Surahammar – a case study of the impacts of installing food waste disposers in fifty percent of households.

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Abstract
This paper reviews 15 years of sewage works' monitoring data to assess the effect of installing in-sink food waste disposers (FWD) and how these effects compare with the published scientific literature. For the first time it has been possible to assess at full scale the load/cost transfer from solid-waste to wastewater management. Within a period of 10 years, 50% of households in the town of Surahammar in Sweden chose to have FWD installed as their means of managing their kitchen food waste. The drainage from the households feeds a single wastewater treatment works (WwTW) that comprises primary settlement, activated sludge followed by chemical phosphate precipitation and mesophilic anaerobic digestion. The sewer system is separate but with overflow between foul and surface water in times of surcharge. The diameters and gradients of the sewers are unexceptional. This paper reviews the influent and biogas monitoring data for the 2½ years before installation started and the 10 years after the first peak of installations (by which time they had been installed in 30% of households). This provides a unique opportunity to verify the published research on FWD. The operational monitoring data are consistent with the already published research that FWD have little or no impact on water use, sewer blockages, vermin or wastewater treatment. The data are consistent with a hypothesis that in-sewer biological processes acclimated to the change in wastewater composition and treated the dissolved and fine particulate load before it reached the WwTW. The digesters produced 46% more biogas than before FWD were installed (P=0.01). There was no significant increase in hydraulic load, or in the loading of BOD_7, COD, N or NH_4. As a result of Surahammar's overall waste strategy, not just the FWD, the tonnage of waste to landfill from the municipality has decreased from 3600 tonnes/year in 1996 to 1400 tonnes/year in 2007.

Keywords
Ammonium, biogas, BOD, COD, cost, food waste, in-sewer process, landfill directive, water resources, wastewater treatment

Introduction
The European Union decided that in order to reduce the landfill emission of methane (a climate change gas with a global warming potential 25 times that of carbon dioxide, IPCC, 2007), Member States (MS) shall send less biodegradable municipal waste (BMW) to landfill. The Landfill Directive (CEC, 1999) set targets for the weight of BMW that can be landfilled compared with the amount that was landfilled in 1995, the reference year. These reductions (to 75%, 50% and 35% of the reference year's weight) are to be achieved by specific target dates, which are respectively 2006, 2009 and 2016 for most MS though the UK has a 4-year derogation to 2010, 2013 and 2020. However, it has to go somewhere (Commoner, 1971). Separate

[kerbside] collection has been promoted from more than 10 years but still only 30% of biowaste (which includes garden waste as well as food waste) is collected separately and treated biologically (CEC, 2008). Clearly some citizens need other solutions.

To achieve the diversion targets, Surahammar in Sweden chose (in 1997) to offer its citizens differential charges for waste collection plus a bring system for cardboard, glass, metal and plastic (i.e. drop-off locations to which residents take these materials). The policy has been effective in that the tonnage of waste to landfill from the municipality has decreased from 3600 tonnes/year in 1996 to 1400 tonnes/year in 2007.

Householders who purchased, used and maintained their own authorised compost bins paid nothing for food waste collection because, in effect, they made no demand on Surahammars KommunalTeknik AB (SKT). The highest charge was for households that chose kerbside collection of source-segregated biodegradable municipal waste, householders were provided with an additional wheeled bin which was collected weekly, or twice a week in hot weather. The third option was an 8-year contract to lease an in-sink food waste disposer (FWD) from SKT. SKT operates the solid waste, water supply, wastewater, wood-fired electricity generation and district heating in Surahammar Kommune, it is a company wholly owned by the municipality. To qualify for the leasing contract SKT inspected the sewer lateral connecting the property to the main sewer using closed circuit television (CCTV). Sometimes this revealed problems such as broken pipes or root growth into the pipes. When the pipework was suitable the householder was eligible to have a FWD installed by the municipality as part of an 8-year leasing agreement during which the municipality repairs any faults. After 8 years the FWD becomes the property of the householder, whose waste collection charge reverts to that of a home composter; alternatively the householder can have a new FWD and start another 8-year contract. The approximate annual costs to householders are leasing £27 and kerbside collection £209. Unsurprisingly, with this cost differential, the uptake of FWD was rapid. Surahammar is a modest-size community of 3700 households all draining to a single WwTW that transformed rapidly from having no FWD to having FWD in 1100 households. This is a rare, if not unique, circumstance; the subject of this paper is the effect on the sewers, WwTW and biogas production.

The municipality of Surahammar comprises Surahammar, Ramnäs and Virsbo about 110 km west of Stockholm in gently rolling countryside. Industry was founded in the 16th and 17th centuries based on iron. Virsbo is about 13km north of Ramnäs which is about 7 km north of Surahammar. The drainage from Surahammar and Ramnäs is treated at Haga wastewater treatment works (WwTW) which is situated at the southern end of the catchment about 2km from Surahammar. A rising main (forced main) connects the Ramnäs and Surahammar catchments. Virsbo has its own WwTW whose sludge is tankered to Haga for digestion.

Sanitary sewers are laid at a gradient of 0.004 to 0.005. Haga WwTW comprises 3 mm screens, grit/sand settlement, primary clarifiers, diffused-air activated sludge, chemical precipitation of phosphorus and mesophilic anaerobic digestion. Aeration of the activated sludge is controlled by dissolved oxygen (DO) probes. The discharge consent is 15 mgBOD_7/L and 0.5 mgP/L; there is no nitrogen limit. The digested sludge is thickened in former drying beds and composted/dried with miscanthus grass. The resultant soil-like biosolids are trucked to Västerås to a topsoil manufacturer.

Even though there has been a substantial amount of research into their effects since they were invented in the USA in 1928, some wastewater operators with no experience of FWD are apprehensive about their introduction. They fear increased sewer blockages, extra wastewater treatment costs and unspecified problems operating WwTW. None of the research, which has been conducted in many countries, bears out these anxieties. The monitoring data from Surahammar from the years before and through this period of rapid installation of FWD (1995 to the present) provide a unique opportunity to assess the validity of the existing research at the scale of a wastewater treatment works' catchment.

Background Research

Before launching the new options for managing household kitchen food waste, SKT commissioned VA-FORSK to research the likely impacts. This pre-project assessment was published together with post-project appraisal in 1999 (Karlberg and Norin, 1999). VA-FORSK was created in 1990 by the Association of Local Authorities and Swedish Water Works Association. It is financed by annual subscriptions from member municipalities; almost all municipalities are members. VA-FORSK is the waste and sewage technology research and development programme for the municipalities in Sweden in the fields of municipal waste and sewage.

