***Washing Machine***	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity Unit***	***Toilet + vanity***	***Total***
Al	2	810.12	19.45	68.56	7.73	6.30	19.41	913.8
As	2	4.78	0.019	0	LOD	0.47	LOD	5.2
B	2	3.63	LOD	102.6	1.9	60.3	9.45	177.9
Ca	2	3,382	318.6	1,409.7	749.5	2320	3056.2	11,236
Cd	2	LOD	LOD	0.015	LOD	0.010	LOD	0.02
Cl	2	6,042	7,573.8	2,600.5	5,613.8	529.6	16,408.4	38,768
Co	2	LOD	LOD	0.12	LOD	LOD	0.18	0.30
Cr	2	0.047	0.017	0.119	LOD	0.068	LOD	0.252
Cu	2	52.0	20.0	22.2	23.05	34.7	81.77	233.8
F	2	474.6	28.34	149.9	72.4	50.3	143.8	919.4
Fe	2	70.8	5.1	21.0	12.5	5.82	97.0	212.3
Hg	2	LOD	LOD	LOD	LOD	LOD	LOD	0
K	2	1262.3	287.9	18.6	1017.2	128.20	15,999.6	18,713.8
Mg	2	1441	90.8	486.8	228.1	95.1	1186.1	3528
Mn	2	LOD	LOD	LOD	LOD	LOD	LOD	0
Mo	2	0.182	0..002	0.119	0	0	0.4606	0.65
Na	2	60,284.3	7489.0	2611.8	3442.4	782.7	16018.7	90,629
Ni	2	15.6	0.456	0.03	LOD	0.158	LOD	16.28
Pb	2	0	1.79	0.09	0.386	0.357	1.399	4.029
S	2	2137	51.7	1377.6	944.5	449.9	3237.3	8198.6
Sb	2	1.350	0.002	0	0	0.003	0	1.355
Se	2	0.006	LOD	LOD	0	0.024	0	0.031
Sn	2	0	0	0.056	0.109	0	0	0.16
Zn	2	1.045	4.55	0.66	0.749	5.871	43.36	56.23
TKN	2	2599.6	477.3	921.4	935.6	373.5	48,675	53,982
TP	2	106.53	348.2	46.98	188.8	1831.9	8,807.2	11,249
TDS	2	193,662	28,556	13,433	29,013	20,860	105,135	390,660

Note: LOD – Concentration measured in wastewater was below the limit of detection.

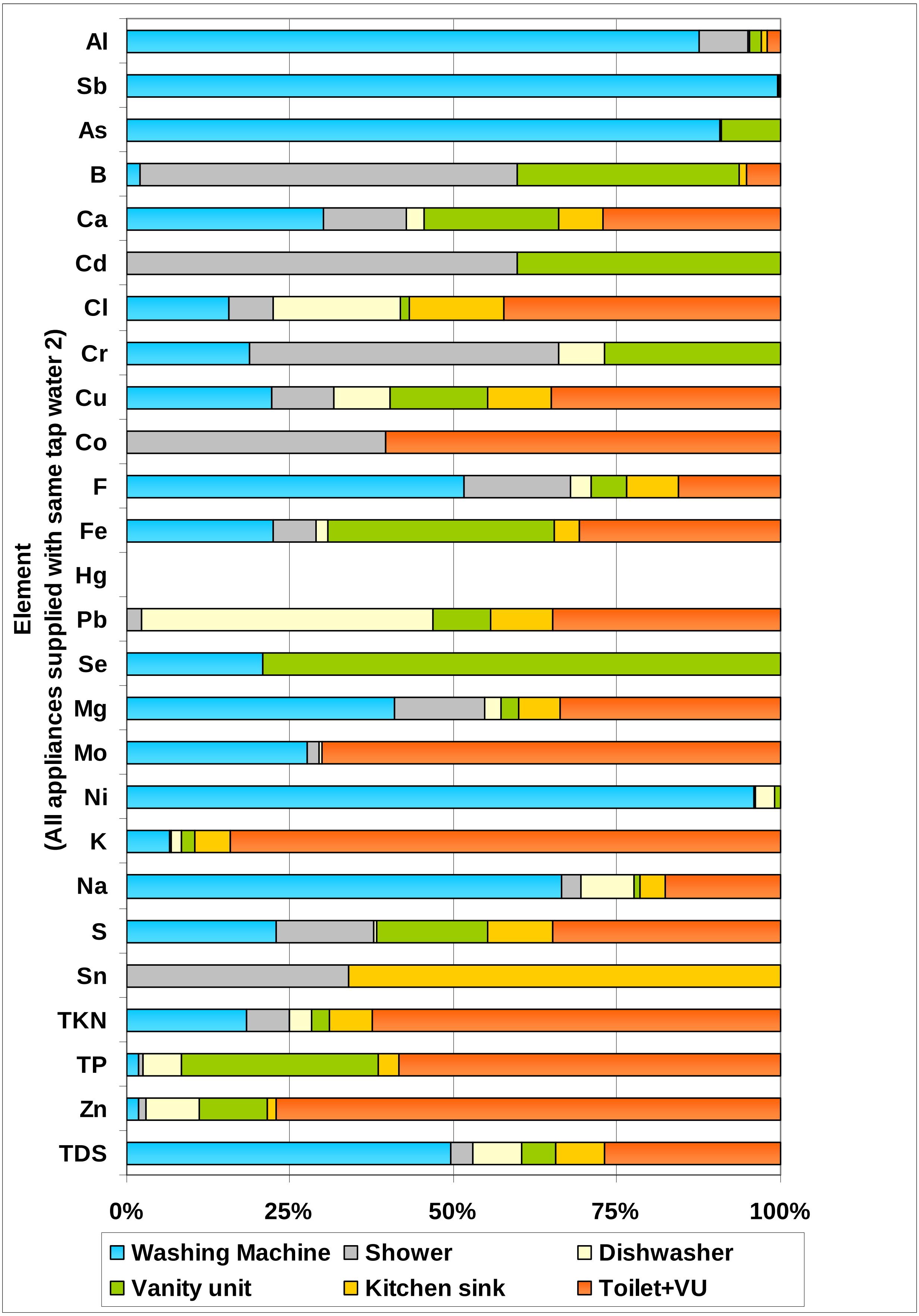
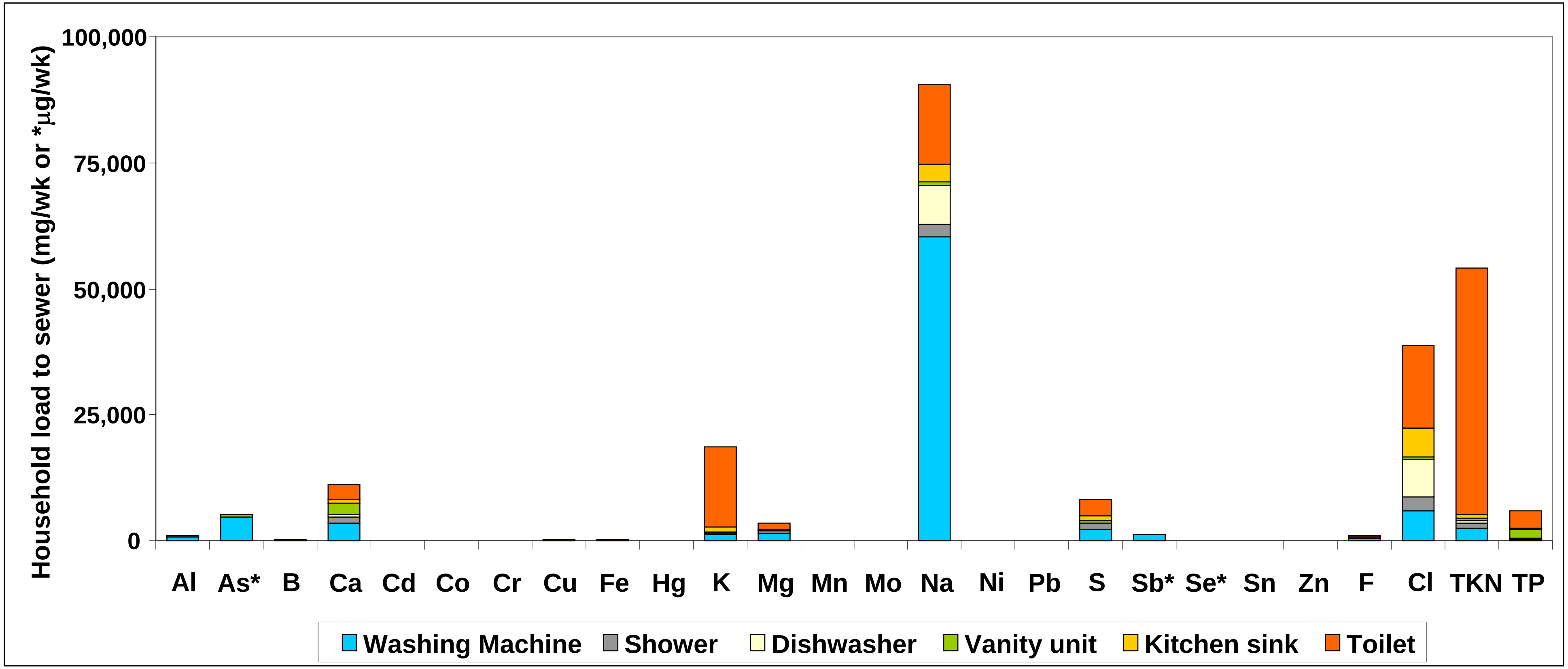


Figure 22: Contribution of each appliance to the load of contaminants in wastewater from the field house with a common water supply (Tap 2).



Note: Units for the loads of As, Sb and Se are in µg/L.

Figure 23: Mass loads from appliances in field house wastewater assuming a common water supply (Tap 2).

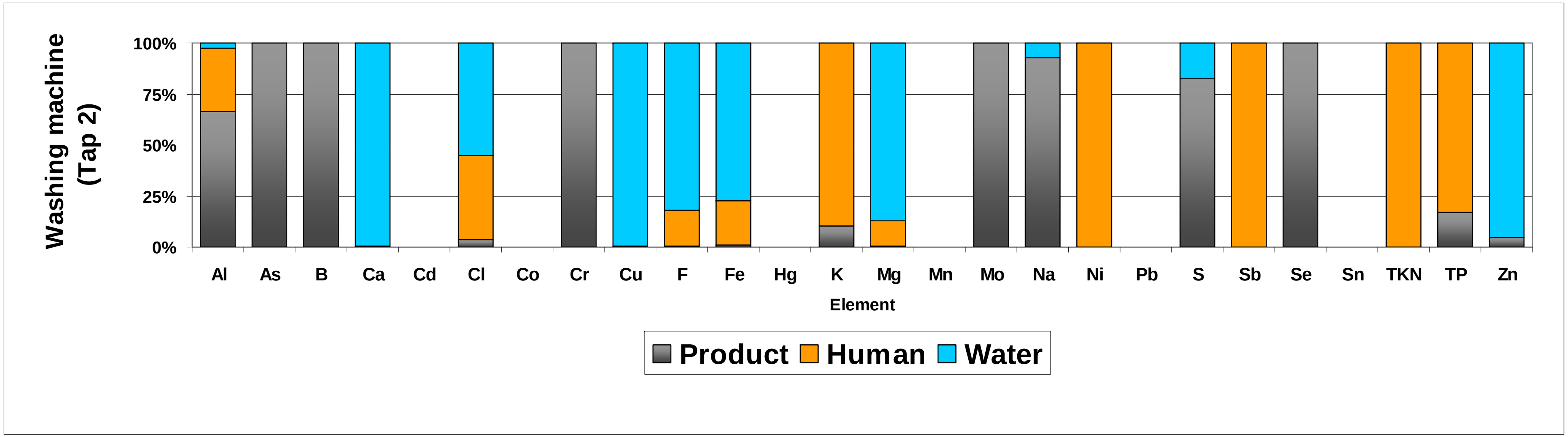


Figure 24: Sources of contaminant loads in washing machine wastewater

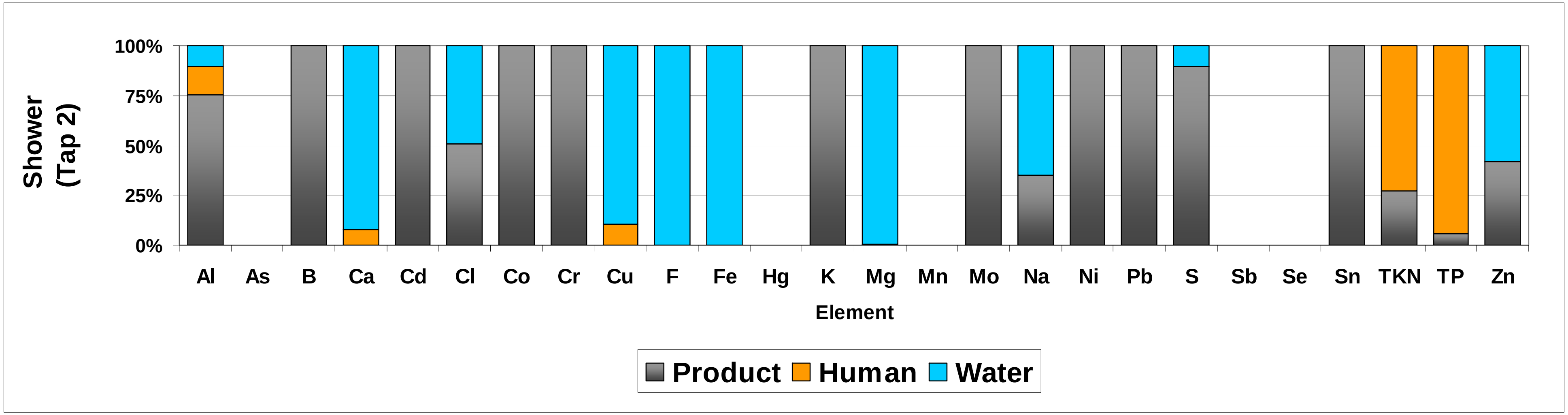


Figure 25: Sources of contaminant loads in shower wastewater

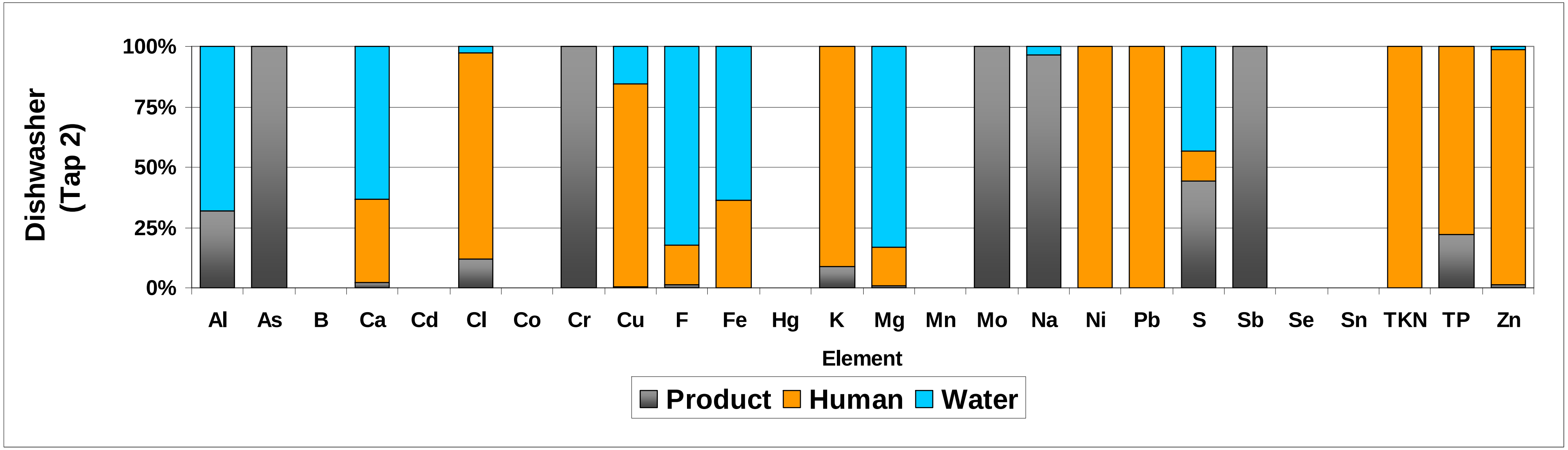


Figure 26: Sources of contaminant loads in dishwasher wastewater

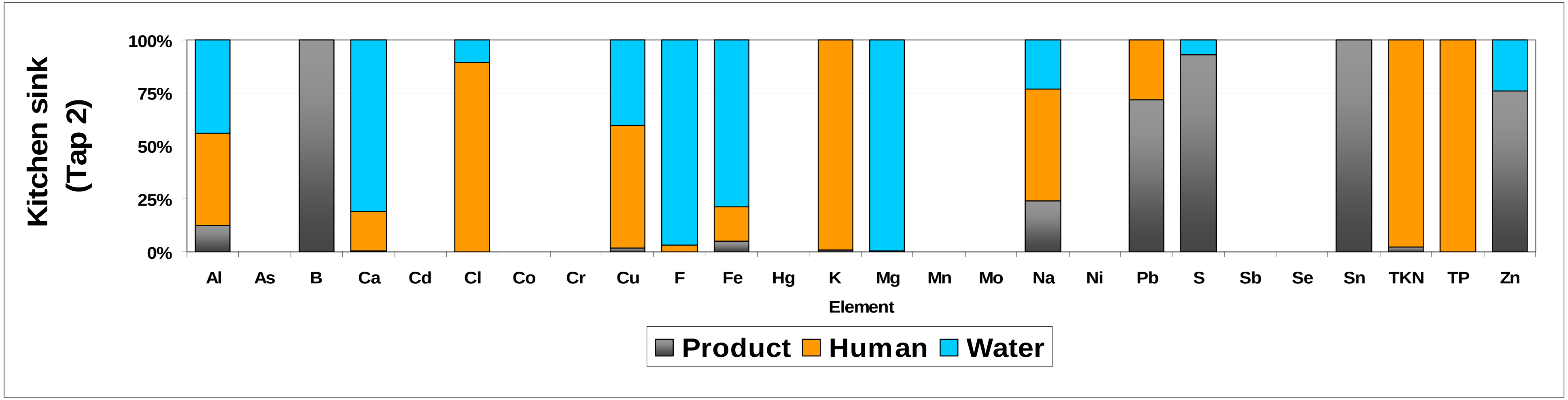


Figure 27: Sources of contaminant loads in kitchen sink wastewater

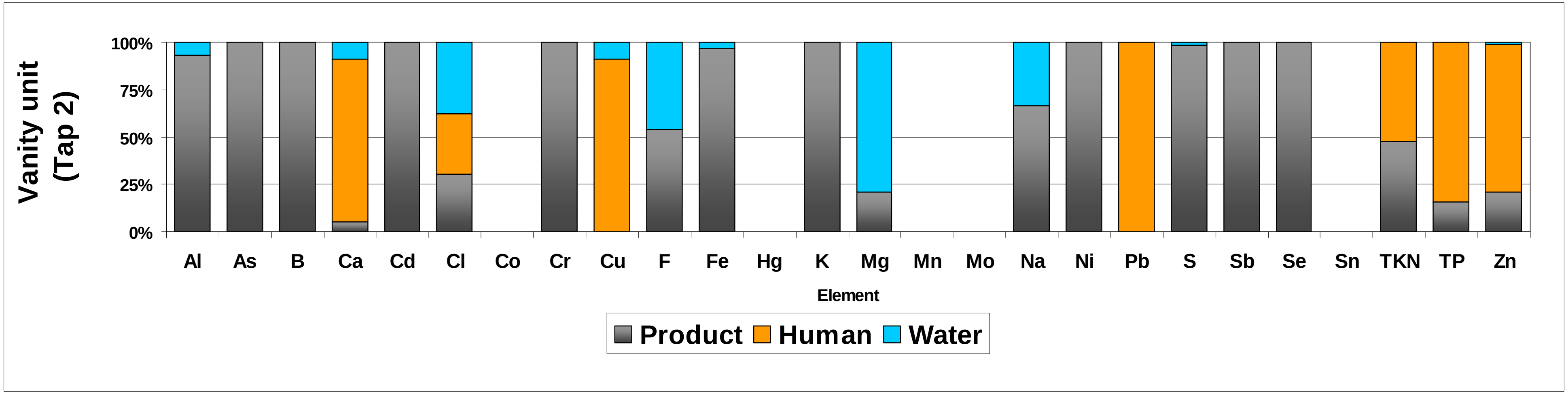


Figure 28: Sources of contaminant loads in vanity unit wastewater

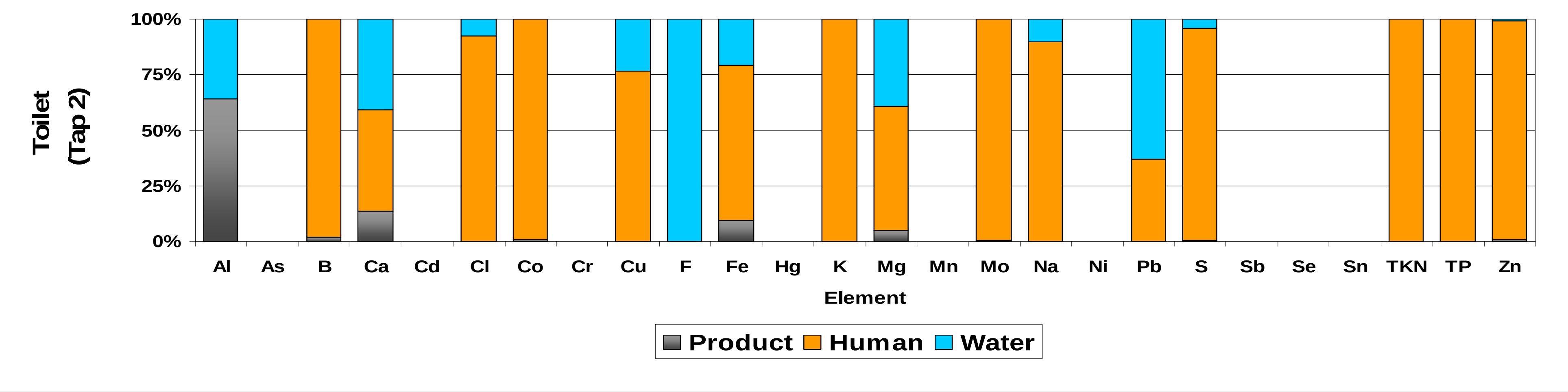


Figure 29: Sources of contaminant loads in toilet wastewater

3.10.3 Analysis of elemental loads

As previously seen in section 3.8.1 the quality of tap water recorded during the testing of the washing machine and the dishwasher differed from that of tap water used for testing of the shower, vanity unit and kitchen sink and the toilet. Because the water supply between appliances differed, the breakdown of the loads was conducted using the mass balance method and assuming the supply of tap water 2 to all appliances. This section evaluates the results based on such adjusted waste streams for each individual element. All comparisons are based on the estimates of the potential load generated assuming Tap 2 as water supply to all appliances estimated in Table **48**. The concentration of elements in the products used in the field house can be found in

Table 56 in Appendix 1.

