

Resource efficient wastewater concepts – technical options and initial experience

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Abstract: Technology for future houses especially in water scarce regions may well include water recycling units that makes tapwater while people drink bottled water of high quality . There may be toilets that produce just a bag of dry fertiliser per year, hopefully without fossile energy. Rainwater infiltration is increasingly replacing storm sewers anyway. Many urban areas of the future could simply be without sewerage systems. Technical feasibility is given even today and economic feasibility is coming closer by advances in membrane technology. However, there are more likely scenarios than this. One person produces about 500 litres of urine and 50 litres of faeces per year (=blackwater). The same person, produces in a range of 20.000 to over 100.000 litres of wastewater. Black- and greywater (wastewater without toilet) do have very different characteristics. If blackwater is collected separately with low dilution it can be converted to safe natural fertiliser, replacing synthetic products and preventing spreadout of pathogens and other pollutants to receiving waters.

New sanitation concepts are now built in several countries as pilot projects. One example is a vacuum-biogas system for around 400 inhabitants that has been built in Lübeck, Germany. It does perform recovery of resources and energy in an urban area. This type of sanitation can serve around up to 10.000 people and can be arranged in independent modules for larger settlements. Another pilot project based on urine-sorting flush toilets (no-mix-toilets) has been buildt in the rural water-mill museum 'Lambertsmühle' near Cologne, Germany. Urine or yellow water is collected with low dilution and can be used as fertiliser as projects in Sweden have shown - the nutrient composition suits many types of soil. Brownwater (the solids and flush from the sorting toilet) is converted to small volume by a two-chamber composting tank with a filtration system. The compost can be used as soil conditioner. These and other concepts can be economic and show new ways for the many water scarce areas around the world, too.

Limitations of conventional sanitation

The traditional sanitation concept is "end-of-the-pipe"-technology. Only acute problems, not the long-term ones are solved instead of avoiding them from the beginning. Source control has become the standard approach in industrial wastewater treatment and resulted in creative and often economically advantageous solutions. In the field of municipal waste-water treatment the discussion about innovative concepts has just started (Henze, 1997). The first installations of the water and nutrient wasting WC and sewerage systems were criticised by many people at the beginning, but 100 years ago alternative systems had not been reliable enough or where not supported (Lange, Otterpohl, 1997; Harremoës, 1997). Easy availability of water for a formerly small population in humid countries, mining of fossil nutrients and cheap energy stopped the development of systems with source control.

Agenda 21 of the United Nations includes no accounts of sustainable sanitation concepts (Agenda 21, 1992) although water and fertile land are core subjects for survival of future generations. 'Sanitation' is not specified in the document and there is no consideration of the consequences of the implementation of the conventional system world-wide. Many experts of sanitation agree on the possibility of resulting disasters even in a short time-span in economically poorer countries. Unfortunately the ongoing preparatory process for the UN conference in Johannesburg, Sept. 2002 shows little improvement or understanding of the dramatic importance of resource-efficient types of sanitation. Freshwater needs can be dramatically reduced by reuse technology, even down to 10 litres per person in a luxury home. Mass production of such units will make them economic soon.

Efficient sanitation concepts will mostly have to co-operate with agriculture in order to avoid emissions and allow for reuse of water and nutrients. Sustainable agriculture has to be water-friendly and improve or at least maintain soil quality. Industrial agriculture often results in degra-dation of fertile top-soils with

alarming progress (Pimentel, 1997). Organic fertilisers produced by sanitation and solid organic waste management can help to care for maintaining and improving the fertile topsoil.

If faeces are mixed with the wastewater by the usage of conventional flush toilets this results in a high water demand, spread out of potentially dangerous pathogens and micropollutants (residues of pharmaceuticals) in a large volume of water but also a loss of an option for economic reuse of greywater and to produce fertiliser. The initially small amount of faeces could be hygienised easily and with cheap methods. For the strange mixture called 'municipal wastewater' hygienisation is an expensive further treatment step.

