SUMMARY RESEARCH LAMBERTSMüHLE

Location and applied sanitation system:

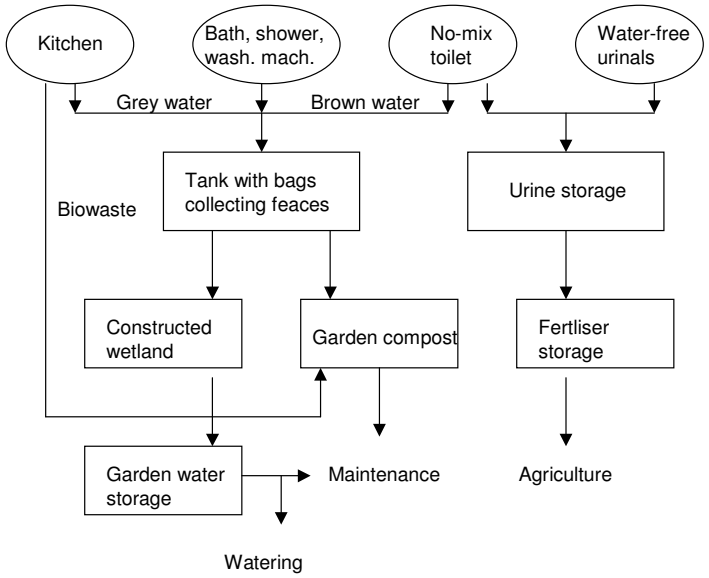
Lambertsmühle is a historical water mill in Bergischen Land in Burscheid (neighbourhood Köln). During its renovation it was decided to apply a decentralised sanitation concept mainly because the connection to the sewer was too expensive. The starting point was separation of wastewater streams based on their characteristics and their separate treatment. It was the first project in Germany dealing with a separate collection of urine so from this point of view it was strategically important to guarantee its success ensuring further development of this new trend in sanitation.

Sanitation concept

There were 3 wastewater streams separately collected:

Sub-stream	**Description**
Yellow water	Urine from no-mix toilets and urinals with or without flushing water
Brown water	Faeces with flush water (minimal contribution of urine)
Grey water	All remaining wastewater streams

The treatment system for all the streams is shown in the Figure, further not explained in detail.



Toilets

Various no-mix toilets were used; usually consuming 0.2 L to flush urine and 3-5 L to flush feaces. Brown water was collected with so called 'Rottesack' for thickening and pre-stabilisation of the content. The filtrate was directed together with grey water to the wetland system. Feaces stored for 6-12 months were further composted together with solid kitchen waste.

Constructed wetland (soil or sand filter)

Constructed wetland (vertical flow) was used to treat grey water and filtrate from brown water 'bags'. Reed (*phragmites australis*) was planted. The surface was calculated with assumption that 2 m^2 is needed for 1 population equivalent. The gravel used to fill the filter had diameter between 2 and 8 mm to prevent the clogging.

Urine

Urine was stored in glass-fiber tank. Urine flow (yellow water) was approximately 20 L per day. The storage volume was 4 m^3 giving max storage time of 200 days.

Results only on fate of pharmaceuticals

The research was performed from the end of 2001 till the beginning of 2003 (a bit more than 1 year).

Selection pharmaceuticals

There were 14 pharmaceutically active compounds (common pharmaceuticals) and/or their metabolites (Table 1) and 7 steroids (Table 2) selected. The analytical methods based on GC-MS and HPLC-MS (different for different group of compounds) were developed to measure these compounds in difficult matrix of urine and wastewater.

Important: the wastewater streams were not spiked with the selected compounds. The found pharmaceuticals were naturally present in the wastewater (visitors of the museum, employees, inhabitants).

Table 1: Selected pharmaceutically active compounds

Compound	**Therapeutic group**
acetylsalicylic acid	Analgesic
Bezafibrate	Lipid lowering agent
carbamazepine	Antiepileptic
Clofibric acid	Metabolite of clofibrate, lipid lowering agent
Diclofenac	Non-steroidal anti-rheumatic (NSAR)
fenofibrate	Lipid lowering agent (LLA)
fenoprofen	Non-steroidal anthirheumatic
Gemfibrozile	LLA
Ibuprofen	NSAR
Indometacin	NSAR
Ketoprofen	NSAR
Pentoxifyllin	Vasolidator
phenacetic	Analgesic
phenazon	Analgesic

Table 2 Steroids and their metabolites

compound	**Therapeutic group**
estradiol	Natural estrogen
estriol	Natural estrogen
estron	Natural estrogen
17α-ethinylestyradiol	Synthetic steroid (contraceptives)
16 α-hydroxyestron	Metabolite
mestranol	Synthetic steroid (contraceptive)
β-sitosterol	Phyto-estrogen

The fate of pharmaceuticals and steroids was monitored in the following points of the system:

For yellow water:

- influent to the storage tank
- storage tank content, 2 periods 2 different pH (pH of 2 attained by addition of acids and natural pH of 8-9). (approximately 20 to 30 samples were analysed).

For remaining wastewater (filter from feces bags and grey water)

- influent to the constructed wetland system
- effluent from the constructed wetland system (6 times every two months, composite sample)

In addition some batch tests were performed to see the effect of pH on urine storage (6 months storage, 3 measurements every 2 months).