3.10.4 Aluminium

A load of 914 mg Al/wk was estimated to be discharged from the field house. The majority of the load, 88.7%, is discharged from the laundry. Wastewater from the shower is the second major contributor at 7.5% of the load and the remainder of the other appliances contributed to less than 0.9%, 0.7% and 0.2% of the total load for the kitchen sink, vanity unit and dishwasher respectively.

WM>>SH>TO>KS>VU>DW

Washing machine

Washing powder was responsible for to 66.6% of the load, human input as soiled clothing contributed 31.1% and water contributed 2.3%. The human input is likely to be from soil and dirt that is included in the wash.

Shower

Products were the source of 75% of the load, human input that is washed off contributed to 14% and water to 11% of the load.

Toilet

In the toilet block toilet paper was the major source of Al with an estimated mean contribution of 64%. The remain 35% was attributed to tap water.

Kitchen sink

Food residues and tap water are considered the major inputs contributing 43.8% and 43.7% of the loads.

3.10.5 Antimony

A load of 1.35 mg Sb/wk was estimated to be discharged from the field house. The majority of the load, 99.6%, is discharged from the laundry. Wastewater from the vanity unit and dishwasher are trace contributors at 0.26% and 0.14%. The load in the remainder from the other appliances was too small to be measured.

WM>>VU>DW

Washing machine

Human input from soiled clothing was the main source the Sb in the washing. No Sb was detected in the detergent, nor in the tap water.

Dishwasher and vanity unit

In each case the potential source of Sb was the product.

3.10.6 Arsenic

Arsenic concentrations were below the limit of detection for all water and wastewater streams. However, traces of As were detected in the products used in the washing machine (1.59 μg/wash, SD 0.091), dishwasher (0.0108 μg/wash, SD 0.0005) and vanity (0.0339 μg/wash, SD 0.0048), but the corresponding concentration was too low to be detected upon dilution. This potential load was equivalent to a 5.27 μg/week.

WM>VU>DW

In each of those appliances, the products adopted are the potential source of As.

3.10.7 Boron

A load of 178 mg B/wk was estimated to be discharged from the field house. The shower, vanity unit and the toilet were the major sources.

Some brands of laundry detergents also contain B, but the load of B from the laundry powder formulation used in the washing (1.21 mg/wash, SD 0.069 mg/wash) was too low to be detected in dilution.

SH>VU>TO>WM>KS

Toilet

Using mean values, B in the toilet was estimated to originate from the toilet paper (2%) and from human excreta (98%).

However, the contribution from the different sources could vary from one day to another. The actual water supplied to the toilet block had B in it. Under that water quality, the contribution from tap water was significant and ranged between 4.8% to 96.7% on different dates. Likewise the contributions ranges were 0.24% to 1.9% and 11.4% to 93.4% for product and human input. The major influencing factors were the anthropogenic discharge.

Washing machine

The B concentration was too small to be detected in the washing machine, but the laundry powder was considered a potential source of B for up to 1.2 mg B/wash.

Shower

Products used in the shower can be a source of B contributing 19.2 mg B/wash. The standard deviation was ±4.3mg/wash.

Kitchen sink

Detergent used could contribute up to 0.18 mg/wash (SD±0.02).

Vanity unit

Products used in the vanity could potentially contribute to 4.3 mg/wash (SD ±0.82).

3.10.8 Cadmium

Cadmium concentrations were below the limit of detection for all water and wastewater streams. Traces of Cd were detected in the products used in the shower and in the vanity unit which would have generated respective loads of 0.015mg/wk and 0.010mg/wk, the corresponding concentration was however too low to be detected upon dilution. This is equivalent to a weekly load of 0.025mg.

SH≈VU

The ranking is partly in agreement with a desktop simulation using Perth water quality data by Gray and Becker (2002). In their simulation, the highest loads estimated for a household were from the bath and the kitchen, although they estimated higher loads 0.199 mg/pe/wk and 0.138mg/pe/wk, respectively. They had also expected loads from toilet and laundry of 0.084mg/pe/wk, which would have resulted in concentrations of less than 0.6 μg/L, i.e. either at or below to the detection limit.

3.10.9 Calcium

A load of 11,236 mg Ca/wk was estimated to be discharged from the field house. Sources were distributed across the major appliances in the house. The washing machine, the toilet, the vanity unit and the shower, each contributed 30%, 27%, 21% and 12.5%. The kitchen sink and the dishwasher contributed the least with 6.7 and 2.8% of the total load.

WM>TO>VU>SH>KS>DW

Washing machine

Human input from soiled clothing was the source of 99.7% of the Ca in the wash machine, the remainder of the load was attributed to tap water.

Toilet

Human input (mainly excreta) was estimated to contribute 45.6% of the load, water 40.7% and toilet paper 13.7%

Vanity unit

Estimates for human input, water and product were estimated to be 86%, 9% and 5%.

Shower

Products were the source of 0.1% of the load, human input that is washed off contributed to 92% and water to 7.9% of the load.

Kitchen sink

Tap water was the main source with 92% of the load, human input 7.9% and the product 0.4%.

3.10.10 Chloride

A load of 38.8 g Cl/wk was estimated to be discharged from the field house, making it the third largest load generated in the field house. The majority of the load, 42.39%, is discharged from the toilet. Wastewater from the dishwasher is the second major contributor at 19.5%, followed by the laundry, the kitchen sink, shower and vanity unit which contributed to 15.6%, 14.5%, 6.7% and 1.7% the of the total load each.

TO>DW>WM>KS>SH>VU

Toilet

Human excreta were the source of 92.5% of the Cl load. The remainder was attributed to tap water.

Dishwasher

Food residues contributed to 85.4% of the load, products to 12% and tap water to 2.6%.

Washing machine

Tap water contributed 55.2% of the load, soiled clothing 41% and laundry powder 3.7%.

Kitchen sink

Food residues are responsible for 89.1% of the load, whilst tap water and detergent contribute only to 10.7% and 0.2%.

Shower

Products and tap water are the main sources of Cl, contributing respectively to 50.6% and 49.4% of the load.

Vanity unit

Sources are distributed equally, with tap water, human input and products contributing 37.6%, 32.3% and 30.1% each to the load.

3.10.11 Cobalt

A load of cobalt of 0.30 mg/wk was estimated to be discharged from the field house. The majority of the concentrations in wastewater were below detection for the field house.

The major load detected, 60%, came from the toilet. The products used in the shower contained traces of Co but these were too low (<0.02mg/wash or 0.119mg/wk) to be detected under dilution.

TO>SH

Toilet

Human excreta were the source of 99.3% of the Co load and the remainder was attributed to toilet paper.

Shower

Personal care products were the major potential source.

3.10.12 Copper

A load of 233 mg Cu/wk was estimated to be discharged from the field house. The major loads, 35% and 22% were discharged from the washing machine and the toilet respectively. The vanity unit contributed 14.9% of the copper and the remainder of the appliances contributed to approximately less than 10% of the total load each.

WM>TO>VU>DW=SH>KS

Washing machine

Tap water contributed to 99.5% of the load and the remainder was attributed to laundry powder.

Toilet

Human input, tap water and products contributed to 76.6%, 23.4% and 0.03% of the total appliance load.

Vanity

Human input, tap water and products were responsible for 91%, 8.9% and 0.1% of the load.

Dishwasher

Food residues, tap water and products contributed 84.2%, 15.5% and 0.3% of the load.

3.10.13 Chromium

Concentrations of Cr were below detection in water and wastewater in the field house.

Analysis of the laundry powder, shower, dishwasher and vanity products have shown traces of Cr, but the respective loads per single use, 0.016 mg, 0.022 mg, 0.0097 mg and 0.005 mg were too small for detection once diluted in water. The weekly load would have been 0.25 mg/wk, with respective contributions of 47%, 19%, 7%, and 27% for each of those streams.

SH>VU>WM>DW

3.10.14 Fluoride

A load of 919 mg F/wk was estimated to be discharged from the field house. The majority of the load, 51.6%, is discharged from the laundry. Wastewater from the shower is the second major contributor at 16.3%, followed by the toilet, kitchen sink, the vanity unit and dishwasher at 15.6%, 7.9%, 5.5% and 3.1%, respectively.

WM>SH>TP>KS>VU>DW

Washing machine

Tap water contributed 82.1% of the load, human input 17.6% and detergent 0.3%.

Shower

Tap water was the source of all F.

Kitchen sink

Tap water was responsible for 96.8% of the load, the remain was attributed to food residues.

Vanity unit

Products contributed to 53.8% of the load and tap water to 46.2%. Fluoride is an ingredient in toothpaste.

Dishwasher

Tap water was the main source of F producing 82.4% of the load, food residues contributed 16.5% and product 1.2%.

Toilet

Water is the main source of fluoride. No fluoride had been detected in the human excretion nor in the toilet paper.

3.10.15 Iron

A load of 212 mg Fe/wk was estimated to be discharged from the field house. The majority of the load, 45.7%, is discharged from the toilet. Wastewater from the laundry is the second major contributor at 33.4%. The shower and the kitchen sink contributed to 9.9% and 5.9% of the load, whilst the vanity and the dishwasher had a small contribution of 2.7% and 2.4% of the total load each.

TO>WM>SH>KS>VU>DW

Toilet

Majority of the load, 69.8%, is caused by human excreta. The remainder was attributed to tap water and toilet paper at 20.8% and 9.3% respectively.

Washing machine

Tap water, soiled clothing and products contributed to 77.2%, 21.7% and 1.1% of the load.

Shower

Water was the major source of iron.

Kitchen sink

Tap water, food residues and product were responsible for 78.7%, 16% and 5.3% of the load.

Vanity Unit

Tap water, human input and products were responsible for 56% and 44% of the load.

Dishwasher

Tap water and food residues were responsible for 63.8% and 36.2% of the load.

3.10.16 Lead

A potential load of 3.1 mg Pb/wk was estimated. The majority of the load, 56.9%, was discharged from the dishwasher. Wastewater from the toilet was the second major contributor at 16.5%. Other contributors were the kitchen sink, vanity unit and the shower at 12.3%, 11.4% and 3% of the total load each.

When discounting the contribution from tap water, the ranking based on loads becomes:

DW>TO>KS>VU>SH

In the field house, the original concentration of Pb in tap water used in the washing machine and dishwasher was 0.5mg/L, whilst water used for the other appliances contained less than 0.01mg/L. If loads were calculated without the tap water correction, the resulting ranking would be dominated by the high loads detected in the first two appliances:

WM>DW>KS=TO>VU

Washing machine

In the field house any Pb load was attributed solely to tap water at the time of the trial. No Pb was detected in the product used nor from the human input.

Dishwasher

No Pb was detected in the detergent used.

In the absence of Pb in tap water, all the load was attributed to human input.

Kitchen sink

Detergent and food residues contributed to 71.9% and 28.1% of the load.

Toilet

Human input and tap products contributed to 99.97% and 0.03% of the load.

Vanity unit

Human input was the major source of Pb.

Shower

Traces of Pb were detected in the products, but the amounts were too small for detection under dilution. The estimated load was 0.0176 mg/use which would be equivalent to an additional contribution of only 0.094 mg/wk.

3.10.17 Magnesium

The load of Mg estimated from the field house was 3,528mg/wk. The major sources are expected to be the washing machine at 40.8%, the toilet at 33.6%, the shower at 13.8%, the kitchen sink at 6.5%, the vanity unit at 2.7% and the dishwasher at 2.6%.

WM>TO>SH>KS>VU=DW

Tap water is the predominant source of Mg in grey water streams. Whilst in black water, human input is estimated to contribute 55.9%, tap water 39.2% and the remainder is attributed to the product.

3.10.18 Mercury

No load of mercury was estimated as all concentrations were below detection in water and wastewater in the field house. No Hg was detected in any of the products used in the field house. Overseas literature suggests that trace amounts (0.5mg/pe/annum) can be present in urine (Koch and Rotard 2001).

3.10.19 Molybdenum

A load of 0.65 mg Mo/wk was estimated to be discharged from the field house. The main source was the toilet (70.2%). Although the concentration in the other wastewater streams was below the limit of detection, the products used in the washing machine, dishwasher and shower contained traces of Mo, but loads in parts per billion were too small to be detected in dilution. Their respective contributions were estimated to be 0.182 mg/wk, 0.002 mg/wk and 0.012 mg/wk, which would have corresponded to 27.7%, 0.3%, and 1.8%.

TO>>WM>SH>DW

In black water 99.7% of the load was came from human excreta and the remainder from traces of Mo in products.

3.10.20 Sodium

A load of 90.6g Na / wk was estimated to be discharged from the field house. This represented the largest elemental load discharged to sewer. The majority of the load, 65.5%, was discharged from the laundry. Wastewater from the toilet and the dishwasher were the second and third major contributors at 17.7% and 8.3%. The remainder of the appliances contributed to less than 4% of the total load each – kitchen sink 3.8%, shower 2.9% and vanity 0.9%.

WM>>TO>DW>KS>SH>VU

Washing machine

The laundry detergent was responsible for 92.74% of the load. The remaining load was attributed to tap water.

Toilet

Human excreta, tap water and products were responsible for 89.7%, 10.2% and 0.1% of the load. But the contribution can vary from day to day.

Dishwasher

Products and tap water were responsible for 96.5% and 3.5% of the load. The input from food residues was negligible in comparison.

Kitchen sink

Food residues, detergent and tap water contributed to 52.7%, 24.2% and 23.1% of the load.

Shower

Tap water and the products used in the shower were responsible for 65% and 35% of the load.

Vanity unit

Products were responsible for 66.3% of the load, the remainder was attributed to tap water.

3.10.21 Nickel

A load of 16.3mg Ni/wk was estimated to be generated in the field house. The load originated mainly from the laundry, 96%, and the dishwasher, 2.8%. The concentrations in wastewater from the other appliances were below the limits of detection, but the potential contributions based on product analysis were less than 1% for the shower and vanity.

WM>>DW>>VU>SH

Washing machine

Soiled clothing was the major source of the load.

Dishwasher

Human input was the major source of the load.

Vanity unit and Shower

Products were the major source of the load

3.10.22 Potassium

A load of 18.7 g K/wk was estimated to be discharged from the field house. This was the fourth largest load to sewer. The majority of the load, 85.5%, was discharged from the toilet. Wastewater from the washing machine was the second major contributor at 6.75%. The other appliances contributed to less than 5.5% of the total load each. Whilst the concentration of K in the shower wastewater was below detection, the product used contained traces of K.

TO>>WM>KS>DW>VU>>SH

Toilet

The load range estimated from the observations was between 98 and 99.98% for human excreta. Tap water and products contributed to less than 1% of the load.

Washing machine

Tap water and soiled clothing contributed to 10.5% and 89.5% of the washing machine load.

Kitchen sink

Food residues and detergent were responsible for 98.9% and 1.1% of the loads.

Dishwasher

Food residues and product contributed to 91.2% and 8.9% of the load, respectively.

Vanity unit

Product input was responsible for the K loads.

3.10.23 Selenium

Se concentrations were below detection in water and wastewater in the field house. However, products used in the washing machine and the vanity unit contained traces of Se, which were approximately 0.002 mg per use for each stream, and thus too small to be detected under dilution. This would result in a potential field house load of 0.03 mg/wk sourced from the vanity unit (79%) and the washing machine (21%).

3.10.24 Sulphur

A load of 8.2 g S/wk was estimated to be discharged from the field house. The majority of the load, 39.5%, was discharged from the toilet. Wastewater from the washing machine and the shower were the second and third major contributors at 26.1% and 16.8% respectively. The contributions from the kitchen sink, vanity unit and dishwasher were 11.5%, 5.5% and 0.6% respectively.

TO>WM>SH>KS>VU>DW

Toilet

Human input was the major source of S, contributing on average 95.3% of the load. Tap water and products contributed only 4.3 % and 0.4%, respectively. The range observed from one day to another was also consistent ranging from 92 to 96% for human input, 4 to 7% for tap water and less than 0.6% for product.

Washing machine

Laundry powder and tap water were the major sources contributing to 82.5% and 17.6% of the load.

Shower

Products and tap water were the major sources, contributing to 89.5% and 10.5% of the load.

Kitchen sink

Detergent was the major source of S, contributing 92.9% of the load, the remainder load was attributed to tap water

Vanity unit

Products were the major source of S, contributing 95% of the load, the remainder was attributed to tap water.

Dishwasher

Tap water, detergent and food residues contributed to 43.5%, 44.4% and 12.1% of the load.

3.10.25 Tin

The concentration of Sn was below the limit of detection in water and wastewater. However, products in the shower and the kitchen sink contained traces of Sn. Whilst loads were too small to be detected in dilution at 0.01 mg/shower and 0.01mg/wash, their potential joint contribution would be equivalent to 0.165 mg/week, with 66% of the load derived from the kitchen sink and the remainder from the shower.

SH>KS

3.10.26 Total Kjeldahl nitrogen

The second largest load from the field house was TKN at 54g TKN/wk. The majority of the load, 90.2%, was discharged from the toilet. The contribution from the other appliances was small: 4.8% for the washing machine, which was the second major contributor, and less than 1.7% for the remainder of appliances.

TO>WM>KS≈SH>DW>VU

Toilet

Human excreta were the major source of N responsible for 99.6% of the load. The remainder of the load was the contribution from the product.

Washing machine

Soiled clothing was the major source of N responsible for 99.6% of the load. Product and tap water were estimate to contribute only 0. 2% each

Shower

Human input was the major source of N, responsible for 73.4% of the load. Product and tap water were estimated to contribute 27.4% and 0.2% each.

Kitchen sink

Food residues were the major source of N, responsible for 97.4% of the load. Product and tap water were estimated to contribute 2.5% and 0.1%, respectively.

Dishwasher

Food residues were the major source of N, responsible for 99.8% of the load. Product and tap water were estimated to contribute the remainder.

Vanity unit

Human input, products and tap water were responsible for 52.3%, 47.7% and 0.01% of the load, respectively.

