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Innovative Technologies for Decentralised Wastewater Management in Urban and Peri-Urban Areas

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Abstract

Introducing source separation concepts in municipal wastewater management does allow adequate treatment of the different flows according to their characteristics. This is the key to technical solutions for the efficient reuse of water, energy and fertiliser. As applied in industrial wastewater management low dilution and collection at the source is necessary to achieve economic systems. Separate collection and treatment of toilet waste in households, which contain almost all pathogens and nutrients, is the first and major step. The range of toilets with very low dilution is from vacuum- over urine sorting to dry toilets. Innovative sanitation systems have been introduced in several projects and have proven feasibility. Fresh water consumption can be reduced by 80% while nutrients can be recovered to a large extent. Source control can be advantageous also for hygienic reasons: low volumes are far easier to sanitise. There are experiences with urine-sorting systems, vacuum-biogas systems and many more available. New ideas as the black- and greywater cycle system are presently researched at the Technical University Hamburg. Such modular integrated systems do have the potential to be installed in densely populated urban areas without the need for central water and wastewater infrastructure. Only recent advances in membrane technologies allow this development.

1. Introduction

Metropolitan areas in water scarce regions can be supplied with local secondary tap water and will not have to feature water intensive centralised infrastructure in future. The fundamental idea of innovative and integrated water concepts is based on the principle of separating different flows of domestic wastewater according to their characteristics. In industrial wastewater management this principle is already widely spread with great advantages in efficiency, often with financial advantages. Fig. 1 shows the very different characteristics of domestic wastewater flows with reference to their volumes and loads per capita an year.

