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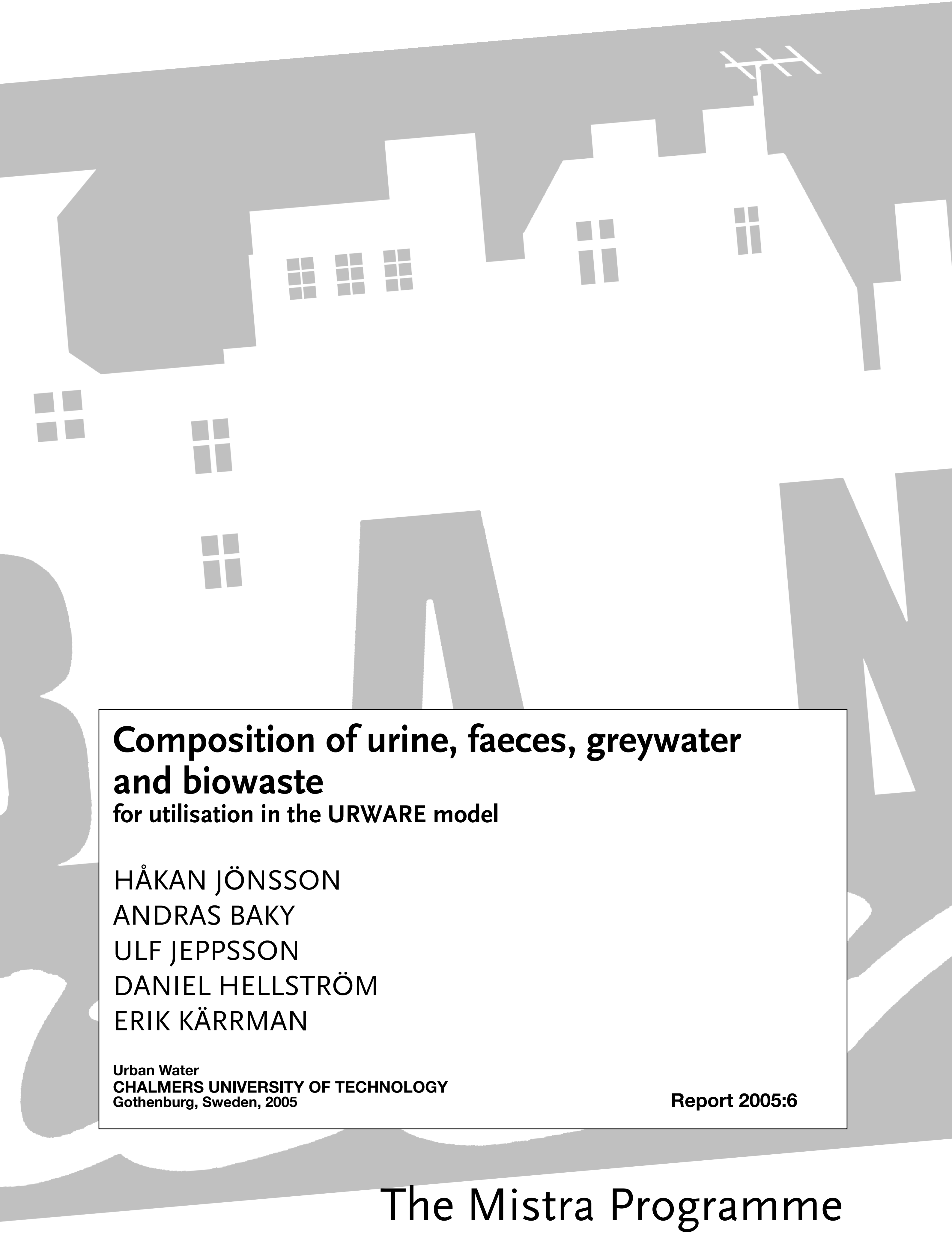
Håkan Jönsson, Andras Baky, Ulf Jeppsson, Daniel Hellström and Erik Kärrman

Dept. of Industrial Electrical Engineering and Automation
Lund University



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HÅKAN JÖNSSON
ANDRAS BAKY
ULF JEPPSSON
DANIEL HELLSTRÖM
ERIK KÄRRMAN

Urban Water
CHALMERS UNIVERSITY OF TECHNOLOGY
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Urban Water
Chalmers University of Technology
412 96 Gothenburg
Sweden
Phone +46 31 772 21 37
www.urbanwater.org

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Preface

When analysing new types of sewage systems, knowledge is needed on the composition of the different wastewater fractions. The computer model URWARE, developed from the model ORWARE, is intended to analyse and compare different wastewater system structures, e.g. to compare wastewater systems where urine and/or faeces are source separated with conventional wastewater systems, where the different wastewater fractions are mixed with each other. To use URWARE for this purpose, knowledge was needed on the composition of the wastewater fractions urine, faeces and household greywater. Sometimes the compostable household waste is mixed into the wastewater by use of a food waste disposer and thus also the composition of the solid compostable household waste is needed. Thus, the objective of the present report was to collect the knowledge on the mass and composition of urine, faeces, greywater and compostable household waste in Sweden.

Håkan Jönsson, Andras Baky and Ulf Jeppsson wrote this report, but it was discussed and developed by the whole URWARE task group (Erik Kärrman, Andras Baky, Daniel Hellström, Ulf Jeppsson and Håkan Jönsson) within the Mistra program Urban Water (Sustainable Urban Water Management). Important input was also received from our reference group consisting of Professor emeritus Peter Balmer (formerly Chalmers University of Technology, Professor Jes la Cour Jansen (Lund University) and Professor Bengt Hultman (KTH – Royal Institute of Technology).

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Abstract

To analyse and compare new types of sewage systems, knowledge on the composition of the different wastewater fractions is needed. In some systems the compostable household waste is mixed into the wastewater by use of a food waste disposer and thus the composition of the solid compostable household waste is also needed. The objective of the present report was to compile well-validated default values on the mass and composition of urine, faeces, greywater and compostable household waste in Sweden for use in Substance Flow Analyses (SFA) of different wastewater systems. The proposed default values are developed to fill the needs of the simulation model URWARE. However, the use of the proposed default values are not limited to URWARE simulations, rather they can be used whenever default flows and composition of the described fractions are needed.

Where local conditions differ significantly from average Swedish conditions then modifications are certainly necessary, but for general base-line investigations of different treatment system the given default vectors should be valuable. However, the vectors contain no stormwater and no industrial wastewater and thus, whenever these fractions enter the wastewater system, their compositions need to be found elsewhere.

The defined default vectors are based on a thoroughly analysed literature study and a few additional measurements. Default flows and composition are given for urine, faeces, household greywater and compostable household waste. For these fractions the composition is described by 31 parameters, the flow of water, total and suspended solids, organic matter, BOD_7, total and fractioned COD, nitrogen, phosphorus, potassium and sulphur and flow of the heavy metals lead, cadmium, mercury, copper, chromium, nickel and zinc. A few main parameters for the proposed default vectors are shortly given in the Table below.

Table. URWARE default vectors for urine, faeces, greywater, household wastewater and compostable waste, expressed as kg pe^{-1}year^{-1}

Parameter	Urine	Faeces & toilet paper	Greywater total	Household wastewater	Compostable household waste
TS	7	19	26	53	25
VS	3	17	15	35	21
COD_{tot}	3	23	23	49	34
BOD_7	2	12	12	27	12
N_{tot}	4.0	0.5	0.6	5.1	0.6
P_{tot}	0.33	0.18	0.25	0.76	0.10
S_{tot}	0.26	0.06	0.17	0.48	0.05
K_{tot}	0.88	0.33	0.29	1.49	0.23

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Introduction

In this report an attempt is made to create a unified and flexible input vector for the URWARE program. The contents of the wastewater are described as the sum of a urine fraction, a faecal fraction (containing faeces and toilet paper), a greywater fraction and a household biowaste fraction. Whether the household biowaste fraction is or is not part of the wastewater depends on the type of wastewater system structure used. The reason for the division of the wastewater into fractions is primarily to simplify simulations of source separation wastewater systems. For each fraction a large number of different compounds are defined based on how much (weight and COD based) is estimated to be released from human activities per day. Some important factors must be emphasised.

- The default values are developed for Swedish conditions.
- The contents of the different fractions do not include the components already present in the water, which will be associated with them. Thus, a drinking water vector showing the composition of the drinking water should be provided from the drinking water production module in URWARE or (if only waste treatment is modelled) as a separate input vector.
- The specific values associated with the different fractions can always be discussed. In many cases they have been rarely measured in practice but at least they should be interpreted as intelligent guesses.
- The given values are assumed to describe the composition of the wastewater fractions as they leave the building site, i.e. the fastest conversions, those which occur already in the sewage system of the building (e.g. that urea is transformed into ammonia in the pipe system) have been taken into account when the vectors of the fractions were developed. Further transformations, especially degradation and transformation of COD and BOD will take place further down in the sewage system, but these are not included in the indata values.
- URWARE is intended for estimating the mass and energy flows of the water and wastewater system in steady state. Its input and output data are yearly flows of substances and energy.

- The amount of water leaking out of the water system is accounted for as a percentage of the amount of water used in the system. This value needs to be checked, and perhaps adjusted.
- The leakages into and out of the sewage system should normally be accounted for and for this the amount and the composition of the water leaking into the system need to be estimated.
- Storm water is not included. If simulations are to be performed for a combined sewer network then this fraction must be included. It will in particular have an impact on the load of heavy metals, the water volume (primarily run-off from roofs and streets during rainfall) and overflow events. As storm water flows are highly fluctuating, while URWARE works with yearly flows, special procedures have to be used.
- Industrial wastewater is not considered. If simulations are to be performed of a system where industrial wastewater plays a significant role, then an extra industrial input fraction must be defined.

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The URWARE input vectors

The URWARE input vector describes a typical wastewater from households entering a wastewater treatment plant (WWTP). The influent wastewater is described as a mixture of urine, faeces and toilet paper, greywater and in some systems also biowaste from households. In order to obtain a description of an incoming household wastewater, the flows and composition of urine, faeces, toilet paper, greywater and biowaste need to be known. Initially only the variables in Table 1 will be taken into consideration for describing different wastewater flows.

Notation	Parameter	Vector position	Comment
H_2O	Water	22	
TS	Total solids	8	Fixed solids, ash = TS-VS
TSS	Suspended solids	42	Dissolved total solids = 8-42
VS	Volatile solids	7	Organic material
COD_{tot}	COD, total	43	= 75+76+77+78
$COD_{sol,bio}$	COD, soluble & biodegradable	75	
$COD_{sol,in}$	COD, soluble & inert	76	
$COD_{part,bio}$	COD, particulate & biodegradable	77	
$COD_{part,in}$	COD, particulate & inert	78	
BOD_7	BOD_7	6	Defined as BOD_7
N_{tot}	Total nitrogen	23	
$N_{NH3/NH4}$	Ammonia/ammonium-nitrogen	24	
N_{NO3}	Nitrate-nitrogen	26	
$N_{sol,org}$	Nitrogen, soluble & organic	44	
$N_{part,org}$	Nitrogen, particulate& organic	81	
P_{tot}	Total phosphorus	30	= 79+80
P_{PO4}	Phosphate-phosphorus	79	
P_{Part}	Particulate phosphorus	80	
S_{tot}	Total sulphur	28	
S_{SO4}	Sulphate-sulphur	29	
S_{S2-}	Sulphide-sulphur	48	
S_{part}	Particulate sulphurs	46	
K_{tot}	Total potassium	32	
K_{cell}	Potassium in cells	49	Dissociated K = 32-49
Pb	Lead	34	
Cd	Cadmium	35	
Hg	Mercury	36	
Cu	Cupper	37	
Cr	Chromium	38	
Ni	Nickel	39	
Zn	Zinc	40	

Table 1
Variables included in the URWARE input vector. The unit for each element is kg/year

2.1 Drinking water

The compositions of the different wastewater fractions are net loads, i.e. the amount of each element added by the respective fraction. Thus, the composition of the incoming drinking water should be added to the above loads by urine, faeces and greywater. This is especially important for the greywater, due to the large amount of drinking water ending up in this fraction and for the mass balances it is very important for the potassium and the sulphur. The composition of the drinking water should for each simulation be set according to available chemical analysis and the analyses of water from different sources given in Table 2 should just be seen as examples.

Table 2
Composition of raw water and drinking water according to a few analyses (mg/l, n.a.=not analysed, n.d.=not detected). The metal content, especially Cu and Zn, of tap water has a large variation due to the piping system.