3.10.27 Total phosphorus

The third largest load from the field house was TP at 11.3 g TP/wk. The majority of the load, 77.7%, was discharged from the toilet. Wastewater from the vanity was the second major contributor at 16.2%. The dishwasher, the kitchen sink, the washing machine and the shower contributed to 3.1%, 1.7%, 0.9% and 0.4% of the total load each.

TO>>VU>DW>KS>WM>SH

Toilet

Human excreta are the main source, responsible for 99.9% of the load. Products contributed to the remainder.

Vanity unit

Products are the source for 15.9% of the load. The remainder was from human input.

Dishwasher

Products and food residues contributed to 22.3% and 77.7% of the load.

Kitchen sink

Food residues and products were the source of 99.8% and 1.2% of the load.

Washing machine

Soiled clothing and detergent contributed to 83% and 17% of the load. The detergent used was an environmentally friendly brand.

Shower

Human inputs and products contributed to 94.2% and 5.9% of the loads.

3.10.28 Zinc

A load of 56.2 mg Zn/wk was estimated to be discharged from the field house. The majority of the load, 77.1%, was discharged from the toilet. Wastewater from the vanity unit was the second largest contributor at 10.4% of the load. The dishwasher and washing machine contributed to the overall load by 8.1% and 1.9%. The load from the shower and kitchen sink was minimal at 1.8 and 1.3%.

TO>VU>DW> SH> KS

Toilet

Human input, tap water and products contributed 98.6%, 0.9% and 0.6% of the load.

Wash machine

Tap water was the major source, contributing 95.4% of the load,the remainder came from the product.

Dishwasher

Food residues, tap water and products contributed 97.5%, 1.3% and 1.2% of the load.

Vanity

Human input, products and tap water contributed 78.3%, 20.7% and 1% of the load.

Kitchen sink

Detergent and tap water contributed to 76.1% and 23.9% of the load.

Shower

Tap water and products contributed 58% and 42% of the load.

3.11 Sources and their influence

The potential contribution of each source: tap water, products and human input, to the overall load generated by the field house is summarised in Figure 30 for all priority elements and shown in Figure 31 to Figure 33 for individual elements. The estimates are based on the corrected load calculated using tap water 2 and the mass balance method.

3.11.1 Tap water

As seen in Figure 31 to Figure 33, tap water (tap 2) was the major source for Ca (62% load), F (87% load), Mg (73% load), Fe (53% load) and Cu (45% load) in the field house.

The results from this study attest to the impact of tap water on the loads generated in a household. This was exemplified for the Pb concentration verified in tap 1, 0.5mg/L, compared to tap 2 and 3, $\leq$0.01mg/L. The Pb case shows that the loads generated can vary significantly for elements that are present at or close to the detection limit, as for heavy metals. The cause for the higher Pb concentration in tap 1 was not determined in this study, it would have either been generated by some contamination from the larger supply infrastructure or from the water source. Methodology quality control suggests that it was unlikely to originate from contamination during analysis.

For elements dominated by tap water, the contribution is proportional to the volume of water used in the household and adopted by each appliance. Hence, larger element loads would be expected from the appliances that consume more water, i.e., washing machine (159L), the shower (34.5L) and toilet (25.2L). Examples of elements with loads derived from tap water include Ca, F and Mg.

Consequently, for elements sourced mainly from tap water demand reduction measures would be effective in reducing the overall load to sewer.

3.11.2 Products

Products played an important role in the loads generated in the field house.

For elements such as Al, As, B, Cr, Cd, Pb, Se, Na, Sn and TDS products were estimated to be the dominant source in the household (Figure 31, **Figure 32** and Figure 33).

The overall load varied depending on the element considered. In grey water, with the exception of Al, Na and TDS, the majority of the elements were generally present in trace amounts.

The loads generated are also expected to vary depending on the different brands and products used in a household. Na and S are commonly present in compounds used in the formulation of household products. But elements such as As, Co, Cr, Cd, Pb and Sn whilst potentially arising from household products are most likely contaminants in raw materials or from the production process.

The contribution of products and water to the nutrient loads was in general small, representing less than 5% of the load for the field house. In individual streams the contribution from products was observed to range from 0.3% to 20% of the load.

Consequently, the reduction of elemental loads dominated by products can be based on (i) product selection, (ii) reformulation, when elements are used as ingredients; or (iii) increased quality and process control during manufacture, for elements present as contaminants. In the case of contaminants, this might be difficult to achieve given the small concentrations expected.

3.11.3 Human input

As expected the human load was the major source of contaminants in black water and also the major source of nutrients within the household, contributing to 94-95% of the loads. Besides nutrients, human input was also a dominant source of Sb (99.6% load), Cl (75% load), Cu (55% load), Co (60% load), K (98% load), Ni (99% load), Fe (41% load), Pb (88% load), Mo (70% load) and Zn (92% load) as shown in Figure 33.

Human input also contributed to a range of other elements including Al, B, Ca, F, Na, Mg, Na, S and Zn in the field house. In individual streams the importance of the contribution to the total load was generally dictated by the contribution from the other two sources, tap water and products.

Overall, human inputs that had a significant input of organic matter and amino acids had a more significant contribution in wastewater streams, such as the toilet which receives excreta, the dishwasher and the kitchen sink, which receive food residues, compared to the vanity unit, shower and the washing machine.

Strategies for load reduction of elements whose major source is human input would have to focus on the separation of black water streams from wastewater.

Conversely, strategies such as water demand management are likely to result in higher concentrations of such elements in the household discharge (but will not change loads).

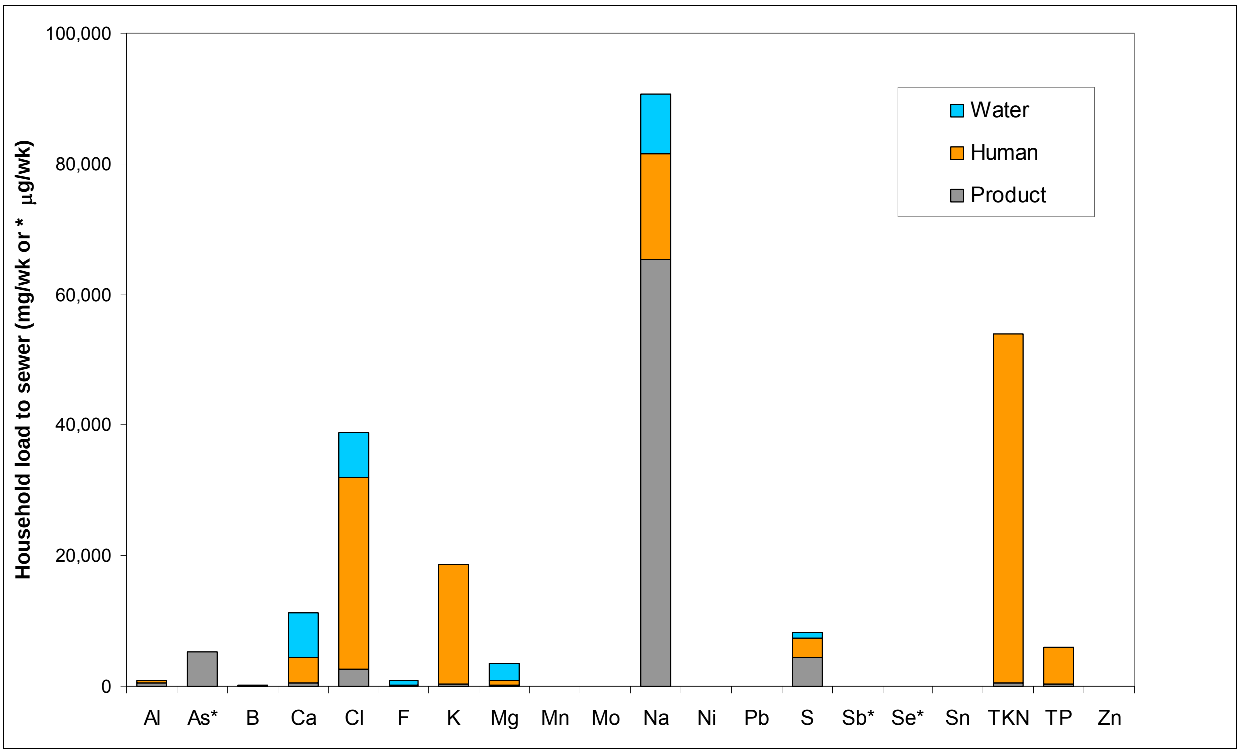


Figure 30: Contribution of tap water, human inputs and products to the household loads discharged to sewer. The units for As, Sb and Se loads are in µg/L.

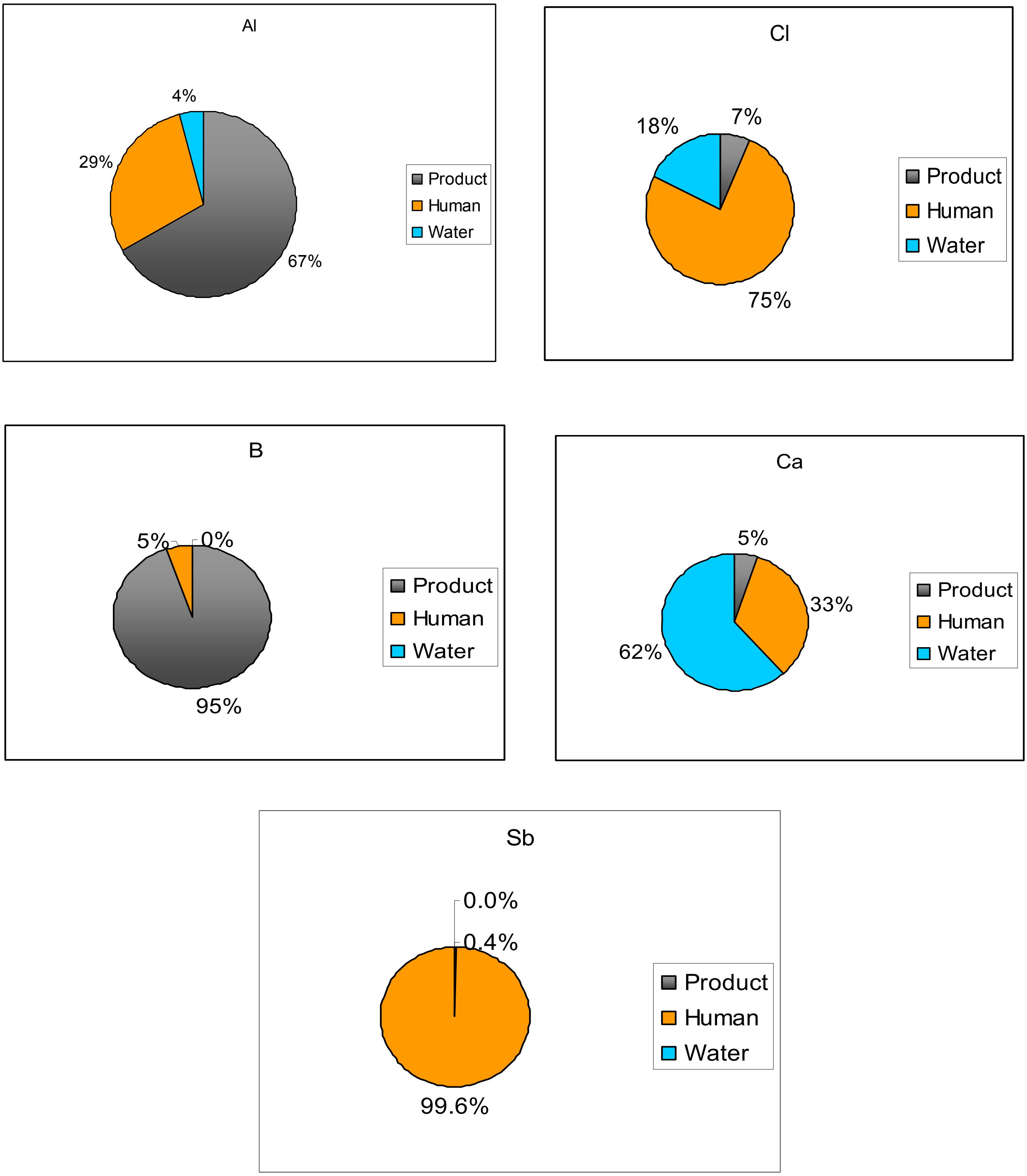


Figure 31: Distribution of field house mass load per sources (Al to Sb)

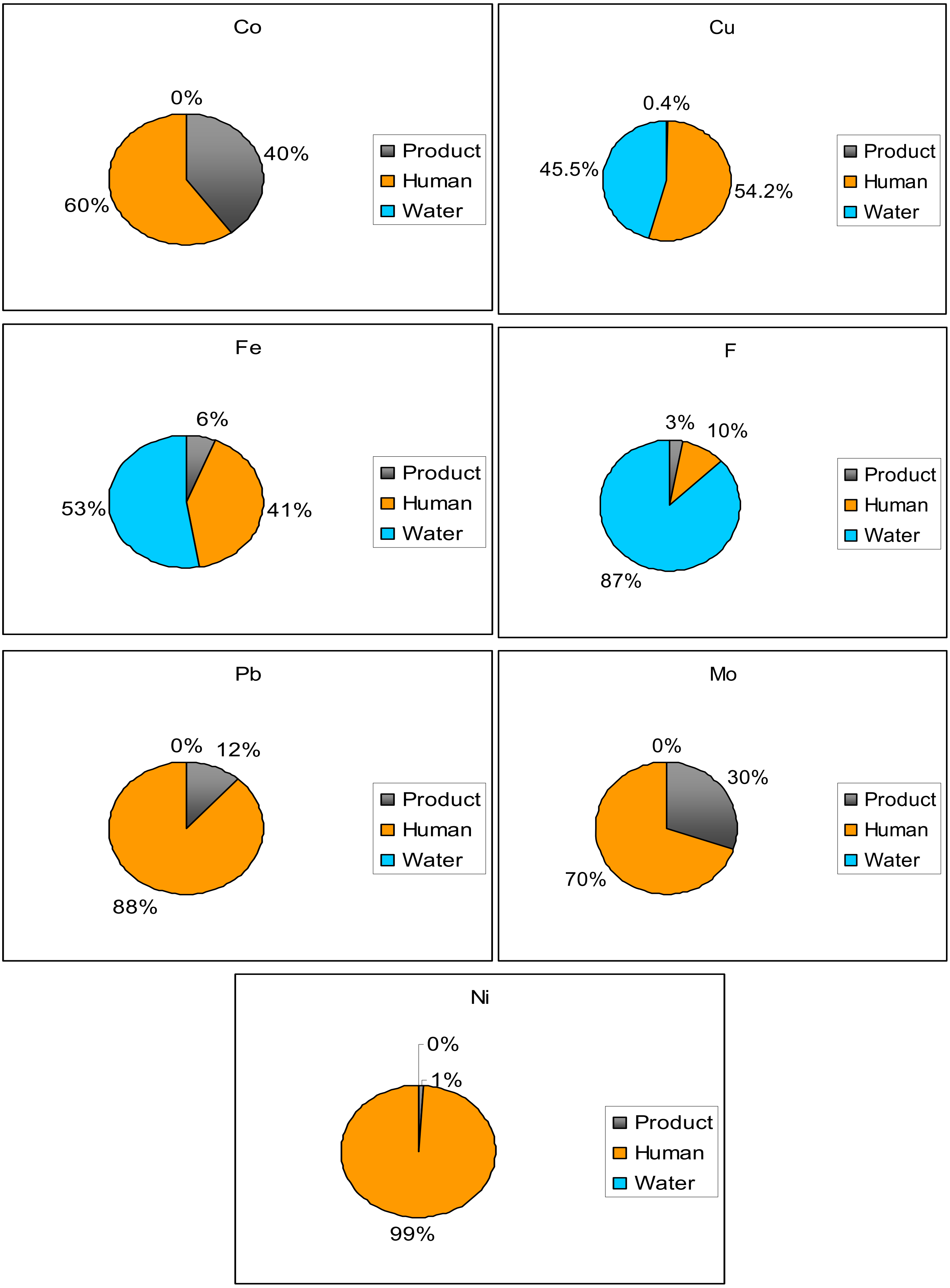


Figure 32: Distribution of field house mass load per sources (Co to Ni)

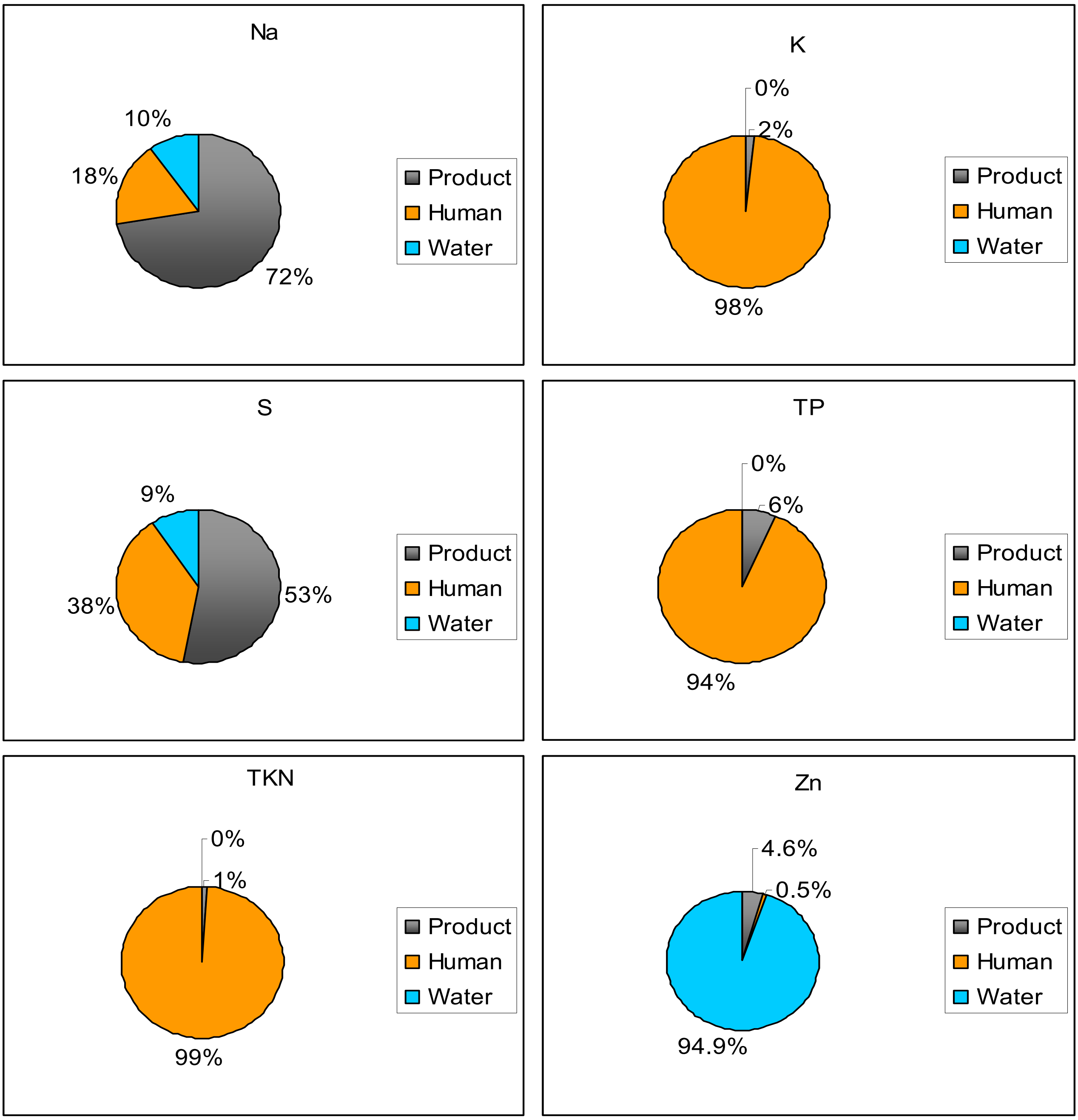


Figure 33: Distribution of field house mass load per sources (Na to Zn)

3.12 Comparison with the literature

The loads estimated for the field house were compared to some of the loads reported using data in the literature. The studies used for comparison included:

- Grey and Becker (2002): a desktop assessment using tap water concentration values from Perth and data collated from the international literature.
- Koch and Rotard (2001): a desktop assessment using faeces data collated from the literature and experimental German data for urine and other wastewater streams.
- Vinneras *et al* (2006): experimental data from the assessment of household wastewater in Sweden.
- Chino *et al* (1991): experimental data from the assessment of household wastewater in selected households in Japan.
- Tjandraatmadja *et al* (2008): Estimates of maximum load from product use based on experimental analysis of a limited number of brands and human input from literature data.

