DIFFERENTIATING MANAGEMENT RESOURCE OF WATER AND WASTE IN URBAN AREAS

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ABSTRACT

The political discussion about future sanitation systems seems to lack input of those working with the further development. Even Agenda 21 is a complete failure in this respect - sadly in a core subject for survival of future generations.

The main task of sanitation besides highest hygienic standards is to keep soil fertile. Sanitation with the mixing up of food and water cycles washes all those substances out to the seas that are extremely harmful there (accumulation) and extremely necessary on the land (depletion of fertility and fossile resources).

New integrated sanitation and waste management systems will mostly have to respect different qualities of matter from human settlements: Blackwater with biowaste, graywater, stormwater runoff and non-biodegradable waste. Based on this distinction 9 differentiating and 1 mixing systems with resources management are presented. Some of them require careful examination in selected pilot projects.

RESPONSIBILITY OF THE WASTE- AND WASTEWATER PROFESSION FOR THE FUTURE DEVELOPMENT

The political processes for directing future development seem to be driven mainly by water resources experts or their thoughts. ‘Sanitation’ is just addressed as something people need.

The traditional sanitation concept and the waste management of industrial countries is working with the "End-of-Pipe"-technology. Acute problems (not the long-term-ones) are solved instead of avoiding them with appropriate systems. This situation has been recognised in waste treatment and results in technologies for separate collection and treatment. In the field of the wastewater treatment the discussion about this has just started (Henze, 1997a). The first installations of the water and nutrient wasting WC and sewerage systems were criticized by many people, but alternative systems had not been reliable enough (Lange, Otterpohl, 1997; Harremoës, 1997). Reckless usage of water, fossile nutrients and energy stopped the development of systems with source control.

Starting-point of the discussion about future development is the feasibility of a sanitation systems, which finally respect responsibility for the future of nature and human beings. There is no reason to wait for public or political pressure, because the publicity relies on the experts. Basic facts for sustainable systems are obvious, nevertheless pilot-projects for new approaches necessary. Serious planning might end the common practice, that the system water closet - sewerage - wastewater treatment plant (WC-S-WWTP) is installed automatically without any serious dissuasion of alternatives.

Agenda 21 of the United Nations includes no accounts of sustainable sanitation concepts (Agenda 21, 1992), sadly in a core subject for survival of future generations. Sanitation is not further defined therefore addressing the WC-S-WWTP without consideration of the consequences of its implementation world-wide. Many experts of sanitation agree on the resulting disasters even in a short timespan for economically poorer countries.

Assessment of the amazing variety of technical options and their respective economic and social implications will be necessary in order to get to a further development of sanitation. A collection with basic considerations and the presentation of a few possible sustainable solutions are given in Henze et al. (1997b). The following will show 10 options for sanitation systems that allow respecting natural cycles under different geographical and social conditions. Possibly sustainable sanitation concepts will mostly have to cooperate with agriculture. Sustainable agriculture has to be water friendly and improve or at least maintain soil quality. Industrial agriculture results often in degradation of fertile topsoils with alarming progress (Pimentel, 1997). Organic farms supplied with the fertilizer produced from the end products of the food they produce - biowaste and human waste - may be capable to make survival or our descendants possible.

Ignoring the most basic needs of our grand children of the 7th generation means participation in a cruel and deadly theft. Sanitation and waste management have to care for maintaining and improving the fertile topsoil. Inappropriate or missing sanitation in difficult climates results in starvation and turns land population into refugees.

DEADLY DISADVANTAGES AND SIDE EFFECTS OF THE TRADITIONAL SANITATION CONCEPT OF INDUSTRIALISED COUNTRIES

In a recent extensive inquiry in the UK flushing toilets were chosen to be the most important invention ever made by humans (SAD, 1997). Computers were second, and the wheel only fifth. This inquiry demonstrates the importance of sanitation for many people.

Central wastewater treatment plants solve acute pollution problems efficiently and require relatively small treatment capacities per inhabitant. Flushing sewers can be a very economic and energy efficient way of transport if they have a reasonably small length per inhabitant. The problem of the traditional sanitation concept is not a question of centralized or decentralized structure, but rather a question of mixing of different qualities.