Parameter	Pos	Stockholm, Norsborg Surface water	Göteborg Lackarebäck Surface water	Uppsala Ground-water	Stockholm, Norsborg Drinking water	Göteborg, Lackare-bäck Drinking water	Uppsala Drinking water	Stockholm, Gebers Tap water[a]
TS	8	114	49*		129	n.a.		n.a.
TSS	42							
VS	7							
COD_{tot}	43	7.2	5	2.0	2.8	1.3	1.5	n.a.
$COD_{sol,bio}$	75							
$COD_{sol,in}$	76							
$COD_{part,bio}$	77							
$COD_{part,in}$	78							
BOD_7	6							
N_{tot}	23	0.288	0.4		0.33	0.4		n.a.
$N_{NH3/NH4}$	24	0.013	n.d.	<0.03	0.052	n.d.	<0.03	
N_{NO3}	26	0.27	0.4	1.1	0.28	0.4	1.6	
$N_{sol,org}$	44							
$N_{part,org}$	81							
P_{tot}	30	n.d.	n.d.		n.d.	n.d.		0.0026
P_{PO4}	79	0.005	n.d.	<0.03	n.d.	n.d.	<0.03	n.a.
P_{Part}	80							
S_{tot}	28	7.3	3.7	15[c]	13.0	8.3	14.7[c]	11.3
S_{SO4}	29			15			14.7	
K_{tot}	32	2.1	1.2	6	2.0	1.2	7	2.23
Pb	34							0.001[b]
Cd	35							0.000009[b]
Hg	36							<0.000002[b]
Cu	37			<0.05			<0.05	0.095[b]
Cr	38							0.000067[b]
Ni	39							0.0038[b]
Zn	40							0.036[b]

a) Water from a tap in the cellar (Andersson & Jenssen, 2002). **b)** Metal content at the tap varies much. In 25 analyses of tap water in Stockholm 2005, the minimum, average and maximum values (µg/l) were for Cu 1, 8, 33 and for Zn <2, 7, 32. For the other metals all analyses were below detection level, Pb <0.5, Cd <0.05, Co <1, Cr <1, Hg <0.05, Mn <1 (Wahlund, pers. com.). **c)** Calculated from S_{SO4} content.

2.2 Urine

The composition of urine based on the variables defined in Table 1 varies between different references. Recently, several analyses of urine have been made and their variation is shown in Table 3.

Parameter	Pos	URWARE	Gebers[a]	Hush-agen[b]	Understens-höjden[c]	Palster-nackan[c]	Miljöhu-set[d]	Eko-porten[e]	ORWARE[f]	Arrhenius[g]	NV-95[h]	Design pro-posal[i]
H_2O	**22**	**1487**							**1500**			
TS	**8**	**20**	**19.1**	**11.2**	**19.2**	**16.8**		**48**	**60**		**60**	**57.5**
TSS	**42**	**0.76**	**0.72**									
VS	**7**	**7.4**	**7.1**									
COD_{tot}	**43**	*8.5*	10.2							**4.5**		**10.2**
$COD_{sol,bio}$	75	*7.23*										
$COD_{sol,in}$	76	*0.67*										
$COD_{part,bio}$	77	*0.46*										
$COD_{part,in}$	**78**	**0.14**										
BOD_7	**6**	**5.0**	**5.01**	**5.5**	**4.82**	**3.55**		**3.26**		**4.5**		**5.01**
COD-filtrate		**7.9**	**9.94**									
BOD_7 filtrate		**4.7**	**4.68**									
N_{tot}	**23**	**11.0**	**10.5**	**7.7**	**8.97**	**6.62**	**5.1**	**5.9**	**11**		**11**	**10.96**
$N_{NH3/NH4}$	**24**	**10.3**	**8.51**	**7**	**8.41**	**6.56**						
N_{NO3}	**26**	**0**										
$N_{sol,org}$	44	*0.6*										
$N_{part,org}$	81	*0.1*										
P_{tot}	**30**	**0.9**	**0.69**	**0.47**	**0.77**	**0.62**	**0.41**	**0.634**	**1**		**1**	**1**
P_{PO4}	79	*0.81*	0.56									
P_{part}	80	*0.09*										
S_{tot}	**28**	**0.70**	**0.6346**	**0.5721**	**0.817**	**0.651**						
S_{SO4}	29	*0.63*										
S_{S2-}	48	*0.07*										
S_{part}	46	*0.00*										
K_{tot}	**32**	**2.4**	**2.25**	**1.6**	**2.47**	**1.78**	**1.23**	**2.21**	**2.5**		**2.5**	**2.73**
K_{cell}	49	*0.003*										
Pb	**34**	**0.012**	**0.0115**	**<0.037**	**<0.025**	**<0.056**	**<0.038**	**0.0418**	**0.024**		**<0.002**	**0.0020**
Cd	**35**	**0.0005**	**0.00022**	**<0.0025**	**<0.0019**	**<0.0025**	**<0.0012**	**0.0013**	**0.0024**		**<0.001**	**0.00068**
Hg	**36**	**0.00082**	**0.00044**	**<0.0033**	**0.0011**	**<0.00069**	**<0.00075**	**0.0008**	**0.0010**		**0.0030**	**0.00082**
Cu	**37**	**0.10**	**0.0471**	**<0.810**	**5.99**	**6.02**	**<9.150**	**4.0760**	**0.1**		**0.1**	**0.10**
Cr	**38**	**0.010**	**0.00045**	**<0.020**	**0.048**	**0.04**	**<0.013**	**0.0283**	**0.044**		**0.010**	**0.010**
Ni	**39**	**0.011**	**0.0114**	**<0.021**	**0.15**	**<0.046**	**<0.0059**	**0.0896**	**0.14**		**0.0070**	**0.0071**
Zn	**40**	**0.3**	**0.2926**	**0.51**	**0.49**	**1.07**		**0.4041**	**0.47**		**0.045**	**0.045**

a) Andersson & Jenssen 2002). **b)** Vinnerås (1998). **c)** Jönsson et al. (1998). **d)** Lindgren (1999). **e)** Weglin & Vinnerås (2000). **f)** Kärrman et al. (1999). **g)** Arrhenius (1967). **h)** NV (1995) **i)** Vinnerås et al. (2004), Vinnerås (2002).

Table 3

Proposed composition of urine to be used in URWARE and composition from different measurements and default values, expressed as g pe^{-1} day^{-1}, mg/ pe^{-1} day^{-1} for the metals (pos 34-40). The meaning of pe^{-1} day^{-1} is the excretion from one person during one full day, i.e. 24 hours. Normally 55-70% of the time is spent at home and the corresponding proportion of the excretion is collected at home. The amounts collected in different measurements have therefore been extrapolated to the excretion during 24 hours. The composition is that expected after transport in a sewage system.

2.2.1 H_2O, TS, VS and TSS

Total solids show large variations and vary between 11 to 60 g $pe^{-1}day^{-1}$(Table 3). This is explained by the fact that the excreted amount of total solids is about 60 g $pe^{-1}day^{-1}$. However, the main part of this consists of urea (CON_2H_4), amino acids and peptides. Approximately 10 grams of the nitrogen is at excretion in the form of urea, corresponding to approximately 21.4 grams of urea and this urea is included in the TS measured at excretion. However, in the piping system this urea is rapidly degraded to ammonium and carbon dioxide and this substance is therefore not detected when the TS analysis is performed on urine which has been led through such a piping system. Similar degradation occurs also for many of the small amino acids and peptides excreted. Therefore, the measured amounts of TS on urine collected in urine collection systems are far below the TS amounts actually excreted. The URWARE data are intended to reflect the urine entering the tank or the sewage treatment plant, and here the most easily degradable organics have already been degraded. Assuming that 95% of the urine was correctly source separated in Gebers, then 20 g TS $pe^{-1}day^{-1}$ would have been collected if 100% had been collected, and this is the figure used in URWARE.

Andersson & Jenssen (2002) is the only reference which has measured the VS. Assuming that 5% of the urine probably was not diverted, their measurement corresponds to 7.4 g VS $pe^{-1}day^{-1}$, which is the value used. The value for TSS is similarly calculated to 0.76 g $pe^{-1}day^{-1}$.

The total volume of the urine was in NV (1995) given as 1.0 l $pe^{-1}day^{-1}$. However, later measurements indicate that the excreted volume is larger than this and several different studies (Andersson & Jenssen, 2002; Hellström & Kärrman, 1996; Jönsson et al., 1997, 1998, 2000; Vinnerås, 1998) indicate that the excreted volume is around 550 l $pe^{-1}year^{-1}$, which is the design value recommended by Vinnerås et al. (2004) and it is also the default value we recommend for URWARE. It corresponds to 1.507 kg $pe^{-1}day^{-1}$. As the TS weighs 20 g, the H_2O weighs about 1487 g.

2.2.2 COD and BOD_7

COD_{tot} is divided into four different subfractions $COD_{sol.bio}$, $COD_{sol.in}$, $COD_{part.bio}$ and $COD_{part.in}$. Andersson & Jenssen (2002) measured COD_{tot} at 10.2 g O_2 pe^{-1} day^{-1} (Table 3), while Arrhenius (1967) and ORWARE suggested 4.5 and 3.48 g $pe^{-1}day^{-1}$, respectively, based on calculations. COD_{tot} can also be estimated from the VS measurement, a sturdy and robust measurement when compared to COD. The theoretical COD/VS value varies from 0 for urea and very low for some aminoacids, e.g. 0.64 for glycine (Haug, 1993) to high for fatty acids e.g. 2.87 for palmitic acid (Haug, 1993). Considering that most of the organics excreted with the urine are small molecules, many of them aminoacids and peptides, the COD/VS ratio should be low and 1.15 is assumed. This gives a COD_{tot} value of 8.5. The COD measurements for other flows in Gebers (Andersson & Jenssen, 2002) raise several questions, which lower the credibility also of the COD measurement for the urine. Since the COD value calculated from VS also agrees well with the BOD_7-values from several measurements (Andersson & Jenssen, 2002; Vinnerås, 1998; Jönsson et al., 1998), this value, 8.5, is used.

BOD_7 has been analysed in several measurements and the variation is surprisingly small, from 3.26 to 5.5. The lowest values are explained by low collection rates in the housing districts Palsternackan (Jönsson et al., 1998) and Ekoporten, while the highest rate is partly explained by a low degree of degradation of that urine, as shown by the proportion of nitrogen found as ammonia. The value is set to 5.0, a value that also was measured at Gebers.

To obtain the values for the different COD fractions, the assumption is made that BOD_7 equals 65% of the total COD_{bio}, i.e. of the sum of soluble and particulate COD_{bio}. For the division between soluble and particulate fractions the values from the Gebers measurement are used, with a minor adjustment, to make the figures fit (Table 3).

2.2.3 NPK and S

The amount of nitrogen varies between 5 to 11 g $pe^{-1}day^{-1}$ (Table 3). Andersson & Jenssen (2002) measured 11 g $pe^{-1}day^{-1}$ and if 5% is assumed to be missed in the sorting, then this corresponds to 12 g $pe^{-1}day^{-1}$ being excreted. The value in NV (1995) is 11 g $pe^{-1}day^{-1}$ based on calculations made from diet measurements (Becker, 1994), and thus this value should give a good picture of the average, and it also agrees well with the measurements in the housing districts with the most dedicated inhabitants and with the measurement by Hellström & Kärrman (1996) and is the value arrived at by Vinnerås et al. (2004) when they evaluated the data. This value is used for URWARE.

In the measurements almost all nitrogen, 81% to 99%, has been in the form of ammonium. The lowest value was found in Gebers, where the urine was collected in a special measurement tank, which was cleaned every week. Thus, this measurement does in this respect not well represent real conditions and therefore the percentage 94% is chosen, close to the average of the other measurements. The amount of organic nitrogen is divided between dissolved and particulate in approximately the same proportions as the COD.

The values on phosphorus in urine vary between 0.41 to 1.0 g $pe^{-1}day^{-1}$. The value in NV (1995) is 1.0 g $pe^{-1}day^{-1}$. This value is based on calculations based on the diet and this value was supported by the small measurements by Hellström & Kärrman (1996). However, the total consumption of phosphorus was 1.43 g $pe^{-1}day^{-1}$ 1997-98 in Sweden for persons between 17 and 74 years of age (Becker & Pearson, 2002). This was also exactly the average consumption by the population between 1 and 74 years of age in a previous study (Becker, 1994). Approximately 6% of the phosphorus consumed by persons between 1 and 17 years old is accumulated in the growing body (Jönsson et al., 2004). As about 20% of the Swedish population is between 1 and 17 years old, the accumulation decreases the excretion by 0.2*0.06=0.012 or 1.2% and thus the total excretion of phosphorus with urine and faeces should be around 1.4 g $pe^{-1}day^{-1}$. As is seen below, 0.5 g $pe^{-1}day^{-1}$ of the phosphorus is expected in the faeces, which means that the urine excretion on average should be around 0.9 g $pe^{-1}day^{-1}$. In the measurements smaller amounts have been collected and this can be explained by the sludge accumulating in the pipes, which supposedly during intermittent cleaning of the pipe system will be flushed down to the collection tank. Thus, P-tot is set to 0.9 g $pe^{-1}day^{-1}$.

Phosphorus in urine is mainly found as PO_4-P. Andersson & Jenssen (2002) measured that 81% of P-tot was PO_4-P while Lentner et al. (1981) states that 95-100% of the P is inorganic, primary phosphate. In URWARE, 90% of the urine P is assumed to be PO_4-P and the rest is assumed to be P-part. Some of this particulate P ought to be PO_4-P, however URWARE distinguishes between soluble and particulate phosphorus. The total soluble part is given as phosphate whereas the particulate part represents both phosphorus associated with organic material and inorganic precipitations. After just a short distance in the pipe, the inorganic precipitations will dominate for urine.

The variations for the potassium values in Table 3 are small and the URWARE-value is set at 2.4 g $pe^{-1}day^{-1}$, a little less than the value (2.5 g $pe^{-1}day^{-1}$) given by NV-95. This is due to the consumption of potassium being 3.3 g $pe^{-1}day^{-1}$ according to two large nutritional studies (Becker & Pearson, 2002; Becker, 1994), which should equal the excretion as only about 0.6% of the potassium consumed between 1 and 17 years of age is accumulated (Jönsson et al., 2004). Thus, in URWARE the potassium excretion is both urine and faeces is set 0.1 g $pe^{-1}day^{-1}$ lower than the design values given by NV (1995).