Table 49 compares the mass loads among the studies. In addition,

Table 50 shows the contribution of tap water and each of the major household streams to the overall household load. As not all elements evaluated in this study were reported in the literature, therefore the mass load comparison was conducted only for the elements available: As, B, Cd, Cu, Cr, K, Pb, Hg, Ni, Na, Zn and TDS; and the source breakdown was conducted for Cd, Cr, Cu, Ni, Fe, Pb, N, and P.

Overall, the results show that the loads estimated and the source attribution differ for studies conducted at different locations.

The probable causes for such variation stem from differences in water quality, diet and infrastructure, as in the case of Japan (Chino *et al* 1996) and Perth (Gray and Becker 2002), whether concentrations or loads were measured experimentally after dilution in wastewater (Vinneras *et al* 2006) or estimated from literature (Gray and Becker 2002) or if they were a combination of both methods as in Koch and Rotard (2001) and in this study.

The analysis of urine samples determined by Koch and Rotard (2001) has shown that the loads expected for elements such as Cd, Cr, Pb and Hg would have resulted in concentrations too low to be detected in wastewater. Although the presence of such elements would be plausible, uncertainties also remain regarding any differences in waste composition between Australia and Germany given the differences in the environment, infrastructure and diet in the two countries. The same argument also applies to the Japanese study (Chino *et al* 1996).

The loads in the earlier CSIRO study are the maximum load estimated based on highest contaminant concentration in a selected range of household products and literature values for human input. They provide an indication of the potential variability due to differences in product brand use (Tjandraatmadja *et al* 2008). A larger number of products was adopted in that study and brands also differed from those used in the field house. For instance, laundry powder and fabric softener were added to the washing machine, toilet freshener and toilet paper were used in the toilet and in the bathroom shaving cream, skin products, sunscreen and deodorant were adopted in addition to the shampoo, conditioner and body wash (Tjandraatmadja *et al* 2008).

Table 49: Wastewater loads from selected studies around the world

	Mass load (mg/pe/wk) (excludes water)				
Reference	This study	Vinneras *et al*	Gray and Becker	Koch & Rotard Blackwater only	Tjandraatmadja *et al* Product maximum
Year	2008	2006	2002	2001	2008
Location	Melbourne	Sweden	Australia	Germany	Melbourne
As	5.3	nd	nd	0.09	6.14
B	177.9	nd	nd	nd	2,088
Cd	0.03	0.31	0.51	0.07	3.12
Cu	127.48	56.33	84.38	13.82	15.52
Cr	0.25	nd	nd	0.42	4.22
Pb	3.15	6.87	30.07	0.28	2.16
Hg	0	0.09	nd	0.01	0.07
Ni	16.28	9.20	nd	nd	3.43
K	18,714	33,178	nd	nd	nd
Na	90,629	nd	nd	nd	111,990
TDS	329,102	nd	863,014	nd	nd
TN	54,028	96,849	103,562	nd	nd
NH_4	nd	nd	81,699	nd	Nd
TP	6,062.15	14,153	12,504	nd	Nd
Zn	53.96	145.1	76.71	78.15	3,404

Note: nd – not determined.

3.12.1 Arsenic

In the literature, Koch and Rotard (2001) and others had identified the presence of As in urine by analysing urine samples. At the concentrations reported by Koch and Rotard any As present in black water would have been below the limit of detection.

Yet, the load estimated in this study for household products was five times the load reported in black water by Koch and Rotard (2001).

Hence, the presence of As in black water is plausible, but the urine contribution would have been minimal compared to the expected grey water load in the field house.

3.12.2 Boron

The field house load was equivalent to 8.5% of the maximum load estimated in Tjandraatmadja *et al* (2008). Thus, in the worse case scenario much larger loads could be expected from household wastewater.

3.12.3 Cadmium

The loads estimated in our study were one and two orders of magnitude lower than the loads estimated by Vinneras *et al* (2006) and Gray and Becker (2002), and for Tjandraatmadja *et a*l (2008), respectively. For Cd, the load in black water reported by Koch and Rotard (2001) would have been below the limit of detection, however it would have increased the field house total load by 133%.

The use of a different range and brands of products could also have produced a load 10 times larger than that observed in the field house (Tjandraatmadja *et al* 2008).

In the Australian studies tap water was a negligible contributor to the Cd load, but not in the Japanese study where it was responsible for 22% of the load (Chino *et al* 1991) as shown in Figure 34.

In this study the bathroom was deemed the major source of Cd, at 60%, whilst in the other studies all streams were expected to add to the load with the toilet considered to be the dominant contributor (

Table 50).

3.12.4 Copper

The loads reported in this study and in the literature (Vinneras 2006 and Gray and Becker 2002) are similar in magnitude, but for Tjandraatmadja *et al* (2008) which was equivalent to 11% of the field house load.

In this study tap water and the toilet were assessed to be the predominant sources of the Cu load. Whilst Chino *et al* (1991) and Gray and Becker (2002) identified the bath as the dominant source (>60% load). However, the loads estimated for the other streams differed markedly between the last two studies as shown in Figure 34.

3.12.5 Chromium

Loads reported in this study, 0.25 mg/pe/wk, were of the same magnitude as those reported by Koch and Rotard (2001) for black water. Although the load for black water reported by Koch and Rotard (2001) is plausible, it would have been below the limit of detection in wastewater.

In this study the product was considered the major source of the load. The earlier CSIRO study shows that a load 17 times larger could be generated with a different range of products (Tjandraatmadja *et al* 2008).

The wastewater streams from the bath, the laundry and the kitchen were considered potential sources of Cr in this study and in Chino *et al* (1996). The Japanese study attributed a larger contribution to tap water, 28% and contributions of 8%, 25%, 37% and 2% to the kitchen, bath, laundry and faeces, respectively.

3.12.6 Lead

The load estimated in this study, 3.15 mg/pe/wk was of a similar order of magnitude as Vinneras *et al* (2006) and Tjandraatmadja *et al* (2008) and one order of magnitude lower than Gray and Becker (2002). The contribution from black water, 2.78 mg/L was higher than the value reported by Koch and Rotard (2001).

In regards to load distribution there were differences between the studies. Tap water and the bath, the laundry and the kitchen were selected as the dominant Pb sources for each of the respective studies, (Chino *et al* 1991, Gray and Becker 2002 and this study) as shown in Figure 34.

3.12.7 Mercury

Hg was reported in the overseas studies at 0.01mg/pe/wk in urine (Koch and Rotard 2001), at 0.07mg/pe/wk ((Tjandraatmadja *et al* 2008) and at 0.09mg/pe/wk for mixed wastewater (Vinneras *et al* 2006). However, it was not detected in this study. The urine load estimated in the overseas studies would have resulted in a concentration too low for detection using the ICP/MS.

3.12.8 Nickel

The estimated Ni load was of the same order of magnitude as the Swedish study (Vinneras *et al* 2006) and approximately 80% larger than the load estimates in the earlier CSIRO study (Tjandraatmadja *et al* 2008).

Regarding source distribution, this study identified the laundry as the dominant source of Ni, whilst in Chino *et al* (1996) the bath had that role and tap water and black water also were also contributing streams.

3.12.9 Potassium

The load of potassium in this study was 44% lower than that reported in the Swedish study (Vinneras *et al* 2006).

3.12.10 TDS

The TDS load estimated in this study was equivalent to 38% of the load reported in Gray and Becker (2002). This may be partly attributed to use of an ‘environmentally friendly’ brand of laundry detergent in the field house which claimed to produce garden safe grey water.

In this study majority of the TDS was attributed to the laundry, whilst in Gray and Becker (2002), which is based on Perth’s tap water, it was attributed to the water supply. Perth‘s water is more saline and has a higher TDS than Melbourne’s.

3.12.11 Total nitrogen

Vinneras *et al* (2006) and Gray and Becker (2002) reported similar loads of nitrogen of approximately 100g/pe/wk. The nitrogen load estimated for the mini-house was approximately 50% lower. All three Australian studies consider the toilet as the major source of nitrogen as shown in Figure 35. The loads expected for the other wastewater streams (kitchen, bathroom, laundry) were of a similar order of magnitude among the studies.

3.12.12 Total phosphorus

Vinneras *et al* (2006) and Gray and Becker (2002) reported loads of total phosphorus of approximately 13 g/pe/wk. The phosphorus load estimated for the field-house was approximately 50% lower. Both Australian studies considered the toilet as the predominant source of P in the household. But the contribution from the vanity unit in this study was estimated to contribute up to 30% of the load, whilst in Gray and Becker 23% of the load was attributed to sources other than the toilet as shown in Figure 35.

3.12.13 Sodium

At 90.6 g/pe/wk, the field house load was equivalent to 81% of the maximum load estimated in Tjandraatmadja *et al* (2008). The other studies (Vinneras *et al* 2006, Gray and Becker 2002 and Koch and Rotard 2001) did not analyse Na in wastewater. However, loads of Na derived from Australian brands of laundry detergents alone could vary from as little as 2 to over 600 g/pe/wk (Choice 2007, Patterson 1999).

Thus, larger loads could be generated in household wastewater.

3.12.14 Zinc

The Zn load was of the same order of magnitude as reported by Gray and Becker (2002), but the load here estimated was 30% lower. The overseas studies reported 90% larger loads for Zn and the loads in the 2008 study were 63 times larger.

Gray and Becker (2002) had also commented that the concentrations they estimated were one to two times the concentrations they had expected (Gray and Becker 2002).

Gray and Becker (2002), Tjandraatmadja *et al* (2008) and Chino *et al* (1991) considered the bath as the major source of Zn within the household (>60% load), whilst in this study the toilet was deemed the dominant source (>75%) and the bath was a minor contributor with less than 1% of the load as seen in Figure 36.

In the case of the earlier CSIRO study, the bulk of the load was due to the contribution of the products used in the bathroom (Tjandraatmadja *et al* 2008).

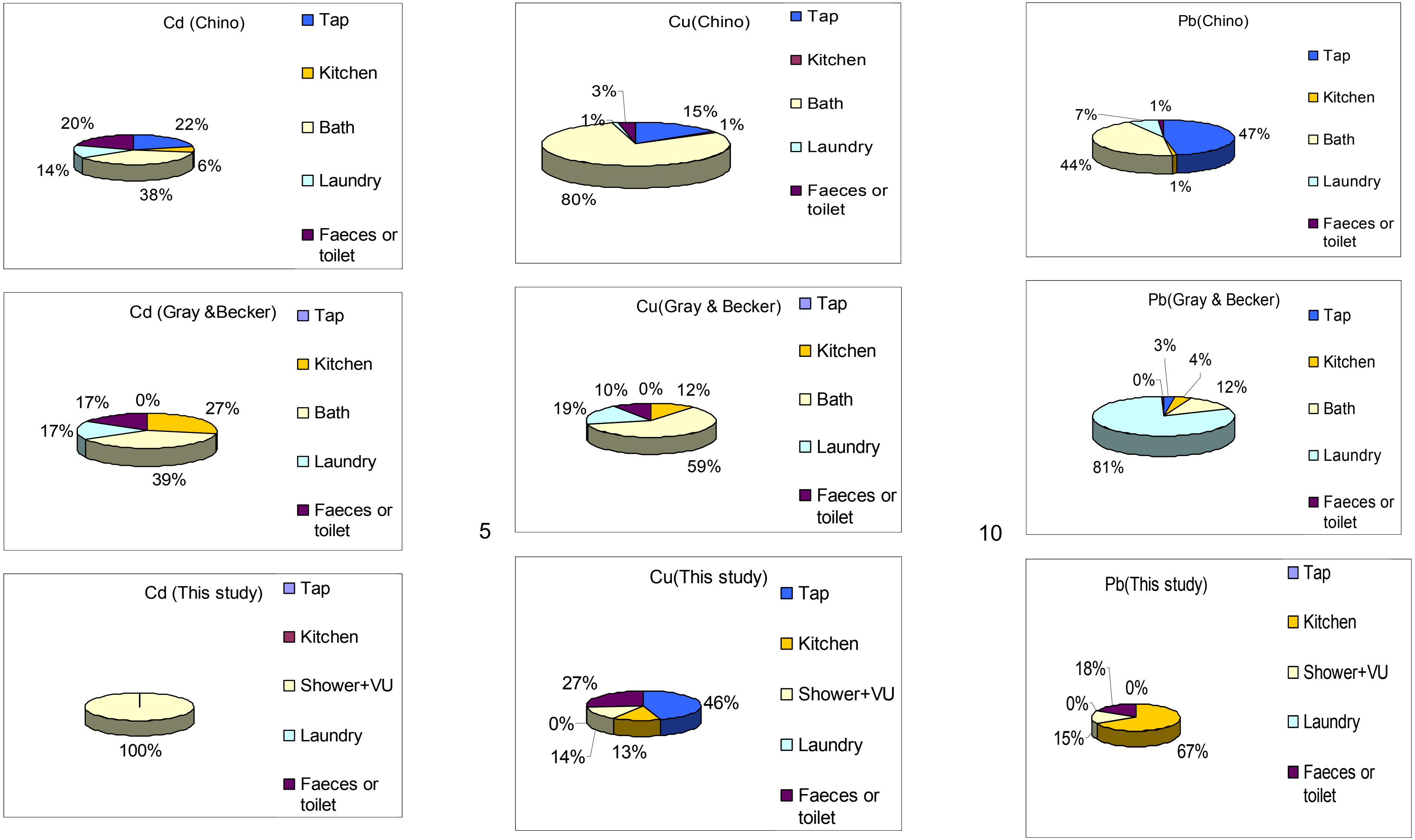


Figure 34: Household loads comparison (Cd,Cu and Pb)

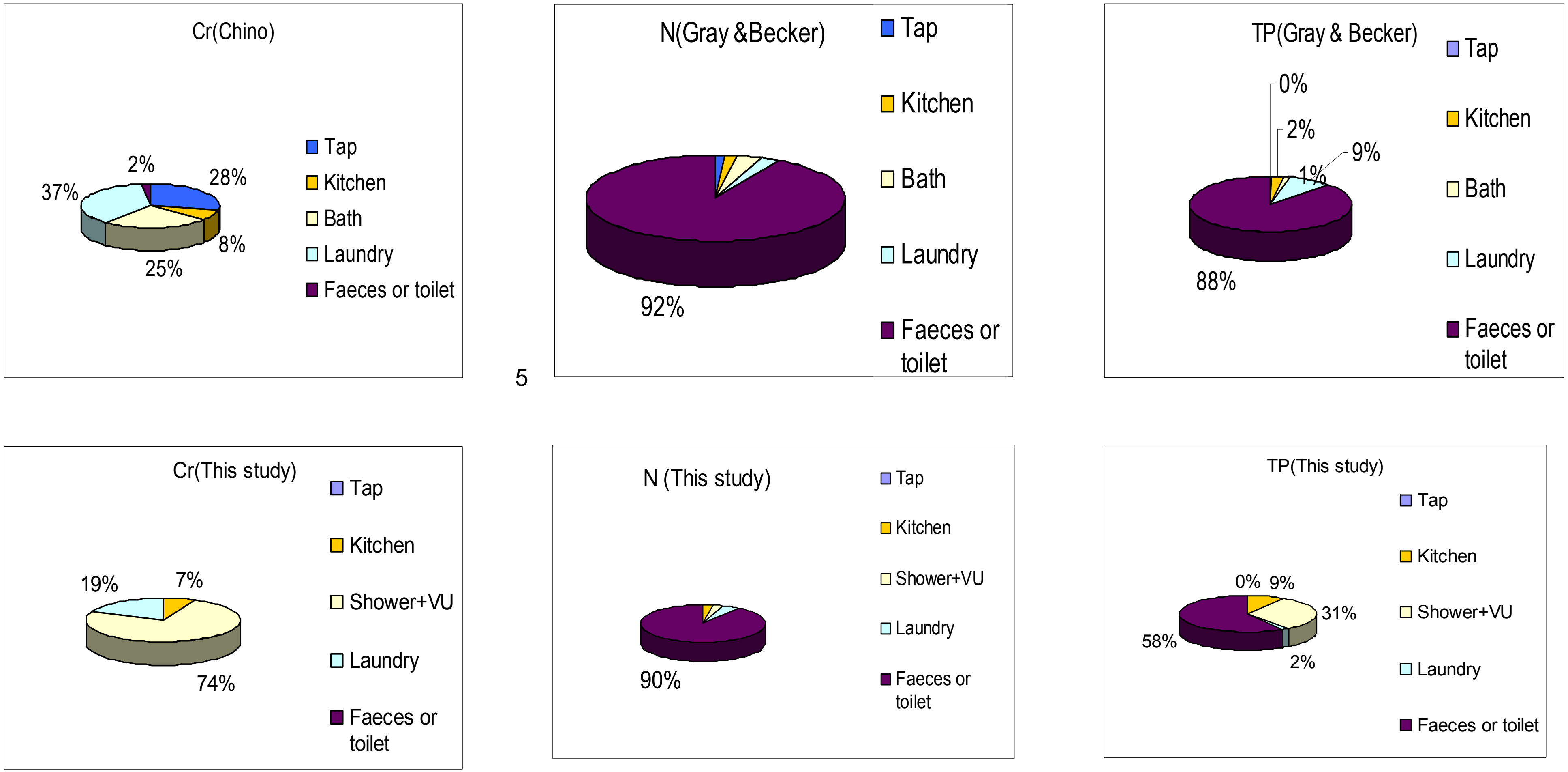


Figure 35: Household loads comparison (Cr, N and P)

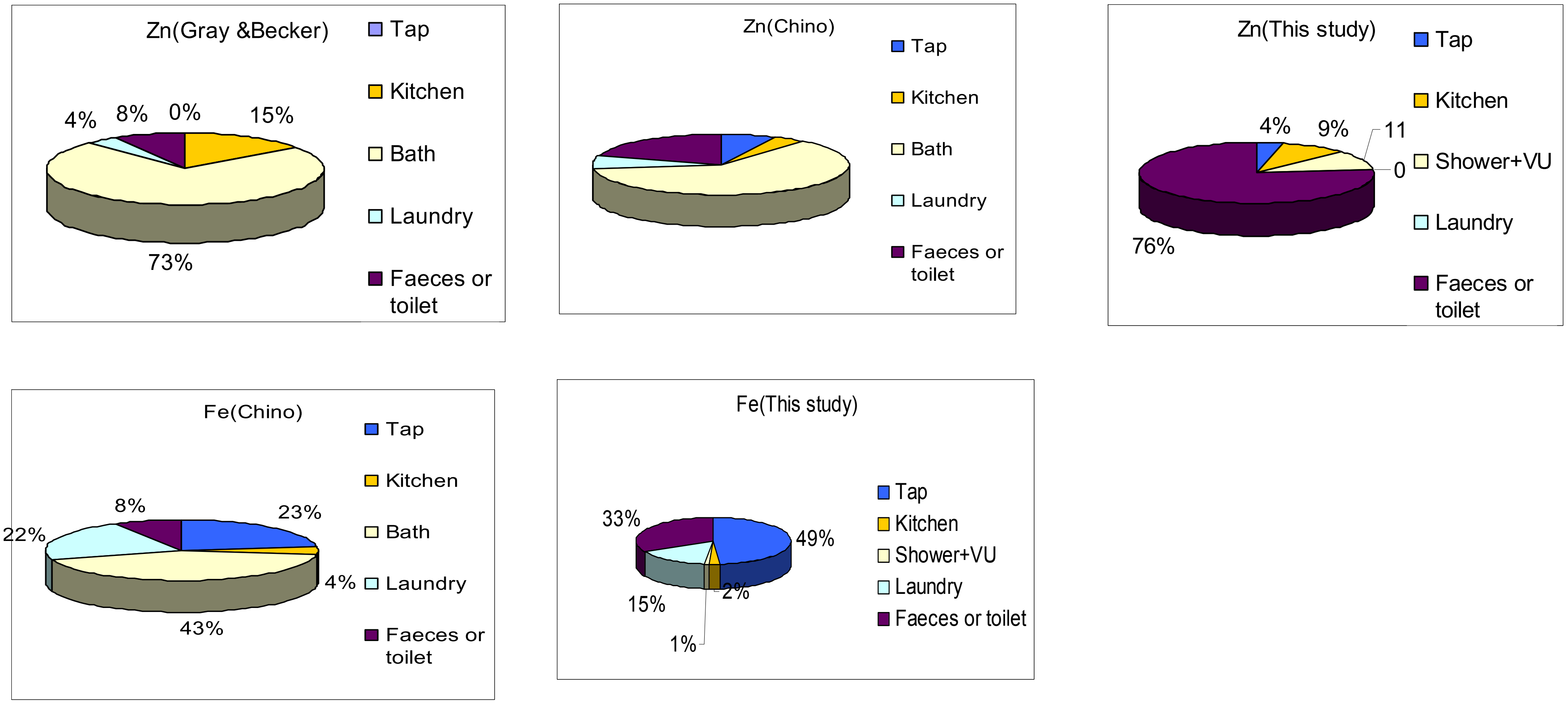


Figure 36: Household loads comparison (Fe and Zn)

Table 50: Load contribution for sources in a household

Element	***Contribution to total load (%)***														
	Tap			*Kitchen*			*Bath*			*Laundry*			*Faeces or toilet*		
	Chino	Gray & Becker	Current study	Chino	Gray & Becker	Current study	Chino	Gray & Becker	Current study	Chino	Gray & Becker	Current	Chino	Gray & Becker	Current study
Cd	22	0	0	6	27.5	0	38	39.5	59.8	14	16.5	0	20	46.5	0
Cr	28	nd	0	8	nd	6.93(DW)	25	nd	47.3	37	nd	18.9	2	nd	0
Ni	23	nd	0	9	nd	2.8(DW)	41	nd	0.19	15	nd	96.04	12	nd	0
Cu	15	0	45.48	1	11.5	10.77-13.25	78	60.1	1.79	1	18.5	0.21	3	9.9	49.15
Fe	23	nd	52.91	4		1.86-2.66	43	nd	0	22	nd	16.1	8	nd	75.8
Zn	7	0	3.66	4	14.6	1.06-8.3	62	73.3	0.52	7	3.8	0.09	20	8.3	79.25
Pb	47	2.6	0	1	3.8	13.2-56.9	44	12.2	2.98	7	81	0	0	0.5	16.49
N	nd	1.2	0.02	nd	1.6	0.88-1.73	nd	3.1	1.7	nd	2.2	4.8	nd	92.2	90.19
P	nd	0.4	0	nd	2.4	3.1-5.7	nd	1.2	0.8	nd	8.5	1.8	nd	87.5	58.4
TDS	nd	63.8	15.76	nd	4.1	6.05-6.85	nd	3.9	0.93	nd	4.4	41.9	nd	33.7	nd

Note: nd – not determined, DW – dishwasher.