In 1993 SKT installed FWD in 32 out of 39 apartments in a housing cooperative; the 7 without FWD were in a building with its own drainage and were the control. The sewers were flushed before installation and video-filmed. They were filmed again after 1 year and 2 years, on both occasions there was no difference. At the end of the second year the sewers were flushed again, SKT concluded there was no discernable difference in particles, sludge or grease. 96% of residents were satisfied with their FWDs. Refuse collection decreased from emptying six 400 litre containers twice a week to emptying three once a week. Water consumption in the cooperative appeared to decrease by 25%, which SKT did not attribute to FWD but the cause remained unexplained. On the basis of this trial the municipality decided to offer FWD as one of the waste management options.

Installations started in May 1997. Karlberg and Norin (1999) undertook intensive monitoring at Haga WwTW in 1998 by which time 30% of households had installed FWD. They concluded that they were not able to measure any change in flow, BOD_7, P or the electricity consumed by the motors for the turbo-blowers for the activated sludge plant. The incoming N decreased and the biogas production increased. Karlberg and Norin (1999) concluded that even though they measured no change in BOD_7, the amount of substrate for biogas production had increased as a result of FWD installation and that there had been no adverse effect on the treatment works or on the sewerage.

<u>Water use</u>

Each time they are used, FWD are flushed with cold water, this cools the motor and conveys the food waste out of the grinding chamber. Use of potable water embodies the energy used for treatment and distribution and the potential impact on water resources.

A detailed stratified survey in the USA (Ketzenberger, 1995) showed that FWD were used for about 15 seconds per start irrespective of the number of people in the household; subjectively this seems sensible (because FWD use is linked to food preparation events) and accounts for the range of reported water-use when expressed as litres per capita. A study in Sweden fitted FWDs in a community of 100 apartments (155 adults and 56 children); the duration of use per start was 38 seconds (Nilsson et al. 1990). The per capita water use was 13 L/day less during the 11 months after the FWDs had been installed than the 6 months prior to installation but like Karlberg and Norin (1999) Nilsson et al. (1990) concluded it would not be appropriate to attribute this directly to the fact that FWD had been installed. Jones (1990) in Canada was unable to detect any greater per-capita volume of water used where FWD had been installed and concluded the influence on water use was not significant within the overall "noise" in measured water use.

Only a few studies have actually measured water use associated with FWD operation and they have found data ranging from a reduction after FWD had been installed (Nilsson et al. 1990, Karlberg & Norin 1999 and Jones 1990) to an increase of 0.29 L/person*day (large families) to 6.4 L/person*day. The extremes of the range are probably anomalous. Other authors have used these data. There has only been one study of water use in the UK that has included FWD, however when the paper was presented the statistical analysis used was criticised during discussion (which is recorded in the proceedings) as having been demonstrated to be inappropriate for this type of work (Thackray et al., 1978 and discussion). Peters and Lundie (2005) estimated water usage data from the literature at 6.4 L/household*day (3 L/person*day) and concluded that, in the context that Australia is the driest inhabited continent on earth, this was an important factor in their life cycle assessment (LCA) study.

The New York City Department of Environmental Protection undertook a study to inform its decision whether to change the regulations regarding FWD installation (NYDEP, 1999); this is probably the largest field study ever undertaken. It involved 514 apartments with FWD compared with 535 apartments without FWD; they were divided into 4 localities to reflect some of the city's diversity. It involved 2014 people in total, i.e. 1.92 people per apartment. The report concluded the average water use attributable to FWD was 3.6 L/person*day. If uses/day averaged 2.2 as in Ketzenberger's study, this would equate to 3.1 L/use, i.e. the same as Ketzenberger. The overall conclusion of the NYDEP study was that the 18-year restriction on FWD installation in New York City was not justified on scientific grounds and consequently it was removed.

Electricity Use

Domestic FWDs typically have a 350 to 500 W motor (0.5 to 0.75 horsepower), if usage averages 2.4 times per day for 16 seconds per use the annual electricity consumption is about 2 to 3 kWh/household*year. The surveys cited under 'water use' found that usage (starts/day) was largely independent of the number of people in a household because it was determined by food preparation events.

Sewers

Sewer systems are designed to remove wastewater to prevent urban flooding and disease; the pipe diameters and gradients are designed such that the flow velocity ensures long-term self-cleansing. During periods when the flow velocity is low, solids might settle but they should be re-suspended when velocities increase. Design standards for “self-cleansing velocity” range from 0.48 m/s to 0.9 m/s (Ashley et al., 2004). The field studies of FWDs already cited have found no significant accumulations in sewers. The times of day when FWDs are used correspond with times of high flow (Nilsson et al., 1990). In an experimental rig using different types of kitchen food waste (KFW), sediment-free transport of the output from FWD was observed at 0.1 m/s, i.e. well within the normal design standards (Kegebein et al., 2001). Kegebein et al. used two mixtures of foods and the waste from the university’s cafeteria, they found that 40-50% of the output of a FWD was <0.5 mm and 98% was <2 mm by sieve analysis. All of the output passed a 5 mm sieve. The largest particles were fragments of lettuce leaves. For the inputs used, between 15 and 36% of the output of the FWD was dissolved. The output of the FWD was very finely divided and very biodegradable.

FOG (fat, oil and grease) is a problem in sewerage operations, it can reduce the capacity of sewers and even block them; FOG can also accumulate inside the cooling jackets of pumps and cause them to overheat if it is not removed. It appears that FOG undergoes chemical transformations that increase its hardness and strength. Field studies have found that domestic FWDs do not increase FOG; it is supposed that the constituents of FOG coalesce onto food waste particles in the cold water flush and that they are therefore not “free” to attach/solidify onto sewer surfaces. De Koning and Graff (1996) concluded that even in Holland where the gradients of sewers are shallower than elsewhere (and as a consequence sedimentation would be more likely) ground KFW from FWD would not result in sewer obstructions from sedimentation or FOG deposition. Ducoste, et al. (2008) analysed 27 samples of FOG from 23 sewer utilities in all the regions of the United States except the north east. They measured the yield strength, chemical composition and fatty acid profile etc. and also examined samples by microscopy. They concluded that the mechanisms by which FOG deposits form remained unknown but, the physical properties and visual characteristics suggest that a majority of deposits (84%) were metal salts of fatty acids formed by saponification. Irrespective of the regional cuisine, saturated fatty acids predominated and accumulated into a hardened mass with a porous structure. The authors hypothesised that the high pH (>10) alkaline detergents, degreasers, and sanitizers commonly used in food service establishments would promote saponification. A secondary cause of FOG deposits may be oil accumulations without saponification, possibly from highly concentrated oil discharges resulting from illegal dumping or improper grease interceptor management. Keener (one of the authors) said there was no evidence of FWD output being involved in FOG deposits (Keener, K. M. personal communication, 2009).