The potassium in URWARE is divided into two fractions: potassium trapped within cells and potassium in the water phase (only available as total K minus K_{cell}). Potassium is always in dissolved form but the concentration of potassium within viable cells may be considerably higher than in the surrounding water. Values in literature suggest that a cell contains 1.5% K on dry weight basis (Brock & Madigan, 1991), which would represent maybe 1.2% on COD basis. However, it is impossible to state how much of the influent wastewater material is made up of viable cells and how much is other materials where the potassium is no longer trapped within living cells (organic molecules, hydrolysed cell material, etc.). A very significant part of potassium is associated with the natural level in water, which should be included in the drinking water vector. As an initial guess we have assumed that the ratio of K_{cell} to COD_{part} is 0.5%. Remaining K thus is included as free soluble potassium. Based on this assumption K_{cell} in the urine is 0.003 g $pe^{-1}day^{-1}$.

Sulphur as S-tot varies between 0.57 to 0.82 g $pe^{-1}day^{-1}$. A guess is that the value is somewhere between 0.57 to 0.65 g $pe^{-1}day^{-1}$ (Table 3). When the proportion of urine that was not sorted and collected in the different measurements also is taken into account then a value of 0.7 g $pe^{-1}day^{-1}$ seems reasonable.

The sulphur in URWARE is divided into sulphate, sulphide and particulate sulphur. For simplicity the particulate sulphur represents both organic sulphur and elemental sulphur. Values in literature suggest that a cell contains 0.3% S on dry weight basis (Brock & Madigan, 1991), which would represent maybe 0.25% on COD basis. With this in mind, we have assumed that relation between particulate S and particulate COD is 0.25%. This assumption has been used not only for urine, but also for the other fractions, even though the amount of particulate S rounds off to 0 g pe^{-1} day^{-1} in the urine. The remaining part is then included as soluble sulphur, which is excreted as sulphate for urine. However, as the input vector is supposed to represent wastewater entering a treatment plant we assume that some sulphate is reduced to sulphide in the sewer network and we have assumed 10% of the total sulphate/sulphide. Obviously, this figure depends on conditions in the sewers, e.g. pH, anaerobic conditions, sulphate reducing organisms.

Important ratios between the different parameters for urine are given in Table 4.

Ratio	**Value**
TSS:TS	**0.038**
VS:TS	**0.37**
COD_{tot}:VS	**1.15**
COD_{tot}:TS	**0.43**
$COD_{tot.part}$:TSS	**0.79**
BOD_7: VS	**0.68**
BOD_7:COD_{tot}	**0.59**
BOD_7:COD_{bio}	**0.65**

Table 4
Ratios between different variables for urine.

2.2.4 Heavy metals (Pb, Cd, Hg, Cu, Cr, Ni and Zn)

For all of the heavy metals, the range is large between the different measurements and recommended design values. Based upon the Swedish diet and the metabolism of Pb, NV (1995) gave the design value as <0.002 mg $pe^{-1}day^{-1}$. Only two measurements have had detectable levels. Extremely little Pb is metabolised and excreted with the urine and this is the reason for the low design values given by NV (1995). Vinnerås et al. (2004) proposed keeping this value, in spite of the two measurements being far above the design value. The reason was the human metabolism and the decreasing flows of lead in society. The measured amounts of lead can be explained by contamination. This is well shown by the the extremely high value measured at Ekoporten, 0.042 mg/ pe^{-1} day^{-1}, which is explained by the fact that it is situated fairly close to a small airport where propeller planes still use highly leaded gasoline. As the input vector for URWARE is intended to show the quality of the urine when leaving the building, it seems natural to include the contamination that can be expected by dust settling in the toilet bowl etc., but assuming dust with less lead than at Ekoporten. Thus, the default input to URWARE is based on the level measured at Gebers, 0.012 mg $pe^{-1}day^{-1}$ (Andersson & Jenssen, 2002).

Only two measurements, at Gebers (Andersson & Jenssen, 2002; 0.00022 mg $pe^{-1}day^{-1}$) and Ekoporten (Weglin & Vinnerås, 2000; 0.0013 mg $pe^{-1}day^{-1}$) have measured Cd above the detection level and theses measurements differ a factor six. The proposed URWARE value, 0.0005 mg $pe^{-1}day^{-1}$, is in between these values. Hg has been above detection limit in three measurements, Gebers (0.00044 mg $pe^{-1}day^{-1}$), Ekoporten (0.0008 mg $pe^{-1}day^{-1}$) and Understenshöjden (0.0011 mg $pe^{-1}day^{-1}$). For URWARE the same value is chosen as that recommended as design value by Vinnerås et al. (2004), 0.00082 mg $pe^{-1}day^{-1}$. It is noticeable that this value only is 27% of the old NV (1995) design value, 0.0003 mg $pe^{-1}day^{-1}$. The old NV (1995) value was based on a study where the urine and faecal excretion of 10 persons with varying numbers of amalgam fillings were measured during 1 day (Skare & Engqvist, 1992). However, as amalgam now rarely is used, the Hg concentrations measured in the measurements at Gebers, Ekoporten, Understenshöjden and Palsternackan are more relevant and up to date.

In all measurements, except Hushagen (Vinnerås, 1998) Cu has been above the detection limit. However, the values vary very much, from 0.047 mg $pe^{-1}day^{-1}$ to 6.0 mg $pe^{-1}day^{-1}$. The reason for this is that the urine piping in one of the old models of urine diverting toilets was made of copper, but this pipe was long since replaced with plastic. Thus, a Cu value of 0.01 is chosen, twice that measured at Gebers, where all the urine piping is made of plastic.

The measured values for Cr vary by a factor 100 between the value measured at Gebers and the ones measured at Understenshöjden and Palsternackan. Cr is used extensively for alloys and this might be one of the reasons for this large span. The value chosen for URWARE is the one given by NV (1995) and recommended by Vinnerås et al. (2004). It is approximately twice the value measured at Gebers. Also Ni is a commonly used alloy and all the detected values are above the design values recommended by NV (1995) and Vinnerås et al. (2004). Even though the value in Miljöhuset (Lindgren, 1999) was lower, it seems reasonable to use the value measured at Gebers, 0.011 mg $pe^{-1}day^{-1}$ for URWARE.

In all the measurements, Zn has been detected and the values have been 6-24 times higher than the design value given by NV (1995) and Vinnerås et al. (2004). It can well be that this is due to contamination after excretion, but even if this is the case, it seems likely that this contamination will be at the level measured at Gebers (Andersson & Jenssen, 2002), 0.3 mg $pe^{-1}day^{-1}$, which is the value chosen for URWARE.

2.3 Faeces

2.3.1 TS, VS and TSS and water

Total solids given by NV (1995) are 35 g pe^{-1} day^{-1}. This is higher than all measurements. Gebers shows lower value for TS (27.4 g pe^{-1} day^{-1} of faeces and 23.4 g $pe^{-1}day^{-1}$ of toilet paper). The measurement of 35 g $pe^{-1}day^{-1}$ at

Ekoporten applies to faecal matter plus toilet paper and the measurement of 68.3 g $pe^{-1}day^{-1}$ by KVVBS (1966) applies to total wet mass. Vinnerås et al. (2004) proposes 30.1 g of faecal dry matter pe^{-1} day^{-1} and this value is also proposed for URWARE. The dry matter of the toilet paper, 23.0 g $pe^{-1}day^{-1}$, is in addition to the dry matter of the faecal matter.

The VS content was measured at Gebers (Andersson & Jenssen, 2002) and Arrhenius (1967) assumes 24.8 g $pe^{-1}day^{-1}$. The proposed value for VS is based on the same proportion of TS as was measured in Gebers, after exclusion of the toilet paper.

TSS should probably be in the range of 20-30 g $pe^{-1}day^{-1}$. The presently assumed value is 25 g $pe^{-1}day^{-1}$.

Table 5 Composition of faeces from different measurements expressed as g pe^{-1} day^{-1}, mg/ pe^{-1} $day^{-1}$for the metals (pos 34-40). The meaning of pe^{-1} day^{-1} is the excretion from one person during one full day, i.e. 24 hours. Normally 55-70% of the time is spent at home and the corresponding proportion of the excretion is collected at home. The amounts collected in different measurements have therefore been extrapolated to the excretion during 24 hours. The composition is that expected after transport in a sewage system. Quality marking: Well-validated data, data based on few references, *initiated estimates.*

Parameter	Pos	URWARE faeces	URWARE toilet paper	URWARE Fec+t.p.	Gebers[a] fec+t.p.	Ekoporten[b]	KVVBS[c]	Arrhenius[d]	ORWARE[e]	Design proposal[f]	NV-95[g]
H_2O	22	109.6	1.0	110.6	170.1						
TS	8	30.1	23.0	53.1	50.9[h]	35	68.3[i]	27.6	35	30.1	35
TSS	42	25.0	23.0	48.0							
VS	7	23.9	22.5	46.4	44.5			24.8			
COD_{tot}	43	37.4	26.7	64.1	4.57			38.8			
$COD_{sol,bio}$	75	5.2	0.0	5.2							
$COD_{sol,in}$	76	0.4	0.0	0.4							
$COD_{part,bio}$	77	29.5	17.7	47.2							
$COD_{part,in}$	78	2.2	9.0	11.3							
BOD_7	6	22.6	11.5	34.1	3.35			29.3			
N_{tot}	23	1.5	0.0	1.5	1.95	1.76			1.5	1.5	1.5
$N_{NH3/NH4}$	24	0.3	0.0	0.3	0.66						
N_{NO3}	26	0.0	0.0	0.0	0.00						
$N_{sol,org}$	44	0.45	0.0	0.45							
$N_{part,org}$	81	0.75	0.0	0.75							
P_{tot}	30	0.5	0.0	0.5	0.69	0.60			0.50	0.50	0.50
P_{PO4}	79	0.1	0.0	0.1							
P_{Part}	80	0.4	0.0	0.4							
S_{tot}	28	0.162	0.004	0.166	0.21						
S_{SO4}	29	0.029	0.0	0.029							
S_{S2-}	48	0.003	0.0	0.003							
S_{part}	46	0.130	0.004	0.134							
K_{tot}	32	0.9	0.0	1.0	0.76	1.5			1.0	1.0	1.0
K_{cell}	49	0.15	0.0	0.15							
Pb	34	0.038	0.002	0.040	0.037	1.200			0.02	0.020	0.020
Cd	35	0.010	0.000	0.010	0.016	0.015			0.01	0.010	0.010
Hg	36	0.009	0.000	0.009	0.009	<0.0068			0.063	0.009	0.063
Cu	37	1.00	0.010	1.10	1.74	2.9			1.1	1.10	1.10
Cr	38	0.124	0.006	0.13	0.135	0.15			0.02	0.02	0.02
Ni	39	0.188	0.002	0.19	0.226	0.19			0.074	0.07	0.07
Zn	40	10.7	0.000	10.7	46.4	13			11	10.68	10.80

a) Andersson & Jenssen (2002). **b)** Weglin & Vinnerås (2000). **c)** KVVBS (1966). **d)** Arrhenius (1967). **e)** Kärrman et al. (1999). **f)** Vinnerås et al. (2004), Vinnnerås (2002). **g)** NV (1995). **h)** 27.4 g $pe^{-1}day^{-1}$ from faeces and 23.4 g $pe^{-1}day^{-1}$ from toilet paper. **i)** Total wet mass, i.e. TS+H_2O, for 10 young nurses measured during 10 days. The TS-content was not measured.

To obtain the amount of water in faeces, the design value proposed by Vinnerås et al. (2004) for wet mass is subtracted by the dry mass, which gives the water content 109.6 g pe^{-1} day^{-1} in the faeces and additionally 1.0 g pe^{-1} day^{-1} in the toilet paper.

2.3.2 COD and BOD_7

The BOD_7 and COD values of the mixture of faeces and paper were measured at Gebers (Andersson & Jenssen, 2002). However, when these values are compared with the VS values it is obvious that these values are almost a factor 10 too small. The COD and BOD values were also calculated by Arrhenius (1967) and those calculations are well described and motivated. However, his BOD values are high compared to the COD values. Therefore, the principles of his BOD calculation were followed, after lowering to 80% and adjusting for the assumed amount of VS in the faecal matter. The COD and BOD_7 values for the toilet paper were also calculated using the same assumptions as used by Arrhenius (1967), that the toilet paper VS consists of cellulose. Two brands of toilet paper (Leni & Lambi) were measured by Stockholm Water Inc. for COD, BOD_7, TOC and TS. The agreement was good between the two measurements, the measured values were for COD 1.2 g $(g\ TS)^{-1}$, BOD_7 0.52 g $(g\ TS)^{-1}$, TOC 0.48 g $(g\ TS)^{-1}$ and TS 96.5% (Mårtensson, pers. com.). Thus, 43% of the COD was degraded during BOD_7 test, with 2% paper mixed into the sample. This value is used in the URWARE vector and it has later been confirmed a second set of 8 BOD_7 measurements, 4 for Leni and Lambi each, showing an average of 0.506 g BOD7 $(g\ TS)^{-1}$ of toilet paper.

Of the faecal organics, 15% are assumed to be soluble, but none of the toilet paper. The same proportions of COD and BOD_7 were assumed to be dissolved.

2.3.3. NPK and S

Nitrogen content in faeces is set to 1.5 g pe^{-1} day^{-1} by both NV (1995) and Vinnerås et al. (2004). This value of N-tot is also used by the ORWARE model. Andersson & Jenssen (2002) measured the N-tot of the mix of faeces and paper at 1.95 g $pe^{-1}day^{-1}$, which agrees well with 1.5 g $pe^{-1}day^{-1}$, if 5% of urine is assumed to end up in the faecal fraction. Therefore, N-tot is set at 1.5 g $pe^{-1}day^{-1}$.

