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 food waste disposers (FWD) and how these effects compare with the published scientific literature. Within a period of 10 years, 50% of households in the town of Surahammar in Sweden chosen 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 diameters and gradients of the sewers are not unusual. This paper reviews the influent, effluent and biogas monitoring data for the 3 years before installation started and the 10 years after the first peak of installations when they were installed in 30% of households. This provides a unique opportunity to "ground truth" the published research on FWD. The paper reviews the monitoring data and confirms the published research that there has been an absence of impacts on water use, sewer blockages, vermin and wastewater treatment. The data also provide an indication that in-sewer biological process may have acclimated to the change in wastewater composition and "treat" the dissolved and fine particulate load before it reaches the WwTW. The digesters produce more than 40% more biogas than before FWD were installed and 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 laws of ecology enunciated by Barry Commoner (1971) are timeless and immutable:

1. Everything is connected to everything else.
2. Everything must go somewhere.
3. Nature knows best.
4. There is no such thing as a free lunch.

Within the European Union it has been decided that in order to reduce the emission of methane (a climate change gas with a global warming potential 25 times that of carbon dioxide, IPPC, 2007) from landfill, Member States (MS) shall send less biodegradable municipal waste (BMW) to landfill (CEC, 1999). However, it has to go somewhere. The Landfill Directive set targets for the weight of BMW that can be landfilled compared with the amount that had been landfilled in 1995, the reference year. These reductions (to 75%, 50% and 35% of the reference year 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.

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. 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.

The lowest annual charge was for home composters; householders are required to purchase and maintain their own authorised compost bins. 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 a food waste disposer (FWD) from Surahammars KommunalTeknik AB (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. 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, and it is this that makes Surahammar an interesting case study.

The municipality of Surahammar comprises Surahammar, Ramnäs and Virsbo about 110 km west of Stockholm in gently rolling countryside. Industry was founded in the 16^{th} and 17^{th} centuries based on iron. Virsbo is about 13km north of Ramnäs which is about 7km 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 connects the Ramnäs and Surahammar catchments. Virsbo has its own WwTW whose sludge is tankered to Haga for digestion.

Sewers are laid at 4-5‰ gradient. 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 USA in 1928, some wastewater operators with no experience of FWD are apprehensive about their introduction. They fear increased sewer blockage and extra wastewater treatment costs and operational problems. 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 "ground truth" 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). 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, 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. It was on the basis of this trial that 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. 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 concluded that even though they measured no change on 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. Water resources in south east England are already under pressure, it has the highest population in the UK and has low rainfall, however the Chartered Institution of Water and Environmental Management has concluded (CIWEM, 2003) "The change in water usage associated with operation of FWD has been measured to be trivial or not significant."

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. 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. Whilst this inability to measure an increase in water use when FWDs are installed seems counter intuitive initially, it is perhaps understandable when one thinks about the routine of food preparation, etc. After using the sink it is normal to wash it down to clean it, if there were a FWD this would also flush the FWD.

The studies that have been able to measure water use associated with FWD operation found data ranged from 0.29 L/person*day (large families) to 6.4 L/person*day. The extremes of the range are probably anomalous. There has only been one study of water use in the UK that has included FWD, however the methodology used was fundamentally flawed. Even when the paper was presented, the statistical analysis used was criticised as having been demonstrated to be inappropriate for this type of work (Thackray et al., 1978).

The study by the New York City Department of Environmental Protection (NYDEP, 1999), which was undertaken to inform its decision whether to change the regulations regarding FWD installation, 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. The survey comprised 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 result of the NYDEP study was that the 18-year restriction on FWD installation in New York City was removed.

Electricity

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 keeps the typically encountered solids in suspension. 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 already cited in this paper have checked the effect of FWDs on the conditions in sewers and found no significant accumulations. 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 significant 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 (possibly involving proteins) that increase its hardness. 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 metallic salts of fatty acids formed by saponification. They hypothesised that saturated oil constituents are preferentially selected and accumulated into a hardened mass with a porous structure and 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 said there was no evidence of FWD output being involved in FOG deposits (priv. comm., 2009).