Sewerage systems have a couple of severe disadvantages although they are a very costly part of the infrastructure (if sufficient rehabilitation is done). Combined systems emit raw wastewater into receiving waters with the overflows, storage tanks are very expensive if the number of overflows shall be low. Separate systems are often not better or even worse because of the large number of wrong connections. Sewerage systems usually drain large amounts of water from the region, even in industrialised countries the drainage often amounts to the same volume as the total amount of wastewater.

Discussion on hormones, their mimics and emission of medical residues by the users including hormones from widely used contraceptives are showing another weakness of sanitation systems. These substances reach receiving waters easily especially because of their polarity in combination with often very low degradation rates in treatment plants. Another potentially very important issue is the possibility of the transmission of resistances against antibiotics through their uncontrolled release to the environment. (Daughton and Ternes, 1999) Biological reactors are an excellent environment for exchanges of resistances while very few plants hold back all bacteria, what can be done by membrane technology.

Sewerage systems are very often designed as combined systems with the major problem of combined sewer overflows (CSO). If blackwater would be kept out of sewers and only a mixture of greywater and stormwater would be discharged, this problem would be much less severe. There would be only very low concentrations of pathogens and nutrients in this case.

Regional planning in wastewater management

Regional planning has an important effect on the economics of the wastewater system. Costs for the sewerage system are on average 70% of the total of sewerage plus treatment plant costs in more densely populated rural and periurban areas in Germany. This figure can well be exceeded if circumstances are less favorable. Since some years decentral on-site treatment is accepted as a long term solution in many countries. Legal requirements for the effluent of these systems are very low compared to those for larger WWTPs, usually there is no nutrient removal required. However, it would be relatively simple to implement new on-site sanitation systems with full nutrient reuse.

Proper decisions on where to connect houses to a sewerage system and where to build on-site facilities or small decentral plants are the key issue for the economics of the whole wastewater infrastructure. Good regional planning can avoid the deadlock of specifically very expensive sewerage systems that use all the money that could serve the environment in highly efficient decentral treatment and collection systems. There are cost calculation procedures that include long-term development in the balance of operation- and investment costs and products (reuse water, fertiliser, soil improver). The price of secondary products can be very relevant in economically weak and water scarce countries where water and industrial fertilisers are no longer subsidised. Reuse oriented sanitation can easily exceed the performance of the most advanced high-tech end-of-the-pipe plant at often much lower costs.

Figure 1 shows tentatively the relationship between population density and feasible designs of sewerage or on-site systems with regard to source control technology in combination with advanced small scale treatment. The combination of densely populated with decentral or semicentral systems is still difficult today, however it does have a high potential for reuse of water and energy production close to users.