Ammonium (NH_4-N) content for faeces has only been measured by Andersson & Jenssen (2002) at 0.66 g $pe^{-1}day^{-1}$, probably approximately 0.5 g $pe^{-1}day^{-1}$ of this came from urine. This means that the faecal matter contained 0.1-0.2 g $pe^{-1}day^{-1}$ of NH_4-N, while the original ORWARE value is 0.85 g $pe^{-1}day^{-1}$. For URWARE the value 0.3 g $pe^{-1}day^{-1}$ is proposed. Of the nitrogen, 0.45 g $pe^{-1}day^{-1}$ is assumed to be in the form of soluble organic nitrogen, which means that 50% of N-tot is water soluble, just as stated by Documenta Geigy (Lentner et al., 1981).

Andersson & Jenssen (2002) measured somewhat higher values for P and lower for K compared to NV-95. In Ekoporten, lower values were measured for P and higher for K. Both ORWARE and Vinnerås et al. (2004) use figures from NV-95 and the same figure is proposed for URWARE for P. However, for K a somewhat lower figure is proposed, 0.9 g $pe^{-1}day^{-1}$ in URWARE. This is to make the total excretion match the potassium consumption, which is 3.3 g $pe^{-1}day^{-1}$ according to two large nutritional studies (Becker, 1994; Becker & Pearson, 2002).

Several references (Lentner et al., 1981; Fraústo da Silva & Williams, 1997) state that most of the faecal P is in the form of small calcium phosphate granules. Vinnerås & Jönsson (2002) filtered faecal matter mixed with water with different pore sizes. More than 10% of the faecal P passed a 70 μm filter when the filtration took place 15 minutes after the faecal matter was introduced into the water. Since the fraction passing the filter increased with time and 15 minutes is very short compared with the retention time of the sewage pipe system, the proportion of dissolved P, P_{PO4}, of the faecal matter is set at 20% of total faecal P.

As the potassium content of the toilet paper in Gebers was analysed to be below the detection limit, which was around 0.3% of the potassium content of the total faecal mix, this amount is neglected. This means that the particulate COD from the toilet paper contains no K, while the same proportion, 0.5%, between K_{cell} and COD_{part} is assumed for faeces as for the other fractions.

Only Andersson & Jenssen (2002) have analysed S_{tot} (0.21 g pe^{-1} day^{-1}). Their ratio between S_{tot} to N_{tot} is used to calculate the proposed value for S_{tot} from the value for N_{tot}. The sulphur in the faecal mix is difficult to divide into different fractions. The S_{tot} content of the toilet paper is much less than what would normally be associated with COD_{part}. Thus, all sulphur contained in the toilet paper is supposed to be in the form of S_{part}. On the other hand, the content of soluble S in the faecal matter should be rather low, since it is easily dissolved and taken up by the intestines. The metabolism of S is often associated with N. Of N, 20% is assumed to be in the form of $N_{NH3/NH4}$ and the same proportion is assumed for soluble S of S_{tot}. This means that for the faecal matter the relationship between S_{part} of COD_{part} will be fairly high, 0.43%. On the other hand, this relationship is somewhat lower for the total faecal mixture, including toilet paper, than what is used for the other fractions in this document, 0.23% compared to 0.25%.

Ratios between some important parameters for faeces are given in Table 6.

Ratio	Faecal mix	Faeces	Toilet-paper
TSS:TS	0.90	0.83	1.00
VS:TS	0.87	0.79	0.98
COD_{tot}:VS	1.38	1.56	1.19
COD_{tot}:TS	1.21	1.24	1.16
$COD_{tot.part}$:TSS	1.22	1.27	1.16
BOD_7: VS	0.73	0.95	0.51
BOD_7:COD_{tot}	0.53	0.60	0.43
BOD_7:COD_{bio}	0.65	0.65	0.65

Table 6
Ratios between different variables for faeces and toilet paper.

2.3.4 Heavy metals (Pb, Cd, Hg, Cu, Cr, Ni and Zn)

It is very hard to decide upon values for the heavy metal contamination of faeces. Besides the two recommendations for design values (NV, 1995) and Vinnerås et al. (2004), the contamination has only been measured at Gebers (Andersson & Jenssen, 2002) and Ekoporten (Weglin & Vinnerås, 2000). The small airport in the vicinity where highly leaded gasoline was used might explain the high value for Pb at Ekoporten together with the fact that scrubbing water was poured into the toilet. Also the value measured at Gebers seems too high to come from just the excreta, it is probably caused by some contamination and more measurements are needed to find this. However, as the URWARE value should include "normal" contamination when the faecal matter reaches the collection bin or leaves the building site, the most reasonable value to use is a Pb value similar to that measured in Gebers, even though it is twice as high as the design value recommended by Vinnerås et al. (2004). For Cd, the measured values coincide surprisingly well. However, at Ekoporten lots of scrubbing water was poured down the toilet and at Gebers the faecal shafts were made out of galvanised iron, which corroded. As Zn is always contaminated by Cd, some of the Cd probably comes from this corrosion. As the faecal system should not be constructed of galvanised steel, the somewhat lower design value recommended by NV (1995) and Vinnerås et al. (2004) is used also for URWARE.

The flows of Hg have decreased in society and this is seen by the amounts in faeces. Both the measurement at Ekoporten (Weglin & Vinnerås, 2000) and Gebers (Andersson & Jenssen, 2002) showed values far below the NV (1995) recommended design value. For URWARE, the value measured at Gebers is chosen, even though the value measured at Ekoporten was lower. The value given by NV (1995) was seven times higher than the value chosen for URWARE and it was very well founded as it was supported by measurements (Skare & Engqvist, 1992) of the Hg excretion via urine and faeces for 10 persons with varying numbers of amalgam fillings. In this measurement a linear relationship was found between the number of fillings and the excretion. For 32 fillings, the average number in Sweden at that time, the relationship meant that the faecal excretion would be 0.06-0.07 mg $pe^{-1}day^{-1}$. However, as amalgam is going out of use and both the measurements at Ekoporten and Gebers yielded far lower values, the highest of those measured, that at Gebers, is used for URWARE.

For Cu, the value measured at Gebers is just some 60% higher than the recommended default value. As this is based also on the diet, this value is considered better than the measurement and is therefore chosen. For Cr and Ni the differences between the measured values and the recommended design values are larger, 7 times and 3 times respectively. These two metals are common in alloys and it will be hard to avoid contamination, thus values similar to the lowest measured, are chosen for URWARE, even though this might be far higher than the excretion. However, for Zn the recommended design value is chosen also for URWARE, as the Zn value at Gebers was due to corrosion on the galvanised shafts and as scrubbing water was poured down the toilet at Ekoporten. The Gebers measurement

(Andersson & Jenssen, 2002) showed that the contribution of the toilet paper to the amount of heavy metals in the faecal mixture was about 5% for Pb and Cr, 1% for Cu and Ni and negligible for the other metals and these relationships are used for the URWARE vector.

2.4 Toilet flush water

The amount of toilet flushwater is neither included in Table 3 nor in Table 5 and thus has to be added to the above vectors in water flushed systems.

The amount of flushwater used depends on parameters in connection to the toilet itself, e.g. the amount of water per flush, whether it provides the possibility to flush with smaller amounts of water and whether one flush is enough to clean the toilet bowl. However, above all the used amount of flush water depends on the practices of the user and the importance that he/she places on saving water. Thus, the data provided below must always be interpreted in relation to the type of users that are expected.

Jönsson et al. (1998) measured the number of number of flushes $pe^{-1}day^{-1}$ in two housing districts with urine diverting toilets, Understenshöjden and Palsternackan. The toilets were double flushed, meaning that the faecal bowl was flushed with one button and the urinal bowl with another. When the user wished to flush both bowls, then both buttons had to be activated and when this was done within one minute of each other, the flush was also registered as a combined flush. The number of flushes per person and 24 hours are found in Table 7. These data have been linearly extrapolated to 24 hours from the number of flushed registered during the time that the inhabitants were at home.

Table 7
Flushes[a] (no $pe^{-1}day^{-1}$) of the faecal and of the urinal bowl in Understenshöjden and Palsternackan (Jönsson et al., 1998).

Type of flush	**Faecal bowl**	**Urinal bowl**	**Combined flushes**	**Total no separate flushes**
Understenshöjden	**4.2**	**6.5**	**2.5**	**8.3**
Palsternackan	**7.3**	**6.5**	**4.3**	**9.5**

a) The number of flushes has been linearly extrapolated from the numbers registered during the time the person was at home to 24 hours $pe^{-1}day^{-1}$.

It seems likely that whenever the toilet was flushed due to a recent excretion, then the urinal bowl was flushed, as faeces seldom is excreted without simultaneous excretion of urine. It is also unlikely that there was a need to flush the urinal bowl at other times, as neither toilet paper nor any other solid material would pass the urine pipe. It is thus not surprising that the same frequency of flushing the urinal bowl was found for both housing districts. This number, 6.5, is probably the number of flushes that is needed $pe^{-1}day^{-1}$ to dispose of urine and faeces from the toilet.

To dispose of the faeces, the faecal bowl probably needs to be flushed just 1-2 times $pe^{-1}day^{-1}$ (Lentner et al., 1981). In both housing areas, the faecal bowl was flushed many more times than this. This is explained partly by the fact that women use toilet paper after urination and to dispose of this, in Sweden they normally flush it down the toilet. This would account for 3-4 flushes of the faecal bowl, as approximately 50% of the inhabitants were women. Furthermore, both toilet paper and e.g. cotton swabs are used for cosmetic purposes in the bathroom and these articles are frequently flushed down the toilet, especially if the users are not environmentally aware. This is the probable explanation behind the difference in faecal flushes between Understenshöjden and Palsternackan. Understenshöjden was an eco-village and its inhabitants were environmentally aware, while the inhabitants in Palsternackan more resembled the Swedish average.

In conclusion, personal habits and priorities are just as important for the use of flush water as the construction of the toilet itself. If the urinal bowl is flushed after each excretion, then 6.5 flushes $pe^{-1}day^{-1}$ (24 hours) seems like a good average. If the faecal bowl is flushed just after faecal excretion, then 1-2 faecal flushes $pe^{-1}day^{-1}$ are needed. However, if the toilet paper used by women after urination is flushed away each time, then on average 3-4 extra flushes $pe^{-1}day^{-1}$ are needed. Furthermore, if the inhabitants also flush away materials used for other purposes in the toilet, then this can add 3-4 extra flushes of the toilet.

2.5 Household greywater

2.5.1 TS, VS, TSS, BOD_7, COD and water

Total solids content varies between 40 to 80 g pe^{-1} day^{-1} and the higher value is the design value from NV-95. According to Vinnerås et al. (2004), recent measurements show lower values and they suggest 54.8 g pe^{-1} day^{-1} (20 kg pe^{-1} $year^{-1}$). This proposal is also used for URWARE (Table 8).

The measured COD values vary from 39 to 52 g pe^{-1} day^{-1}, excluding the Ekoporten measurement as the analysed COD and BOD_7 values obviously were wrong in this measurement. Vinnerås et al. (2004) proposed 52 g pe^{-1} day^{-1}, for URWARE a slightly lower value, 48 g pe^{-1} day^{-1}, is proposed (Table 8).

The BOD_7 measurements are, except for the Ekoporten one, well collected around 26.0 g pe^{-1} day^{-1}, which is the value proposed for URWARE. This yields a ratio of BOD_7/COD_{tot} of 0.54, close to the average 0.57 of the ratios in the Tuggeliten, Vibyåsen and Gebers measurements.

The ratios for the distribution of COD-fractions are calculated from the ratios between BOD_7 and COD filtered and unfiltered values from Gebers (weighted 3) and Bromsten (weighted 1) and the assumption that the ratio between BOD_7 and COD_{bio} is 0.65.

At Gebers 69% of the TS was VS, while at Bromsten it was 57%. The VS can also be calculated from the proposed COD value and an assumed proportion between COD and VS. For this relationship “Wastewater Engineering” (Tchobanoglous & Burton, 1991) in an example gives a value of 1.37. Using this relationship, the proposed VS value is 32 g pe^{-1} day^{-1} and thus the VS is 58% of the TS, close to the value measured in Bromsten.