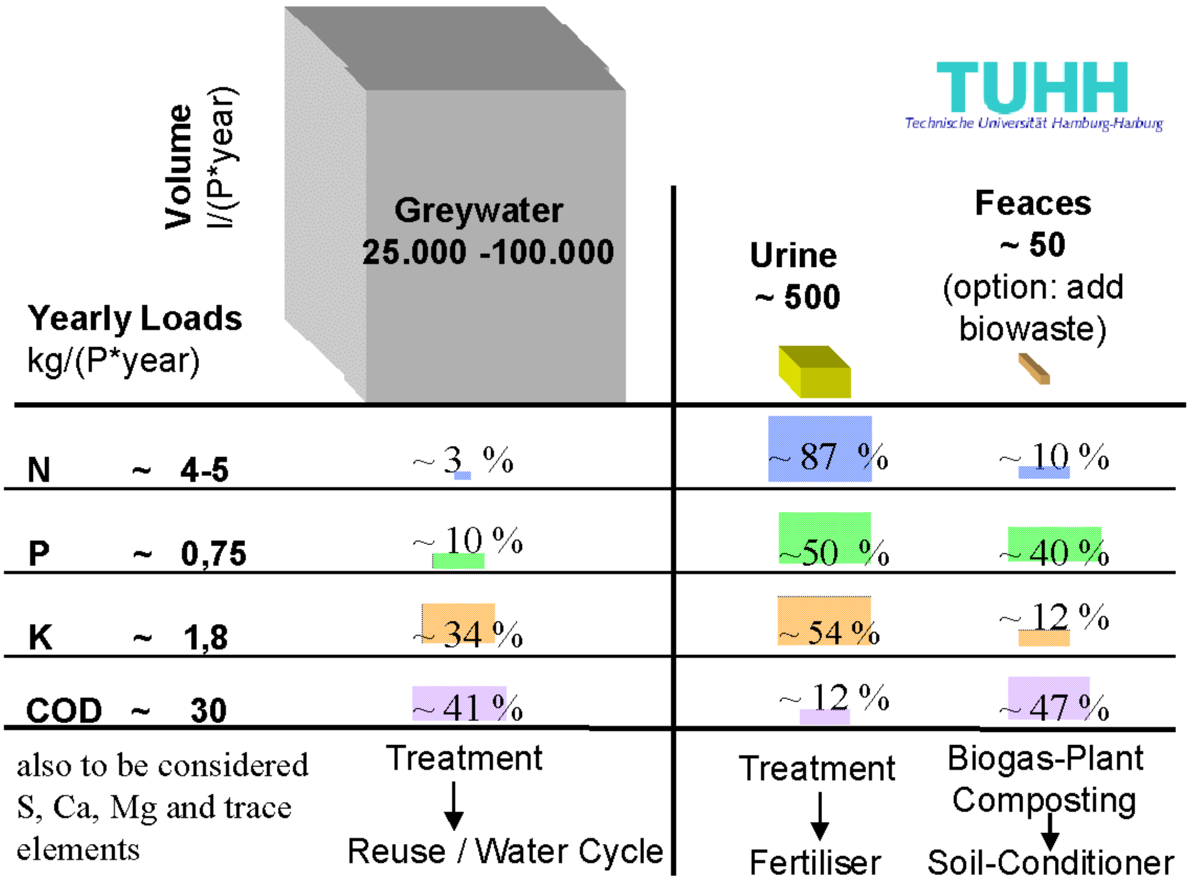

Fig 1: Characteristics of domestic wastewater flows with no dilution for urine and faeces (wet weight) (compiled from: Geigy, Wissenschaftliche Tabellen, Basel 1981, Vol. 1, LARSEN and GUJER 1996, FITSCHEN and HAHN 1998)

Source control and adequate treatment of these flows leads to the vision as follows:

- Greywater is processed to safe tap water with drinking water quality by biological treatment and membrane technology possibly including local ground infiltration. Bottled drinking water of high quality should be available as well. In order to prevent concentration of metabolites in grey water cycle processes, household chemicals (e.g. detergents) have to be mineralisable, not only degradable. Freshwater consumption can be reduced by up to about 80%.
- Low diluted flows produced by innovative toilets can be utilised for the production of renewable fertiliser and energy. Additionally, the flush water for the toilets can be reclaimed and treated for the production of flush water including solid-liquid separation and membrane technology.
- Water losses of the different water uses can be compensated by local water resources, such as ground-, rain-, and seawater. The local withdrawal of renewable water resources is compensated by rainwater that is infiltrated.

Currently, a fundamental paradigm change in wastewater technology can be observed. The trend goes to intelligent, synergetic, and decentralised structures. First hand experiences with these technologies are available. At the same time, several years of experience with first pilot installations and a broad variety of know-how about operating of the technical compounds exist. Some of these developments and projects are described below.

2. Principles for the development of innovative decentral water concepts

The prevention of wastewater should have first priority. The re-use of water can contribute to large savings of water and thus to a prevention of wastewater. Therefore, used water can be considered as the closest water resource in urban areas. Most condensed populated areas with water scarcity can be independent of large freshwater flows from outside in the future. For example, membrane-biology followed by reverse-osmosis renders the re-use of water as tap water possible.

If the re-use of wastewater for drinking water purposes is desired, the water should not have been previously used as toilet flushing water for ethnical and technical reasons. The mixing of faeces and urine with the domestic wastewater inhibits economic re-use. The hygienically very dangerous, extremely small quantity of faeces contaminates large amounts of water via conventional flush toilets and sewerage. Consequently, the essential step for innovative water management are toilet systems as part of a technology for the production of fertiliser. For densely populated areas anaerobic treatment for energy production and the production of a dry mineral fertiliser can be the method of choice. Due to the small flow quantities, technologies being used in industrial water management such as vacuum-evaporation can be employed here as well. There are interesting synergies with the increasingly decentralised energy supply technologies that will more often be solar and hydrogen powered in future and with effective communication structures. The economic base is to abandon central water and waterwater networks. They generate the lion's share of costs by just non-productive transport. Searching for new ways in municipal water management, decentralised solutions for the rainwater run-off must also be found as a matter of course in order to refill the aquifers when using them for local water supply.