Technological options for wastewater infrastructure

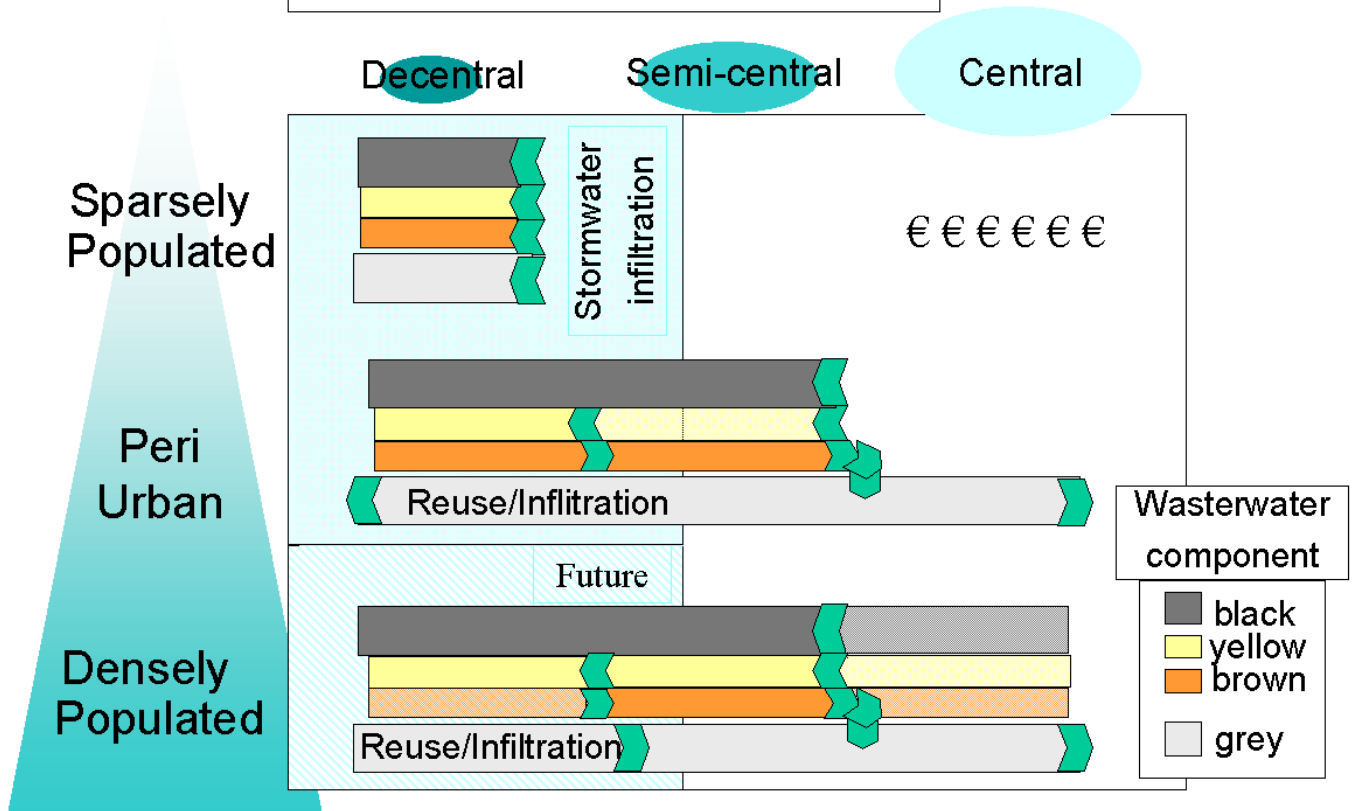


Figure 1: Population density and feasible designs of sewerage or on-site systems

Giving up on central sewerage systems in appropriate cases can open the door for highly efficient reuse systems by redirecting this huge investment away. Spending the largest percentage of the money for wastewater infrastructure just for transport and storage of combined water and still having overflows and very limited reuse is not satisfactory. The key issue for densely populated areas is the feasibility of stormwater infiltration or trench/channel systems. It will often be too expensive to have both sewerage and efficient on- or near-site reuse systems. However, conventional wastewater infrastructure can well be converted to a greywater system where the treatment plant produces reuse water.

The design of source control sanitation and proper management of water

Design of source control sanitation aims for a high hygienic standard and full reuse of re-sources. Naturally socio-economic conditions have to be taken very seriously. The background of the new systems has to be explained to the users. The fundamental step is the identification of the very different characteristics of the main components of household wastewater that are presented in Table 1. There is a certain variation as conditions are different, Table 1 gives a typical range of values. Measurements in the settlement Lübeck-Flintenbreite where source separation has been realised indicate higher phosphate levels in greywater mainly originating from automatic dishwashers. Most other household chemicals in Germany are free of phosphate.