An important question is whether putting more food into the sewers will increase the number of rats. A spokesperson for the British Pest Control Association [Adrian Meyer, Rodent Control Consultant, priv. comm. 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 nobody really knows how rats find their food in sewers, which are dark, but rats have been seen scooping grains etc. out of the flow. There is invariably 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 not feed in sewers at all but merely use them as refuges and feed on the surface from waste bins, etc.

Energy

Kegebein et al. (2001) estimated that where the WwTW receiving the KFW treated its sludge by 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. a saving compared with the 6 kg CO_2e /t KFW to run the FWD).

Battistonia et al. (2007) reported a field study in central Italy where KFW from 67% of the population equivalent of a village that drained to its own WwTW installed FWD. The area is rural with scattered communities mostly <10,000 population. Gagliole, the village chosen for the study is 38km from the composting plant; 35 families (95 people) decided to participate also a FWD was installed in the canteen of the local school (population equivalent 60 people). This 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. Battistonia et al. monitored the WwTW for 275 days: 96 before and 179 after FWD were installed. The chemical–physical characterization of the WWTP influent, effluent and activated sludge was determined twice a week on daily averaged samples analysed for: COD, soluble COD, NH_4-N, TKN, total phosphorus, total suspended solids, mixed liquor suspended solids and mixed liquor volatile suspended solids, pH and total alkalinity. High-performance liquid chromatography was used to determine concentrations of anions (NO_2^-, NO_3^-, PO_4^{3-}, Cl^-, SO_4^{2-}, F^-) and cations (Na^+, K^+, Mg^{2+}, Ca^{2+}). The specific rates for nitrogen removal, nitrate utilisation rate, and oxidation, ammonium utilisation rate, were determined by means of batch tests in order to study the impact of the FWDs on the biological kinetics and, in particular, on the denitrifying capability of the activated sludge.

Video inspection found no sedimentation even in a length of sewer where the gradient was only 1‰. The daily flow rate (hydraulic loading / water use) did not change. Battistonia et al. found it was hard to distinguish the impact of FWD on the WwTW’s loading. FWDs had no significant impacts 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.

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 3mm inlet screens and before grit settlement. Samples were not filtered before analysis. Generally samples were collected on Wednesdays. 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 using SE EN 1899-1 *Water quality. Determination of biochemical oxygen demand after n days (BOD_n). Dilution and seeding method with allylthiourea addition*, COD *Chemical oxygen demand by oxidation with dichromate*, Total phosphorus using ISO 6878 *Water quality - Spectrometric determination of phosphorus using ammonium molybdate*, Total-N using SS13395 (modified) and SS028131(modified) and ammoniacal-N using SS-EN ISO 11732 (modified) *Water quality - Determination of ammonium nitrogen - Method by flow analysis (CFA and FIA) and spectrometric detection*.

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%.

Results and Discussion

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

Figure 1 shows that although there has been considerable variation in daily flow (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, which has remained at about 4500 m^3/day, indeed the fitted trend line shows a slight decline. The median for January 1995 to April 1997 was 4020 m^3/d whereas the media for January 1999 to April 2009 was 3575 m^3/d. The scatter of results shows that despite maintenance work, some of it triggered by the CCTV surveys) there has still been a significant 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.

Figure 1 Daily flow of influent after 3mm screens and grit settlement (m^3/day) at the time of 4-weekly sample collection and the 13-sample moving average (trend line for all data)