3. Historic Errors and Ignorance Characterise the Beginning of Wastewater Management

Conventional wastewater management utilises a disadvantageous approach by mixing different flows in central sewerage systems. Urgent hygienic problems in the houses could be solved on the one hand. On the other hand, water resources used for drinking water supplies were thus polluted at the source simultaneously. Consequently, epidemics, which have been locally contained before, could now spread rapidly via the supply of drinking water. One prominent example is the dreadful epidemic of cholera in Hamburg, Germany in 1892 [Evans, :1991]. The technically developed world has solved this problem without ever proving seriously alternatives to this concept. Historically, reasonable alternatives have existed [Lange and Otterpohl, 2000]. Nevertheless, they were widely ignored. This was caused by the fatal expansion of flushing toilets, as well as the missing knowledge about epidemic infection pathways. Even nowadays, the historical error of mixing faeces with large water amounts is not being addressed openly. Furthermore, this error is still repeated all over the world. According to WHO figures, 5 Million deaths are caused by water born diseases annually. The continuously wide spread construction of seepage pits causes – especially in drinking water catchment areas – a contamination of soil and ground water, thus directly hygienically endangering the population in dense areas. After introducing drinking water supply systems on the wastewater disposal side, simple drainage brings faecal matter into receiving waters. Wastewater treatment is globally poorly spread. If sewage treatment plants – often with financial aid of the wealthy countries - are constructed, they fail or are out of order after a few years. The innovation potential is very high – it is about time to envisage this reality.

4. Shortage of resources in wide areas of the world makes the development and implementation of innovative methods a necessity

4.1 Central sewer nets and flushing toilets contribute to increasing water shortage

The wastewater system with flushing toilets and sewer nets is dependent on a high flow of water. In many parts of the world these amounts of water are either not available, or the operating costs of this system are not affordable for the users due to high drinking water prices. Construction without reflecting those systems being designed for a high flow increases water shortages. Moreover, very strong water shortages lead to intolerable hygienic situations. These are currently occurring if the water supply fails not only routinely during a day, but for several days.

Therefore, the municipal water management itself should search for innovative resource efficient methods of sanitation. If the current branch of industry cannot bring innovation forward, decentralised systems especially if they go for the scale of single houses or even flats can make costly central infrastructure unnecessary within a few decades. The early consideration of alternatives is of great advantage to avoid mistakes in investment. It can be expected, that the rigid legal conditions will be changed by liberalisation tendencies. By source control and multiple usage of water, such technologies could manage the water consumption with around 20% of the current demand. This amount can be provided by local ground or storm water, as well as from the seas water resources. For areas with water scarcities the advantages are obvious. For other areas the avoidance of central supply and disposal infrastructures may be financially advantageous soon, especially by mass production.

4.2 Conventional wastewater systems are inadequate for effective recovery of nutrients

Principally, domestic wastewater contains valuable substances, like the nutrients Nitrogen, Phosphorous, Sulphur, Potassium and Magnesium, and the many trace elements being essential for fertile soils. Due to their high dilution with conventional wastewater systems, they are barely recoverable. Sewage sludge contains only a fraction of valuable substances; so reuse of sludge in very inefficient. According to new researches, the green-plant availability of Phosphorous being precipitated in sewage sludge with Fe- and Al-salts is only 20% [UBA, 2001], thus further restricting the agricultural utilisation of nutrients.

A feasible kind of nutrient recovery in suited climatic zones is the combination of agricultural irrigation and fertilisation with treated wastewater. Unfortunately, this is practised with untreated wastewater in many cases and therefore hygienically very problematic. Furthermore, the sole irrigation with wastewater leads to a strong over-fertilisation. In addition, the non-biodegradable residues of industrial wastewaters and domestic detergents are disposed in soils. Additionally, fertilising has to be adapted to horticultural growth periods. Even in cases of two to three crops p.a. a sustainable fertilising with wastewater is exceptional. Also here, the decoupling of nutrient content and water quantity by separate collection of urine would be the more consequent solution. A comparative study in India was carried out by analysing the coherence between the effectiveness of school-kids subject to the concentration of heavy metals in agricultural irrigation water. The results showed that the intelligence of the contaminated students became about 20% worse [DtE, 1999]. The grave neuro-toxic consequences of heavy metal contamination are insufficiently considered as of yet.