Table 1: Typical characteristics of the main components of household wastewater

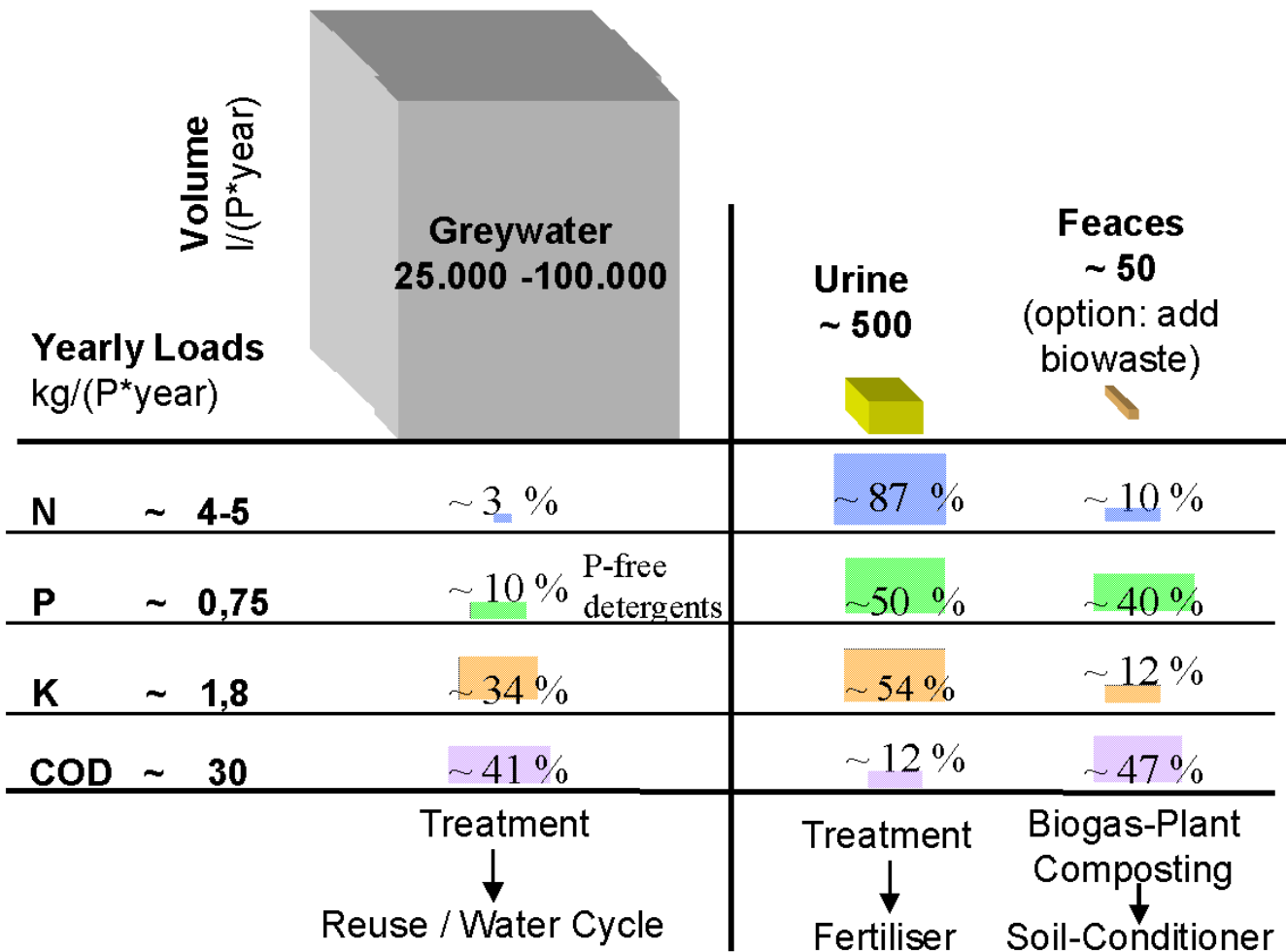


Table 1 suggests the following conclusions:

- Most of the soluble nutrients are found in urine. If urine is separated and converted to agri-cultural usage, the biggest step towards nutrient reuse and highly efficient water protection will be taken.
- The hygienic danger of wastewater comes mainly from faecal matter. Separation and low or no dilution opens the way to excellent hygienisation with the end product 'organic soil improver'.
- Wastewater that is not mixed with faeces and urine is a great resource for high quality reuse of water. Bio-sandfilters and membrane technology open cost efficient ways of production of secondary water - on-site, local or regional scale can be appropriate.
- Source control should include evaluating all products that end up in the water. High quality reuse will be far easier when household chemicals are not only degradable (original substance dis-appears, even if metabolites do not degrade) but can be mineralised with the available technology. Pipes for drinking water should not emit pollutants (e.g. copper or zink)
- If decentralised systems are built rainwater runoff has to be taken care of. Economic reasons will often prohibit to construct sewers for rainwater if decentral sanitation systems are to be installed. Local infiltration or trenches to surface waters for relatively unpolluted rainwater is often feasible and can be combined with its usage, too. Prevention of pollution includes avoiding copper or zink gutters and roof materials that can cause heavy metal pollution of the rainwater runoff.