3.13 Evaluation limitations and constraints

The field house study was conducted within the constraints generated by the site's conditions and the experimental environment. The appliance operation was dependent on the volunteer family and on the individuals that participated in the trial. The location and the site's infrastructure impacted the quality of tap water. The time of sampling was also impacted by the operation patterns of each appliance. Studies described in the literature suffer from similar constraints and are affected by their specific environmental conditions.

It can be argued that this study and similar studies that focus on source characterisation are typically constrained by their specific study envelope, and hence that results need to be viewed under that context. This itself is a source of variance and uncertainty between studies.

3.13.1 Infrastructure constraints

Attempts were made to control the environmental conditions and to maximise the reproducibility in the assessment. For example when evaluating the impact of contaminant sources:

(a) The mini-house provided an environment with infrastructure comprised of known materials (copper pipes for water, PVC for wastewater), known age (the set-up was less than one year old) and known history. The mini-house had been purposefully built for a previous Smart Water fund project, the 'Smart meter monitoring of water use'. In that project, appliances were operated with water only, and during this study all appliances and pipework were flushed before and after each use to minimise the accumulation of residues and contamination in the pipe infrastructure. This was intended to ensure that cross-contamination due to corrosion or leaching of infrastructure or due to organic matter deposition did not occur, and hence that each load assessed was caused only by the contaminants in the wastewater stream discharged at the time.

(b) The earlier use of the mini-house with the water monitoring project also allowed the initial flushing of the system which would have removed any excess contaminants present in appliances or infrastructure from manufacture.

Whilst infrastructure within the mini-house was controlled, infrastructure and water quality to the mini-house building could not be controlled. Particularities dictated by the site infrastructure, were observed here, for example in the high water pH supplied into the building that housed the mini house and in the different qualities recorded for the tap water supplied to the house during the occasions of the testing of the washing machine and the other appliances.

3.13.2 Householder behaviour

Householder preferences are very particular and difficult to monitor – this study aimed to characterise in the greatest detail possible the variables of householder behaviour by measuring the amount, brand and chemical composition of the products used in the evaluation, as well as the volume of water discharged by each appliance and setting adopted.

The field house assessment is based on conservative assumptions for conservative product use and operational settings. For instance, the assessment assumed that the washing machine was used only for full wash loads; it did not consider the inclusion of laundry aids or fabric softeners in the laundry, nor the use of household cleaning products in the toilet and other appliances. Under such condition higher elemental loads would be expected.

Human input was the source of greatest uncertainty in the data obtained. It is difficult to measure, particularly in grey water. It is also highly variable and therefore it was assessed using a mass balance approach. However, this also meant that in the assessment, there is a tendency to under represent the human contribution compared to the other sources (water and products) which were evaluated first.

3.13.3 Sampling and equipment constraints

This study and also a number of earlier ones including (Diaper *et al* 2008) showed the importance of temporal effects on the evaluation of wastewater (Almeida *et al* 1999). That is given the variability in schedules and operation of appliances within a household, the sampling process needs to be evaluated in the context of the discharge volume and profile. In such cases composite or flow proportional samples representative of the total wastewater discharge as used here would give a better indication of the actual load discharged, than grab samples which could suffer if samples experienced uneven dispersion of solids during wastewater discharge.

The sensitivity of instrumentation and the detection limits of analysis can also pose constraints in the assessment. As observed in the data, and in particular in the case of heavy metals, such as for Cd, and Se, these elements were at times present in ppb or lower concentrations, and as a result, when diluted in wastewater, the final concentration was below detection. This was exemplified for elements such as Cd, Cr, Mo, Sn and Se, which were detected in products but not in the final wastewater stream. The same argument would apply to the loads for Cd, Cr and Hg in urine, as reported by Koch and Rotard in Germany (Koch and Rotard 2001) .

3.13.4 Assessment limitations

Hence, while understanding the range of concentrations of contaminants encountered in wastewater gives an indication of the quality of wastewater generated, it does not allow the direct comparison of the actual load generated by the different sources, nor the evaluation of the impact of those wastewater streams on the overall wastewater discharged by the household in view of differences in volume of wastewater generated by different appliances, their patterns of use, initial water quality, etc. For example, as seen for Pb, variability in source water quality from one day to another affected the absolute concentrations and can mask the actual contribution that passage of water through a household has.

Thus to better understand the distribution and sources of priority contaminants in the field house and to facilitate comparison with other studies, the approach of estimating the mass load and the correction of the water source was adopted.

Comparison of the contaminants on a load basis allows a more rigorous evaluation of the true impact of the different household streams to the composition of wastewater. The weekly mass load takes into account the volume of wastewater generated and the frequency of appliance use in each application based on a comparable time unit.

The mass loads are not applicable to pH, ORP, colour and EC, which are the result of the combined effect of the different wastewater streams.

Among the activities monitored, the largest uncertainty demonstrated was verified for the vanity unit and the toilet. The toilet was affected by variability in the number of users and the type of waste discharged each day. In addition in the assessment it was not possible to monitor the mass of products discharged in the toilet as accurately as for the other appliances due to privacy. For the vanity unit, despite the small volume of water used the loads estimated indicate that tap water was the major contributor for a range of elements.

As the assessment method combined results from the experimental analysis with results from the laboratory analysis of products as received the detection limits in products were larger than in the wastewater samples.

As a result, the theoretical load estimated from the sum of each of the individual sources (product, water and human input) was at times larger than the wastewater load. This was particularly observed for elements that were present in minute amounts either at or close to the limits of detection. In such case, the variance associated with the loads was often as large as or even larger than the concentration or load itself. This was observed in the standard deviation values estimated for each of the loads (Appendix 3).

In a few streams and elements the discrepancy between the loads estimated using the mass balance method were significantly larger (Z>3). This was the case for Al, Fe, K and S in the vanity unit and Al in black water attributed to products (Table 60 and Table 62 in Appendix 2). A number of factors could have contributed to this discrepancy, for instance potential uneven dispersion of the product sample used in the analysis given the small size of the analytical sample (1-2 g).

Recapitulating, the results often show a higher mass of contaminants based on the product analysis compared to the wastewater flow measurements, most often any discrepancy between the estimated values based on break down of streams and the actual wastewater composition was explained by the variance in product doses, the concentrations and volumes.

Overall, it would be expected that the results here shown and the loads estimated are conservative.

Removal of contaminants was assumed to be insignificant in comparison to the amount that remains, e.g. conditioner and shampoo in hair, residues in washed laundry, but this might not necessarily be true.

Breakdown of the data on a source basis provides an indication of the potential loads that could be generated and assists to understand the role of sources on wastewater quality. For some elements the breakdown is simple as specific sources have a much more significant role than others. Typical examples are nutrients in black water and sodium in washing machines. However, in the case of elements present in small amounts or close to detection limit, the breakdown could vary significantly based on the concentrations measured.

Blackwater was the stream that carried the greatest uncertainty in regards to source breakdown. Volume and concentrations of the total discharge per day were evaluated and the mass of toilet paper used was recorded on a daily basis, however the values displayed significant variability from one day to another. This was partly caused by the difficulty in controlling the number of users on a day to day basis and also in ensuring that every single user logged his/her appliance use.

Hence, in the case of black water, the mean contribution for specific elements was used to provide an indication of the contribution per source. But the actual allocation per source could vary significantly for elements equally derived from tap water and also from human excreta as in the case of B. For other elements such as nutrients, K, Cl and S the major input comes from human excreta. Overall the elemental contribution from toilet paper to black water pales in comparison to the other sources.

The literature suggests that human excreta could potentially contribute to the load of metals such as As, Cd, Cr and Hg, as verified in overseas studies (Schouw *et al* 2002, Koch and Rotard 2001, Chino *et al* 1991) and result in ppb loads, but as previously discussed its quantification in wastewater would be a challenge and therefore the loads for these metals may be underrepresented in this study.

The results also showed that the quality of tap water can have a major role in the overall loads in wastewater. As observed from the loads derived using the three water qualities (Tap 1, 2 and 3), the quality of water supply always needs to be included to access the baseline for quality. For parameters, such as fluoride and magnesium which are derived mainly from water supply, the elemental loads will generally correspond to the volume adopted by the different appliances. But for other parameters, present in minute amounts, such as heavy metals this relationship does not apply.

4 Conclusions and recommendations

Common household activities such as laundry washing, showering, doing the dishes and using the bathroom were analysed in a controlled environment. The activities undertaken by volunteers were conducted in the manner that the volunteers usually undertake them in their homes, but were conducted instead at the Highett laboratories to minimise the influence from disparate infrastructure. For each activity the volume of wastewater generated was recorded and samples of water, wastewater and products used were analysed for priority contaminants.

Results were used to estimate the contribution of each of the appliances to the total contaminant load discharged from a household and also to quantify the impact that each contaminant source (tap water, products and/or human input) has on the quality and loads of contaminants in wastewater using a mass balance method.

pH

The range of pH values observed in the field house wastewater varied from 7.1 to 10.1. The pH in wastewater is predominantly determined by human inputs in streams that have a significant organic content, such as kitchen wastewater and black water, and is determined by products added to the wash in grey water from the shower, washing machine and vanity unit. The pH of wastewater was generally basic.

Electrical conductivity

Electrical conductivity ranged from 114 to 1354 μS/cm. In individual household wastewater streams, it ascended in the order of: Tap water, vanity unit, kitchen sink, wash machine, dishwasher and toilet.

Oxidation-reduction potential

Oxi-reduction potential (ORP) ranged from +57.93mV to +173mV, i.e. within the oxidative range. It varied across the wastewater streams generated by each appliance and readings were also influenced by the temperature of wastewater. The ORP ascended in the order of: washing machine, shower, dishwasher, tap water, kitchen sink, vanity unit.

Colour

Colour: Human input was the major source of colour within the field house with values in wastewater ranging from 8 to 727 PCU. Colour measurements based on Platinum Cobalt readings should be considered as a qualitative comparator as some of the wastewater generated was characterised by a different hue from yellow and also exhibited some turbidity after filtration, both factors that can affect the true colour reading.

Total dissolved solids

The weekly load of total dissolved solids (TDS) in individual household wastewater streams ascended in the order of: shower, vanity unit, dishwasher, kitchen sink, toilet and washing machine. In grey water from the washing machine, dishwasher and vanity unit its major cause were the products added to the wash. In black water and in the kitchen sink the major source of TDS was human input (human and food waste).

Element concentrations

The concentration of priority contaminants was compared to selected earlier studies from Australia and overseas. The literature did not always have data on all of the specific streams and elements monitored in the field house. Hence, the comparison refers to specific streams only.

(a) Elements in the field-house wastewater which were generally present within a similar concentration magnitude as previously reported in the Australian literature included Al, As, Ca, Cd, Cl, Cr, Cu, F, Pb, Hg, K, Mg, Mn, Mo, TKN, Na, Ni, S and Se. The concentrations for Sb, B, Cd, Co, Hg, Mn, Se and Mo were often below the limit of detection and estimated to be either in the ppb range or lower in both Australian and overseas studies.

(b) Concentrations of Fe and Zn were lower than those reported in the Australian literature.

(c) On the other hand, the concentrations for Al, Ca, Cr, Cu (for black water), K, TP, S and Zn reported in overseas studies were significantly higher compared to the field-house values. And the concentrations for Cu (for washing machine and dishwasher grey water) and TKN reported overseas were lower than those reported here. These differences may be attributed to variation in water quality, infrastructure and lifestyle for different countries.

Load distribution per appliance within the field house

Loads for each of the elements discharged from the field house were assessed. The washing machine wastewater was responsible for the majority of the field house load for Al, Sb, As, Ca, Cu, F, Fe, Na and Ni. The shower was the prevalent contributor for B, Cd, Cr and Sn. Whilst the toilet was the major contributor of Cl (in conjunction with the dishwasher and washing machine), Fe, Mo, K, S, TKN, TP and Zn.

The loads evaluated for the field house differ from some of the earlier results reported in the literature. For example the loads for TKN and TP were approximately 50% lower than those reported in studies such as Gray and Becker (2002) and Vinneras *et al* (2001).

Furthermore, the load contribution per wastewater stream within the field house differed from those reported in studies such as Gray and Becker (2002) and Chino *et al* (1991). For instance, Cu was estimated to originate mainly from the bathroom (≈60% and 78% load) in those two studies, whilst in the field house the bathroom contribution was estimated to be only 14.5% of the total load, with tap water contributing to most of the load from the household 45.5%.

According to overseas studies, the load of heavy metals in human excreta is usually too small to be detected once diluted in wastewater. Hence, metals such as Cd and Ni, whilst undetected in the waste streams could still be present in black water. In addition, the concentrations and hence the loads for metals such as Pb and Cr which are detected at or close to the limits of detection have a larger probability of being subject to a larger error.

In assessing concentrations variability was observed between the runs in regards to water quality, human inputs, doses of products and consequently the characteristics of the wastewater. The wastewater streams which carried the greatest uncertainty were the toilet and the vanity unit. In the case of the toilet this was caused by the variability in use patterns and the difficulty in quantifying inputs due to privacy. In the case of the vanity unit, the elemental loads for Fe, K and S and for Al in both the vanity and in black water were in excess of the observed loads.

Origin of contaminants

The breakdown of the overall field house load per source: tap water, products or human input, using the mass balance model considers:

(a) Products used in the field house as the major potential sources of Al, As, B, Cd, Cr, Pb, Na, Se, Sn and TDS;

(b) Tap water as the major potential source of Ca, Cu, F, Fe, Zn and Mg;

(c) Human input as the major potential source of Sb, Cl, Mo, Ni, S, TKN and TP.

Implications

This report aimed to develop an understanding of the different contaminant sources in the Melbourne context and their impact on wastewater. Whilst the data generated is in many aspects specific to the field house set-up, it did encompass current appliances, water quality and products and also tried to minimise the interference from external sources, such as pipe corrosion or biofilm.

Overall, the mass balance model adopted in this study and the loads estimated will tend to be conservative. The model may also tend to under represent some of the loads derived from human inputs. A more accurate evaluation of the heavy metal input from human excreta would require the evaluation of undiluted samples, which was not within the scope of this study.

The study does however, provide an indication of the role that the different sources have on the loads generated in the household and by each of the individual appliances.

Understanding the source of contaminants allows the evaluation of strategies for controlling loads at the source. For instance, in the field house (i) reduction in water demand would be effective in decreasing the load of Cu, F, Mg and Zn discharged to sewer; (ii) product selection could potentially be used to limit the loads of Na, As, B, Cd, Cr and TDS; and (iii) for loads derived from human input, control measures would be more complex, but separation of streams such as urine separation could be used to alter the loads entering the sewer.

It was not within the scope of this report to evaluate the effectiveness of different source control strategies in reducing the loads of priority contaminants into sewer. This will be evaluated as a future task in the research.

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Appendix 1 – Field house results

Table 51: Appliance runs

Washing Machine	**TKN mg/L**	**TP mg/L**	**Fluoride mg/L**	**Chloride mg/L**
Wash 1	7.2	0.18	1	11
Wash 2	3.7	0.16	0.99	10
Wash 3	7.6	0.25	0.99	13
Wash 4	2.5	0.12	1	9
Wash 5	6.7	0.46	0.99	15
Dishwasher	**TKN mg/L**	**TP mg/L**	**Fluoride mg/L**	**Chloride mg/L**
Wash 1	25	11	0.98	270
Wash 2	26	18	1	260
Wash 3	17	8.5	0.98	270
Wash 4	5.3	9.9	0.99	260
Wash 5	17	8.7	1	280
Shower	**TKN mg/L**	**TP mg/L**	**Fluoride mg/L**	**Chloride mg/L**
Wash 1	6	0.12	0.98	2
Wash 2	4.6	0.16	0.97	9
Wash 3	4.2	0.12	0.95	8
Wash 4	5.6	0.12	0.97	8
Wash 5	4.1	0.12	0.98	12

Table 52: Appliance runs (Sinks)

Kitchen sink	DO mg/L	pH	EC (uS/cm)	ORP mV	Temp °C	TDS mg/L	TKN mg/L	TP mg/L	Fluoride mg/L	Chloride mg/L	Wash Volume (L)	Mass of Products used g/L
Run1	6.7	6.6	279	156	32.2	270	0.6	<0.08	0.83	24	8.00	0.829
Run2	6.4	7.5	354	127	32.2	260	14	3	0.85	51	8.125	1.047
Run3	6.2	7.3	327	112	37.3	420	7.8	1.3	0.86	77	9.25	0.944
Run4	6.2	8.2	321	104	38.3	270	18	4.1	0.91	57	8.25	0.980
Run5	6.1	5.9	347	206	37.5	470	7.4	1	0.8	68	7.25	1.268
BLANK	5.8	9.3	192	86	39.9	140	7.3	1.6	0.8	74	3.50	1.549

Bath-room Sink	DO mg/L	pH	EC (uS/cm)	ORP	Temp °C	TDS mg/L	TKN mg/L	TP mg/L	Fluoride mg/L	Chloride mg/L	Wash Volume (L)	Mass of Products used g/L
Run1	8.8	7.9	193	187	18.0	550	9.7	42	1.4	15	2.5	9.461
Run2	8.7	7.6	246	161	18.5	1000	18	85	1.3	22	1.375	18.384
Run3	8.7	8.0	205	149	19.2	610	14	59	1.5	18	2.125	13.190
Run4	8.1	8.6	180	180	16.0	640	12	48	1.1	17	2.17	11.932
Run5	8.7	7.8	210	190	16.4	870	13	86	1.7	21	2.00	13.984
BLANK	6.2	8.6	247	118	36.5	920	12	66	1.4	18	2.00	14.8186

Table 53: Mean concentration of priority elements in wastewater from the field house

		Washing Machine	*Dish washer*	*Shower*	*Kitchen sink*	*Vanity unit*	*Toilet block*	*Tap 1*	*Tap 2*	*Tap 3*
Volume of water discharged per appliance[1] (L/wash or as stated)		159	15.9	34.4	8.2	2.0	25.2 L/pe/d			
Element	**units**	**6 washes**	**6 washes**	**5 washes**	**5 washes**	**5 Washes**	**11 days**	**6 samples**	**9 samples**	**10 samples**
Al	mg/L	1.91	0.27	0.37	0.09	0.22	0.082	0.25	0.039	0.11
Sb	μg/L	3.40	3	<2	<2	<2	<0.5	2.50	<2	<0.5
As	μg/L	<5	<5	<5	<5	<5	<4	<5	<5	<4
B	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	0.0915	<0.02	<0.02	0.0433
Ca	mg/L	7.17	11.733	7.681	8.730	81.470	15.4615	7.652	7.066	5.03
Cd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<1	<0.001	<0.001	<1
Cl	mg/L	13.200	265	12.4	58.5	18.5	90.3	7.0	7.0	4.5
Co	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.001	<0.005	<0.005	<0.001
Cr	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<2	<0.005	<0.005	
Cu	mg/L	0.17	0.811	0.121	0.250	1.22	0.470769	0.22	0.109	0.105
F	mg/L	0.996	0.992	0.76	0.844	1.4	0.02	0.817	0.817	<0.1
Fe	mg/L	0.09	0.121	0.110	0.140	0.19	0.5462	0.06	0.115	0.1
Hg	μg/L	<2	<2	<2	<2	<2	<2	<2	<2	<2
K	mg/L	5.80	13.225	<0.01	9.880	4.5	92.0769	3.15	<0.01	0.77
Mg	mg/L	1.47	1.628	2.132	2.630	2.5	5.5846	1.09	2.637	1.39
Mn	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.1	<0.0002	<0.0002	<0.1
Mo	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	0.0026	<0.005	<0.005	<0.001
Na	mg/L	116.58	260.644	13.474	37.430	27	87.2308	8.34	9.252	4.75
Ni	mg/L	0.01	0.020	<0.003	<0.003	<0.003	<0.003	<0.01	<0.003	<0.003
P	mg/L	0.22	12.18	0.256	1.83	64.33	47.1	<0.05	<0.05	0.25
Pb	mg/L	0.50	0.563	<0.01	0.01	0.01	0.0046	0.50	<0.01	0.0017
S	mg/L	3.53	2.363	6.790	9.790	16	18.538	1.34	0.786	0.84
Se	μg/L	<5	<5	<5	<5	<5	<2	<5	<5	<4
Sn	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.2
TKN	mg/L	5.45	16.7	5.02	9.09	13.12	276.7	0.01	0.01	0.01
Zn	mg/L	0.01	0.220	<0.001	0.0030	0.15	0.26	0.07	0.002	0.013

Note: [1] Denotes the volume of water used by each appliance in the field house. The washing machine and the dishwasher were supplied with Tap water (1), the toilet was supplied with Tap water (3) and the remainder appliances with tap water (2).