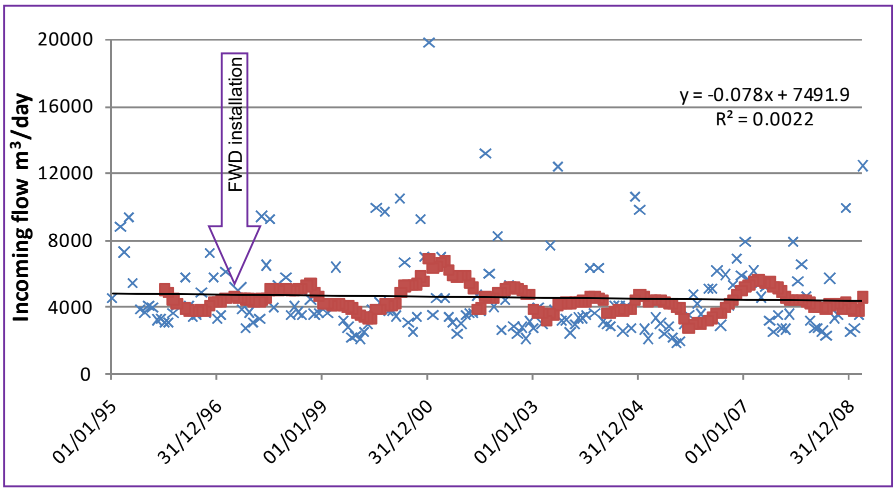


Figure 1 verifies, against the background of these confounding effects, the conclusion from earlier field studies that the net effect on water usage in households with FWD is negligible and that the hydraulic loading on sewerage and wastewater treatment is negligible or immeasurable. Comparing the influent data for 11/01/95 to 30/-4/97 (before FWD were installed) with 12/01/99 to 01/04/09 (when the majority of FWD had been installed) using Student's t-test confirmed that the daily flows were not different (P=0.34).

One of the largely unknown factors from earlier research is the proportion of the output from FWDs that actually arrives at a WwTW. We know that sewers are linear bioreactors but our understanding of in-sewer processes is imperfect. In gravity sewers with free headspace the bulk of the wastewater is aerobic but biological activity soon strips out the dissolved oxygen when the sewer becomes surcharged; 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. 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., Stockholm Water reversed its antipathy to FWD and now encourages them as a means of generating more biogas to fuel the city's busses etc.

The data in Figure 2 have been calculated from the analyses of the composite samples taken 4-weekly and the daily flows on the days that samples were collected. They show that even when 50% of households use FWD as their means of managing kitchen food waste, the effect on the BOD_7 loading on the WwTW has not increased (samples collected after 3mm inlet screens and before grit settlement). Figure 3 shows that the COD loading did not increase either.

Figure 2 BOD_7 loading (kgBOD_7/day) - 4 weekly samples and 13-sample moving average (trend line for all data)

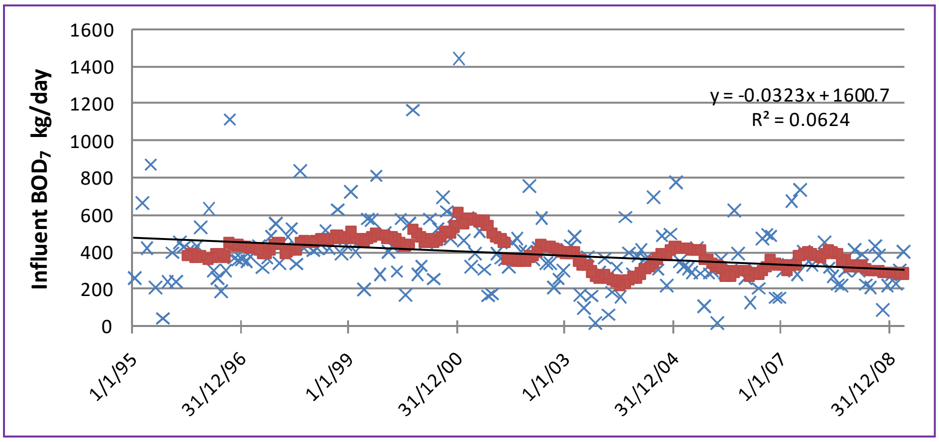


Figure 3 COD loading (kgCOD/day) - 4 weekly samples and 13-sample moving average (trend line for all data)