TSS from ORWARE is calculated as 18% of TS. The ratio between TSS:

	Pos	URWARE home (100%)	URWARE total (130%)	Bromsten 1967[a]	Bromsten 1977[b]	Tug-gelite[c]	Eko-porten[d]	Viby-åsen[e]	Ge-bers[f]	OR-WARE	Design proposal[g]	NV-95[c]
H_2O	22	100[h]	130[h]	121.5	133[b]	108	104	70	110	150	100	150
TS	8	54.8	71.2	77.1		80	59.1	41.5	40.5	80	54.8	80
TSS	42	13.5	17.6	17.3		9.1			10	14.38		16
VS	7	32.0	41.6	43.9					27.9[f]	45.2		
COD_{tot}	43	48.0	62.4	-[i]	-[i]	51.7	6.71	39	48	51.7	52.05	
$COD_{sol,bio}$	75	19.0	24.7									
$COD_{sol,in}$	76	1.0	1.3									
$COD_{part,bio}$	77	21.1	27.4									
$COD_{part,in}$	78	6.9	9.0									
BOD_7	6	26.0	33.8	27.5[j]	31.3[j]	27.7	7.71	27.7	21.7	27.9	26.03	28
N_{tot}	23	1.18	1.53	1.1	0.75	1.17	1.7	0.64	1.4	1	1.37	1
$N_{NH3/NH4}$	24	0.19	0.25			0.07	< 0.02		0.19	0.07		
N_{NO3}	26	0.01	0.01				< 0.02		0.006	0.008		
$N_{sol,org}$	44	0.36	0.47									
$N_{part,org}$	81	0.62	0.80									
P_{tot}	30	0.52	0.68	2.2	0.33	0.36	0.44	0.5	0.6	0.3	0.52	0.6
P_{PO4}	79	0.22	0.29						0.48			
P_{Part}	80	0.30	0.39									
S_{tot}	28	0.35	0.46				1.97	1.6	1.6[f]	4.08		
S_{SO4}	29	0.26	0.34									
S_{S2-}	48	0.03	0.04									
S_{part}	46	0.06	0.08									
K_{tot}	32	0.6	0.79				4.14	0.54	0.95[f]	0.5	1	0.5
K_{cell}	49	0.14	0.18									
Pb	34	0.2 (1.0)	0.26 (1.3)				1.4	0.17	0.24[f]		1.0	<3
Cd	35	0.01 (0.04)	0.013 (0.05)				0.031	0.0064	0.015		0.041	<0.6
Hg	36	0.001 (0.004)	0.0013 (0.005)				<0.01	0.001	0.003		0.004	<0.06
Cu	37	4 (7.9)	5.2 (10.3)				11.5	4.1	6.5[f]		7.9	<6
Cr	38	0.2 (1.0)	0.26 (1.3)				1	0.25	0.4		1.0	<5
Ni	39	0.4 (1.2)	0.52 (1.6)				0.83	0.73	0.66[f]		1.2	<3
Zn	40	4 (10)	5.2 (13)				13.1	4.3	7.0[f]		10	<50

Table 8

Flow, l $pe^{-1}day^{-1}$, and composition of greywater expressed as g $pe^{-1}day^{-1}$, mg pe^{-1} $day^{-1}$for the metals (pos 34-40). Normally only 55-70% of the time is spent at home and we expect the person to generate an additional 30% of greywater when not at home. The composition is that expected when collected just outside of the house. Quality marking: Well-validated data, data based on few references, initiated estimates. The measurements, but not the URWARE-figures, include the contributions from the drinking water quality as leaving the waterworks. For the heavy metals, two cases are given, one with new, clean infrastructure and one reflecting a present Swedish average Parameter.

a) Olsson (1967). **b)** Karlgren et al. (1977). The flow 133 l $pe^{-1}day^{-1}$ is from kitchen and bath. The flow from laundry was not measured. **c)** NV (1995). The values are for one person during a full day, 24 hours. **d)** Weglin & Vinnerås (2000). **e)** Palmquist (2001). **f)** Andersson & Jenssen, 2002; Note that in this measurement the tap water in the cellar contained approximately 60% of the contaminations of Pb, Ni and Zn, as well as 120% of the contamination of Cu. The copper piping in the cellar explains the latter. Note also that in their report the amount of ash, which was 12.6 g pe^{-1} day^{-1}, due to a mistake is reported as 0.004 g pe^{-1} day^{-1}. Of the S_{tot}, 1.24 g pe^{-1} day^{-1} came from the drinking water. Of the K_{tot}, 0.24 g pe^{-1} day^{-1} came from the drinking water. **g)** Vinnerås et al. (2004), Vinnerås (2002). **h)** The flow of greywater should be set according to the technology and habits in the studied area. **i)** The COD was measured with two different methods using $KMnO_4$, which make them difficult to use. **j)** Calculated as 1.1 times the BOD_5, which was measured.BOD_7 varies somewhat between different analyses of greywater. In most cases the values are just under the design value for BOD_7 according to NV-95 and Vinnerås et al. (2004) proposes a slightly lower design value. COD show some variation in the same fashion as BOD_7. The estimate for BOD_7 by Vinnerås et al. (2004) seems good and is proposed.

TS from Andersson & Jenssen (2002) is 25% and this ratio is proposed for URWARE, which gives 13.5 g pe^{-1} day^{-1}.

The amount of water should be set for each simulation according to local conditions. However, as a default value the value suggested by Vinnerås et al. (2004) 100 l pe^{-1} day^{-1} is proposed.

2.5.2 NPK and S

For N, the average of the latest measurements, Ekoporten, Vibyåsen and Gebers is 1.2 g pe^{-1} day^{-1}. However, NV (1995) and the measurement in Tuggeliten estimated the total N generation in greywater to 1 and 1.17 g pe^{-1} day^{-1}, respectively (Table 8). Considering these data, it seems reasonable to use 1.18 g pe^{-1} day^{-1} (430 g pe^{-1} $year^{-1}$) for N_{tot} generated in greywater at home, yielding 1.53 g pe^{-1} day^{-1} total N emission, including the greywater generated outside of home.

For NH_4-N and NO_3-N the values from Andersson & Jenssen (2002) are proposed and the amounts of both these are small, for NO_3-N it is even negligible. The difference between N-tot and NH_4-N and NO_3-N is assumed to be present as soluble or particulate nitrogen. Distribution between particulate and soluble nitrogen is unknown and assumed to be the same as that of BOD_7, i.e. 47% soluble.

For P-tot, the estimation by Vinnerås et al. (2004) seems good. However, it deserves to be pointed out that the amount of P found in greywater is directly proportional to the amount of P used in detergents and washing-up powders used. A large proportion of the P found as PO_4 in the greywater is probably in the form of particulate calcium phosphates, as the phosphorus is used for reacting with the calcium. In the URWARE vector only the solute PO_4 should be given as the particulate P element contains both organic and inorganic particulate P. Lacking better data, the proportion of particulate P is set the same as the proportion of particulate COD, 58%.

Only a few measurements have included K among the measured parameters, and the values measured vary very much, from 0.54 g pe^{-1} day^{-1} in Vibyåsen, 0.95 g pe^{-1} day^{-1} in Gebers and 4.14 g pe^{-1} day^{-1} in Ekoporten, thus the Ekoporten measurement of K really looks like an outlier. Furthermore, of the potassium measured in Gebers, the drinking water contributed with 0.24 g pe^{-1} day^{-1} and this contribution was probably approximately of the same size in Vibyåsen. Thus, the net contributions in Gebers and Vibyåsen were approximately 0.7 and 0.3 g pe^{-1} day^{-1}, respectively. The design value for K from NV (1995), 0.5 g pe^{-1} day^{-1} is just based on a small measurement in an ecovillage and the measurement in Ekoporten was considerably larger. Thus, a value of 0.6 g pe^{-1} day^{-1} seems appropriate for K. This is fractioned according to the previously stated assumptions.

Sulphur content in greywater is almost twice as large in ORWARE as in other sources. Both Gebers (Andersson & Jenssen, 2002) and Vibyåsen (Palmquist, 2001) give similar values and Ekoporten a slightly higher value. However, it should be noted that 1.24 g pe^{-1} day^{-1} of the sulphur at Gebers came from the incoming water. Excluding this, the amount of sulphur added to the greywater is just 0.35 g pe^{-1} day^{-1} and this is the value proposed for URWARE. For the fractioning of the S, the previously used general assumptions are used. A relationship between COD_{part} and S_{part} of 0.25% is used to calculate the amount of S_{part} and the remaining soluble S is divided with 90% as S_{SO4} and 10% as S_{S2-}.

Important ratios between the different parameters for urine are given in Table 9.

Ratio	Value
TSS:TS	0.25
VS:TS	0.58
COD_{tot}:VS	1.50
BOD_7: VS	0.81
BOD_7:COD_{tot}	0.54
BOD_7:COD_{bio}	0.65
COD_{tot}:TS	0.88
$COD_{tot.part}$:TSS	1.60

Table 9
Ratios between different variables for greywater.

2.5.3 Heavy metals (Pb, Cd, Hg, Cu, Cr, Ni and Zn)

Detectable levels have been measured for all of these heavy metals in all measurements, except for Hg in Ekoporten, but for that measurement the detection limit was high. The level of Pb differs by almost a factor of 10 between Vibyåsen and Ekoporten and even the highest value was less than half of the NV (1995) design value. The probable reason for the high value at Ekoporten is the small airfield in the vicinity, where leaded gasoline still was used (Vinnerås et al., 2004). It thus seems reasonable to use a lower value than the NV (1995) design value.

The design value recommended by Vinnerås et al. (2004) for Pb seems high compared to the values measured. The reason is probably that Vinnerås et al. (2004) also considered the average wastewater values in Gothenburg during a 10 year period. However, the URWARE input data will probably mainly be used for simulations of areas, which have undergone a major renovation. As lead is banned in new construction materials and its concentration in the air is steadily decreasing, a lower value than the one recommended by Vinnerås et al. (2004) seems appropriate for URWARE and 0.2 mg pe^{-1} day^{-1} is proposed. As is shown by the measurements in Gebers and Vibyåsen, this can be expected to be an average "normal" contamination of Pb from dust etc. in such an area. However, if the simulation is done mainly for an area with old infrastructure, with old buildings, roads etc. then a value of 1 mg pe^{-1} day^{-1}, as proposed by Vinnerås et al. (2004) probably is more appropriate, as the lead contaminated dust continues to blow around in such an area for many years.

Also for the other listed heavy metals two values are proposed, one reflecting new clean infrastructure and one more similar to the present

Swedish average. For the new infrastructure value usually a value is used that is close to the lowest measured.

The Cu value depends mainly upon the type of piping used and the corrosiveness of the water. Thus, it should preferably be set according to local values. However, if local values are not available the specific values given in Table 8 can be used. The Zn value of the greywater is largely influenced by the use of different Zn containing lotions and shampoos as well as by the piping system and the corrosiveness of the water.

The Ni value is set lower than any of the measured values. This is done because measurements on mixed household wastewater shows that the contamination can be this low (Magnusson, 2003; Lundin, pers. com.).

2.6 Greywater also from society

The section above describes the amount and composition of greywater that emanates from a household. However, in addition greywater of similar composition is also produced in offices, shops, restaurants, sports arenas, theatres etc.

We do not know of any measured data on this greywater. However, in order to somehow take it into account we propose that the household greywater production is supplemented an additional amount of the same type of greywater and its amount is initially estimated to 30% of the amount produced at home. The reasoning for this is that from our measurements in Understenshöjden, Palsternackan, Hushagen and Gebers it appears that people on average are at home 60-65% of the total time. If they produced greywater at the same rate as at home, then this would mean that some additional 54-67% of greywater would be produced in the rest of the society. For the initial estimation we have assumed that the rate of greywater production in society is half of that at home, which means an additional 30% of greywater is being produced in the rest of society, i.e. the URWARE total values are 130% of the URWARE home values (Table 8).

2.7 Total wastewater

In Table 10 the composition of default URWARE household wastewater, the sum of urine, faeces and greywater, is given.

Table 10
URWARE household wastewater, summation of urine, faeces and greywater, expressed as g pe^{-1}day^{-1}, mg/ pe^{-1} day^{-1}for the metals (pos 34-40). For heavy metals in greywater, only the "old system" contamination level is given.

Parameter	**Pos**	**Urine**	**Faeces & toilet paper**	**Greywater total**	**Household ww total society**
H_2O	22	1487	*110.6*		
TS	**8**	**20**	**53.1**	**71.2**	**144.3**
TSS	42	0.76	*48.0*	17.6	66.36
VS	**7**	**7.4**	**46.4**	**41.6**	**95.40**
COD_{tot}	43	*8.5*	*64.1*	62.4	*135.0*
$COD_{sol,bio}$	75	*7.23*	5.2	*24.7*	*37.13*
$COD_{sol,in}$	76	*0.67*	**0.4**	**1.3**	**2.37**
$COD_{part,bio}$	77	*0.46*	*47.2*	*27.4*	*75.06*
$COD_{part,in}$	78	*0.14*	*11.3*	*9.0*	*20.44*
BOD_7	6	5.0	*34.1*	33.8	**72.90**
N_{tot}	**23**	**11.0**	**1.5**	**1.53**	**14.03**
$N_{NH3/NH4}$	24	10.3	*0.3*	0.25	10.85
N_{NO3}	26	0	*0*	0.01	0.01
$N_{sol,org}$	44	*0.6*	*0.45*	*0.47*	*1.52*
$N_{part,org}$	81	*0.1*	*0.75*	*0.80*	*1.65*
P_{tot}	**30**	**0.9**	**0.5**	**0.68**	**2.08**
P_{PO4}	79	*0.81*	**0.1**	**0.29**	**1.2**
P_{part}	80	*0.09*	*0.4*	*0.39*	*0.88*
S_{tot}	**28**	**0.70**	**0.166**	**0.46**	**1.33**
S_{SO4}	29	*0.63*	*0.029*	*0.34*	**1.00**
S_{S2-}	**48**	**0.07**	**0.003**	**0.04**	**0.11**
S_{part}	**46**	**0.00**	**0.134**	**0.08**	**0.22**
K_{tot}	**32**	**2.4**	**0.9**	**0.79**	**4.09**
K_{cell}	**49**	**0.003**	**0.15**	**0.18**	**0.33**
Pb	34	0.012	*0.040*	1.3	1.35
Cd	**35**	**0.0005**	**0.010**	**0.05**	**0.06**
Hg	**36**	**0.00082**	**0.009**	**0.005**	**0.01**
Cu	**37**	**0.10**	**1.10**	**10.3**	**11.50**
Cr	**38**	**0.010**	**0.13**	**1.3**	**1.44**
Ni	**39**	**0.011**	**0.19**	**1.6**	**1.80**
Zn	40	0.3	*10.7*	13	*24.0*

In Table 10, the unit is g pe^{-1}day^{-1}, mg/ pe^{-1} day^{-1}for the metals (pos 34-40). Some readers may be more used to units of kg pe^{-1}year^{-1}and this is provided in Table 11 (g pe^{-1}year^{-1} for the heavy metals). Moreover, the concentrations of different components represent what are normally measured at wastewater treatment plants. Therefore Table 11 also contains a concentration value for each variable based on the assumption that the wastewater flow is 200 l pe^{-1}day^{-1} (equivalent to 73 m^3 year^{-1}). For a separated sewer system without, storm water and leakage, this would seem to represent a reasonable value. Again, note that the contents of the drinking water are not included, which is especially important for S and K.