Table 54: Standard deviation of wastewater readings

SD Element	units	***Washing Machine*** 6 washes	***Dish washer*** 6 washes	***Shower*** 5 washes	***Kitchen sink*** 5 washes	***Vanity unit*** 5 Washes	***Toilet block*** 11 days	***Tap 1*** 6 samples	***Tap 2*** 9 samples	***Tap 3*** 10 samples
Al	mg/L	0.3977	0.0505	0.0754	0.0170	0.1132	0.0186	0.0706	0.0085	0.0350
Sb	µg/L	1.7224	1.2111	0	0.1090	0	0	1.3663	0	0
As	µg/L	0	0	0	0	0	0	0	0	0
B	mg/L	0	0	0	0	0	0.0828	0	0	0.0184
Ca	mg/L	0.9995	3.6098	0.1931	0.7809	19.6592	2.3381	0.8919	0.3702	0.3974
Cd	mg/L	0	0	0	0	0	0	0	0	0
Cl	mg/L	3.4928	10.4881	1.5166	19.6036	2.5884	94.5473	0	0	0.5477
Co	mg/L	0	0	0	0	0	1.3205	0	0	0
Cr	mg/L	0	0	0	0	0	0	0	0	0
Cu	mg/L	0.0867	0.1958	0.0185	0.1097	0.9866	0.0794	0.0714	0.1051	0.0321
F	mg/L	0.0055	0.0098	0.0524	0.0417	0.2000	0.0816	0.0354	0.0354	0
Fe	mg/L	0.0972	0.0716	0.0213	0.0206	0.0781	0.1169	0.0209	0.0736	0
Hg	µg/L	0	0	0	0	0	0	0	0	0
K	mg/L	1.9264	5.2753	0	7.9632	2.9177	17.4289	0.0131	0	0.1889
Mg	mg/L	0.2498	0.2463	0.0598	0.4081	0.4479	0.6535	0.0757	0.6802	0.0568
Mn	mg/L	0	0	0	0	0	0	0	0	0
Mo	mg/L	0	0	0	0	0	0	0	0	0
Na	mg/L	23.3363	17.9072	0.9456	8.3119	4.3229	20.1957	0.5524	0.0828	0.2759
Ni	mg/L	0.0134	0.0230	0	0	0	0	0	0	0
P	mg/L	0.1234	4.2273	0.0654	1.4760	18.4029	2.1909	0	0	0.1080
Pb	mg/L	0.0081	0.0368	0	0.0093	0.0141	0.8165	0.0052	0	0.0015
S	mg/L	0.4932	0.3136	1.1669	2.5598	4.0731	3.5449	0.1836	0.0373	0.0516
Se	µg/L	0	0	0	0	0	0	0	0	0
Sn	mg/L	0	0	0	0	0	0	0	0	0
TKN	mg/L	2.0599	8.1457	1.1692	6.2090	2.7860	52.4087	0	0	0
Zn	mg/L	0.0246	0.2759	0.0000	0.0062	0.1577	0.0868	0.0963	0.0063	0.0048

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Table 55: Field house product dosages and appliance volume

Appliance		***Washing machine***		***Shower***		***Dishwasher***		***Kitchen sink***		***Vanity Unit***	
Element	**Units**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Dose	g/wash	56.9	3.3	30.8	6.3	10.8	0.5	10.5	0.1	26.3	2.15
Volume	L/wash	159	33.05	34.5	2.88	15.9	0.88	8.2	0.71	2.03	0.41

Table 56: Elemental composition of household products used in field house

Element	***units***	***Laundry***	***Deodorant***	***Shampoo***	***Conditioner***	***Bath gel***	***Dishwashing powder***	***Kitchen detergent***	***Hand wash***	***Tooth paste***	***Mouth wash***
Al	mg/kg	3160	10240	1.1	4.1	13.2	27	11.25	229	9.57	9.4
As	mg/kg	0.028	0	0	0	0	1	0	6	0.0295	0.47
B	mg/kg	21	0.0000	2575.0000	0	0	<4	22	1,028	29.3	4.7
Ca	mg/kg	70	0.85	6.7	16	6.5	597	35.00	1156	2325.4	9.8
Cd	mg/kg	0	0	0	0.31	0	<0.05	1.7	0.18	0	0
Co	mg/kg	0	0.0000	0.8800	0	1.2	<0.1	0.05	0	0	0
Cr	mg/kg	0.279	0.0000	0.8800	0	1.2	0.9	0.185	1.2	0	0
Cu	mg/kg	1.58	0	0	0	0	3.2	5.00	0.61	0	0
Fe	mg/kg	4.37	0	0	0	0	<10	7.65	40	101.6	357
Hg	mg/kg	0	0	0	0	0	0	0	0	0	0
K	mg/kg	775	74198	66.0	18	214	1310	129.00	1027	12.2	1223.9
Mg	mg/kg	31	0	16	4	27	35	18.00	220	306	0
Mn	mg/kg	0	0	0	0	0	0	0	0	0	0
Mo	mg/kg	1	1.1800	0.0580	0.049	0.02	0.1	0	0	0	0
Na	mg/kg	327318	248.5	3477	51	10974	326000	9636.00	6839	5067	24.5
Ni	mg/kg	0	0	0.0300	0.21	0.27	0	1.5	2.6	0.442	0
Pb	mg/kg	0.00	0	0.158	1.755	0.023	0	3.21	0	0	0
S	mg/kg	10325	104	16139	3	8383	1180	9889.00	25821	1800	149
Sb	mg/kg	0	0	0	0	8383	0.1	0	0	0.143	0
Se	mg/kg	0.04	0	0	0	0	0	0	0	0	0.0844
Sn	mg/kg	0	0.4	0	0	0	0	1.26	0	0	0

Element	*units*	*Laundry*	*Deodorant*	*Shampoo*	*Conditioner*	*Bath gel*	*Dishwashing powder*	*Kitchen detergent*	*Hand wash*	*Tooth paste*	*Mouth wash*
Zn	mg/kg	0.28	0	0.8	1.3	2.6	2.7	6.60	17	0.04	0.88
F	mg/kg	8.00	0	0	0	0	17.12	0.00	0	1098	0
Cl	mg/kg	1310.00	52117	1828	13749	13749	46639	10789	2712	5	20
TKN	mg/kg	31.20	3724	7447	1327	2373	29.95	269.70	3143	0	0
TP	mg/kg	106.00	3.4	14.2	5.5	27	8340	1.9	4613	196.31	6.3

Appendix 2 – Field house: Load estimation by mass balance method

Load evaluation process

(a) Estimate total mean load and evaluate standard deviation (SD);

(b) Estimate load expected from water supply for blank field house run and evaluate SD;

(c) Estimate load expected from product for field house run and evaluate SD;

(d) Calculate anthropogenic load (total load –load from supply –load from products –load from infrastructure if known)

(e) Compare total estimated load with experimental load, evaluate discrepancy based on SD.

(f) Identify significant outliers and apply correction if required (Variation > 3SD). Correction is based on maximum experimental load. The load estimation is prioritised following Tap>product> human.

Grey water

The estimated contribution per source and the discrepancy between the experimental and evaluated results for grey water appliances using the mass balance method are illustrated in Figure 37 and shown in detail in Table 57 to Table 61.

As seen in Figure 37, the mass balance method overestimated the mass load of 25.9%, 22.2%, 11%, 11% and 25.9% of a total of 27 elements in the washing machine, shower, dishwasher, kitchen sink and vanity unit.

In the estimation, a number of streams were present in trace amounts (ppb or lower) which were not detected experimentally given the detection limits of the analytical instrumentation. The resulting loads whilst small can be significant to the overall load generated by a catchment containing many houses. Examples include As and B in the washing machine wastewater shown in Table 57, Cd, Cr and Mo in the shower wastewater shown in Table 58 and As, Cr and Mo in the dishwasher (Table 59), etc.

Majority of the variation in mass loads were within 2.5 standard deviations of the wastewater results, SD_{ww}, and could be explained by a normal data distribution or were attributed to the variance in the loads attributed to individual sources. In such cases, the distribution per sources based on the estimated loads was adopted in the mass balance model.

The major exception was in the vanity unit for Al, Fe, K and S. In that case the difference between the loads estimated using the 2 methods was larger than 3 SD_{ww}. The respective Z-values were 3.08, 37, 3.2 and 3.8 as shown in Table 61.

For those elements the mass load for the product and distribution per sources were re-evaluated based on the experimental load and the load of tap water and is also shown in the table.

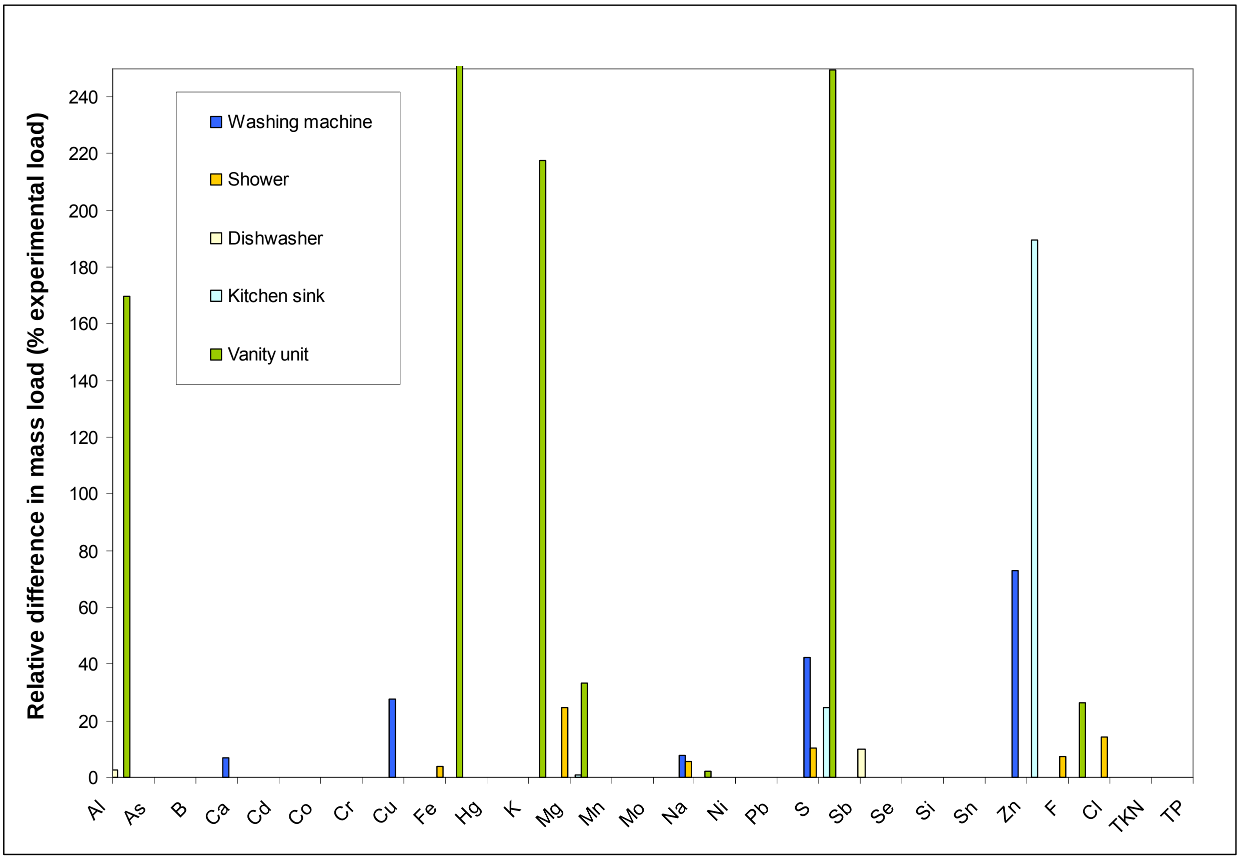

Figure 37: Difference in mass loads estimated using the experimental and mass balance methods.

Table 57: Estimated Load contribution per source in wastewater for wash machine in field house

Wash machine					
Element	***Product***	***Human***	***Water***	***(Est. load –Exp.load) Δmass (% experimental load.)***	***Comment***
Al	59.08	27.59%	13.32	0	
As	100	0	0	<LOD	Load detected in product, but too small for detection in wastewater
B	100	0	0	<LOD	Load detected in product, but too small for detection in wastewater
Ca	0.33	0	99.67	+7.04	Discrepancy within SD_{ww}.
Cd	<LOD	<LOD	<LOD	<LOD	
Co	<LOD	<LOD	<LOD	<LOD	
Cr	100	0	0	<LOD	
Cu	0.26	0	99.74	+27.82	Discrepancy within SD_{ww}.
Fe	1.74%	35.94%	62.32%	0	
Hg	<LOD	<LOD	<LOD	<LOD	
K	4.78%	40.85%	54.37%	0	
Mg	0.74%	25.36%	73.89%	0	
Mn	<LOD	<LOD	<LOD	<LOD	
Mo	100.00%	0.00%	0.00%	<LOD	
Na	93.35%	0.00%	6.65%	+7.62	Discrepancy within SD_{ww}.
Ni	0.00%	100.00%	0.00%	0	

Pb	0	0	100	0	
S	73.38%	0.00%	26.62%	+42.49	Conc tap> conc ww, but less than 1 SD_{ww}
Sb	0.00%	99.91%	0.09%	0	
Se	100.00%	0.00%	0.00%		Load detected in product, but too small for detection in wastewater
Sn	<LOD	<LOD	<LOD	<LOD	
F	0.29%	17.64%	82.08%	0	
Cl	3.70%	41.04%	55.26%	0	
TKN	0.20%	99.61%	0.18%	0	
TP	16.98%	83.02%	0.00%	0	
Zn	0.15%	0.00%	99.85%	+72.82	Conc tap> conc ww, but less than 1 SD_{ww}
F	0.15%	0.00%	99.85%	0	
Cl	0.29%	17.64%	82.08%	0	
TKN	3.70%	41.04%	55.26%	0	
TP	0.20%	99.61%	0.18%	0	

Table 58: Estimated Load contribution per source in wastewater for shower in field house

Shower					
Element	**Product**	**Human**	**Water**	***(Est. load –Exp.load) Δmass (% exptal load.)***	**Comment**
Al	75.29%	14.16%	10.55%	0.00	
As	<LOD	<LOD	<LOD	0.00	
B	100.00%	0.00%	0.00%		Load detected in product, but too small for detection in wastewater
Ca	0.11%	7.89%	92.00%	0.00	
Cd	100.00%	0.00%	0.00%	<LOD	Load detected in product, but too small for detection in wastewater
Co	100.00%	0.00%	0.00%	<LOD	Load detected in product, but too small for detection in wastewater
Cr	100.00%	0.00%	0.00%	<LOD	Load detected in product, but too small for detection in wastewater
Cu	0.00%	10.26%	89.74%	0.00	
Fe	0.01%	0.00%	99.99%	+3.94	Difference within 1 SD of water
Hg	<LOD	<LOD	<LOD	0.00	
K	100%	0.00%	0.00%	<LOD	
Mg	0.56%	0.00%	99.44%	+24.42	Mass in water larger than wastewater but SD_w=27%
Mn	<LOD	<LOD	<LOD	0.00	
Mo	100%	0.00%	0.00%	<LOD	Load detected in product, but too small for detection in wastewater
Na	34.99%	0.00%	65.01%	+5.61	
Ni	100.00%	0.00%	0.00%	<LOD	
Pb	100.00%	0.00%	0.00%	<LOD	
S	89.52%	0.00%	10.48%	+10.54	More in sum than in wastewater, but

					SD_p=11.7%
Sb	<LOD	<LOD	<LOD	0	
Se	<LOD	<LOD	<LOD	0.00	
Sn	100%	0.00%	0.00%	<LOD	
Zn	42.03%	0.00%	57.97%	<LOD	Load detected in product, but too small for detection in wastewater
F	0.00%	0.00%	100.00%	+7.46	Difference within 1 SD of water SD_w=9.41%
Cl	50.59%	0.00%	49.41%	+14.26	Difference within 1 SD_{ww}
TKN	27.43%	72.37%	0.20%	0.00	
TP	5.85%	94.15%	0.00%	0.00	

Table 59: Estimated Load contribution per source in wastewater for dishwasher in field house

Dishwasher					
Element	**Product**	**Human**	**Water**	***(Est. load –Exp.load) ∆mass (% exptal load.)***	**Comment**
Al	6.72%	0.00%	93.28%	+2.56	Within SD
As	100.00%	0.00%	0.00%	<LOD	Load detected in product, but too small for detection in wastewater
B	<LOD	<LOD	<LOD	0.00	
Ca	2.18%	32.60%	65.22%	0.00	
Cd	<LOD	<LOD	<LOD	0.00	
Co	<LOD	<LOD	<LOD	0.00	
Cr	100.00%	0.00%	0.00%	<LOD	Load detected in product, but too small for detection in wastewater
Cu	0.27%	72.59%	27.15%	0.00	
Fe	0.00%	53.76%	46.24%	0.00	
Hg	<LOD	<LOD	<LOD	0.00	
K	6.74%	69.42%	23.84%	0.00	
Mg	1.46%	31.80%	66.74%	0.00	
Mn	<LOD	<LOD	<LOD	0.00	
Mo	100.00%	0.00%	0.00%	<LOD	Load detected in product, but too small for detection in wastewater
Na	96.81%	0.00%	3.19%	+0.18	
Ni	0.00%	100.00%	0.00%	0.00	
Pb	0.00%	11.15%	88.85%	0.00	
S	33.98%	9.29%	56.73%	0.00	
Sb	0.00%	0.00%	100.0%	+7.15	Variation within 1SD_{ww}, SD_w=54%
Se	<LOD	<LOD	<LOD	0.00	
Sn	<LOD	<LOD	<LOD	0.00	
Zn	0.82%	69.53%	29.65%	0.00	
F	1.18%	16.47%	82.35%	0.00	
Cl	11.98%	85.38%	2.64%	0.00	
TKN	0.12%	99.82%	0.06%	0.00	
TP	22.31%	77.69%	0.00%	0.00	