An important question is whether putting the output of FWD into sewers will increase the number of rats. A spokesperson for the British Pest Control Association (Adrian Meyer, Rodent Control Consultant, personal communication, 2005) advised that installing FWDs would probably be detrimental to rats and certainly not advantageous because finely ground food waste would be less attractive to sewer rats than un-ground waste. Meyer said there is uncertainty about how rats find food in sewers, which are dark, but rats have been seen scooping grains etc. out of the flow. Invariably there is identifiable food such as sweet corn grains in the grit and screenings skips at WwTWs; these would have been large enough to be identifiable by rats. However, if they had been through a FWD they would have been liquidised and hence not identifiable by rats; food residues <2mm would be non-identifiable by rats. Meyer said rats might use sewers mainly as refuges and get most of their food on the surface from waste bins, etc. There is a similar finding in UKWIR, 2000.

Energy and Global Warming Potential

Kegebein et al. (2001) estimated that where the WwTW receiving the kitchen food waste (KFW) treated its sludge by anaerobic digestion (AD), the biogas from KFW would amount to approximately 300 MJ/resident*year, which they said corresponds to a heating value of 8 litres of diesel fuel or 183 kWh/household*year (2.2 people per household). At 40% electricity generation efficiency, this is 73 kWh_e/household*year electricity generation, which at the EU average for electricity generation is a Global Warming Potential of -33 $kgCO_2e$/household*year (i.e. compared with the +1 kg CO_2e /t KFW used to run the FWD).

Peters and Lundie (2005) concluded "FWD performed well in terms of energy usage, climate change and acidification potentials, although it makes a large contribution to eutrophication and toxicity potentials. … centralised composting has a relatively poor environmental performance due to the energy-intense waste collection activities it requires. Implementing a separate collection and transportation system for organic waste results in relatively high environmental impacts due to the frequency of collections and the small quantities of green waste collected per household … home composting is clearly the best option in terms of the categories examined in this LCA, there is an important caveat to this result. If operated without due care, home composting loses its allure due to the high greenhouse gas emissions consequent to anaerobic methanogenesis. Although home composting has the capacity to be the best food waste management option, it can also perform worst in relation to a subject in which Australia is already at the bottom of its class."

Evans (2007) showed that the global warming potential of delivering source segregated food waste to anaerobic digestion (AD) via FWD and the sewers was equivalent to kerbside collection and transport to AD by road (≈ -170 $kgCO_2e$/t food waste). Both routes to AD were better than composting, incinerating or landfilling food waste (-14, +13 and +740 $kgCO_2e$/t food waste respectively). The incineration and landfilling scenarios both included energy recovery. The composting scenario was based on a survey of in-vessel plants in Netherlands, but they were not compliant with the Animal by-Products Regulation (CEC, 2002) which would have increased energy and carbon use. The FWD route saved the local authority (Herefordshire and Worcestershire) more than £19/household*year (based on their 2005 audited data) but the cost transfer to wastewater treatment was unknown.

Load on WwTW

One of the largely unknown factors from earlier research on FWD is the proportion of the output from FWDs that actually arrives at a WwTW. It is known that sewers are linear bioreactors but understanding of in-sewer processes is incomplete. In gravity sewers with free headspace the bulk of the wastewater is aerobic but when a sewer becomes surcharged there is no air to replenish the dissolved oxygen used by biological activity; the biochemistry is further complicated because biofilms on sewer walls can be anaerobic closer to the walls even if they are aerobic at the interface with the wastewater. Raunkjaer et al. (1995) measured considerable removal of dissolved organic matter and protein in wastewater during three-hour transport through a sewer. This was related to temperature and concentration. They found no net removal of wastewater particulate organic matter in the gravity sewer and they also found dissolved oxygen was replenished when there was head-space air. Tendaj, et al. (2008) cited Cedergren (2007) as showing (with respect to the output of FWD) that it is mostly the organic material that is already in dissolved form that decomposes during transportation in the sewerage system whereas the particulate portion does not decompose. As a result of Tendaj et al. (2008), Stockholm Water reversed its antipathy to FWD and now encourages them as a means of generating more biogas to fuel the city's buses etc.

Battistoni et al. (2007) reported a field study at Gagliole in central Italy, a village that drains to its own WwTW. 35 families (95 people) decided to participate and have a FWD, one was also installed in the canteen of the local school, which the authors estimated gave a total ''market penetration factor'' of about 67%. The WwTW design was extended aeration for control of BOD and ammonia; it was modified to remove N and P by alternate oxic and anoxic operation under the control of DO and redox meters. Battistoni et al. monitored the WwTW for 275 days: 96 before and 179 after FWD were installed. The chemical–physical characterisation of the WWTP influent, effluent and activated sludge was determined twice a week on daily averaged samples.

Video inspection found no sedimentation even in a length of sewer where the gradient was only 0.001. The daily flow rate (hydraulic loading / water use) did not change. Battistoni et al. (2007) found it was hard to distinguish the impact of FWD on the WwTW's loading. FWDs had no measurable impact on the energy consumption but they found that the better availability of biodegradable carbon can optimize the use of the nitrogen-bound oxygen and thus save energy for air blowing. They concluded that for a rural town of 10,000 inhabitants, FWDs would have a payback of only 4 years compared with kerbside collection of BMW.

Thomas (2010) analysed the output from a FWD, albeit from a very small sample of input food waste (18 volunteers on two separate weeks). The study took no account of in-sewer processes.

Methods

Between 11th January 1995 and 1st April 2009, 180 samples of influent were collected at Haga WwTW, i.e. one sample every 4 weeks over 742 weeks. Influent samples were 24-hour composites collected after the 3 mm inlet screens and before grit settlement. Samples were not filtered before analysis. Generally samples were collected on Wednesdays (8 Tuesday, 165 Wednesday, 5 Thursday and 2 Friday). At the time of sampling the daily flow was recorded (m^3/day). Effluent samples were 24-hour composites collected every 2 weeks.

Samples were analysed for BOD_7 and COD using SE EN 1899-1:1998, total phosphorus using SS-EN ISO 6878:2005, total-N using SS-EN ISO 13395:1997 (modified) and SS 028131:1976 (modified) and ammoniacal-N using SS-EN ISO 11732:2005 (modified).