At the Global Water Forum in The Hague, 2000 there were big disputes about water scarcity. The CSE (Centre for Science and Environment, Delhi, India) presented a different opinion: "There is no water scarcity, only mismanagement". They presented evidence from great success of decentralised rainwater harvesting on local scale. In times of devastating draughts in Gujarat in 1999 there were many villages that had enough water. These vil-lages had introduced many fold measures to bring rainwater to the aquifers with

small check-dams, directing rainwater runoff to the wells and filling cisterns some years ago (Manish Tiwari, 2000). We can add that the introduction of conventional sanitation can well be mismanagement, except where reuse of the mixed wastewater in a combination of irrigation and fertilisation can be done around the year. Source control sanitation and greywater reuse can probably bring the demand of fresh water (e.g. from the cistern) down to low figures as to 10% of what is considered efficient today.

Up to some years ago development of source control sanitation was almost always working with composting toilets. There is a lot of experience from many thousand installations all over Europe. Many of those are working successfully, but acceptance is usually limited to people who have high regard for ecological issues. Furthermore most of the nutrients are trickling through as leachate (see table 1) that is often put into the greywater. There is a need of further development, urine diversion and other concepts for real reuse by fertilising soil of 200 to 300 m² per person.

New types of sanitation i: sorting-toilets and gravity flow

This concept is suitable for single houses and rural settlements based on sorting toilets(see figure 2). The urine (yellow-water) flows over a separate pipe into a storage tank where it stays until it is used mainly for agricultural purposes. The storage period should be at least half a year, since this is an appropriate time for collection and part of the eventual medical residues can be destroyed during this time period. These substances are always of concern, but fast emissions to surface waters may be the worse of two bad options. Production of pharmaceutical products does increasingly consider the fate of residues after use. There are some projects in Sweden that show the potential of urine collection also for complete settlements, however the storage will be more difficult in warmer climates. A further recent development in Germany is to provide an additional low-cost and low maintenance system with a potential of full resources recovery also for the solids. It was built for the historic watermill 'Lambertsmühle' near Cologne and collects the brownwater (faeces) that is flushed with an appropriate amount of water (e.g. 4 or 6 litres) and is discharged into one chamber of a two chamber composting tank (with filter-floor or filter bag) (see Figure 2) where the solids are pre-composted. After a one-year collecting, de-watering and composting period, the flow is directed to the second chamber while the first one is not fed for one year. This allows further de-watering and pre-composting and makes removal from the tank safer (although the matter is not hygienised then).