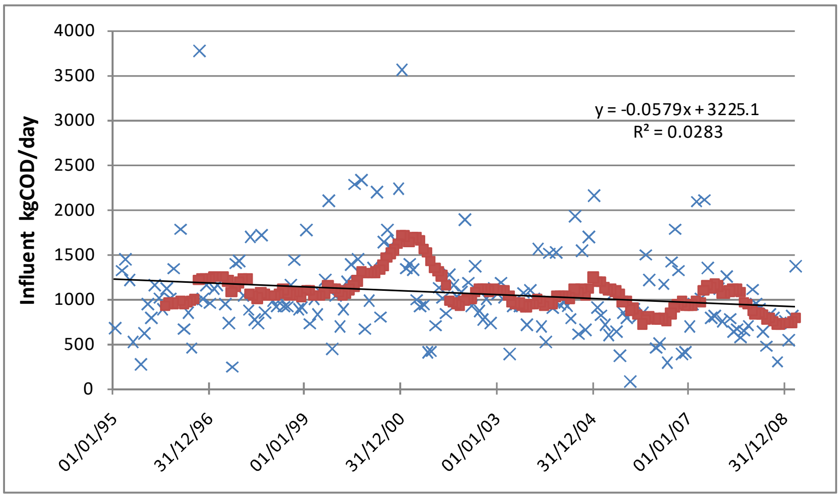


Figure 4 shows that despite the BOD_7 data, there has been a progressive increase in the amount of biogas produced by mesophilic anaerobic digestion as more households have installed FWD. Biogas production was continuously measured by gas flow meter. The first four data points (1995, 1996, 1997 and 1998) 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.). This indicates that the content of biodegradable material entering the WwTW has increased substantially. Since the BOD_7 was not changed significantly, presumably the additional substrate for biogas production was composed of particles that settled in the primary clarifiers.

Figure 4 Average annual biogas (m3/day) [1995, 1996, 1997 and 1998 are from Karlberg & Norin, 1999]

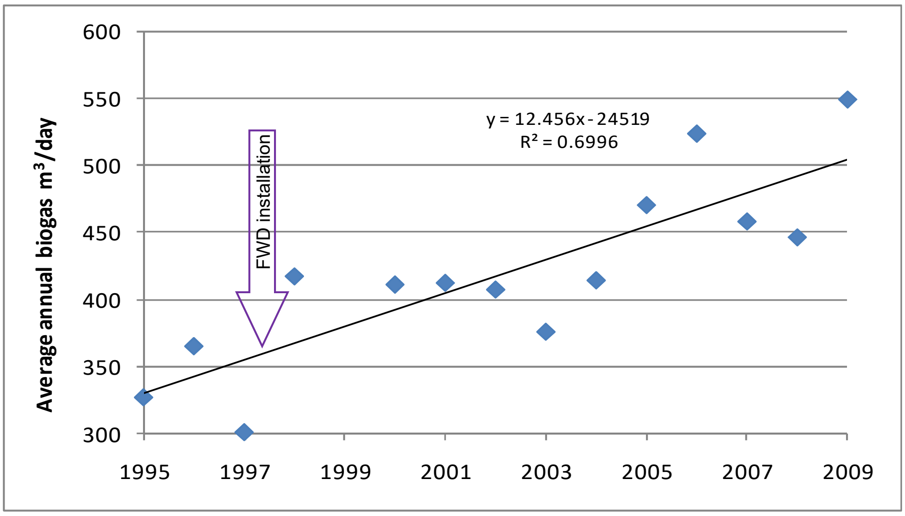


Figure 5 and Figure 6 show that installing FWD in 50% of households has had negligible impact on the total nitrogen load or the ammonium-nitrogen load on the WwTW. This is consistent with Karlberg and Norin's observation over a much shorter time-scale that electricity use for the air blowers for secondary treatment had not changed. Presumably part of the biochemistry in the sewerage linear bioreactor system has been nitrification and denitrification fuelled by BOD.

Figure 5 Total nitrogen loading (kgN_{tot}/day) - 4-weekly samples and 13-sample moving average (trend line for all data)