5. Scenarios and projects of innovative water concepts

Naturally, there is a broad variety of solutions, which cannot be presented here completely. In [Otterpohl et al., 1999] ten basic scenarios are classifying the variety of combinations of modules in dependence of the different geographic and socio-economic conditions around the world. Paris and Wilderer [Paris, 2001] elaborated an extensive overview of realised concepts based on source control.

5.1 The vacuum / biogas concept

In Lübek-Flintenbreite, Germany, an innovative decentralised sanitation concept has been realised in a peri-urban area. Currently, 100 inhabitants are connected to the plant and the capacity of the system is up to the 350 persons that shall be living in the settlement when it will be finalised. Grey and black water are collected and treated separately. With a very low water consumption of about 0,7 l per flush, black water is collected via vacuum toilets in a collection tank. After mixing with shredded biowaste the material is thermally sanitised and fermented anaerobically [OtterWasser, 2002]. Grey water is drained by gravity and treated with a bio-sand filter (vertical constructed wetland). Parts of the compounds are in operation since the beginning of 2000. A detailed description can be found in [Otterpohl et al., 1999].

The average water consumption since 1,5 years is about 72 l/(PE*d), whereof 65 l/(PE*d) is grey water. About 90% of the Nitrogen load can be found in black water. Thus, grey water is very short of nitrogen as extensive measurement campaigns have proven. The vacuum toilets and drainage pipes are running failure-free under regular operation. Failures caused by the users (cat litter, sanitary towels; etc.) could be eliminated by more explanation to the users.

Surprisingly, grey water shows a relatively high concentration of phosphorous caused by almost exclusively by dishwasher detergents. This concentration could be reduced by educational advising of the inhabitants. Final results of this campaign and the willing co-operation of the people by organising bulk purchase of a good phosphate free brand has proven to drop concentrations by 60%.

In Freiburg-Vauban a similar project has been realised in the building “Wohnen und Arbeiten” [Lange, Otterpohl, 2000] with 40 inhabitants. Also here, grey and black water are drained and treated similarly as the project in Lübeck-Flintenbreite.

In Norway several years of experience with a vacuum drainage project exist. Different to the projects above, black water is treated here aerobically thermophilic [Skjelhaugen, 1998].

Recapitulating the utilisation of vacuum technology for the collection of little diluted black water flow is readily available and functional. The treatment technology for black water is available as well. Important for these plants is the proper operation. The professional maintenance of the plants and education of the staff is necessary and indispensable:

Besides the projects being described above, other pilot installations are in the state of planning or already under construction in China and the Netherlands.

The project group AQWA 2100 has published an interesting comparative feasibility study of the vacuum / biogas concept combined with urine separation. One of the surprising results of the study is that the additional costs of source control systems for an urban system are relatively small [Herbst, Hissl, 2002].

5.2 Concepts for yellow water with water flushing – central and decentralised

The essential requirements for a separating toilet system are: comfort for the users, preferably little dilution of urine and faeces, and a satisfactory drainage of both different flows.

For separate collection of urine as yellow water the sanitary technology is available. Especially for buildings with public toilets (schools, motorway service areas, etc.) water-less urinals have a growing market due to their remarkable savings of water. According to the model, urine-sorting toilets (also called no-mix toilets) are draining urine with or without water. This renders a simple collection of urine (where appropriate with acid-stabilisation) and treatment (e.g. solar drying, which has to be developed still) possible. Urine can be worked into brown soils undiluted as fertiliser. After dilution with the 5 – 10 fold volume of water, urine can be directly used to fertilising grassland, but better not directly for vegetable horticulture. After research from Sweden some results are available; urine should be stored for approx. half a year. In summary, a source separating sanitation system with treatment of its different flows renders the re-use of fertiliser possible.

Separating toilets have been developed in Sweden mainly. All of these toilets are draining urine with more or less flushing water, causing urine dilution and thus enlarging the storage volumes. A new developed separating toilet tries to avoid this disadvantage [Ulrich Braun, 2001] (s. Fig 2).

Fig 2: No-Mix-Toilets for separate collection of urine and faeces (www.Roevac.de)

Sitting down on the toilet seat causes an opening of the urine drain, to upraise causes closure. With this mechanism urine can be drained without the dilution of flushing water and nutrients are collected concentrated for utilisation.