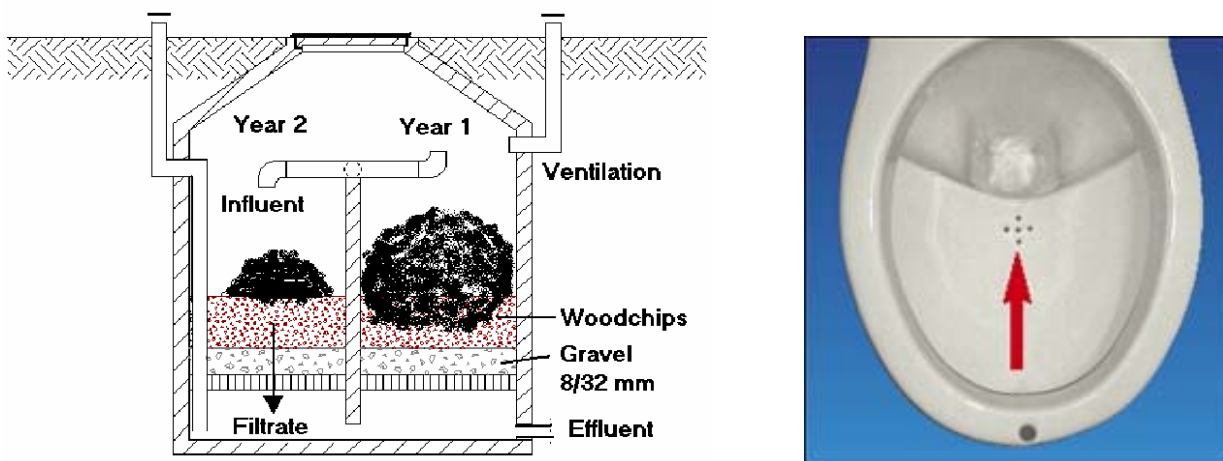


Figure : Two chamber composting tank and Roediger sorting toilet with waterless urine collection (a valve opens when a person sits down)

The products are removed from the composting tank and either used as soil conditioner on brown land or brought to further full composting. They could be mixed with kitchen- and garden waste to decompose completely and allow further hygienisation. The filtrate from the composting tank is low in nutrients due to the previous separation of urine. Therefore, the filtrate can be treated together with the greywater except if high quality reuse is planned.

The greywater is pre-treated either in the composting tank with the brownwater (avoiding 3rd pipe inside and from the house to the tank) or treated completely separate for quality reuse. The next step of efficient treatment can either be a bio-sandfilter (constructed wetland with a vertical intermittent flow) or in a

combined activated sludge reactor with micro- or nano-filtration. These two technologies form an efficient barrier against pathogens and can achieve high quality effluents.

Practical experiences with urine sorting toilets exist mainly in Sweden with more than 3000 installations. It has been clearly demonstrated that this technology is feasible. Drawbacks are observed from too small diameters of urine pipes that clog from scaling. The step to waterless collection has not been done yet in Sweden. A German company has recently started to distribute a sorting toilet with waterless urine collection (see fig. 2). But even with waterless separating toilets one major problem is left. Men are often reluctant to sit down for urinating, despite the unavoidable spraying of urine in the bathroom. This would cause a loss of urine to the brownwater. Younger people seem to accept sitting more easily and understanding the strong effect on water protection can help adapting. The luxury solution is the private waterless urinal. The business of waterless urinals had severe problems with the wrong type of cleaning chemicals and faults in construction. New models are available in ceramic material, combination with hydrophobic nano-coating is available. Another problem with sorting toilets is the disposal of paper that is used after urinating by most women and some men. There could be a paper bin for this paper, otherwise it can be disposed into the faecal bowl without flushing.

New types of sanitation ii: vacuum-toilets and vacuum transport to a biogas plant

An integrated sanitation concept with vacuum toilets, vacuum sewers and a biogas plant for blackwater has been implemented for the new settlement 'Flintenbreite' within the city of Lübeck (Baltic Sea, Germany, NN 2000, Otterpohl 2001). The area with a total of 3.5 ha is not connected to the central sewerage system. The settlement will finally be inhabited by about 400 inhabitants. All components of the project are in use in different fields of application since many years and therefore well developed. Vacuum toilets are used in ships, airplanes and trains. There are already some implementations in flat buildings for saving water. Conventional vacuum sewerage systems serve hundreds of communities. Anaerobic treatment is in use in industrial wastewater treatment, biowaste treatment, on many farms and for faeces in ten-thousands of applications in South East Asia and elsewhere. The system that is built in Lübeck consists mainly of the following components (Fig. 3):

- vacuum closets (VC) with vacuum sewers and anaerobic treatment, co-treatment of organic household waste in a biogas-plant, recycling of digested anaerobic sludge to agriculture with further storage for growth periods. Use of biogas in a heat and power generator (heat for houses and digester plus electricity) in addition to natural gas.
- decentralised treatment of grey wastewater in vertical constructed wetlands with interval feeding (very energy efficient)
- rainwater retention and infiltration in a swale system

The infrastructure for Flintenbreite including the integrated sanitation concept has been pre-financed by a bank and is operated by the private company infranova GmbH, where the house- and flat-owners are financially integrated and have the right to vote on decisions. Parts of the investments are covered by a connection fee, just like in the traditional systems. Money saved by not having to construct a flushing sewerage system, by smaller fresh-water consumption and by co-ordinated construction of all pipes and lines (vacuum sewers, local heat and power distribution, water supply, communication-lines) where essential for the economical feasibility of this concept. The fees for wastewater and biowaste charged cover operation, interest rates on additional investment and rehabilitation of the system. A part of the operation costs cover the salary of an operator, this does offers local employment. The company cares for operation of the whole technical structures including heat and power generation and distribution, active solar systems and an advanced communication system that is available for the inhabitants.