Some of the disadvantages of the unified (mixing and diluting) sewerage system listed below are well known, others are rarely adressed:

1. Hygienic problems in receiving waters downstream as a result of combined sewer overflows and non-hygienized WWTP effluents (clorination damages receiving waters, but microfiltration, UV, or ozone can be used to solve the second problem). Severe problems without adequate treatment in low-income countries where even existing plants fail within a couple of years.
2. Feacal wastewater is flushed to receiving waters, from where drinking water for other people is produced. Even with an excellent purification of the wastewater and of the river water trace contaminations of dissolved matter are present in the tap-water. These trace contaminations can be very

effective even in extremely low concentrations (e.g. residues of medicines and their metabolites, or hormones from originating from birth control).

3. Nutrient losses even with the best affordable treatment plants are over 20% for nitrogen (N), over 5% for phosphorous (P) and about 90% for potassium (K). Small plants are often much worse. Even a complete agricultural usage of excess sludge results in minor proportions of reuse of N and K. Accumulation of the lost nutrients in the seas as a slow but steady process is the consequence (see Fig. 1). P and K resources that are used to replace these losses are likely to run out within a time span of concern (order of magnitude of 10 human generations with a wide variation in different publications). Phosphates are changed in a dissolved form and can be leached in receiving waters (Beck et al., 1994).
4. Ignoring responsibility for maintaining fertile topsoil. Erosion and degradation of soil is one of the most dramatic threats for our descendants (Pimentel, 1997). Sanitation flushes the valuable matter that comes from soil (far more than N, P, S and K) and farmers replace the many substances and valuable trace substances by inorganic fossile fertilizer with a very limited composition.
5. High energy demand for degradation of the organic wastewater compounds and for nitrification, increasing use of added carbon sources to improve N-removal (e.g. Methanol) on the one hand. On the other hand synthesis of ammonia from air-nitrogen for production of fertilizer is very energy demanding.
6. Mixing of different wastewater qualities including industry often results in a polluted excess-sludge no longer usable as fertilizer.
7. Central sanitation systems may break down completely after catastrophes (e.g. earthquakes, floodings), while decentral or semicentral systems may be affected only locally. A vacuum sewer system can also work during floodings. The disadvantage of decentral systems is vulnerability to disturbances caused by users.
8. The joint presence of sulphur (S) and heavy metals in sewers can lead to a mobilisation of the metals (Beck et al., 1994).
9. The missing recycling of organic matter from biowaste and faece reduce the production of humus, which can counteract the global warming by carbon-storing (Arrhenius, 1992).
10. A high amount of water is necessary to flush human waste (promotes disasters especially in water scarce metropolitan areas).
11. Leaking of the sewerage system causes exfiltration of wastewater into the groundwater or infiltration of groundwater into the sewers. This is a general problem of sewerage systems and can also occur in separate greywater collection systems.
12. High operation and rehabilitation costs for the drainage system and the sewage treatment plant. Most municipalities do not rehabilitate the average 1% to 2% of the drainage and treatment system per year due to the systems lifetimes of 50 to 100 years.
13. The WC-S-WWTP system as the one and only technology is inflexible, inappropriate in many cases and makes further development difficult.
14. Little sense of responsibility for the water cycle and the fate of pollutants is developed on the users side due to the invisibility and invulnerability (mainly by dilution) of the wastewater infrastructure in the local environment.

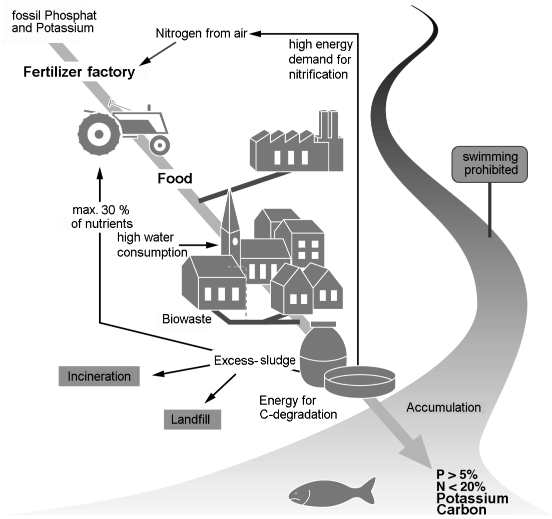


Figure 1: Scheme of linear mass fluxes in the traditional sanitation concept of industrialised countries (FC-S-WWTP concept)