Results and Discussion

Karlberg and Norin (1999) reported that food waste disposer installation started in May 1997 and that by October 1998, 1100 households had had one installed (30% of the total number of households in the municipality). By June 2008 the proportion of households with FWD installed had increased to 50%. For statistical analysis of the monitoring data, the samples 11th January 1995 to 30th April 1997 (120 weeks) inclusive were treated as the pre-FWD-installation control. The samples 28th May 1997 to 9th December 1998 were not included in statistical analysis because this covered the period of most intensive FWD installation. However all of the data are included in the graphs.

Sewers

The sewer maintenance team reported there has been no change in septicity or in corrosion to, or deterioration of, the fabric of the sewers (including the rising main from Ramnäs to the Surahammar network).

The pest control contractor for Surahammar observed that there have been rat problems associated with some [poor] home composting but none associated with FWD installation.

Water Use / Hydraulic Load

Although daily flow showed considerable variation (as one would expect with rainfall, snow-melt and drought, etc.) there has been negligible change in the overall trend between January 1995 and April 2009 (Figure 1). The mean of all the flows was 4579 m^3/d with a skewness of 2.44 and a long tail.

The shaded areas in Figure 1 indicate the periods used for statistical comparison of flow before FWD installation (January 1995 to April 1997); after the first surge of installations when approximately 30% of households had FWD (January 1999 to April 2001) and the most recent period when approximately 50% of households had FWD (December 2006 to April 2009). The same periods have been used for the other parameters (figures 2, 3, 5, 6 and 7) and for assessing differences statistically (Table 1).

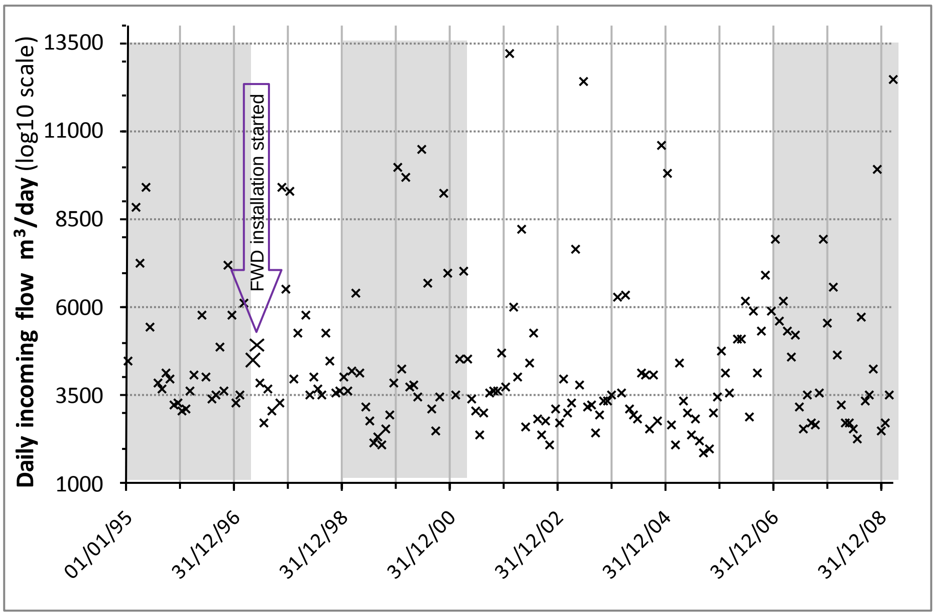

Figure 1 Daily flow of influent (m^3/day) measured after 3mm screens and grit settlement at the time of 4-weekly sample collection (data point for 10 January 2001, 19813 m^3/day omitted)

The mean and median influent flow for January 1995 to April 1997 (before FWD) were 4706 and 4020 m^3/d whereas the mean and median for mid-December 2006 to April 2009 (when 50% of household had FWD) were 4678 and 3575 m^3/d respectively. The scatter of results shows that despite maintenance work, some of it triggered by the CCTV surveys) there has still been a substantial amount of surface water and infiltration. Inevitably, some old appliances will have been replaced by more water efficient ones during this 14 year monitoring period and this could have accounted for some reduction in water use.

The flow data are consistent with the conclusions from earlier field studies that the net effect on water usage in households with FWD is negligible and that the hydraulic loading on sewerage and wastewater treatment is negligible or not measurable. Comparing the means of the influent data for 11/01/95 to 30/04/97 (before FWD were installed) and for 13/12/06 to 01/04/09 (when the majority of FWD had been installed) using Student's t-test confirmed that the daily flows were not significantly different ($P = 0.50$) (Table 1).

<u>Treatment Load on WwTW</u>

The analytical data from the 4-weekly, 24-hour composite samples (collected after the 3 mm inlet screens and before grit settlement) were surprising in the trends they showed for loadings of BOD_7, COD, N_{tot} and NH_4-N following installation of FWD. The daily loads have been calculated from the concentrations and the daily flows. They show that even when 50% of households use FWD as their means of managing kitchen food waste, the effect on the loadings of these parameters to treatment has not increased.

The average BOD_7 load during the 120 weeks before FWD were installed (January 1995 to April 1997) was 408 kgBOD_7/d, but during the period when FWDs had been installed in 30% rising to 50% of households (January 1999 to April 2009) the mean was 381 $kgBOD_7/d$ (Figure 2) the difference is not statistically significant ($P = 0.27$).