Table 11
URWARE household wastewater, summation of urine, faeces and greywater, expressed as kg pe^{-1}year^{-1}, g pe^{-1} year^{-1} for the metals (pos 34-40). For heavy metals in greywater, only the "old system" contamination level is given. The wastewater composition is also given as concentrations (mg l^{-1}, for metals mg m^{-3}) assuming 200 l pe^{-1}day^{-1} of wastewater.

Parameter	Pos	Urine	Faeces & toilet paper	Greywater total	Household ww total society	Household ww conc
H_2O	22	543	40			
TS	8	7	19	26	53	722
TSS	42	0	18	6	24	332
VS	7	3	17	15	35	477
COD_{tot}	43	3	23	23	49	675
$COD_{sol,bio}$	75	3	2	9	14	186
$COD_{sol,in}$	76	0.2	0.1	0.1	0.9	12
$COD_{part,bio}$	77	0	17	10	27	375
$COD_{part,in}$	78	0	4	3	7	102
BOD_7	6	2	12	12	27	365
N_{tot}	23	4.0	0.5	0.6	5.1	70
$N_{NH3/NH4}$	24	3.8	0.1	0.1	4.0	54
N_{NO3}	26	0.00	0.00	0.004	0.004	0.1
$N_{sol,org}$	44	0.2	0.2	0.2	0.6	7.6
$N_{part,org}$	81	0.0	0.3	0.3	0.6	8.3
P_{tot}	30	0.33	0.18	0.25	0.76	10
P_{PO4}	79	0.30	0.04	0.11	0.44	6.0
P_{part}	80	0.03	0.15	0.14	0.32	4.4
S_{tot}	28	0.26	0.06	0.17	0.48	6.6
S_{SO4}	29	0.23	0.01	0.12	0.36	5.0
S_{S2-}	48	0.03	0.00	0.01	0.04	0.6
S_{part}	46	0.00	0.05	0.03	0.08	1.1
K_{tot}	32	0.88	0.33	0.29	1.49	20
K_{cell}	49	0.00	0.05	0.07	0.12	1.7
Pb	34	0.00	0.01	0.47	0.49	6.8
Cd	35	0.000	0.004	0.018	0.022	0.30
Hg	36	0.0003	0.0033	0.0018	0.0054	0.074
Cu	37	0.0	0.4	3.8	4.2	58
Cr	38	0.00	0.05	0.47	0.53	7.2
Ni	39	0.00	0.07	0.58	0.66	9.0
Zn	40	0.1	3.9	4.7	8.8	120

It should be pointed out that also the URWARE heavy metal loads with the "old system" values represent a fairly clean system. This is obvious by comparing the concentrations for Pb, Cd, Hg, Cu, Cr, Ni and Zn in Table 11 with the concentrations that Magnusson (2003) measured for the influent to Henriksdalsverket in Stockholm, which were 9, 0.4, <0.13, 112, 5.1, 8.4 and 122 mg m^{-3}, respectively. Thus, only Cr and Ni were below the URWARE concentrations, while the others were above, in spite of the fact that the specific flow of wastewater to Henriksdal was 300-400 l pe^{-1}day^{-1}.

2.7.1 Comparisons of BOD_7, COD, P and N with wastewater measurements

From Tables 9 and 10 relations can be calculated and compared to relations measured in wastewater. In Table 12 the relationship between BOD_7, COD, P and N is compared with those of influent wastewater in a few major Swedish wastewater treatment plants and wastewater measured at Båtbryggaregatan in Stockholm (Magnusson, 2003). This water comes from a newly built housing area in Stockholm and contains no industrial wastewater.

Table 12
Relations between COD_{tot}, BOD_7, N and P for influent to a few major Swedish wastewater treatment plants and values measured at Båtbryggaregatan in Hammarby, Stockholm compared to URWARE values according to Table 11.

Treatment plant	BOD_7/COD	COD/P	BOD_7/P	N/P
Bromma 2003[a]	**0.44**	**83.3**	**42.8**	**7.2**
Henriksdal 2003[a]	**0.43**	**66.7**	**33.3**	**5.8**
Käppala 2001[a]	**0.47**	**64.2**	**29.3**	**5.8**
Käppala 2002[a]	**0.47**	**69.9**	**31.5**	**5.8**
Käppala 2003[a]	**0.31**	**71.6**	**33.3**	**5.8**
Rya 2001[a]	**0.34**	**68.3**	**32.0**	**5.4**
Rya 2002[a]	**0.47**	**65.8**	**28.3**	**5.9**
Rya 2003[a]	**0.45**	**67.8**	**29.6**	**6.3**
Syvab 2001[a]	**0.46**	**77.8**	**26.7**	**6.7**
Syvab 2002[a]	**0.50**	**75.0**	**23.0**	**6.0**
Syvab 2003[a]	**0.51**	**66.7**	**31.4**	**5.7**
Minimum of above	**0.31**	**64.2**	**23.0**	**5.4**
Maximum of above	**0.51**	**83.3**	**42.8**	**7.2**
Median of above	**0.46**	**68.0**	**31.5**	**5.8**
Båtbryggaregatan, from averages	**0.46**	**58.8**	**27.1**	**5.5**
Båtbryggaregatan, from medians	**0.49**	**57.1**	**27.8**	**5.8**
URWARE, household ww	**0.54**	**64.9**	**35.0**	**6.7**
URWARE, household – 20% BOD_7	**0.48**	**57.9**	**28.0**	**6.7**

a) Data from the environmental report of each WWTP.

The ratio BOD_7/COD in the URWARE input vector is slightly higher than the maximum measured for the influent to the major Swedish wastewater treatment plants in Table 12. It is also above the ratios for household wastewater from Båtbryggaregatan (Magnusson, 2003). Also, the BOD_7/P ratio is high, although within the range of the treatment plant influents. However, together these two ratios, BOD_7/COD and BOD_7/P indicate that the estimation of BOD_7 might be a little high. One reason for this can be that some BOD_7 is degraded already in the pipes on the way to the wastewater treatment plant. This effect is naturally included in the figures in Table 12, but not at all to the same extent in the URWARE figures for BOD_7 and COD in greywater. The reason for this is that the URWARE figures are based on measurements where greywater has been collected separately and such collection has only been possible in the houses or close to them. Thus, the URWARE values for BOD_7 and COD, just as for the other parameters reflects the composition of the fractions when they leave the piping system of the building site , when they are about to enter the municipal piping system. At this point some of the fastest transformations, like that of the urine urea degrading into ammonium and carbon dioxide, have already happened and thus are included in the URWARE values. However, the main part of the BOD_7 and COD transformation is not quite this fast and thus is not included in the URWARE values. The fractions of the BOD_7 and the COD that are degraded in the municipal piping system before reaching the WWTP depend upon the retention time, temperature and oxygen conditions in the pipe system. This degradation, which can be large, will influence all columns in Table 12, except the last one, the N/P column.

If it is assumed that 20% of BOD_7 is degraded on the way to the treatment plant, then these new URWARE ratios agree well with measured data (Table 12). The BOD_7/COD ratio agrees well with the measurements from Båtbryggaregatan (Magnusson, 2003) and is close to the median for the listed wastewater treatment plants. The BOD_7/P ratio is close to the measurement at Båtbryggaregatan, where the measured flow mainly consisted of household wastewater and well within the range of the ratios measured at the inlet of the wastewater plants, even though it is a little lower than the median for those measurements (Table 12). The reason for this might be that the influent to the wastewater treatment plants contains industrial wastewater and some stormwater, while the URWARE wastewater in Table 12 just contains household wastewater.

The somewhat higher N/P ratio for the URWARE input vector, 6.7 (Table 12) compared to the median values at Båtbryggaregatan and the WWTPs, 5.8, might be due the measured wastewaters containing not only household wastewater, but also some additional wastewater fractions containing P and COD. While this explanation might be the most likely, other possible explanations are that the amount of N is overestimated in the URWARE household wastewater or that some N has been lost in the measured wastewaters.

One possible explanation to the difference between the measured ratios and the calculated ones (Table 12) might be that the amount of P is underestimated, e.g. if more washing-up powder or scrubbing powder is used than estimated. To keep also the COD/P and the BOD_7/P ratios close to the values at Båtbryggaregatan then also an extra contribution of COD has to be assumed. If extra contributions of 0.3 g $pe^{-1}day^{-1}$ of P and 14 g $pe^{-1}day^{-1}$ of COD are assumed, then the ratios BOD_7/COD, COD/P, BOD_7/P and N/P would be 0.46, 59.0, 27.0 and 5.9, i.e. they would all be close to the values measured at Båtbryggaregatan. In this estimation, the BOD fraction of the COD is assumed to stay constant and 20% of the BOD is assumed to be degraded in the pipes.

If the amount of N is overestimated by 2 g $pe^{-1}day^{-1}$, or the same amount of N_{tot} is lost, and 20% of the BOD_7 is degraded in the pipes, then the ratios BOD_7/COD, COD/P, BOD_7/P and N/P will be 0.48, 57.9, 28.0 and 5.8, i.e. close to the values measured for Båtbryggaregatan (Table 12). However, it is hard to understand how that much N could be lost and the N excretion with urine and faeces is probably not overestimated. In a study of the food consumption by in Sweden 1997/98, the daily protein consumption was 73 grams on average for women and 90 grams for men (Becker & Pearson, 2002). The study covered 626 women and 589 men between 17 and more than 74 years. As the food protein content normally is calculated as 6.25 times the total N content of the food, the average protein consumption, 81.5 g pe^{-1} day^{-1}, corresponded to 13.0 grams of N consumed. This is a little higher than the N excretion estimated by URWARE. However, the food study did not cover the approximately 20% of the Swedish population that is younger than 17 years (SCB, www). The food consumption of also younger persons was studied in a previous food study (Becker, 1994) and in this the average protein consumption of youngsters 1-17 years old was found to be on average 87% of that of persons 17-74 years old. Furthermore, while the body grows it accumulates some nutrients and between the age of 2 and 17 years of age, youngsters accumulate in their bodies approximately 2%, 6% and 0.6% of the consumed N, P and K respectively (Jönsson et al., 2004). Thus, the omission of persons below 17 years of age ought to lower the average excretion of N by (0.2*(0.13+0.02)) = 3%, from 13 to 12.6 g $pe^{-1}day^{-1}$, a value which agrees well with the URWARE value of 12.5 g $pe^{-1}day^{-1}$ of N in urine and faeces (Table 10).

The total consumption of P in Sweden was 1997-98 for persons between 17 and 74 years of age, 1.43 g $pe^{-1}day^{-1}$ (Becker & Pearson, 2002), which also exactly the average consumption by the population between 1 and 74 years of age in the previous study (Becker, 1994). However, as approximately 6% of the P consumed between 1 and 17 years of age is accumulated in the growing body (Jönsson et al., 2004), the average excretion in urine and faeces is around 1.4 g $pe^{-1}day^{-1}$, which agrees with the total excretion in URWARE (Table 10).

The consumption of K in both the nutritional studies is 3.3 g $pe^{-1}day^{-1}$ (Becker & Pearson, 2002; Becker, 1994). As only about 0.6% of the K consumed between 1 and 17 years of age is accumulated (Jönsson et al., 2004), the average excretion in urine and faeces should be around 3.3 g $pe^{-1}day^{-1}$, which agrees with the total excretion in URWARE (Table 10).

The ratio $N_{part,org}$:COD_{part} is 1.72%. Suggested values in literature are 2-4% organic N associated to particulate biodegradable COD, not including bacteria where the value is higher (Brock & Madigan, 1991; Henze et al., 2000), and 0.5-2% organic nitrogen associated to particulate inert COD (Henze et al., 2000). Thus, the ratio $N_{part,org}$:COD_{part} is a little low, but it is within the range given in literature.

The ratio of P_{PO4}/P_{tot} at Båtbryggaregatan (Magnusson, 2003) was 0.62 and 0.68 when calculated from averages and medians respectively. In the URWARE data this ratio is 0.58. The reason for this value being a little lower than that measured at Båtbryggaregatan might be some additional contributions of P_{PO4} (discussed above) or a somewhat higher dissolution of P in faeces and greywater than assumed.

Based on the COD fractionation we can calculate the ratio of P_{part}:COD_{part} for the combined wastewater, which gives 1.01%. Suggested values in literature are 1-1.5% organic P associated to soluble biodegradable COD, 0-0.8% organic P associated to soluble inert COD, 1-1.5% organic P associated to particulate biodegradable COD, not including bacteria where the value is higher, 1-2% (Brock & Madigan, 1991; Henze et al., 2000), and 0.5-1% organic P associated to particulate inert COD. The value for particulate P thus agrees with literature. Furthermore, in the phosphate pool there is enough P to account for the P associated with soluble organic material (0.15 kg pe^{-1} $year^{-1}$) while still allowing for a reasonable amount of actual phosphate in the combined wastewater.