Urine (yellow water) line

Influent:
Carbamazepine, clofibric acid and fenoprofen were found only in some influent samples. Diclofenac and ibuprofen were present in higher concentrations throughout the whole period. Ibuprofen concentrations showed a lot of variations. End May, beginning June and end June 2002 peak values of ibuprofen were measured (186, 381 and 720 µg/L). The highest values of diclofenac were 28, 53 and 67 µg/L. Bezafibrate, indometacin, pentoxifyllin, phenacetin and phenazon were not found in the influent. From steroids only natural steroid estron and β-sitosterol were found in the influent.

Storage tank:
Clofibric acid was found in the tank only till December 2001 and fenoprofen was measured for a relatively short time of approx. 3 months (January till March 2002). Carbamazepine was detected in the period of September 2001 untill middle August 2002; concentrations were in the range between 0.8 µg/L upto 6.5 µg/L. After emptying the tank in August 2002, carbamazepine was found only once. Ibuprofen and diclofenac was found in almost all samples from the storage tank. Diclofenac concentration was relatively stable throughout the whole time (except of one value). From August till January 2003 the avg. value of diclofenac increased when comparing with the previous research period. (*not really clear from Table).* It can be related to the increased pH value in the storage tank preventing degradation of diclofenac (???), reported elsewhere in the report.
The concentration of ibuprofen in storage tank underwent strong variations. The influence of the influent concentrations were clear to see. Concentration of ibuprofen was on its average factor 10 higher than other monitored pharmaceuticals. The remaining pharmaceuticals (from Tab 1) were not detected in any of the samples. Only natural steroid estron and β-sitosterol were found in the storage tank content.

Results from in- and effluent of the wetland system (soil- sand filter for grey water and filtrate brown water)

The in- and effluent of the soil filter was investigated for the presence of pharmaceuticals and steroids. The samples were taken in March 2002, in May, July, October, December, January 2002 mixed weekly samples were taken. From pharmaceuticals, carbamazepin, diclofenac, ibuprofen, were detected in the influent and effluent of the treatment unit. Phenazon was found just once, in both in- and effluent samples.
Presence of these compounds in the soil filter can be explained by the presence of the examined compounds also in feaces and/or not complete separation of urine from feces. Here, it has to be also added that one conventional toilet was connected to the treatment system. Based on the 'reduction' of investigated compounds in the soil filter, no final conclusions can be given, although the trend of very low concentrations in the effluent is clear. From steroids, estron and β-sitosterol, were clearly present in the influent. The estron concentrations between 1.6 and 10 µg/L were significantly lower than these in urine storage tank. In the effluent the estron was hardly measured, meaning that it got almost completely eliminated in the soil filter.
Based on the measurement of β-sitosterol in the in/ and effluent of the filter indicates its high reduction, sometimes upto 80%. This result confirms the results obtained in municipal STPs. Remarkable is a high increase of β-sitosterol in the influent to the wetland system starting from October 2002. An explanation can be a use of another material for the compost bags for feaces (effect of adsorption).

Pharmaceuticals degradation in batch tests

In addition, batch tests into degradation of pharmaceuticals from urine in relation to pH. Urine samples were put in batches at 2, 7 and 9. The samples were analysed in the beginning, after 3 and 6 months. A clear declining of measured pharmaceuticals was observed: For instance at pH = 2 indometacin was reduced with 30%, while carbamazepine, pentoxifyllin, phenazon, fenofibrate and phenacetic between 45 – 70%. The diclofenac and ketoprofen were reduced up to 90%. Acetylsalicylic acid was completely eliminated. Similar observations for other pH values. No comment on possible transformations of considered compounds and/or abiotic changes.

Conclusions and relevance to the research in Anderen

1. There were 14 (commonly used) pharmaceuticals and 7 steroids selected to follow their fate in an alternative sanitation system comprising separate collection and treatment of three wastewater streams.

2. Analytical methods based on GC-MS were developed (two different procedures for sample preparation both using solid phase extraction) for difficult matrix of urine and wastewater.

3. **The influent was not spiked with pharmaceuticals**; pharmaceuticals and steroids were naturally present (or not) in the influent.

4. **No treatment system was used for urine (yellow water), only storage**

5. Separate collection of (little diluted) urine allows to obtain the highest concentrations of pharmaceutically active compounds and steroids (e.g. ibuprofen up to 700 μg/L) when comparing with traditional sanitation concept.

6. **Pharmaceuticals were monitored in the influent to- and in the storage tank content, where, in fact, not much is expected to happen.**

7. Effect of pH on the selected compounds in separately collected urine was in addition examined; expecting some effect on the reduction of the considered compounds; there is no comment on possible transformation of parent compound; the conditions of the experiment are not described in detail – possible other abiotic reaction may occur (e.g. photolysis).

8. In addition the influent and effluent from the sand filter (soil filter, constructed wetland with reed plants) treating grey water and feaces filtrate was measured for presence (and reduction) of pharmaceuticals and steroids. Only few pharmaceuticals and 2 steroids were detected in low concentrations. Presence of pharmaceuticals and steroids in this treatment line can be explained by the fact that some pharmaceuticals and steroids are excreted also with feaces, the separation of urine in no-mix toilet is never complete and contribution of urine from one conventional toilet used in Lambertsmühle. Reduction of detected compounds was observed, sometimes significant.

9. The applied in Lambertsmühle wetland system is not comparable to soil filter with energy crops to be applied in Anderen (e.g. large diameters of filter media, restricted depth, different type of crop, very different loading rate and composition of the influent- in Lambertsmuhle continuous inflow of wastewater containing little nutrients and micropollutants; Anderen – 1 a 2 times per year loaded + effect of rain).

10. Adsorption was not investigated.