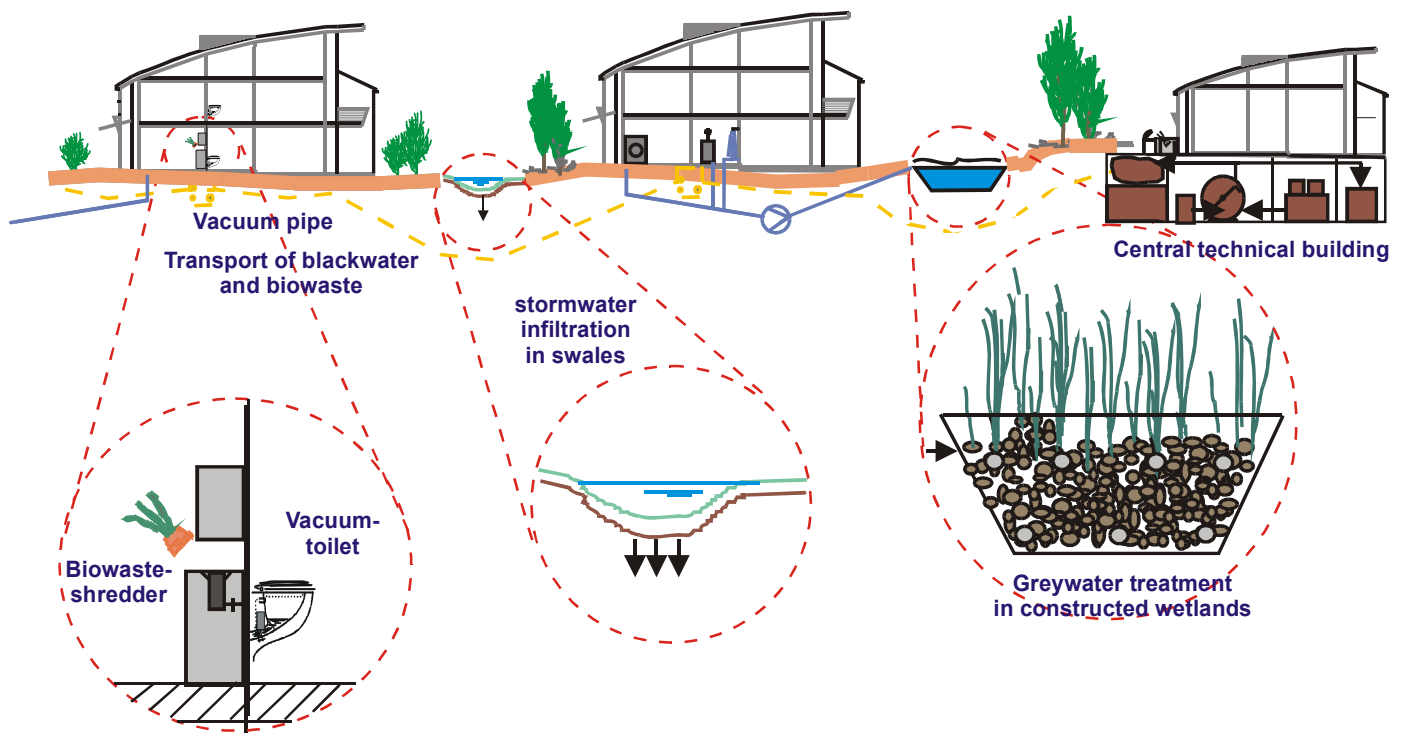


Figure 3 - Vacuum - biogas system developed by Otterwasser, Lübeck, combined with greywater bio-filter

The material and energy intensity of the structure has been studied by the MIPS-method in comparison to a traditional system at the Wuppertal Institute in Germany (Reckerzügl and Bringezu, 1998). Material and energy intensity is less than half for the decentralised system as for a conventional central system serving a medium densely populated area (see Figure 1). For the central system most of the material intensity results from the construction of the sewerage system.