In a project being supported by the „Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz“ of North-Rhine-Westfalia, Germany, the problem of substances with endocrine activity (pharmaceutics, hormones, etc.) are investigated [Oldenburg et al, 2002; Lambertsmühle, 2002]. A major project on this issue is performed at EAWAG in Switzerland lead by T. Larsen.

Currently existing experiences with urine separating systems are demonstrating the feasibility separation and utilisation of the nutrient content. Several large-scaled projects with urine separation are in the planning state or under construction. For a part of the new settlement “Solar City” (88 flats and 1 school) in Linz, Austria, a urine separating wastewater system is planned by Otterwasser, Lübeck. The nutrients shall be utilised for agriculture. In Berlin, Germany, the "Berliner Wasserbetriebe“ intends the retrofitting of a maintenance building for a sewage plant with the urine separating vacuum technology [BWB, 2002].

5.3 Decentralised systems of dehydrating for rural and peri-urban areas with high solar radiation

Many proposals and common technologies for a source control wastewater management including different flow treatment of human excretions exist [Winblad, 1998], [Otterpohl et al, 1999]. Some of these concepts are more suitable for rural areas; whereas some are more applicable for city centres. The basic technologies for low-tech low-cost treatment with or without biodegradable garbage are:

- Heating and drying (solar heating, double chamber system), which is problematic for wet anal-hygiene (ca. 50% of worlds population, Muslim countries), requires urine separation
- Digesters for blackwater provided a sufficient number of users is connected
- Double-chambered soil toilets, after usage over-strewn with soil, requires urine separation
- Composting (operation often problematic, further research necessary)
- Low-diluting toilets in combination with biogas systems
- Separate urine collection in combination with biogas systems for faeces

The toilet systems for urine separation by sitting usage and dry anal-hygiene (toilet paper) have been described above. In cultures with wet anal-hygiene squat-toilets are widely spread. Here, different urine separating toilets being specifically adapted to local conditions exist [Winblad, 1998]. In case of water scarcity, treated grey water is often suited to replace missing fresh water. Combined with the faecal desiccation systems, this can make the entire system financially very attractive.

Within the “Gesellschaft für technische Zusammenarbeit (GTZ)” a specialised sector project, called „EcoSan“ (Ecological Sanitation), for this flow oriented concept was established. Together with the specialist group “Sustainable Sanitation” of the

International Water Association (IWA)" a large international conference is planned on April, 2003 [GTZ, 2002].

5.4 Reuse oriented processes for black- and grey water for urban and peri-urban areas

Separate collection and treatment of black water and grey water is the foundation of the method "black water cycle process" (see Fig. 3). The idea of appropriate treatment and reclaiming the toilet flushing water for toilet usage renders a very high concentration of nutrients during daily operation possible. This can be an important contribution for a new viewpoint in domestic wastewater management. This method is protected by international patents of the inventor [Ulrich Braun, 2001], giving capital investment organisations the opportunity to invest in developing the technology. At the Technical University Hamburg first experiments with promising results have been carried out. Currently, a half-technical sized pilot plant is being installed. Per capita and day only 1 – 2 litre of an ideally clear, odourless and colourless liquid nutrient mineral solution will be produced by this method.