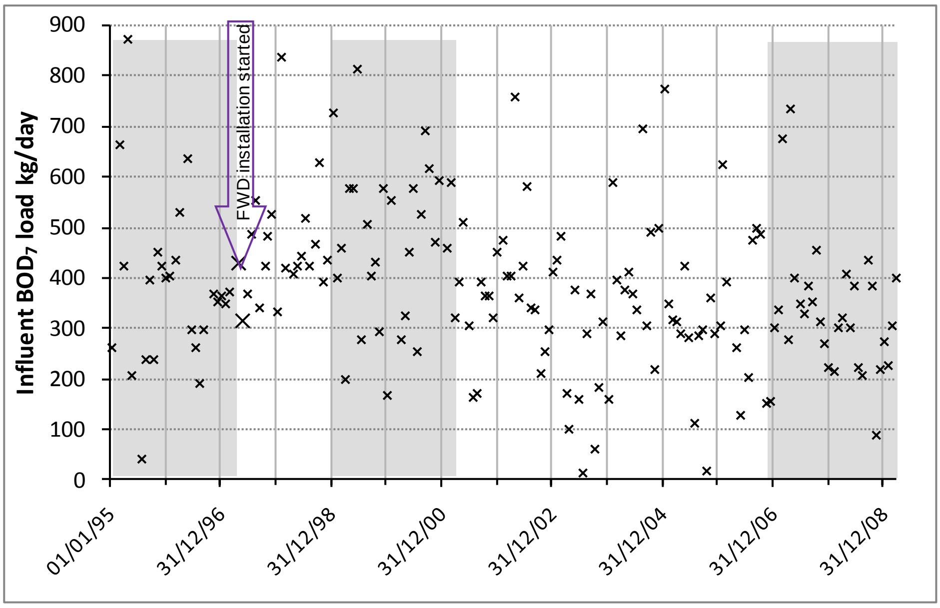

Figure 2 BOD_7 loading ($kgBOD_7/day$) - 4 weekly 24-hour composite samples (extreme data points omitted: 16/10/96 1117 kgBOD/d; 08/03/00 1166 kgBOD/d; 10/01/01 1446 kgBOD/d)

The trend in COD loading was similar to BOD, i.e. 1084 kgCOD/d, before FWD were installed and 1062 kgCOD/d after the first surge of installations until 2009 (Figure 3) the difference is not statistically significant ($P = 0.43$).

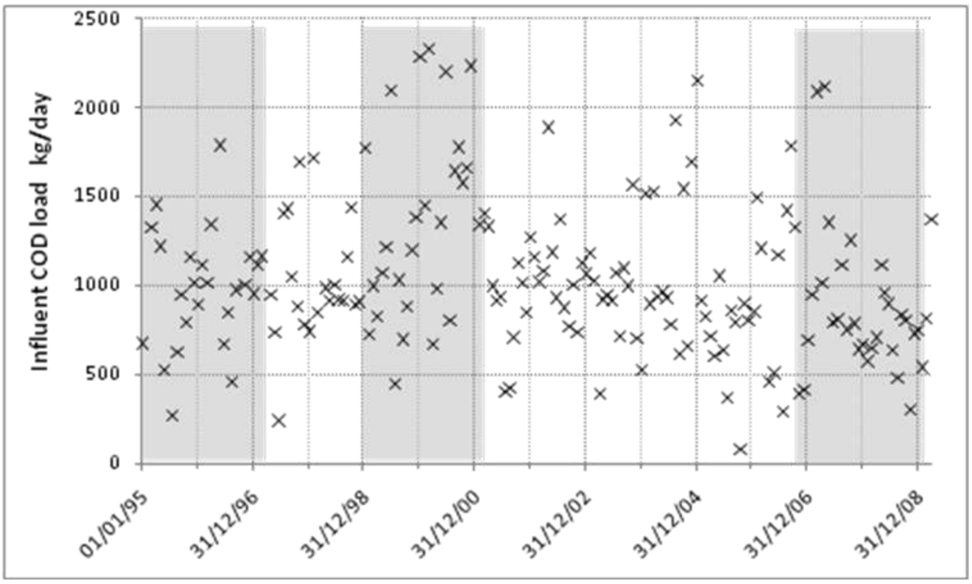

Figure 3 COD loading (kgCOD/day) - 4 weekly 24-hour composite samples (extreme data points omitted: 16/10/96 3782 kgCOD/d; 10/01/01 3566 kgCOD/d)

There has been a progressive increase in the amount of biogas produced by mesophilic anaerobic digestion as more households have installed FWD (Figure 4). Biogas production was measured continuously by gas flow meter. The first four data points (1995, 1996, 1997 and 1998) are from Karlberg and Norin (1999) who actually quoted the averages for the 4 months September to December inclusive because these were the months that consistently had no operational irregularities (e.g. maintenance, valves, etc.). To reiterate, they reported that installation started in May 1997 and by October 1998 30% of households had installed FWD. The biogas data indicate that the content of biogas substrate entering the WwTW increased substantially following FWD installation. Since the BOD_7 did not show a distinct change (Figure 2), presumably the additional substrate for biogas production was composed of particles that settled in the primary clarifiers. The mean biogas before May 1997 was 331 m^3/d whereas the mean for 1999 to 2009 was 447 m^3/d; the difference is statistically significant ($P = 0.002$).

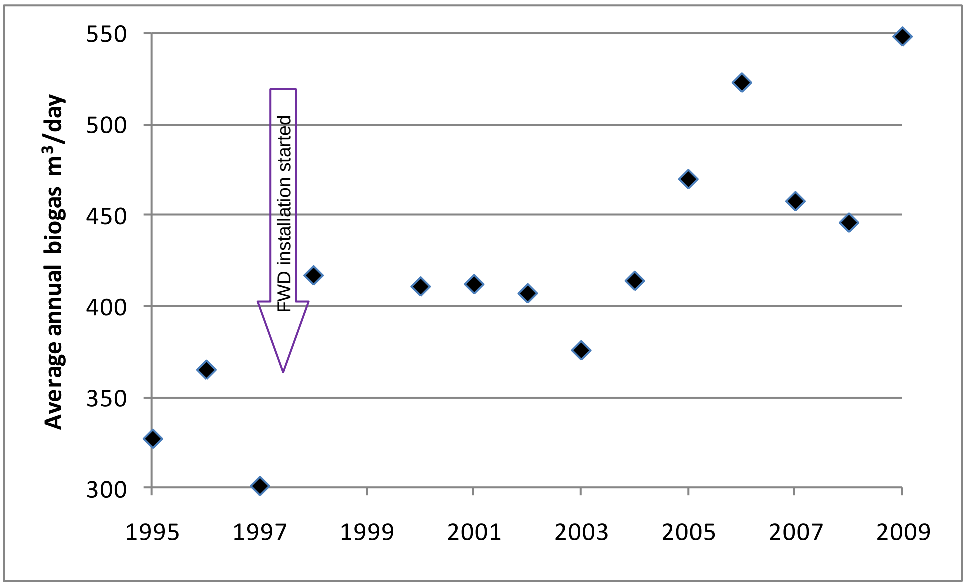

Figure 4 Average annual biogas (m^3/day) [1995, 1996, 1997 and 1998 are from Karlberg & Norin, 1999]

Installing FWD in 50% of households has had negligible impact on the total nitrogen load or the ammonium-nitrogen load on the WwTW (Figure 5 and Figure 6). The means before FWD were installed were 114 mgN/d and 74 $kgNH_4$/d and for the period 1999 to 2009 they were 108 mgN/d and 67 $kgNH_4$/d ($P = 0.19$ and 0.06 respectively). This is consistent with Karlberg and Norin's observation over a much shorter time-scale that electricity use for the air blowers for secondary treatment had not changed. Presumably part of the biochemistry in the sewerage linear bioreactor system has been nitrification/denitrification (or nitritation/denitritation) fuelled by BOD; anammox bacteria in the biofilms are probably implicated.