Source control systems can be considered high efficiency technology. Research on pilot projects will bring more development and show new ways for all the different social and geographical situations of our crowded planet. A somewhat similar approach was installed at the same time in Freiburg in southern Germany (Lange & Otterpohl, 1997) and in a rural area near Oslo in Norway, where blackwater from vacuum-toilets is collected by trucks and brought to treatment (Skjelhaugen, 1998).

New types of sanitation iii: upgrading existing infrastructure

Urine collection can convert a conventional sewerage system to one with a very high rate of nutrient reuse and very low nutrient emissions. When most of the urine is kept out of the wastewater treatment plant, nutrient removal becomes obsolete (Larsen and Udert, 1999). There are two basic approaches: Central or decentral (semi-central) collection. The central approach would be to store urine in small tanks and to open them at late night times when the sewerage system is nearly empty. A remote control system would empty the tanks at the respective correct time to create a concentrated flow that can be caught at the influent of the treatment plant (Larsen and Gujer, 1996). This method is limited to sewerage systems with a good gradient and appropriate retention times, however it could be applied to branches of the sewerage system, too. Decentral storage and collection is the other possibility. There is no project yet, but there are certainly many situations where this type of system would be suitable.

If all the blackwater is collected and treated separately, a conventional sewerage system can become a greywater recycling plant and produce secondary water. At the same time combined sewer overflows (CSOs) will become a lot less harmful. Conversion could be done over decades if necessary. Economics have to be considered well, because except in very densely populated areas rehabilitation of sewerage systems requires high specific investment.

Risks, obstacles and restrictions

The first objective for sanitation must be minimising hygienic risks. New systems should be better than the conventional sanitation systems, that have a good hygienic standard for inside the houses but in most cases not for the receiving waters.

Sanitation is a very sensitive matter with respect to the strong wish for clean bathrooms and to the taboos around the issue. Failure can be the consequence (and has been in many cases) if this is not considered and included in project development. The issues around new sanitation systems is somehow complex, but they cover an area of basic needs of humans. Not mixing of food and water cycles, returning matter from the land to the land and zero emissions to the waters can be explained to prospective users of new sanitation systems. Wastewater infrastructure is usually built to be extremely long lasting. This restriction of change seems so overpowering for many people that they can not even imagine different solutions for the future. We have to consider the lifetime of existing house installations, sewerage systems and treatment facilities in order to avoid financial problems. Change is easier for newly constructed settlements or rehabilitation of complete houses. The lifetime of house installation is far shorter than that of sewerage systems. Components of source control sanitation could be installed in each renovated flat and be connected to the conventional systems first. This can be economic with the water saving from the beginning, later after conversion of a group of houses separate treatment can be implemented.

Conclusions

Pilot projects of new types of sanitation systems are built in different places around the world. The examples indicate that new technologies are feasible not only concerning technology but also economics. Many of the new systems will require stormwater infiltration or surface transport via trenches or channels.

It is quite a challenge to participate in the development of emerging new technology. Professional skills and open-minded search for solutions are needed to find better ways for future sanitation. Open dialogue and exchange of experience are essential in order to bring the matter forward. There are so many technological options, that most social and economic conditions can be met. Creativity is needed to find the appropriate technology and the best way of implementing, operating and financing. Even though many industrialised countries will need decades for conversion due to the long lasting existing infrastructure, these countries are the ones with good resources for research and pilot installations. The pilot installations described above are only a part of worldwide quest for better solutions. A lot more pilot plants and research is needed, preferably projects that do operate without subsidies in typical conditions.

The tremendous investment into wastewater infrastructure should be done based on evaluation of the options that we have, not just on working the same way as before. It could be shown that there are many different solutions that can be appropriate in different socio-economic and geographical situations.

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