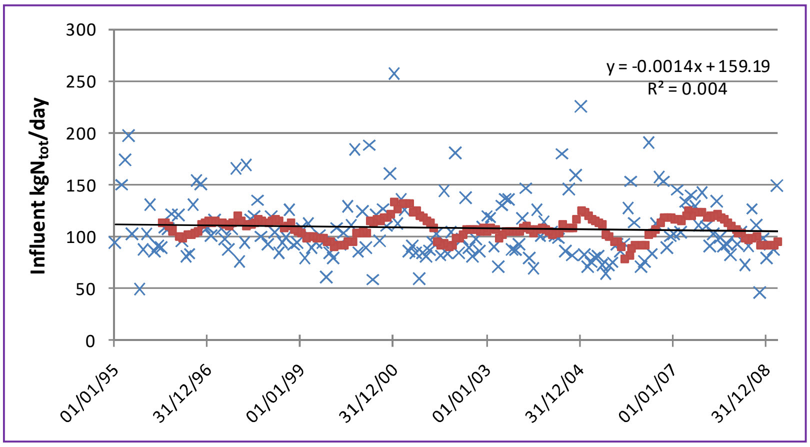
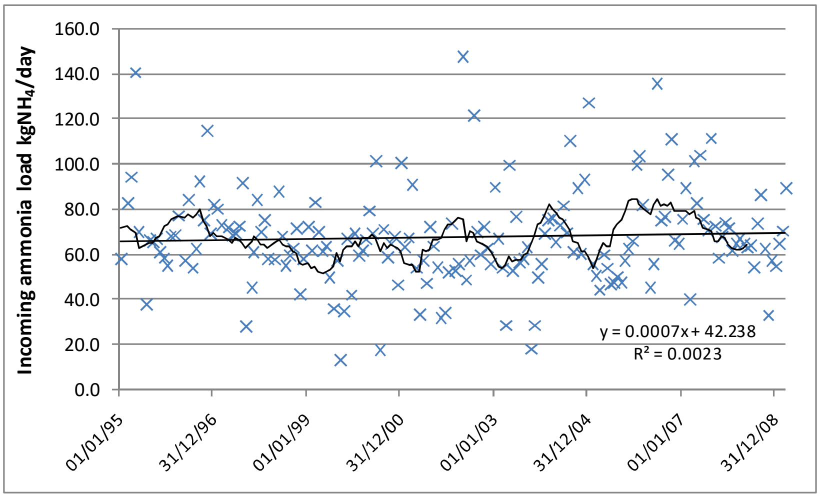


Figure 6 Ammonium loading (kgNH_4-N/day) - 4-weekly samples and 13-sample moving average (trend line for all data)



Rather surprisingly the total phosphorus 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 Battistonia et al. observed a similar effect. We have no explanation for this other than a contemporaneous change to phosphate-free and low-P detergent products. Sweden introduced a voluntary limit of 7.5%P in laundry detergents in 1970. The 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 samples and 13-sample moving average (trend line for all data)

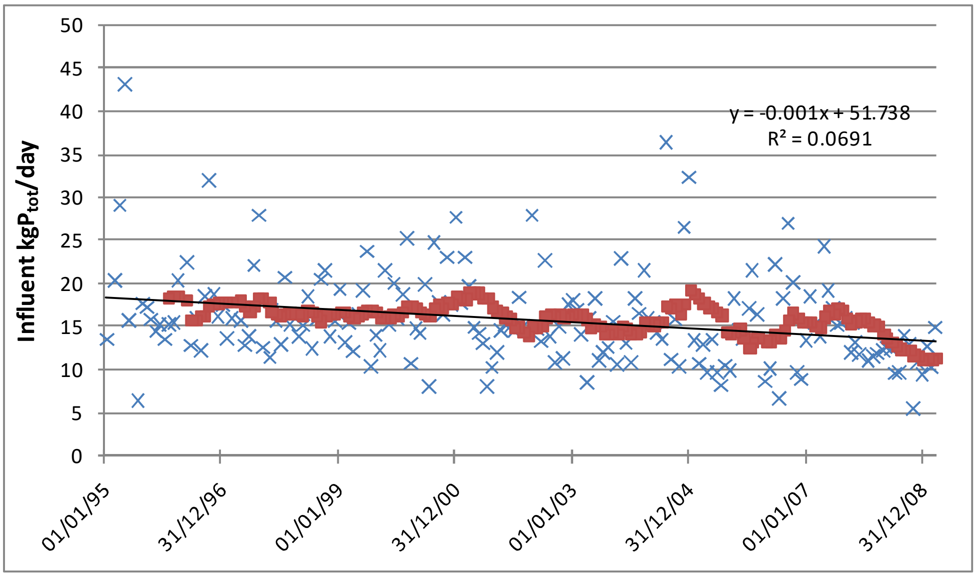


Figure 1through Figure 7 give a very clear picture of the effects of installing FWD as one of the options for householders to manage their food waste. As a further test, the influent data for the pre-installation period were compared with the post installation data using one-tail Student's t-tests. The 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 data from 12th January 1999 to 1st April 2009, which was 533 weeks and the latest 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 was excluded from Table 1.

Table 1 shows that, comparing the 120 weeks pre installation with 120 weeks after the first surge of installations, when 30% of households had FWD, there were 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 Battistonia 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) were significantly different 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).

There was no major change 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).