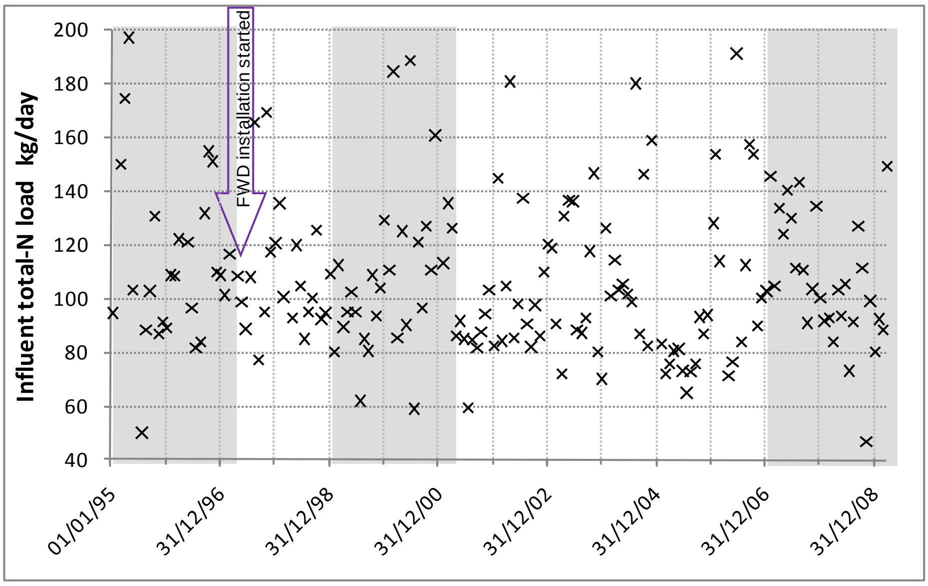

Figure 5 Total nitrogen loading (kgN_{tot}/day) - 4-weekly 24-hour composite samples (extreme data points omitted: 10/01/01 258 kgN/d; 12/05/05 255 kgN/d)

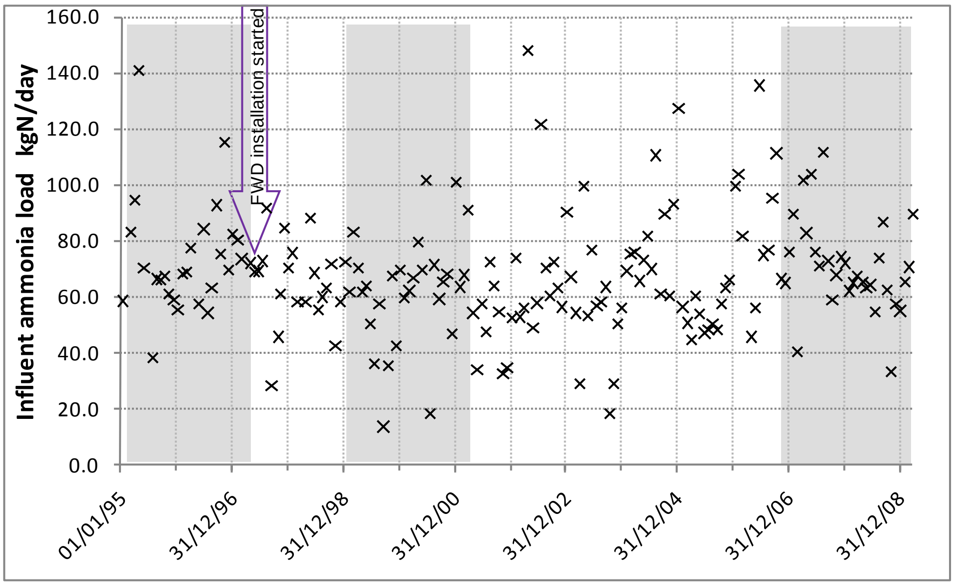

Figure 6 Ammonium loading (kgNH_4-N/day) - 4-weekly, 24-hour composite samples

Rather surprisingly the total phosphorus (P) loading has decreased over the period (Figure 7). The P content of food waste is less than toilet waste, but that does not explain the decrease, though Battistoni et al. (2007) observed a similar effect. Some P would be bound in biofilms but that would reach equilibrium; unlike N, P is not volatilised. The most likely explanation for this decrease in P load is that there was a contemporaneous change to P-free and low-P detergent products. Sweden introduced a voluntary limit of 7.5%P in laundry detergents in 1970. The voluntary switch to P-free laundry detergents was so effective that the government was able to introduce a ban of P in laundry detergents from 1st September 2008 (as part of concerted action by Baltic countries) and to propose a ban of P in domestic dishwasher detergents from 1st July 2011.

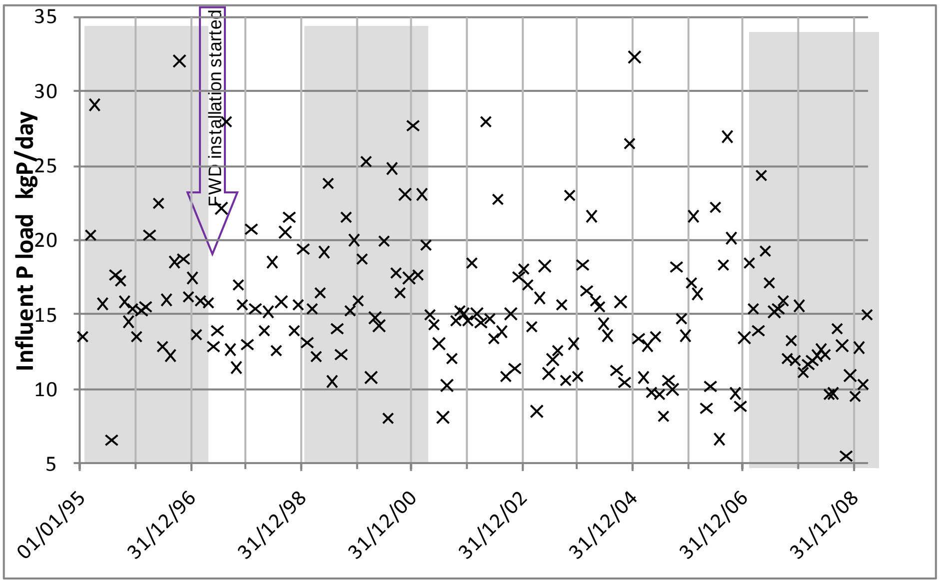

Figure 7 Phosphate loading (kgP_{tot}/day) - 4-weekly 24-hour composite samples (extreme data points omitted: 03/05/95 43 kgP/d; 18/08/04 36 kgP/d)