Table 60: Estimated Load contribution per source in wastewater for kitchen sink in field house

Kitchen sink					
Element	**Product**	**Human**	**Water**	***(Est. load –Exp.load)*** ***Δmass (% exptal load.)***	**Comment**
Al	12.6%	43.7%	43.7%	0.00	
As	<LOD	<LOD	<LOD	0.00	
Ca	0.40%	18.67%	80.92%	0.00	
Cd	<LOD	<LOD	<LOD	0.00	
Co	<LOD	<LOD	<LOD	0.00	
Cr	<LOD	<LOD	<LOD	0.00	
Cu	1.87%	57.69%	40.43%	0.00	
Fe	5.29%	15.97%	78.74%	0.00	
Hg	<LOD	<LOD	<LOD	0.00	
K	1.10%	98.90%	0.00%	0.00	
Mg	0.57%	0.00%	99.43%	+20.56	Within 1 SD_w
Mn	<LOD	<LOD	<LOD	0.00	
Mo	<LOD	<LOD	<LOD	0.00	
Na	24.19%	52.74%	23.07%	0.00	
Ni	<LOD	<LOD	<LOD	0.00	
Pb	71.86%	28.14%	0.00%	0	Potential more from prod
S	92.85%	0.00%	7.15%	-24.65	Load generated by product higher than expected, within $1.65SD_p$
Sb	<LOD	<LOD	<LOD	0.00	
Se	<LOD	<LOD	<LOD	0.00	
Sn	100.00%	0.00%	0.00%	<LOD	Load detected in product, but too small for detection in wastewater
Zn	76.06%	0.00%	23.94%	+189.55	Amount generated by product higher than expected,SD_w is high, results within SD of both and SD_{ww} .
F	0.00%	3.24%	96.76%	0.00	
Cl	0.22%	89.08%	10.70%	0.00	
TKN	2.49%	97.42%	0.09%	0.00	
TP	0.18%	99.82%	0.00%	0.00	

Table 61: Estimated Load contribution per source in wastewater for vanity unit in field house

Vanity unit					
Element	**Product**	**Human**	**Water**	***(Est. load –Exp.load) Δmass (% exptal load.)***	**Comment**
Al	93.40% (82.20%)	0.00% (0.00%)	6.60% (17.8%)	+169.69	Amount generated by product higher than expected. But variation within 3.08 SD_{ww}, SD_p=16%, SD_w=29.7%
As	100.00%	0.00%	0.00%	<LOD	Small amount detected in Product, but too small for detection in ww
Ca	5.41%	85.92%	8.67%	0.00	
Cd	100.00%	0.00%	0.00%	<LOD	Small amount detected in Product, but too small for detection in ww
Co	<LOD	<LOD	<LOD	0.00	
Cr	100.00%	0.00%	0.00%	<LOD	Small amount detected in Product, but too small for detection in ww
Cu	0.10%	91.00%	8.90%	0.00	
Fe	97.02% (43.87%)	0.00% (0.00%)	2.98% (56.13%)	+1786.52	Amount generated by product higher than expected. Variation 37.4 SD_{ww}, SD_p=4.75%, SD_w=67.3% (outlier)
Hg	<LOD	<LOD	<LOD	0.00	
K	100.00%	0.00%	0.00%	+217.74	Amount generated by product higher than expected. But variation within 3.2 SD_{ww}, SD_p =5.07%
Mg	21.03%	0.00%	78.97%	+33.40	
Mn	<LOD	<LOD	<LOD	0.00	
Mo	<LOD	<LOD	<LOD	0.00	
Na	66.34%	0.00%	33.66%	+1.95	Within 1 SD_{ww}
Ni	100.00%	0.00%	0.00%	<LOD	Small amount detected in Product, but too small for ww detection
Pb	0.00%	100%	0.00%	0.00	
S	98.58% (95.02%)	0.00% (0.00%)	1.42% (4.98%)	+249.48	Amount generated by product higher than ww detected. Variation=3.8SD_{ww}, SD_p=18.6%,
Sb	100.00%	0.00%	0.00%	<LOD	Small amount detected in Product, but too small for ww detection
Se	100.00%	0.00%	0.00%	<LOD	Small amount detected in Product, but too small for ww detection.
Sn	<LOD	<LOD	<LOD	<LOD	
Zn	20.70%	78.29%	1.01%	0.00	
F	53.75%	0.00%	46.25%	+26.13	Variation within 1.05 SD_{ww}
Cl	30.11%	32.25%	37.63%	0.00	
TKN	47.68%	52.25%	0.08%	0.00	
TP	15.94%	84.06%	0.00%	0.00	

Note: (##) – breakdown after correction.

Blackwater

In the case of black water, the mass loads were estimated using the individual readings and used to determine means, standard deviations, ranges and the distribution per source. In black water the concentration of some elements and the volumes of backwater were observed to vary markedly from one day to another, which affected the load estimations and are also reflected in the standard deviations. In Table 62 data is shown as a range: minimum and maximum, average and standard deviation of the loads as a percentage of the total load.

The mass of product, toilet paper, was generally very small compared to the mass of water adopted in the appliance. The contribution from toilet paper to the elemental load was similarly minute, being equivalent to less than 1% of the total load for 84% of the elements compared to the other streams. Products were identified as a major contributor to the Al load only, but there was a very high standard deviation associated with the loads 192% and hence results should be used cautiously. Product analysis had been carried in duplicate.

The largest variability in loads among all elements was observed for B, as seen in Table 62. The contribution that tap water and human input can have varies from less than 10% to almost 90%. The human input can be assumed as the dominant source though given that the concentration of B in tap water tends to have a narrower range of variability.

The individual elements are here discussed.

Al	Tap water in the building contained less than 0.011mg/L (SD ± 0.035 mg/L). Hence values in tap water samples was either low or below the limit of detection. In wastewater Al was present. Analysis of the toilet paper revealed a high load of Al which was assumed to be the main source contributing between 90-100% of Al. however, the mass of product estimated was also characterised by a high SD equivalent to 53.2% of the mean.
As	Concentrations were below the limit of detection in all streams (water supply, products and wastewater).
B	It was detected in all streams and exhibited high variability from one day to another. The tap water contribution ranged from 4.8-86.7%, Product 0.24-1.9%, human 11.4-93.4%. Standard deviations of the mass loads were high for tap and product respectively 56.5% and 53.2% of the means.
Ca	It was detected in all streams. Tap water contribution ranged from 26.5-41%, Product 6.42-20.4%, human 38.9-62.14%. Standard deviations of the mass loads were high for tap and product respectively 56.5% and 53.2%.
Cd	Concentrations were below the limit of detection in all streams (water supply, products and wastewater).
Co	It was detected in all streams. Tap contribution ranges from 1.5-6%, Product 0.48-1.6%, human 93.4-98%. Standard deviations were high for tap water and product respectively 56.5% and 53.2%.
Cr	Concentrations were below the limit of detection in all streams (water supply, products and wastewater).
Cu	It was detected in all streams. Tap water contribution ranges from 19-33%, Product 0.01-0.05%, human 67-89 Standard deviations of the mass loads were high for tap and prod respectively 27% and 53%.
Fe	It was detected in all streams. Tap water contribution ranges from 14-25%, Product 4-

	14%, human 60-78%. Standard deviations of the mass loads were high for tap water and prod respectively 27% and 53%.
Hg	Concentrations were below the limit of detection in all streams (water supply, products and wastewater).
K	It was detected in all streams. Tap water contribution ranges from 0.74-1.31%, Product 0.01-0.03%, human 98-99.8%. Standard deviations of the mass loads were high for tap and prod respectively 27% and 53%.
Mg	It was detected in all streams. Tap contribution ranges from 22-30%, Product 2.8-7.7%, human 62-71%. Standard deviations of the mass loads were high for tap and prod respectively 27% and 53%.
Mo	It was not detected in tap water, but present in product 0.11%-0.57% and human inputs 99.4-99.9%. The standard deviation for product load was 53%.
Na	It was detected in all streams. Tap water contribution ranged from 4.4-9.7%, Product 0.03-0.17%, human input 90-96%. Standard deviations of the mass loads were high for tap water and product respectively 27% and 53%.
Ni	Concentrations were below the limit of detection in all streams (water supply, products and wastewater).
Pb	It was detected in all streams. Tap water contribution ranges from 25-38%, Product 0-0.01%, human 62-74%. Standard deviations of the mass loads were high for tap and prod respectively 56.5% and 53.2%.
S	It was detected in all streams. Tap contribution ranges from 4-7%, Product 0.1-0.6%, human 92-96%. Standard deviations of the mass loads were high for tap and prod respectively 56.5% and 53.2%.
Sb	Concentrations were below the limit of detection in all streams (water supply, products and wastewater).
Se	Concentrations were below the limit of detection in all streams (water supply, products and wastewater).
Sn	Concentrations were below the limit of detection in all streams (water supply, products and wastewater).
Zn	It was detected in all streams. Tap contribution ranges from 3.3-7.6%, Product 0.3-0.8%, human 91.5-96.4%. Standard deviations of the mass loads were high for tap and prod respectively 27% and 53%.
F	The concentrations in tap water and product were below the limit of detection. The mean concentration estimated in wastewater was 0.003mg/L. However, it was not detected in all samples (the LOD was 0.1mg/L), hence the standard deviation was extremely high SD(ww)=0.087mg/L.
Cl	It was detected in all streams. Tap water contribution ranges from 0-13.2%, product <LOD and human contribution from 0-97%. In two dates it was below the limit of detection. Standard deviations were high for tap and product loads, being respectively 27% and 53% of the mean. SD was also very high for wastewater, 107%. The average load for human input discounting the blank was estimated as 93.14%.
TKN	It was detected in all streams. Tap water contribution ranges from 0.003-0.006%, Product 0.03-0.16%, human 99.92-99.96%. Standard deviations were high for tap

water and product loads, respectively 27% and 53%. The standard deviation of the wastewater load was 38%.

TP Detected in all streams. Tap contribution ranges from 0.013-0.042%, Product 0-0.03%, human 99.92-99.98%. Standard deviations were high for tap water and product loads respectively 27% and 53%. The standard deviation for the wastewater load was SD(ww)=52%.

Overall, the black water concentrations and loads displayed the largest variance as expressed in the high standard deviation values. A number of elements were also consistently below the limit of detection in tap water, products and the black water in the mini-house as observed for As, Cd, Cr, Hg, Ni, Sb, Se and Sn.

The mean source breakdown values were adopted for the estimation of loads using the mass balance method and assuming a different water source (Tap 2).

The loads derived from human input were determined using the original wastewater concentration and the volume of water used in a single person household.

The mass loads hence obtained for the product and the human input were assumed to remain constant despite of changes in water source.

Using the characteristics of a new water supply, the loads for each element derived from the water supply were estimated.

The sum of the new tap water load, the product load and the human load was considered to be the total load of an element in black water.

Using the revised mass loads the breakdown by source as a percentage of the total load was calculated accordingly for tap water, product and human input.

Table 62: Distribution of sources for black water (load per day)

Element		***Water (% Total load)***				***Product (% Total load)***				***People (% Total load)***			
	LOD	***Min***	***Max***	***Average***	***SD***	***Min***	***Max***	***Average***	***SD***	***Min***	*Max*	***Average***	***SD***
Al	0.010	10.00	18.3	13.24	3.15	90.00	100.00	100	192	0.00	0		
As	0	0.00	0	0	0	0.00	0	0	0	0.00	0	0	
B	0.026	4.80	86.67	41.37	32.08	0.24	1.9	1.16	0.78	11.40	93.4	57.47	32.49
Ca	5.03	26.50	41.9	33.45	5.19	6.42	20.42	15.32	5.42	38.90	62.14	51.22	8.45
Cd	0	0.00	0	0	0	0.00	0	0	0	93.40	98	95.75	1.83
Co	0.00017	1.51	6.06	3.58	1.72	0.48	1.16	0.66	0.24	93.37	98	95.75	1.83
Cr	0	0.00	0	0	0	0.00	0	0	0	0.00	0	0	0
Cu	0.105	19.09	32.81	25.42	4.67	0.01	0.05	0.03	0.013	67.10	80.9	74.54	4.68
Fe	0.1	14.29	25	20.16	5.2	4.17	14.31	9.41	3.79	60.70	77.9	70.42	6.922
Hg	0	0.00	0	0	0	0.00	0	0	0	0.00	0	0	0
K	0.77	0.74	1.33	0.97	1.39	0.01	0.027	0.0177	0.0084	98.22	99.79	99.007	0.22
Mg	1.39	22.00	30.9	25.82	3.19	2.87	7.73	5.92	1.95	62.00	70.6	68.25	3.36
Mo	0	0.00	0	0	0	0.11	0.5668	0.324	0.1688	99.43	99.89	99.68	0.169
Na	4.75	4.40	9.69	6.34	1.85	0.03	0.17	0.098	0.051	90.13	95.6	93.566	1.879
Ni	0	0.00	0	0	0	0.00	0	0	0	0.00	0	0	0
Pb	1.53	25.50	38.25	36.12	5.21	0.00	0.0133	0.0107	0.004655	61.73	74.49	63.86	5.2
S	0.84	4.00	7	5.08	1.14	0.13	0.623	0.3915	0.19457	92.39	95.86	94.52	1.299
Sb	0	0.00	0	0	0	0.00	0	0	0	0.00	0	0	0
Se	0	0.00	0	0	0	0.00	0	0	0	0.00	0	0	0
Sn	0	0.00	0	0	0	0.00	0	0	0	0.00	0	0	0
Zn	0.01	3.25	7.65	6.1	1.61	0.28	0.824	0.5589	0.2445	91.52	96.45	93.33	1.73
F	0	0.00	0	0	0	0.00	0	0	0	0.00	0	0	0
Cl	7	0.00	13.2	4.57	5.03	0.00	0	0	0	0.00	96.9	62.09	48.23
TKN	0.01	0.003	0.0059	0.0041	0.001	0.03	0.159	0.0985	0.0493	99.92	99.96	99.89	0.05
TP	0.01	0.013	0.0418	0.0265	0.013	0.00	0.0297	0.013	0.01	99.92	99.98	99.917	0.022

Appendix 3 – Standard deviation for field house loads

Table 63: Standard deviation for washing machine mass loads using tap 2

WM	*Load(mass/use)*				
Element	***Units***	***SD(mww)***	***SD(mproduct)***	***SD(mHI)***	***SD(mtap)***
Al	mg	89.4508	10.2970	87.7406	14.04
As	mg	0	0.0912	0	0
B	mg	0	0.0694	0	0
Ca	mg	285.4115	0.2274	0	289.98
Cd	mg	0	0	0	0
Co	mg	0	0	0	0
Cr	mg	0	0	0	0
Cu	mg	14.9221	0.0052	6.3726	13.49
Fe	mg	15.7314	0.0142	15.2650	3.80
Hg	mg	0	0	0	0
K	mg	361.3350	2.5254	345.9619	104.24
Mg	mg	62.7664	0.0997	50.0480	37.88
Mn	mg	0	0	0	0
Mo	mg	0	0.0035	0	0
Na	mg	5349.4798	1066.5777	5234.0882	289.25
Ni	mg	2.3883	0	0	0
Pb	mg	16.6255	0	0	16.62
S	mg	140.6932	33.6444	125.8851	53.06
Sb	mg	0.2894	0	0	0.23
Se	mg	0	0.0001	0	0
Sn	mg	0	0	0	0
Zn	mg	4.1175	0.0009	0	15.47
F	mg	32.9003	0.0261	17.9484	27.57
Cl	mg	695.5030	4.2687	655.8738	231.38
TKN	mg	373.7904	0.1017	373.7902	0.33
TP	mg	20.9628	0.3454	0	0

Table 64: Standard deviation for shower mass loads using tap 2

SH	***Load(mass/use)***				
Element	***units***	***SD(mww)***	***SD(mproduct)***	***SD(mHI)***	***SD(mtap)***
Al	mg	2.8163	4.0774	0	0.32
As	mg	0	0.0000	0	0
B	mg	0	4.2811	0	0
Ca	mg	23.1083	0.0356	0	24.03
Cd	mg	0	0.0006	0	0
Co	mg	0	0.0031	0	0
Cr	mg	0	0.0031	0	0
Cu	mg	0.7276	0.0000	0	3.64
Fe	mg	0.7998	0.0001	0	2.56
Hg	mg	0	0.0000	0	0
K	mg	0	0.5094	0	0
Mg	mg	6.4783	0.0684	0	24.67
Mn	mg	0	0.0000	0	0
Mo	mg	0	0.0005	0	0
Na	mg	50.7060	26.0963	34.227	26.81

Ni	mg	0	0.0007	0	0
Pb	mg	0	0.0033	0	0
S	mg	44.7599	33.1340	29.980	2.61
Sb	mg	0	0	0	0
Se	mg	0	0.0000	0	0
Sn	mg	0	0.0023	0	0
Zn	mg	0	0.0066	0	0.22
F	mg	2.8403	0.0000	1.022	2.65
Cl	mg	63.3544	38.1696	46.370	20.17
TKN	mg	42.8513	6.2282	42.396	0.03
TP	mg	2.3745	0.0677	0	0

Table 65: Standard deviation for dishwasher mass loads using tap 2

DW	***Load(mass/use)***				
Element	units	SD(mww)	SD(mproduct)	SD(mHI)	SD(mtap)
Al	mg	0.8361	0.0124	0	1.14
As	mg	0	0.0005	0	0
B	mg	0	0	0	0
Ca	mg	58.2642	0.1726	56.1149	15.68
Cd	mg	0	0	0	0
Co	mg	0	0	0	0
Cr	mg	0	0	0	0
Cu	mg	3.1903	0.0015	2.9753	1.15
Fe	mg	1.1430	0	0	0.34
Hg	mg	0	0	0	0
K	mg	84.6071	0.6002	84.5595	2.77
Mg	mg	4.1659	0.0160	3.8730	1.53
Mn	mg	0	0	0	0
Mo	mg	0	0	0	0
Na	mg	364.9277	170.1726	322.6190	11.42
Ni	mg	0.3655	0	0	0
Pb	mg	0.7656	0	0	0.45
S	mg	5.3958	0.5407	4.3516	3.14
Sb	mg	0.0193	0.0000	0	0.02
Se	mg	0	0	0	0
Sn	mg	0	0	0	0
Zn	mg	4.3883	0.0012	4.1124	1.53
F	mg	0.8835	0.0078	0	0.91
Cl	mg	285.9404	21.3700	285.0747	6.14
TKN	mg	130.2354	0.0137	130.2354	0.01
TP	mg	68.0024	1.8301	0	0

Table 66: Standard deviation for kitchen sink mass loads using tap 2

KS	*Load(mass/use)*				
Element	units	SD(mww)	SD(mproduct)	SD(mHI)	SD(mtap)
Al	mg	0.1533	0.0110	0.1330	0.08
As	mg	0	0	0	0
B	mg	0	0.0215	0	0
Ca	mg	8.9350	0.0343	6.7145	5.89
Cd	mg	0	0	0	0
Co	mg	0	0	0	0
Cr	mg	0	0	0	0
Cu	mg	0.9172	0.0049	0.3111	0.86
Fe	mg	0.1983	0.0075	0	0.61
Hg	mg	0	0	0	0
K	mg	65.6493	0.1263	0	0
Mg	mg	3.8313	0.0176	0	5.87
Mn	mg	0	0	0	0
Mo	mg	0	0	0	0
Na	mg	73.7665	9.4370	72.8568	6.66
Ni	mg	0	0	0	0
Pb	mg	0.0758	0.0031	0	0
S	mg	21.8594	9.9394	19.4585	0.64
Sb	mg	0	0	0	0
Se	mg	0	0	0	0
Si	mg	1.5954	0	0	2.36
Sn	mg	0	0.0012	0	0
Zn	mg	0.0504	0.0065	0	0.05
F	mg	0.6936	0	0	0.65
Cl	mg	166.9582	0.1371	166.8830	5.01
TKN	mg	51.3553	0.2641	51.3546	0.01
TP	mg	12.1689	0.0038	0	0