The excess usage of fossile resources means theft from our children and delays development of clever technology. Some regions in South-America have lost their soil fertility due to the waste of the natural fertilizers by inappropriate sanitation while farmers are not able to buy expensive (in the local context) mineral fertilizer (NZZ, 1997). A similar reason leads to desertification in the Sahel region in West Africa, too. Former agricultural soil is loosing fertility due to the decrease of organic compounds. Dosage of mineral fertilizers had to be 6 times as much as would be necessary in France. The mineralising soil in the Sahel region just binds phosphorous to iron. Proper management of organic human- and kitchen waste would have avoided this development. (Arrhenius, 1995) The processes could have been easily foreseen as they can now for the rest of the world. Inappropriate waste and wastewater management is followed by starvation at a time when those engineers and politicians responsible will long have turned to soil. They might not rest that quiet after all.

Large scale sanitation is a big business conquering the rest of the world. Business likes win-win situations and profits can also be made by appropriate technologies that meet the needs of people that are only becoming visible when it will be too late. Public awareness has a potential for fast and radical changes. Those companies investing into the wrong technology could find themthelves in the situation of loosers soon...

DIFFERENTIATING SANITATION SYSTEMS - THE BASIC STEP TO SUSTAINABLE DEVELOPMENT

Source control and reuse of treated waste is the basic prerequisite for sanitation systems that care for the survival of our descendants of the 7th generation. Future sanitation concepts should produce a rich organic fertilizer for agriculture rather than waste. One person can produce as much fertilizer as necessary for the food needed for one person (Niemczynowicz, 1997). However the cycles should not be too short (industrial/energy crops first) and appropriate treatment is necessary. First priority of all possible concepts is the consideration of hygienic aspects - alternative concepts can and should be better solutions in this respect, too.

The type of wastewater and waste management affects soil quality very strongly in the long run. Care for soil quality with source control and reuse of matter that originates from the soil will automatically decrease the accumulation of these substances in the final receiving waters, the oceans. Water saving technologies are necessary in many regions of the world. Once again source control will save water as a very welcome side effect.

When human settlements or single houses are under construction, the installation of new sanitation system can be taken into consideration. As one of many technical solutions separated blackwater can be treated anaerobically in biogas plants. The combination with the digestion of organic household wastes results in a mixture that is suitable for this process. Anaerobic treatment is very advantageous especially for wet biowaste and became more economic in the last years (Stegmann et al., 1997).

Separation of different qualities and their respective appropriate treatment for reuse is common in industry and is fundamental for new concepts (table 1).

TABLE 1: CLASSIFICATION OF DOMESTIC WASTE AND WASTEWATER FOR ADEQUATE TREATMENT PROCESSES

Classification	treatment	type of cycle
1.) Kitchen-waste and low-diluted faces with urine (or further separation of urine)	anaerobic or composting (urine reuse)	food cycle
2.) Gray wastewater (greywater) from bath-rooms, washing machines and kitchen (little nutrients)	aerobic with biofilm plants	water cycle
3.) Stormwater runoff	local discharge or infiltration	water cycle
4.) Non-biodegradable solid waste (small fraction with reuse of packages)	processing to raw material	raw materials

The blackwater and kitchen waste (group 1) contains nearly all of the nutrients nitrogen, phosphorus and potassium. In blackwater the majority of nutrients is concentrated in urine thus making separate treatment feasible (Larsen & Gujer, 1996). Blackwater should be protected from pollution at source by usage of biodegradable toilet cleaning chemicals and especially by avoiding copper or zinc pipes for drinking water. Further precaution will have to be taken with regard to medical remedies that have to be designed for degradability in usual treatment processes. If the blackwater is kept anaerobic with a following anaerobic treatment many medicines are better degraded than in the conventional pathway (Dalhammer, 1995).