Figure 1through Figure 7 give a very clear picture of the effects of installing FWD as one of the options for householders to manage their food waste. As a further test, the influent data for the pre-installation period were compared with the post installation data using one-tail Student's t-tests. The results are shown in Table 1. The pre-installation period was 11th January 1995 to 30th April 1997 which was 120 weeks. Installation started in May 1997 and by October 1998 1100 (30%) of the 3700 households had had FWD installed (Karlberg and Norin, 1999). Three post installation periods have been compared, the 120 weeks from 12th January 1999 to 2nd May 2001, the whole post-installation period from 12th January 1999 to 1st April 2009, which was 533 weeks, and the most recent 120 weeks from 13th December 2006 to 1st April 2009. Table 1 also includes the annual average daily biogas production for 1995 to 1997 compared with 2000 to 2002, 2000 to 2009 and 2007 to 2009. Thus the major installation period, when installations went from 0% to 30% of households, was excluded from Table 1.

Comparing the 120 weeks pre installation with 120 weeks after the first surge of installations, when 30% of households had FWD (Table 1), there were statistically significant increases in BOD_7, COD and NH_4-N loadings, the BOD_7:N ratio and the biogas production (>95% confidence level). The increase in the BOD_7:N ratio was beneficial to nutrient removal, as also observed by Battistoni et al. (2007). However, when the post-installation period was extended to 533 weeks, the picture changed. Only the P loading (-14%, P=0.002) and the biogas production (+35%, P=0.04) had changed significantly between pre- and post- FWD installation at the 95% confidence level. The decrease in ammonium-N was only just outside the 95% confidence test. Comparing the pre-installation 120 weeks and the most recent 120 weeks, these were still the only significant changes (P_{tot} -26%, P=0.002 and biogas +46%, P=0.01). The increase in mean annual biogas equates to 76 kWh_e/household.year electricity generation, which agrees very well with the prediction of Kegebein et al. (2001) from experimental work.

There was no major change in the domestic population or in trade effluent (non-domestic) discharge that could have influenced the data to produce these results. As confirmation that residents continued to use their FWD (they had no other means of legally disposing of their kitchen food waste), the biogas production continued to increase (see also Figure 4).

Table 1 Student's t-test comparing influent and biogas pre and post FWD installation

	Flow m^3/d	kgBOD_7/d	kgCOD/d	kgN/d	kgNH_4/d	kgP/d	BOD_7:N	m^3 biogas/d
Mean pre FWD 120 weeks 11/01/95-30/04/97	4706	408	1084	113.6	74.0	18.0	3.50	331
Variance	3034123	46620	394192	979	405	49.9	1.695	1036
Mean post FWD 533 weeks 12/01/99-01/04/09	4538	381	1062	108	67	15.4	3.55	447
Variance	7171537	38370	262063	1084	490	26.6	1.902	3005
Difference ($post_{533}$-pre)	-3.7%	-7.1%	-2.0%	-5.3%	-9.5%	-14%	+1.63%	+35%
P (1-tail T-test)	0.34	0.27	0.43	0.19	0.06	**0.04**	0.42	**0.002**
Mean early post FWD 120 weeks 12/01/99-02/05/01	5194	520	1420	113.8	62.4	17.5	4.60	410
Variance	13156275	69225	425475	1507	391	22.4	2.341	6.937
Difference (early $post_{120}$ - pre)	+10.3%	+27.4%	+31.0%	+0.16%	-15.7%	-2.6%	+31.5%	+23.9%
P (1-tail T-test)	0.25	**0.04**	**0.03**	0.49	**0.02**	0.39	**0.002**	**0.03**
Mean late post FWD 120 weeks 13/12/06-01/04/09	4678	331	892	107	71	13.3	3.11	484
Variance	5675190	17138	167426	548	282	12.7	1.191	3147
Difference (late $post_{120}$ - pre)	-0.59%	-19.0%	-17.7%	-6.1%	-3.9%	-26.1%	-11.1%	+46%
P (1-tail T-test)	0.50	0.06	0.09	0.18	0.28	**0.002**	0.11	**0.01**

The evidence from extended monitoring at Haga WwTW (533 weeks) answers the question of how much the output of FWD affects the costs of wastewater treatment. It shows that the loads to secondary treatment have not increased and therefore it has not increased costs, indeed, where value can be gained from the biogas, it is a positive financial contribution to the WwTW.

Sewers are linear bioreactors with some activity in the suspended biomass, which is flushed through continuously, and more in the biofilms attached to the sewer walls. DNA profiling has revealed that biofilm ecology differs from one location to another reflecting the sewage flowing past (Catherine Biggs, Sheffield University, private communication, 2009). Anammox bacteria, which convert nitrite and ammonia to nitrogen gas, are found in sewer slimes, estuary mud, etc. The trends in the influent monitoring data are consistent with a hypothesis that the biofilm ecology has acclimated to the change in sewage composition. Perhaps the difference between the 120 week and the 533 week post-installation data reflect acclimation of biofilms etc.

to the additional dissolved and fine particulate load. It also indicates the length of studies that is needed when interpreting field studies.

The installation of FWD has not reduced Haga's ability to meet its 15 mgBOD_7/L and 0.5 mgP_{tot}/L effluent discharge consents.

Conclusions

This examination of wastewater monitoring data has shown the benefits of data archives maintained over extended periods of time and of using standardised methods of analysis. The archived data have revealed the effects on the wastewater system of offering citizens food waste disposers (FWD) as one of the options for separating food waste at source.