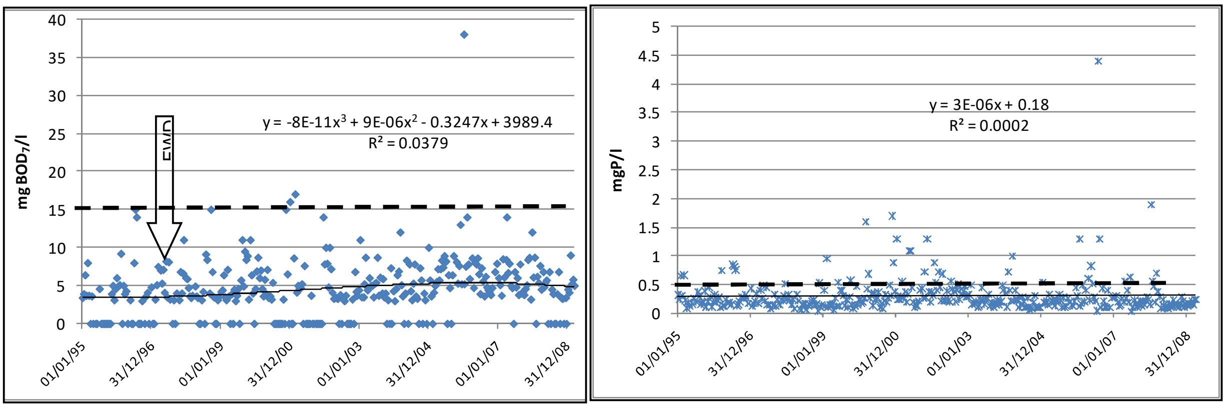
Table 1 Student's t-test comparing influent and biogas pre and post FWD installation

	Flow m3/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	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 120 weeks	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 ($post_{120}$-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 post FWD 533 weeks	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 post FWD 120 weeks to 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 ($post_{120}$-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

Evans (1997) 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 and that these were better than composting, incinerating of landfilling food waste. However the unanswered question was how much the output of FWD affected the costs of wastewater treatment because of the uncertainty about how much load is "treated" in the sewers and how much arrives at the WwTW. The evidence from extended (533 week) monitoring at Haga WwTW shows that it has not increased costs, indeed, where value can be gained from the biogas, it is a positive financial contribution. As stated in the introduction, sewers are linear bioreactors, the processes are complex but our understanding of them is incomplete. Perhaps the difference between the 120 week and the 533 week post-installation data reflect acclimation of sewer processes (biofilms etc.) to the additional dissolved and fine particulate load. It also indicates the care that is needed when interpreting field studies.

Not surprisingly, since the influent loads did not change, the installation of FWD has not reduced Haga's ability to meet its effluent discharge consents. Figure 8 shows that Haga met its 15 mgBOD_7/L and 0.5 mgP_{tot}/L discharge limits.

Figure 8 Effluent monitoring results, trendlines and consent standards (dashed lines, 15 mgBOD_7/L and 0.5 mgP/Ll)



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. From the archived data we have been able to examine the effects on the wastewater system of offering citizens food waste disposers (FWD) as one of the options for separating food waste at source.

The data from analysing 24-hour composite samples of influent and effluent 4-weekly and 2-weekly respectively between 11th January 1995 and 1st April 2009 showed significant dispersion as can be expected from the real world circumstance but they did not reveal much effect from installing food waste disposers in 50% of households, except that the biogas production has increased by more than 40% between the pre-installation period and 2009 by which date 50% of households have FWD. There is no indication that water use has increased. The sewerage team has reported that there has been no increase in sewer blockages, accumulation of solids, fat oil and grease or corrosion. 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. P_{tot} had decreased significantly over this period but this could be partly because of contemporaneous reductions in the P content of detergent products. An explanation for the decrease in treatment load, which is consistent with the data analysis, is that in-sewer biological processes acclimated to the new wastewater composition and removed the treatment load before it got to the WwTW. If acclimation is the mechanism, it is a slow process that can only be revealed by extended periods of monitoring. The fact that biogas production increased over the whole period shows that biogas substrate (which presumably settling in the primary clarifiers) was getting through to Haga WwTW. There was no impediment to the WwTW achieving its effluent quality requirements. By the time that 50% of households had installed FWD, the biogas production had increased by more than 40%.

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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