The greywater (group 2) contains little nutrients supposed phosphorous free detergents are used. This fraction can easily be treated to a reusable quality as it had no contact with toilet wastewater. However, a small content of feacal bacteria has to be taken into account (washing of diapers, showering). Opposite to common belief greywater often has a high COD concentration due to a smaller dilution when water is used in smaller quantities. Mechanical pre-treatment is necessary for most biological treatment technologies. Treatment should be made with biofilm methods as activated sludge may disintegrate with too low nutrient concentrations. Biofilm systems like trickling filters, rotating disk or sandfilters (technical or as constructed wetland) can reuse nutrients released by lysis of biomass. Additional effort has to be made in the production of household chemicals. They have to be designed to be waterfriendly down to the endproducts. Technology is available and prices of products will have to reflect damage to the watercycle or problems caused in treatment.

Avoidance of central stormwater sewers is an important step towards economically feasible source control sanitation. Stormwater infiltration has become increasingly popular in many countries since a couple of years. The advantages are obvious with a recharge of groundwater and respect to the local water cycle. Unfortunately stormwater runoff is often loaded with a wide variety of organic and inorganic chemicals (Förster, 1996). Direct infiltration into the soil should be avoided.

Infiltration through swales with biologically active soil can be a fairly good treatment, but even here a fair amount of the initial concentrations can reach the groundwater especially when the flow does not pass all of the area but mostly the rim near sealed surfaces (Meißner, 1998). This indicates that great precaution has to be taken to protect groundwater. The flow of the groundwater has to be considered: There may be a difference in infiltrating stormwater near a river where it discharges to the river all year through or to a place with groundwater reservoirs with little exchange other than evaporation. Surface runoff in ditches directed to receiving waters might be the saver choice depending on the situation. The stormwater has to be kept clean by means of source control in any case. Roofs and gutters should not be made from zinc plated metal or by copper and also air- and road pollution have to be minimised. Parking lots can be equipped with pans to collect dripping oil from the engines.

Sustainable sanitation concepts will mostly have to leave the path of traditional wastewater management. In some cases the conventional system can be further used to treat graywater. The following aspects should be considered:

1. Source separation of blackwater as basic step towards flexibility

2. Adequate treatment and utilisation of the waste and wastewater contents (waste mining)

3. Integration of agriculture as service providers (transport, treatment) and as users of the endproduct

4. Connection to energy concepts, e.g. utilisation of the energy content of blackwater and biowastes, loss of energy by aeration of composting toilets, energy needed for aerobic treatment

5. Evaluation of overall efficiency with tools as LCA (lifecycle assessment), MIPS (material intensity per service unit) or SPI (Sustainability Index)

6. Reutilisation of separated flows or substitution (e.g. rainwater as laundry water, treated water for toilet flushing)

7. Use and integration of existing infrastructure and long-termed planning of conversion

8. Design for flexibility

9. Social impacts, awareness of the public, motivation, good looking components

10. Stable structure for operation and reasonable fees

An idealised scheme of the general mass flows in a possibly sustainable sanitation concept is shown in figure 2. A separate greywater collection and treatment is performed, the treatment can be done decentral. The treated greywater can have bathing water quality and can be reused, given to surface waters or infiltrated with precaution preferably through soil with plant cover.

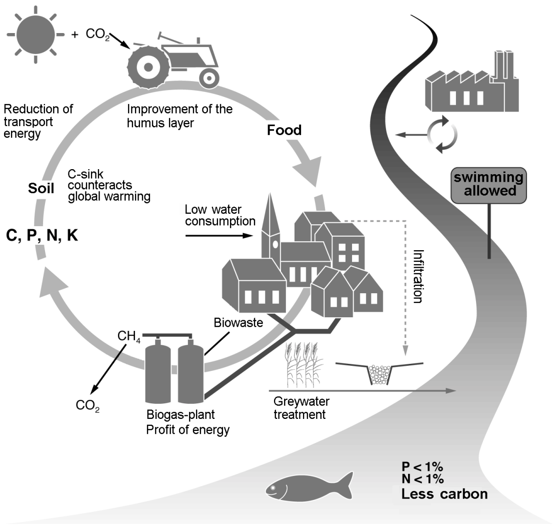


Figure 2: Scheme of mass fluxes in a possibly sustainable sanitation concept

OVERVIEW OVER DIFFERENTIATING SANITATION CONCEPTS FOR DIFFERENT SOCIAL AND GEOGRAPHIC CONDITIONS
PREREQUISITES FOR SOURCE CONTROL

Traditional western flush sanitation solves problems rather than avoiding them. Source control can completely avoid the problems and furthermore produce valuable products.