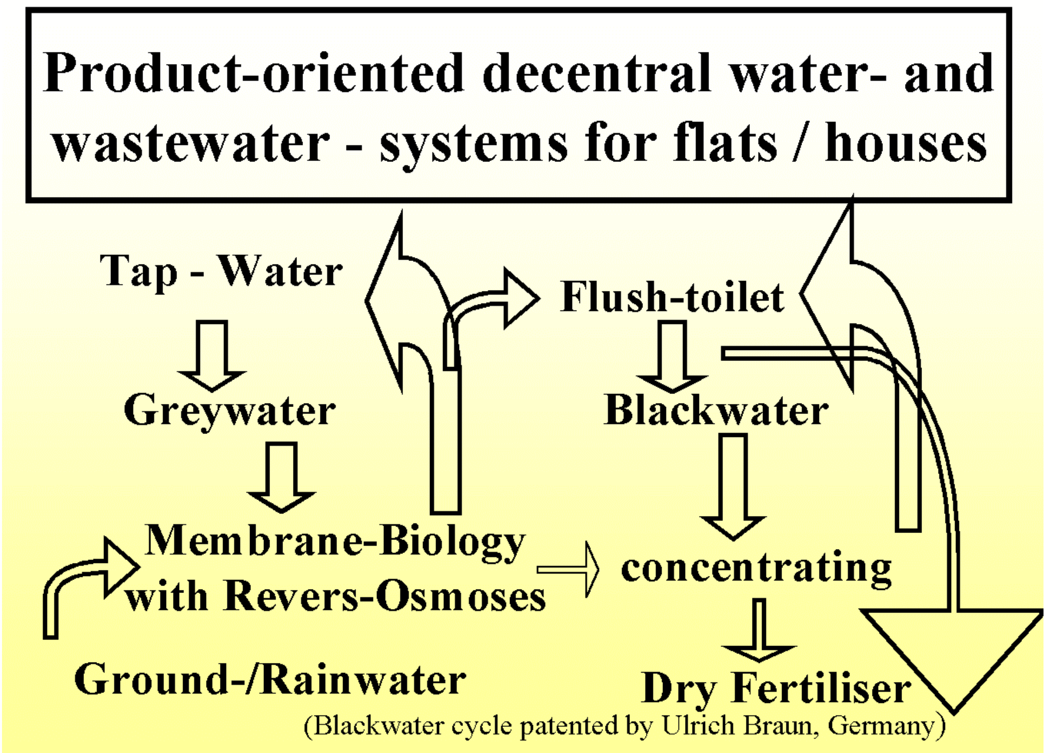

Fig. 3: Flow diagram of black and brown water cycle processes

With this blackwater cycle technology the freshwater consumption of flushing toilets can be reduced down to zero; independent of the water consumption of the specific toilet model by the recirculation after treatment. For countries with limited water resources this can be an interesting and important option. The high concentration of nutrient containing toilet-flushing water opens up completely new treatment options. Due to the very small volumes the usage of sophisticated technologies becomes feasible. The technology of the blackwater cycle became economically feasible with the development of membrane-bioreactors during the last years. The method is also possible with urine separating toilets and re-circulating “brown water cycle processing” modules. Feasible connection-sizes are above about 200 residents. Grey water recycling plants can be realised on an apartment or housing-level. High quality water recycling as tap water is more accepted, if the “own” water is recycled. Fig 3 shows both method options and their embodiment into local water resources.

From a theoretical point of view, no fundamental problems are to be expected by the black or brown water cycle processes. Required is the full oxidation of Ammonia to Nitrate (Nitrification). No hygienic and health risks are expected, because the treated water is treated thoroughly and also only reused for toilet flushing. By utilising the excess-water for direct fertilising, nitrate is not as suitable as ammonia, which is a disadvantage. The de-colouring of the circulating liquid has been an occurring problem due to the concentration of the gallbladder dyes (Urobillin, etc.). That problem has been solved with the research work done at the TUHH. Disinfection of black or brown water is a minor problem due to the employed membrane bioreactors. It is expected, that even a case of the full automation of these plants, on mid-term a regular maintenance keeps necessary.

In summary, the methods of black and brown water cycle processes are very interesting. They contain a high potential especially in areas of the world, where water, energy, and fertiliser are costly and scarce. This is an approach for gaining a water autonomy in settlements. By production of high numbers of the necessary modules, even in cases of small connection sizes, competitive water prices can be reached.