2.7.2 Comparisons of heavy metal content

Magnusson (2003) measured the heavy metal content of household wastewater, without other significant contributions at Båtbryggaregatan and Lundin (pers. com.) has done the same in a few pumping stations in Kungsbacka. In Table 13 these Me/P ratios are compared with those from URWARE, both with the new system and the old system input vector.

Table 13
Me/P ratios (µg/mg) for the URWARE default vector for old and new system respectively compared to measurements of household wastewater at Sjöstadsverket, Stockholm (Magnusson, 2003) and averages of five measurements of household wastewater in pumping stations in Kungsbacka (Lundin, pers. com.).

Ratio	URWARE old system	URWARE new system	Sjöstadsverket	Kungsbacka
Pb/P	0.65	0.21	0.31	0.37
Cd/P	0.0291	0.0113	0.0122	0.0158
Hg/P	0.0071	0.0053	<0.0056	0.0037
Cu/P	5.5	3.1	4.1	4.1
Cr/P	0.69	0.19	0.29	0.17
Ni/P	0.87	0.35	0.78	0.31
Zn/P	12	7.8	7.6	7.6

According to the measurements, the URWARE new system values seem to represent the measured clean household water (Magnusson, 2003; Lundin, pers. com.) well. It is possible to reach this low contamination level, even though this for Pb better was shown by the measurements in Gebers and Vibyåsen (Table 8). For Hg the Kungsbacka measurements indicate that it is possible to reach even lower. However, the largest contribution to Hg is with faeces and the low level reached in Kungsbacka could hypothetically be due to fewer than usual dental amalgam fillings, resulting in less Hg in the faeces.

2.8 Compostable household waste

For compostable household waste, there are several measurements of the composition available, but only a few of the collected amount (Table 14). Thus, when deciding upon the substance flows with compostable household waste, first the amount of waste is decided upon and then its composition. Therefore, most of the parameters in Table 14 are given as concentrations.

Since compostable household waste can be source separated or mixed with other waste, the collected mass is as absolute as that of the wastewater fractions, urine, faeces and greywater. The collected source separated amount depends upon the waste generation, but also on the system and the intensity of the information. The collected amount is usually also related to

Table 14
Amount and composition of compostable household waste.
Quality marking: Well-validated data, data based on few references, *initiated estimates.*

Parameter	Unit	URWARE	Median measurements	Average measurements	Eko-porten[a]	Upp-sala[b]	Gebers[c]	Skultuna[d]	Styrsö[e]	Food waste[f]	Design proposal[g]	ORWARE[h]
Wet weight	g/pd	220	204	204	226		182				220	220
TS	% ww	31	31	31	26	34	26	30	32	36	34	35
TS	g/pd	68.2	53.1	53.1	59		47				75	77
VS	g/pd	58.0	50.3	49.9	50.3	57.6	41.9					61.6
VS	% TS	85	86	84	85	75	89	87	80	88		80
TOC	% TS	43.4	43.4	44.1		36.8	52.8	47.0	39.8			43.4
N	% TS	2.3	2.3	2.3	2.6	2.2	2.0	2.4	2.3	2.4	2.0	2.0
$N_{NH3/NH4}$	% TS	0.26	0.26	0.26	0.01[a]		0.29			0.23		
P_{tot}	% TS	0.39	0.39	0.40	0.42	0.41	0.34	0.54	0.36	0.32	0.38	0.38
K_{tot}	% TS	0.92	0.92	0.90	0.92	0.80	1.10	0.92		0.73	0.30	0.93
S_{tot}	% TS	0.22	0.22	0.22	0.24	0.22	0.20					0.24
Pb	ppm TS	3.8	3.8	5.3	9.5	9.8	2.4	<5.0	2.4	2.6	10.0	10.0
Cd	ppm TS	0.14	0.14	0.14	0.13	0.13	0.15	0.18	0.16	0.08	0.10	0.30
Hg	ppm TS	0.021	0.021	0.036	<0.010	0.028	0.015	<0.050	0.100	0.014	0.009	0.100
Cu	ppm TS	16.0	15.9	25.1	14.2	34.0	9.8	17.5	62.0	13.0	20.0	20.0
Cr	ppm TS	7.5	7.5	7.8	12.2	10.0	11.1	<5.0	3.9	4.4	5.0	5.0
Ni	ppm TS	3.8	3.8	4.0	1.6	6.7	5.4	<2.0	2.2	6.1	3.0	3.0
Zn	ppm TS	45.0	45.0	48.5	30.7	79.0	41.0	55.0	49.0	36.0	25.5	130.0

a) Weglin & Vinnerås (2000). The $N_{NH3/NH4}$ measurement of is considered and outlier and not included in the average and median. **b)** Eklind, et al. (1997). **c)** Andersson & Jenssen (2002). **d)** Lundkvist (1997) according to Eklind et al. (1997). **e)** Jarlsvik (pers. com.) according to Eklind et al. (1997). **f)** Berg et al. (1998). **g)** Vinnerås et al. (2004), Vinnerås (2002). **h)** Sonesson & Jönsson (1996).

the contamination of the collected waste. When the information on source separation stresses the quality of the source separated waste, less waste is sorted out, but usually of a higher quality. When the information instead stresses the importance of sorting everything, then usually more waste is source separated but usually the sorted waste contains more contaminants. The generated amount of compostable household waste in the homes is roughly estimated at 90 kg $pe^{-1}year^{-1}$, with and additional 20 kg pe^{-1} $year^{-1}$ of similar waste generated by restaurants, shops and catering businesses (NV, 2002). But lower figures are also found in the literature, e.g. Olsson & Retzner (1998) measured the amount generated in the households to 75 kg pe^{-1} $year^{-1}$. The amount actually source separated with good quality sometimes reaches around 80 kg $pe^{-1}year^{-1}$ including source separated compostable waste from restaurants, shops and catering businesses.

In the measurements, the collected amount has only been measured in two houses, Ekoporten (Weglin & Vinnerås, 2000) and Gebers (Andersson & Jensen, 2002). The collected amounts vary widely between these measurements, 226 g $pe^{-1}day^{-1}$ in Ekoporten (Weglin & Vinnerås, 2000) and 182 g $pe^{-1}day^{-1}$ at Gebers (Andersson & Jensen, 2002). However, at Gebers, the tenants cook collective dinners three times per week, which probably decreases the amount of compostable waste generated. Thus, the amount of collectable compostable waste is set to 220 g $pe^{-1}day^{-1}$ in URWARE, including the compostable waste generated in society by restaurants, shops and catering businesses.

The measured dry matter content in the compostable waste at Ekoporten and Gebers was low, just 26%. In these houses the waste was composted on site, which meant that many tenants used buckets for collecting the waste. In the waste measured after collection, Uppsala, Skultuna, Styrsö and Berg et al. (1998) in Table 14, the average dry matter content was higher, 33%, which shows the influence of the collection system. Both the mean and the average of all the measurements is 31%, which is the value chosen for URWARE. Thus, the collectable amount of dry matter is estimated at 68.2 g $pe^{-1}day^{-1}$. While this is somewhat higher than what was reached in the Ekoporten and Gebers measurements, it definitely is possible to reach when restaurants etc. are included.

The percentage of VS of TS is set at 85%, right in between the median and the average of the measurements and somewhat higher than previously used in ORWARE. Still, TOC is not changed. It remains at 43.4% of TS as this was also the median of the measurements. For nutrients, the percentages of N, P, K and S are changed to the medians of the analyses, which means slight changes compared to the old ORWARE values. However, the changes are surprisingly small considering that the ORWARE values (Sonesson & Jönsson, 1996) were partly based on calculations from the types of food consumed.

Also for the heavy metals the median values of the measurements are considered the best values to use as default values for URWARE. Due to improved source separation and decreased flows of the most prioritised heavy metals (Cd, Hg and Pb), the URWARE default values are only 21-46%

of the old ORWARE values. However, the contamination of non-prioritised metals have developed in different direction, for Zn the URWARE default value is only 35% of the old value, while for Ni and Cr it has increased to 127% and 150% of the old value respectively.

From the URWARE values in Table 14, the URWARE default vectors in Table 15 are calculated. One vector is given for source separated municipal (household, restaurant, shops and catering businesses) compostable waste and one for the fraction of this waste that can be passed through a kitchen disposer. This amount is estimated at 80% of the compostable solid waste, as 20% is considered non-disposable in a kitchen disposer (Karlberg & Norin, 1999). This disposed fraction is assumed to contain 20% TS according to measurements by Lövstedt & Norlander (2002). The amount given in the column 'Kitchen disposer' is an optimistic estimation, as it contains those 24% of the compostable waste that is only indirectly disposable in a kitchen disposer (Karlberg & Norin, 1999), i.e. waste that has to be taken out of the wrapping to pass through the kitchen disposer. Lacking better data, the TS of the waste passing the kitchen disposer is assumed to have the same composition as the rest of the compostable waste.

As we have found no reliable measurements of the COD_{tot} value for waste, the value is calculated using the organics to COD conversion factors given in the following section "Conversion of C-fractions to COD" and assuming that the volatile substance consists of 15.6% protein, 22.3% fat, 5.5% slowly degradable organics, 28.9% medium degradable carbohydrates and 27.8% fast degradable carbohydrates, as given by Sonesson & Jönsson (1996). As the waste is solid none of the COD in the Compostable waste is considered to be dissolved. The COD_{tot} is partitioned into $COD_{part,bio}$ and $COD_{part,in}$ using the conversion factors 0.704 for COD_{bio} to VS and COD_{inert} 0.526 used in the URWARE model (Jeppsson et al., 2005).

The BOD_7 value is calculated as 0.65 times the COD_{bio} value.

The fractions N_{tot} found as $N_{NH3/NH4}$ and N_{NO3} are assumed to be the same as in the Gebers measurement (Andersson & Jenssen, 2002) and the remainder of the N is assumed to be $N_{part,org}$. The same fractions of P_{tot}, K_{tot} and S_{tot} are assumed to be found as P_{PO4}, K outside of cells and S_{SO4} as that of N_{tot} found as $N_{NH3/NH4}$.

When the waste passes the kitchen disposer, 5% is assumed to dissolve, as Lövstedt & Norlander (2002) found that 95% of the waste passing a kitchen disposer remained in a sedimentation tank following the disposer. Thus, 5% of the particulate COD fractions, $N_{part,org}$, $N_{part,in}$, P_{part}, S_{part} and K_{cell} are assumed to dissolve.

Table 15
The URWARE default vectors for compostable solid waste expressed as g pe^{-1} day^{-1}, mg pe^{-1} day^{-1}for the metals (pos 34-40). The column URWARE Compostables represents the amount that that can be source separated with a high quality. The column Kitchen disposer shows the amount that can be passed through a kitchen disposer in a dedicated family, taking out wrapped food and disposing of it in the disposer.

Parameter	Pos	URWARE Compostables	URWARE Kitchen disposer
H_2O	22	151.8	140.8[a]
TS	8	68.2	35.2
TSS	42	68.2	33.4
VS	7	58.0	29.9
COD_{tot}	43	93.1	48.0
$COD_{sol.bio}$	75	0	1.3
$COD_{sol.in}$	76	0	1.1
$COD_{part.bio}$	77	51.2	25.1
$COD_{part.in}$	78	41.9	20.5
BOD_7	6	33.3	17.2
N_{tot}	23	1.57	0.81
$N_{NH3/NH4}$	24	0.18	0.09
N_{NO3}	26	0.00	0.00
$N_{sol.org}$	44	0.00	0.04
$N_{part.org}$	81	1.39	0.68
P_{tot}	30	0.27	0.14
P_{PO4}	79	0.03	0.02
P_{part}	80	0.24	0.12
S_{tot}	28	0.15	0.08
S_{SO4}	29	0.02	0.01
S_{S2-}	48	0.0	0.0
S_{part}	46	0.13	0.07
K_{tot}	32	0.63	0.32
K_{cell}	49	0.56	0.27
Pb	34	0.26	0.13
Cd	35	0.010	0.005
Hg	36	0.0014	0.0007
Cu	37	1.1	0.6
Cr	38	0.51	0.26
Ni	39	0.26	0.13
Zn	40	3.1	1.6

a) Water contained in the disposed food. Flushing water for the disposer is not included.

2.9 Conversion of C-fractions to COD

In the ORWARE model the organic wastes are specified with respect to their content of the organic carbon fractions; carbohydrates fast degradable (chfd), carbohydrates medium degradable (chmd), organics slowly degradable (chsd), fat and proteins. While the conversions in ORWARE are modelled using these organic fractions, the wastewater models in URWARE are modelled based on the different COD fractions. Thus, conversion factors between organic carbons and COD are needed. In Table 16 the COD conversion factors is given for the different organic fractions. The calculations for obtaining them are given further down.

Table 16
The COD conversion factors for the different organic fractions.

Organic fraction	g COD/g organic	C fraction	g COD/g C
Carbohydrate – fast	1.067	C-chfd	2.67
Carbohydrate - medium	1.185	C-chmd	2.67
Organics – slow	1.846	C-chsd	2.83
Fat	2.90	C-fat	3.74
Protein	1.42	C-protein	2.67

2.9.1 Easily degradable carbohydrates (chfd)

To calculate COD for degradation of C-chfd, it is assumed that C-chfd is represented as glucose ($C_6H_{12}O_6$).

$C_6H_{12}O_6 + 6O_2$ ® $6CO_2 + 6H_2O$

Glucose has the molecular weight of 180 g mol^{-1}. To totally degrade glucose to CO_2 and H_2O 6 mol O_2 is needed, with a total mol weight of 192 g. Thereby, 1.067 (192/180) g oxygen or COD is consumed for each g of glucose or chfd (Haug, 1993).