Table 67: Standard deviation for vanity unit mass loads using tap 2

VU	*Load(mass/use)*				
Element	**units**	**SD(WW)**	**SD(mProd)**	SD(HI)	SD(mtap)
Al	mg	0.2478	0.1830	0.1653	0.02
As	mg	0	0.0048	0	0
B	mg	0	0.8203	0	0
Ca	mg	52.2146	1.2295	52.1134	3.01
Cd	mg	0	0	0	0
Co	mg	0	0	0	0
Cr	mg	0	0	0	0
Cu	mg	2.0688	0	0	0.22
Fe	mg	0.1798	0.3613	0	0.16
Hg	mg	0	0	0	0
K	mg	6.2179	1.4761	0	0
Mg	mg	1.3764	0	0	1.76
Mn	mg	0	0	0	0
Mo	mg	0	0	0	0
Na	mg	14.1695	5.7373	12.3811	3.82
Ni	mg	0	0	0	0
Pb	mg	0.0291	0	0	0
S	mg	10.5371	20.6133	v	0.33
Sb	mg	0	0	0	0
Se	mg	0	0	0	0
Sn	mg	0	0	0	0
Zn	mg	0.3317	0.0136	0.3312	0.01
F	mg	0.7060	0	0	0.34
Cl	mg	9.2993	2.1641	8.5716	2.88
TKN	mg	7.8315	0	0	0.00
TP	mg	45.8700	3.6826	0	0

Appendix 4 – Field house: Load estimation using wastewater results

Table 68: Mass loads of elements in field house wastewater streams using original wastewater results

Element	***Mass load (mg/week)*** [$]						
	Washing Machine	***Dish washer***	***Shower***	***Kitchen sink***	***Vanity Unit***	***Toilet + vanity***	***Total***
Al	912.95	7.62	69.36	7.73	6.25	14.36	1,017
As	LOD[1]	LOD	LOD	LOD	LOD	LOD	LOD
B	LOD	LOD	0.00	LOD	LOD	16.12	16
Ca	3,421	335.6	1,405.6	733.1	2,375.4	2,722.9	10,934
Cd	LOD	LOD	LOD	LOD	LOD	LOD	LOD
Cl	6,296	7,580	2,269	5,021	525.8	15,902	37,595
Co	LOD	LOD	LOD	LOD	LOD	0.19	0.19
Cr	LOD	LOD	LOD	LOD	LOD	LOD	LOD
Cu	82.41	23.21	22.14	21.46	34.67	82.91	267
F	475.1	28.4	139.1	72.5	39.8	LOD	755
Fe	42.80	3.46	20.20	12.02	5.42	96.18	180
Hg	LOD	LOD	LOD	LOD	LOD	LOD	LOD
K	2,766.4	378.3	LOD	848.1	127.9	16,215.3	20,356
Mg	701.39	46.57	390.11	225.75	71.05	983.48	2,418
Mn	LOD	LOD	LOD	LOD	LOD	LOD	LOD
Mo	LOD	LOD	LOD	LOD	LOD	0.461	0.46
Na	55,609.4	7,455.5	2,465.9	3,212.9	766.2	15,361.9	84,872
Ni	2.62	0.57	LOD	LOD	LOD	LOD	3.2
Pb	239.2	16.10	LOD	0.8584	0.37	0.81	257
S	1,685.7	67.60	1,242.64	840.35	454.72	3,264.73	7,556
Sb	1.62	0.086	LOD	LOD	LOD	LOD	1.71
Se	LOD	LOD	LOD	LOD	LOD	LOD	LOD
Sn	LOD	LOD	LOD	LOD	LOD	LOD	LOD
Zn	4.7700	6.2929	LOD	0.2575	4.2857	45.5166	61
TKN	2,599.7	477.7	918.7	780.3	372.8	48,728.5	53,9
TP	106.5	348.5	48.9	157.1	1,828.3	8,815.9	11,303.2
Discharge Volume[2] (L/wash)	159	15.9	34.4	8.2	2.0	25.2 L/pe/d	
F[3] (washes/ wk)	3	1.8	5.3	10.5	14	7	

Note: [$] Mass load = Volume X Frequency x Measured Concentration in wastewater for field house.

[1] LOD – Concentration measured in wastewater was below the limit of detection.

[2] Average volume of water use for each appliance

[3] Frequency of appliance use per week assumed for a one person household.

Appendix 5 - Allocation of sources in field house wastewater streams (original data)

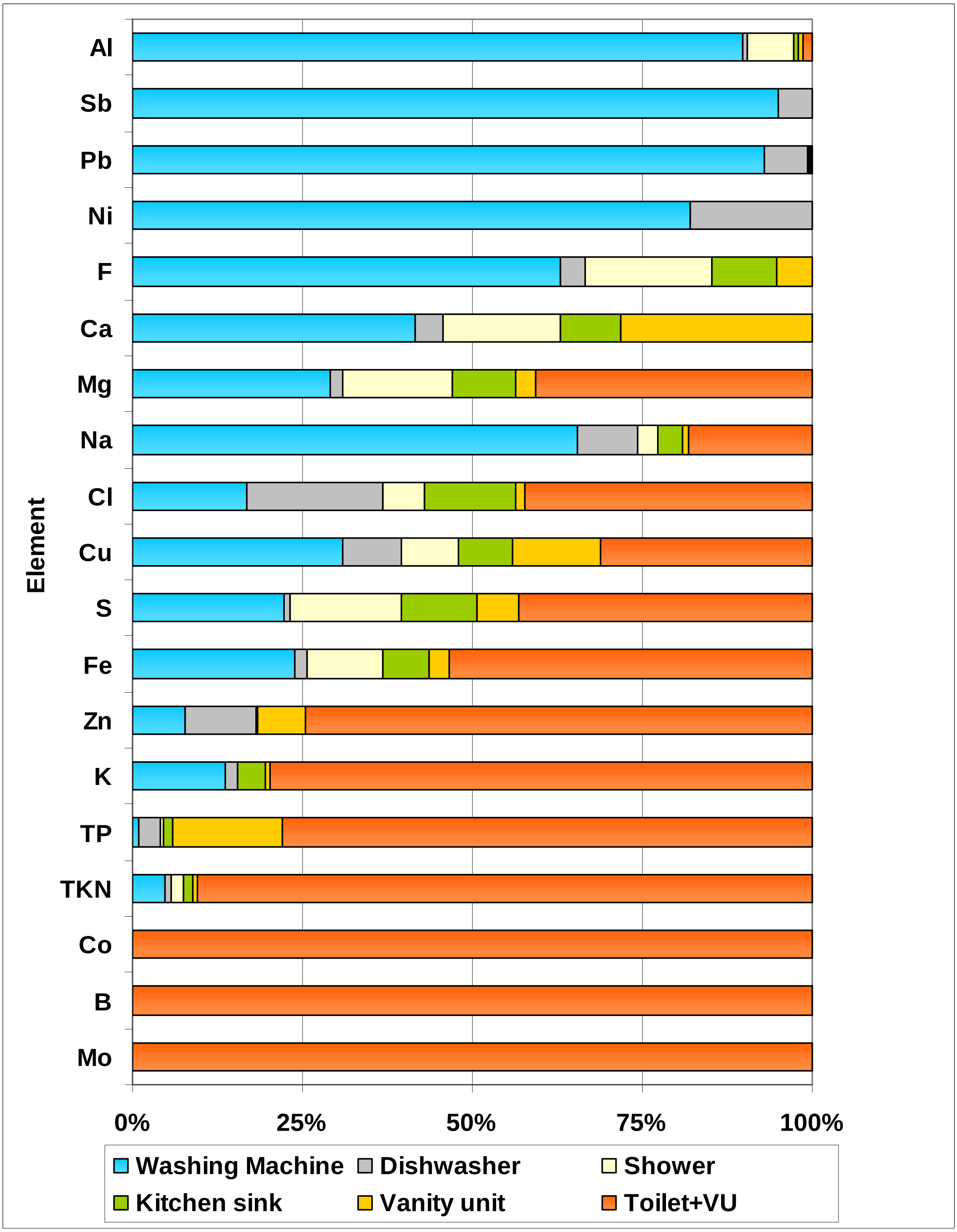

Figure 38: Contribution of each appliance to the load of contaminants in wastewater from the field house based on concentrations measured in wastewater and original water sources (Tap 1, 2 and 3).

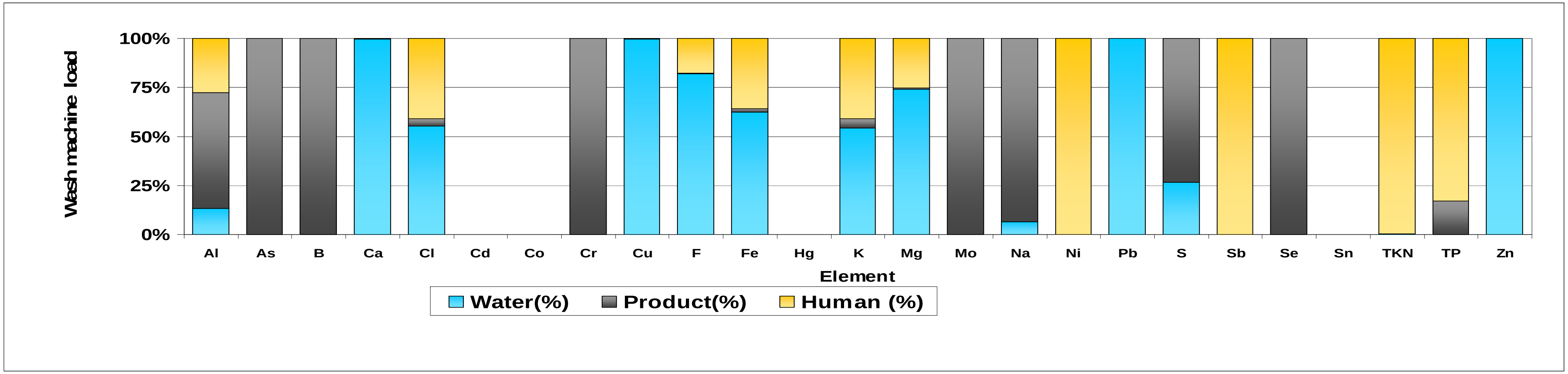

Figure 39: Load distribution for washing machine wastewater in field house

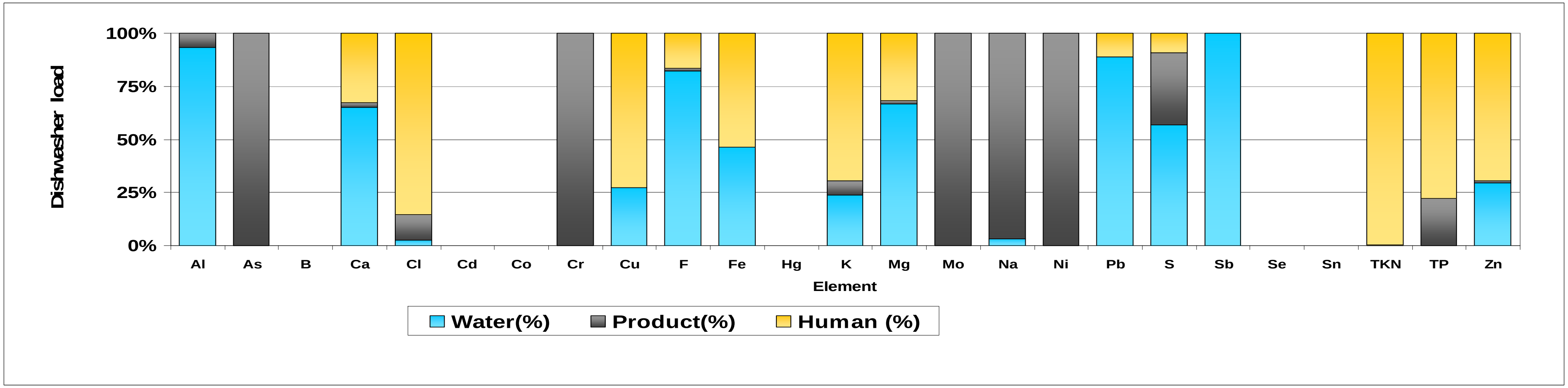

Figure 40: Load distribution for wastewater from dishwasher in field house

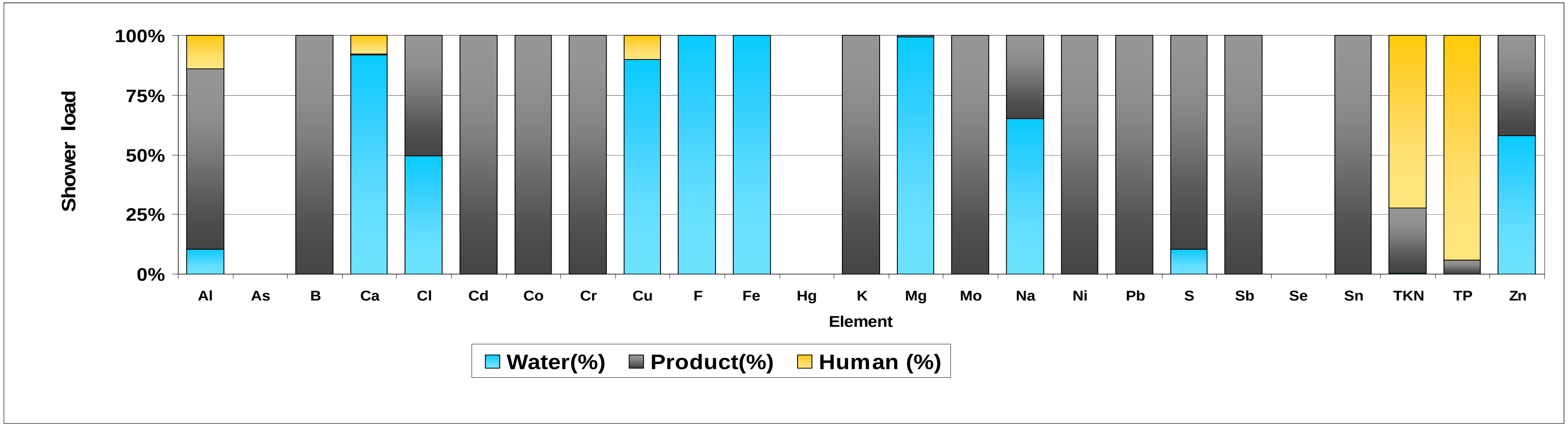

Figure 41: Load distribution for shower wastewater in field house

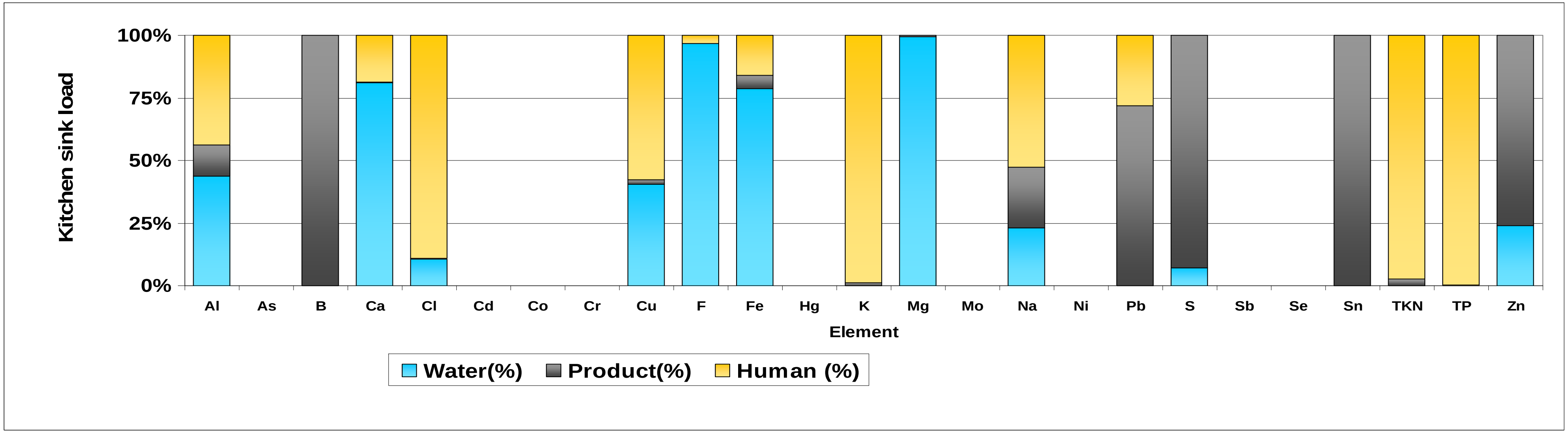

Figure 42: Load distribution wastewater from kitchen sink in field house

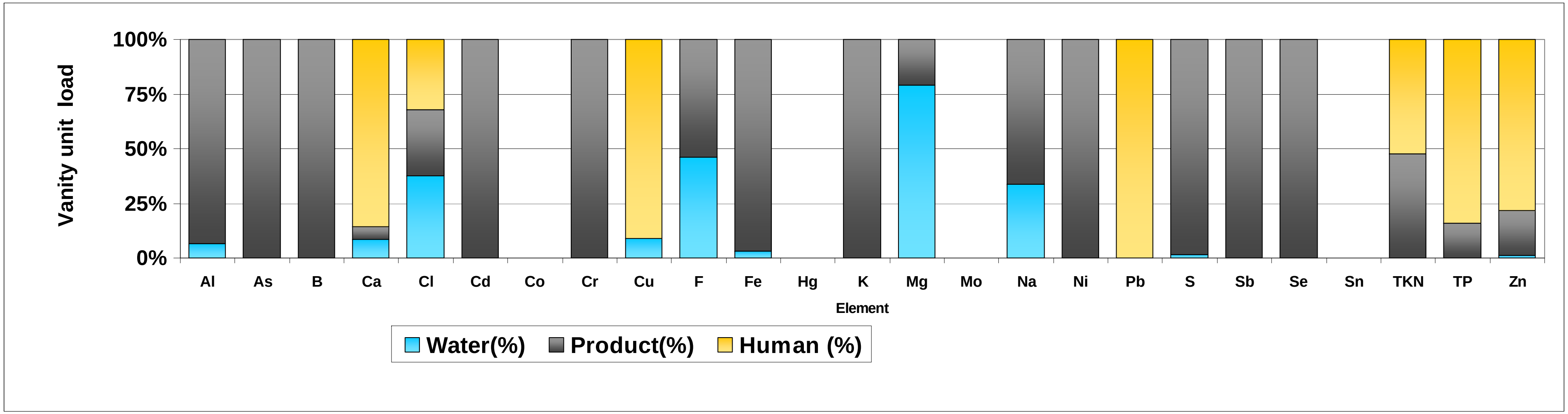

Figure 43: Load distribution for wastewater from vanity unit in field house

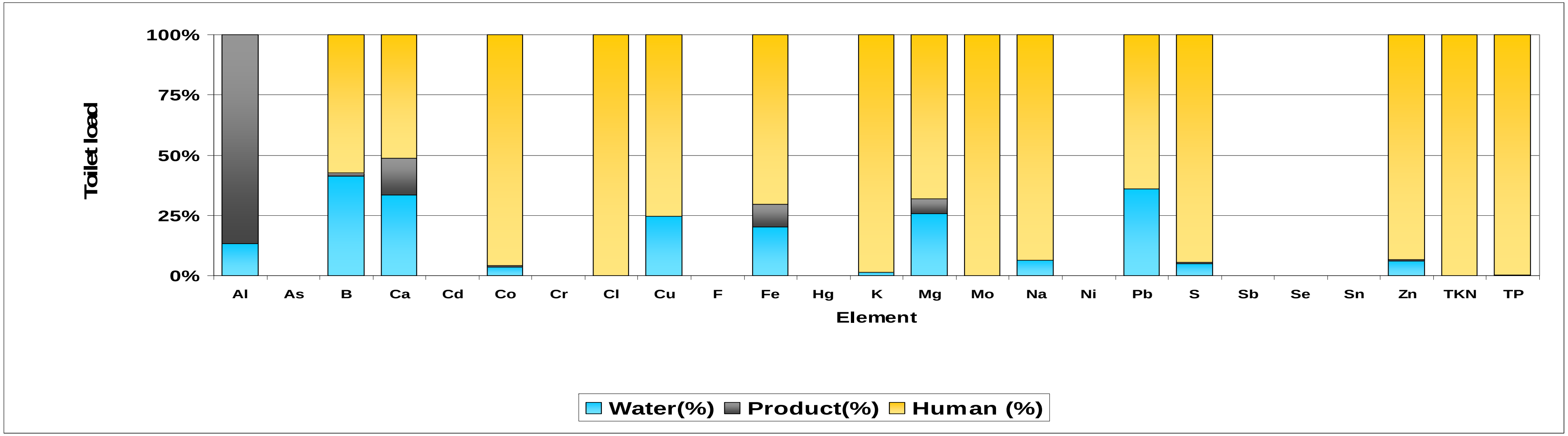

Figure 44: Load distribution for blackwater in field house

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