5.6 Adaptation of existing central water infrastructures

By subsequent successive employment of urine separating toilets with storage tanks, the conventional central wastewater system can be changed into a with almost full reuse of nutrients: Urine separating toilets and additional pipes can be installed during renovations. The drainage pipes are connected to the sewers, so that the toilets first “only” are saving water. If a sufficient number of connections in a specific neighbourhood is reached over the years, the high concentrated nutrient solution can be utilised for fertiliser production. In case of sewer nets with little external water influx (no rain water, industrial wastewater, etc.) and a sufficient slope, the collection of urine can be done by a time-controlled emptying of the storage tanks in the early morning [Larsen, Gujer, 1996]. If a sufficient separate collection of urine is established, the central sewage plant does have enough nutrients, however requires no N-elimination (denitrification) any more. The remaining nutrients will be incorporated by microorganisms, and thus be transported into the sewage sludge. With this method, a conventional system can reach a fairly good nutrient resource efficiency.

Successive de-coupling of toilets and employment of appropriate and decentralised black water treatment systems would be another adaptation. This would transform the central sewage plant into a grey water treatment plant, but including industrial wastewater. According to surrounding conditions, the central sewage plant can be converted to water works for reuse.

The disadvantage of these scenarios has to be seen in the necessity of the decentralised investment costs adding to the maintenance costs of the central infrastructure. Due to the pure transport of wastewater as the main cost factor, the economic balance has to be proven precisely. On the other hand, the enormous cost of stormwater storage tanks can be reduced by disconnection of black water. The over-flow of solely untreated grey water would be much less problematic.

6. Socio-economic consequences and models of operation and impact assessment

Many of these innovative concepts demand only a minor change of the user’s behaviour. Another toilet is often the only change. For urine separating toilets and males it has to be considered that they should sit down during urinating. This renders an effective separation of urine and faeces possible. An according demand will generate new and comfortable resolutions very fast. At the moment, the sanitary market is absolutely design-oriented, and poorly innovative technically.

A very important issue is the informing and training of the users to an innovative water technology - or at least about it’s basic philosophies. It has been shown that in many cases, after an according explanation, users are very co-operative and interested. In Lübeck, Germany, the residents have been informed about the context between the high concentrations of Phosphorous in the grey water and dishwasher detergents. After that campaign, the residents started an initiative of corporate acquirement of Phosphate-free detergents. Comprehensible courses of action change the behaviour of many human beings.

The ‘economy of scale’ of central sewage pants is very often pointed out in wastewater management. However, this essentially correct fact cannot be seen isolated. In most urban areas wastewater collection and transport cause 70 to 80% of the total costs. Consequently, savings on the side of the sewage plant have only a small effect in total. Contradicting that, decentralised treatment plants can become very economically priced if they are produced standardised and in a high numbers. On the other hand, the much higher operation costs of decentralised plants have to be considered. In summary, investments in decentralised concepts flow into production and maintenance of plants, whereas investments in central concepts flow mainly into large sewerage systems. Thus, decentralised concepts produce more jobs than central. The decentralised concept in Lübeck produced one job for a caretaker including the technical management of energy / water technology with total costs of system plus labour not higher than for conventional wastewater services.

Professional management of operating innovative water systems is of utmost importance. Ideal legal possibilities are local private operating companies or co-operatives. In case of small units, regular maintenance by an external company is suitable as well.

In case of catastrophes like floods and earthquakes, central systems are highly sensitive. Impact assessments are demonstrating, that failures of central systems have grave consequences, but are more rare compared to decentralised systems. The risk of many decentralised resp. semi-central plants can be effectively minimised by professional maintenance and modern sensor-based controls with alarm messaging and remote inquiry. The large number of plants can cause more disturbances. But altogether, their impact may be much less than one failure of a central system.

Conclusions

Innovative decentral wastewater systems can change the current ways of water management dramatically. They can be designed for almost full recovery of water and nutrients in an economic way. Considering the dramatically increasing water shortages water efficient reuse technology should be put high on the agenda. More pilot installations and research is needed, however there are many solutions that are available for implementation. There is a vast potential of radically new approaches, while small improvements are often not very economic. Societies should finally face their responsibility for taking good care of the most precious resources: water and fertile soil. It is good news indeed, that decentral solutions will probably be the choice even in urban areas. This way people can act without waiting for media-driven governments that are often so blind for the most obvious needs of the future. The future is open for decentralisation, as it is for energy systems it will be for integrated water systems, too.

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