1) The data from analysing 4-weekly 24-hour composite samples of influent between 11th January 1995 and 1st April 2009 showed the sort of dispersion that can be expected from the real world circumstance but they did not reveal much statistically significant effect from installing food waste disposers in 50% of households, except that the biogas production had increased by 46%.
2) Hydraulic load [water use] did not change significantly.
3) The sewerage team has reported that there has been no increase in sewer blockages, accumulation of solids, fat oil and grease, hydrogen sulphide or corrosion.
4) After an initial increase following the main surge of installations in 1997/8, the treatment load (BOD_7, COD, N_{tot}, and NH_4-N) returned to the pre-installation values.
5) P_{tot} decreased over the period, which could be because of contemporaneous reductions in the P content of detergent products.
6) An explanation for the decrease in treatment load, which is consistent with the data, is that in-sewer biological processes acclimated to the new wastewater composition and removed the treatment load before it arrived at the WwTW.
7) If acclimation is the mechanism, it is a slow process that can only be revealed by extended periods of monitoring. Short-duration studies involving in-sewer biological processes have limited value because biofilm ecology acclimates to changes in sewage composition rather slowly. The fact that biogas production increased over the whole period shows that biogas substrate (which presumably settled in the primary clarifiers) was getting through to Haga WwTW. By the time that 50% of households had installed FWD, the biogas production had increased by 46%.

This appraisal of operational monitoring data has verified the information from field studies and laboratory investigations reported in the literature. It has shown that even when 50% of households have installed FWD as their means of segregating food waste at source and managing it, and the system has equilibrated to the new load, the cost effect on wastewater treatment is neutral and that if value is obtained from the additional biogas, FWD make a positive financial contribution.

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References

Ashley, R.M.; Bertrand-Krajewski, J.-L.; Hvitved-Jacobsen, T. and Verbanck, M. (2004) *Solids in sewers: characteristics, effects and control of sewer solids and associated pollutants*. IWA Publishing, London.
Battistoni, P.; Fatone, F.; Passacantandoa, D. and Bolzonella, D. (2007) Application of food waste disposers and alternate cycles process in small-decentralized towns: a case study. *Water Research* **41** 893 – 903
CEC (1999) *Directive on the landfill of waste*. (1999/31/EC) Council Directive. Journal of the European Communities 16.7.1999 No L 182/1.
CEC (2002) *Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption*. Official Journal of the European Communities L 273/1 10.10.2002
CEC (2008) *Green Paper on the management of bio-waste in the European Union.* Commission of the European Communities COM(2008) 811 final, Brussels.
Cedergren J. (2007) *Köksavfallskvarnars betydelse för reningsverk*. Stockholm: Stockholm KTH.
Commoner, Barry (1971) *The closing circle; nature, man, and technology*. Knopf, New York.
de Koning, J. and Graaf, J.H.J.M. van der (1996) *Kitchen food waste disposers, effects on sewer system and wastewater treatment.* Technical University Delft.
Ducoste, J.J.; Keener, K. M.; Groninger, J. W.and Holt, L. M. (2008) *Fats, roots, oils, and grease (FROG) in centralized and decentralized systems.* Water Environment Research Foundation. IWA Publishing, London.
Evans, T. D. (2007) *Environmental Impact Study of Food Waste Disposers: a report for The County Surveyors' Society & Herefordshire Council and Worcestershire County Council*, published by Worcestershire County Council www.sinkyourwaste.com <environmental report> [accessed 17 August 2009]
IPCC (2007) *Climate Change 2007 - Intergovernmental Panel on Climate Change Fourth Assessment Report (AR4)* Cambridge University Press, UK. http://www.ipcc.ch [accessed 17 August 2009]
Jones, P. H. (1990) *Kitchen garbage grinders (KGGs/food waste disposers) the effect on sewerage systems and refuse handling*. Institute for Environmental Studies, University of Toronto.
Karlberg, Tina and Norin, Erik, (1999) *Food Waste Disposers – Effects on Wastewater Treatment Plants. A Study from the Town of Surahammar*. VBB VIAK AB. Köksavfallskvarnar – effekter på avloppsreningsverk, En studie från Surahammar. VA-FORSK RAPPORT 1999-9.
Kegebein, J.; Hoffmann, E. and Hahn, H.H. (2001) Co-Transport and Co-Reuse, An Alternative to Separate Bio-Waste Collection? *Wasser. Abwasser* **142**, 429-434

Ketzenberger, B.A. (1995) *Effect of ground food wastes on the rates of scum and sludge accumulation*, University of Wisconsin-Madison.
Lundie, S. and Peters, G.M. (2005) Life cycle assessment of food waste management options. *J. Cleaner Production* **13** 275–286
New York City DEP (1999) *The impact of food waste disposers in combined sewer areas of New York City*. New York City Department of Environmental Protection.
Nilsson, P.; Lilja, G.; Hallin, P.-O.; Petersson, B. A.; Johansson, J.; Pettersson, J.; Karlen, L. (1990) *Waste management at the source utilizing food waste disposers in the home; a case study in the town of Staffanstorp*. Dept. Environmental Engineering, University of Lund.
Raunkjaer, K.; Hvitved-Jacobsen, T. and Nielsen, P.H. (1995) Transformation of organic matter in a gravity sewer. *Water Environment Research* **67**, 181-188
Tendaj, M.; Snith, Å; von Scherling, M.; Hellström, D.; Mossakowska, A.; Millers-Dalsjö, D.; Jonsson, Å.; Berglund, L. and Reinius, L-G. (2008) *Kitchen disposal units (KDU) in Stockholm*. Stockholm Water
SS 028131:1976 *Determination of nitrogen compounds in water. Oxidation with peroxodisulphate*. Swedish Standards Institute, Stockholm
SS EN 1899-1 (1998) *Water quality. Determination of biochemical oxygen demand after n days (BODn). Dilution and seeding method with allylthiourea addition, COD Chemical oxygen demand by oxidation with dichromate (ISO 5815:1989, modified).* Swedish Standards Institute, Stockholm
SS-EN ISO 6878:2005 *Water quality - Spectrometric determination of phosphorus using ammonium molybdate.* Swedish Standards Institute, Stockholm
SS-EN ISO 13395:1997 *Water quality - Determination of nitrite nitrogen and nitrate nitrogen and the sum of both by flow analysis (CFA and FIA) and spectrometric detection (ISO 13395:1996).* Swedish Standards Institute, Stockholm
SS-EN ISO 11732:2005 *Water quality — Determination of ammonium nitrogen — Method by flow analysis (CFA and FIA) and spectrometric detection (ISO 11732:2005).* Swedish Standards Institute, Stockholm
Thackray, J.E.; Cocker, V.; Archbald, G. (1978) The Malvern and Mansfield studies of domestic water usage. *Proc. Inst. Civ. Eng*. (1978) 37-61 and discussion 483-502
Thomas, P. (2010) The effects of food waste disposers on the wastewater system: a practical study. *Water Environ. J.* in press
UKWIR (2000) *Rodent Control in Sewers*. Report Ref. No. 00/WM/07/4. ISBN: 1 84057 220 5 UK Water Industry Research, London