Carbon content in chfd is 40% and thus the COD demand for C in chfd (C-chfd) is 2.67 g COD per g C-chfd (Haug, 1993).

2.9.2 Medium degradable carbohydrates (chmd)

According to Haug (1993) chmd can be represented by polysaccharides (cellulose and starch) with the average chemical composition of ($C_6H_{10}O_5$).

Degradation of cellulose and starch can be expressed accordingly:

$3C_6H_{10}O_5 + 18O_2$ ® $18CO_2 + 15H_2O$

This means that 576 g O_2 is needed to degrade 486 g of chmd or 1.185 g O_2/g chmd. The carbon content in chmd is 44.4% (72/162) and therefore the demand for degradation of organics in chmd is 2.67 g COD per g C-chmd (1.185/0.444).

2.9.3 Slowly degradable organics (chsd)

Humus and lignin are classified as slowly degradable organics and they can be represented by lignin. When Sonesson & Jönsson (1996) described the composition of the solid organic waste, they used the composition of lignin given by Fries (1973), 65.3% of carbon, 4.5% of hydrogen and 30.2% of oxygen. This corresponds fairly well to $C_{46}H_{38}O_{16}$.

Degradation of chsd can be expressed according to:

$C_{46}H_{38}O_{16} + 47.5\ O_2$ _ $46\ CO_2 + 19\ H_2O$

Molecular weight for chsd equals 846 g mol^{-1}. Each mol of chsd equals 47.5 mol COD (1520 g O_2) and thus 1 g of chsd equals 1.797 g COD. Carbon content in chsd is 65.3% (Fries, 1973). Thus, the COD correspondence is 2.75 g COD per g C-chsd (1.797/0.653).

2.9.4 Proteins

A general chemical composition for protein is $C_5H_7NO_2$ (Christensen et al., 2003). The need of oxygen (O_2) is calculated as:

$C_5H_7NO_2 + 5O_2$ ® $5CO_2 + 2H_2O + NH_3$

Molecular weight for the suggested protein equals 113 g mol^{-1}.

Each mol of protein uses 5 mol O_2 (160 g O_2) for total degradation.

Thereby, 1 g of protein for degradation requires 1.42 g of COD.

Carbon content of the protein is 53.1% (60/113), therefore the demand for degradation of proteins is set to 2.67 g COD per g C-prot (1.42/0.531).

2.9.5 Fat and oil

A general composition of fat and oil is assumed from Christensen et al. (2003) to equal $C_{57}H_{104}O_6$.

Degradation of fat and oil can thus be expressed according to:

$C_{57}H_{104}O_6 + 80O_2$ ® $57CO_2 + 52H_2O$

Molecular weight of this fat equals 884 g mol^{-1}. Each mol of fat and oil needs 80 mol O_2 (2 560 g O_2) for degradation. Thus, 1 g of fat for degradation requires 2.90 g of COD.

The carbon content in the selected fat and oil is 77.4% (684/884), therefore the demand for degradation of organics in fat and oil is 3.74 g COD per g C-fat (2.90/0.774).

2.10 Content of C-fractions in faeces

As the process models of the other ORWARE sub models, e.g. the composting and anaerobic sub models are based on the flows of organic carbon in the forms of fat (C-fat), protein (C-protein), carbohydrates that degrade fast e.g. sugars and starch (C-chfd), carbohydrates that degrade with medium speed e.g. cellulose and hemicelluloses (C-chmd) and organics that degrade slowly (C-chsd), there is a need to describe faecal matter with respect to these organic fractions (Table 17).

Table 17
VS, COD and total organic carbon, TOC, of the URWARE default faeces, toilet paper and faecal mixture, fractioned into different organic fractions (g pe^{-1} day^{-1}).

Parameter	**Pos**	**URWARE faeces**	**URWARE toilet paper**	**URWARE Fec+t.p.**
VS	**7**	**23.9**	**22.5**	**46.4**
COD_{tot}	**43**	**37.4**	**26.7**	**64.1**
$COD_{sol,bio}$	**75**	**5.2**	**0.0**	**5.2**
$COD_{sol,in}$	**76**	**0.4**	**0.0**	**0.4**
$COD_{part,bio}$	**77**	**29.5**	**17.7**	**47.2**
$COD_{part,in}$	**78**	**2.2**	**9.1**	**11.3**
TOC	**1**	**14**	**11**	**25**
C-chfd	**3**	**0.0**	**0.0**	**0.0**
C-chmd	**41**	**6.7**	**9.1**	**15.8**
C-chsd	**2**	**0**	**1.9**	**1.9**
C-fat	**4**	**3.3**	**0**	**3.3**
C-protein	**5**	**4.0**	**0**	**4.0**

The toilet paper is processed in such a way that proteins, fats and fast degradable carbohydrates are removed. Thus, the toilet paper contains essentially only cellulose and lignin, i.e. medium degradable carbohydrates and slowly degradable organics. According to Haug (1993) medium degradable carbohydrates (cellulose and hemicelluloses) contain approximately 44.4% carbon, while slowly degradable organics contain approximately 65.3% carbon (Fries, 1973). Measurements by Stockholmvatten Inc. (Mårtensson, pers. com) on two brands of toilet paper showed that their dry matter on average contained 48% carbon. Based on this and the concentrations of C in chmd and chsd, the proportions of C-chmd and C-chsd of TOC were estimated at 83% and 17% respectively.

According to Lentner et al. (1981), only indigestible carbohydrates, such as cellulose and hemicelluloses, are found in the faeces of normal adults. Thus, faeces contain no fast degradable carbohydrates (C-chfd). Furthermore, the amount of lignin and humus is very low and thus it is neglected and set at 0. Concerning fat, Lentner et al. (1981) cites one measurement where the amount of fat excreted with the faeces was 4.2 g pe^{-1}day^{-1} and this value was multiplied by the carbon fraction in fat and fatty acids, 77.4% (Christensen et al., 2003). The amount of proteins and amino acids in faeces was calculated by multiplying the amount of organic N (Table 5) by 6.25 (Livmedelsverket, www) and this amount was then multiplied by the carbon fraction in proteins and amino acids, 53.1% (Christensen et al., 2003). TOC was measured for the faecal mixture at Gebers (Andersson & Jenssen, 2002) and this value was used, after linear adjustment to the total amount of VS in faeces and toilet paper. Thus, the value for C-chmd in faeces was calculated by subtracting C-fat, C-protein, C-chfd and C-chsd for faeces and toilet paper from the total TOC for the mixture and thus the value 6.7 g pe^{-1} day^{-1} was arrived at for C-chmd. This value agrees well with the amount of fibres in the Swedish diet, which has been measured at 15.0 g pe^{-1} day^{-1} (Becker, 1994) and 17 g pe^{-1} day^{-1} (Becker & Pearson, 2002), as these amounts of fibres correspond to C-chmd contents of 6.7 and 7.5 g pe^{-1} day^{-1} respectively, assuming that the fibres consist of cellulose and hemicelluloses.

2.11 Transformation of COD in sludge to C-fractions

There is a need to transform the COD-values of the sewage sludge to the five C-fractions used in other ORWARE sub models.

Both $COD_{sol,in}$ and $COD_{part,in}$ are virtually inert in both the aerobic and anaerobic environments of the wastewater treatment plant, which means that they correspond to C-chsd. According to the calculations in the section “Conversion of C-fractions to COD”, the conversion factor is 2.83 g COD_{in}/1 g C-chsd.

The COD_{bio} in the sludge consists mainly of bacteria and therefore the bacterial composition is used for dividing the COD_{bio} in sludge into C-fractions. The composition of bacteria is in percent of TS approximately 55% protein, 7% fat, 9% carbohydrates, 23% nucleic acids and 6% ash (Haug, 1993). Assuming that the chemical composition of nucleic acids approximately equals that of proteins and that all of the bacterial carbohydrates can be describes as chmd, the composition of bacteria can be described in terms of COD (Table 18).

Table 18 Composition of aerobic bacteria given in percent of TS (Haug, 1993) and the corresponding calculated COD_{bio} values assuming 1 g of bacteria.

Component	Fraction of TS	COD value g COD/g TS	1 g COD (bacteria) is g TS/g COD	C-content in bacteria g C/g COD
Nucleic acids	23%	0.33	0.162	0.0862
Protein	55%	0.78	0.388	0.2061
Carbohydrates	9%	0.11	0.064	0.0282
Fat	7%	0.20	0.050	0.0382
Ash	6%	0	0.042	
Total	100%	1.42	0.706	0.3587

Thus, assuming that all COD_{bio} in the sludge consists of bacteria and proteins can approximate nucleic acids, each gram of COD_{bio} corresponds to 0.0282 g C-chmd, 0.0382 g C-fat and 0.2923 g C-protein.

It should be noted that the characteristics of sludge might be very different when comparing primary, secondary and digested sludge. The values given in Table 18 appear most reasonable for a secondary sludge, where the biodegradable part of the sludge primary consists of bacteria, and can possibly be used with caution also for digested sludge. Primary sludge is not made up of bacteria but rather a mixture of different organic compounds from the influent wastewater and, consequently, some of the proposed values in Table 18 may need to be adjusted if primary sludge is a major fraction of the total sludge that is to be converted from COD fractions into C-fractions.

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Personal communication

Lundin, Margareta. Chalmers University of Technology, Sweden. Tel: +46-(0)31-772 86 06 Email: margareta.lundin@esa.chalmers.se.

Mårtensson, Kerstin. Stockholm Water Inc. Tel: +46-(0)8-52 21 2464

Wahlund, Anders. Stockholm Water Inc. Tel: +46-(0)8-52 21 2000.

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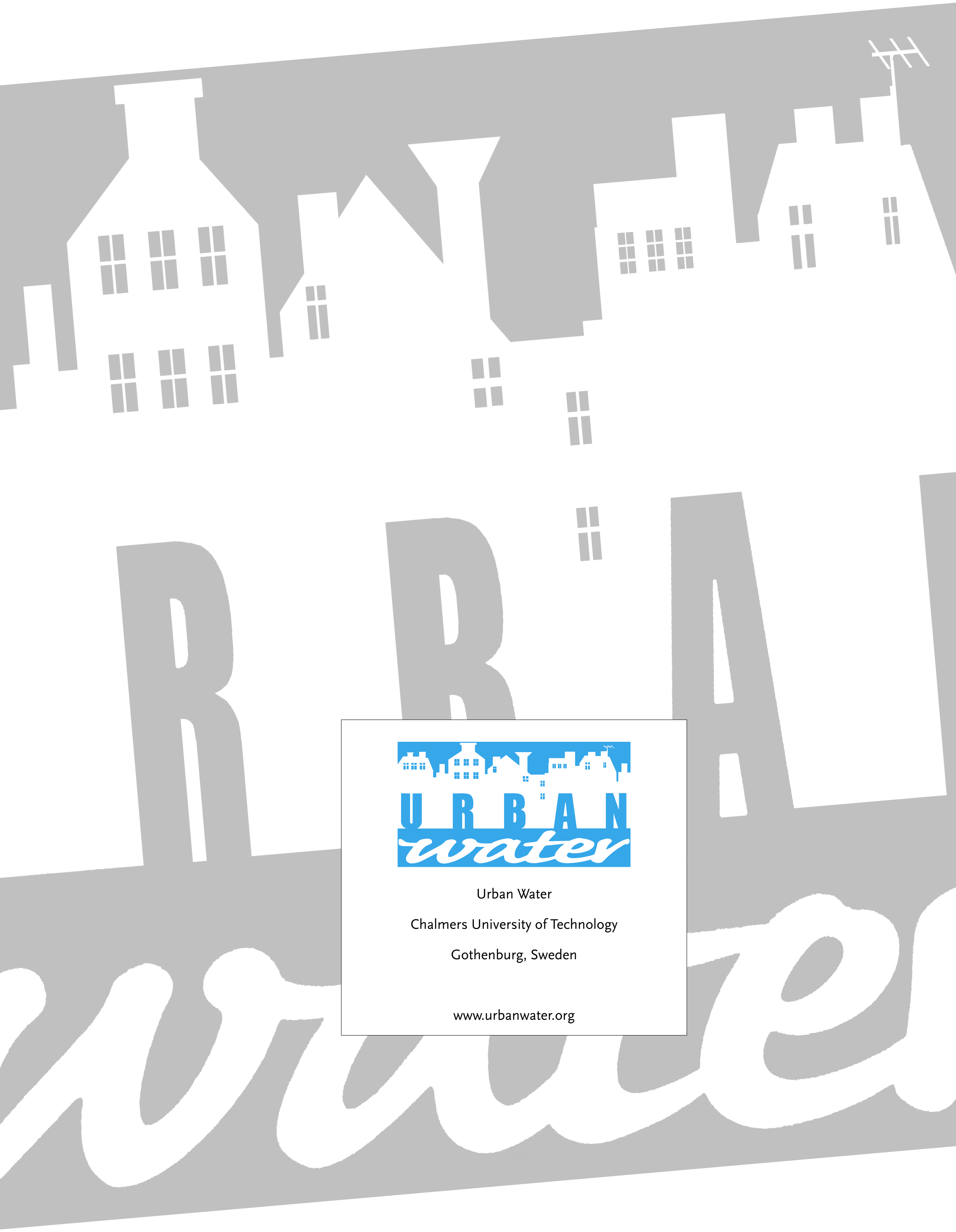

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Gothenburg, Sweden

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