The choice of sanitation systems is a task that has to take many circumstances into account. First must be the hygienic safety followed by cultural acceptance.

The most important tool for source control is the toilet system. It is in no way prestigious or scientifically rewarding to deal with toilets, but it is one of the most important questions for the survival of man on earth in the long run. It is also a question of life and death in many regions of the world where inappropriate sanitation systems kill people by spreading of pathogens, spoiling waters needed for fishery and further degradation of agricultural land (see above). In the last couple of years there is a rapid development of new sanitation systems. More experts are taking a wider view on the overall aspects rather than just cleaning the wastewater. Figure 3 demonstrates a choice of toilets usable for source control sanitation.

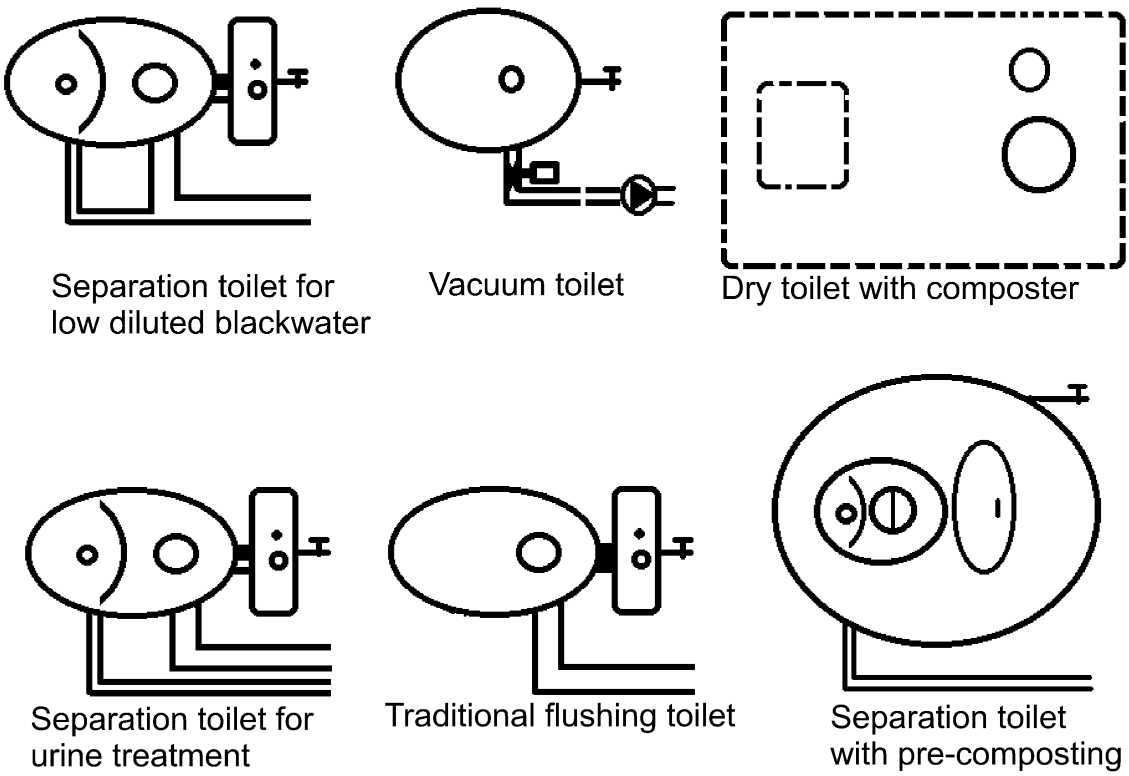


Figure 3: Selection of toilet systems for source control sanitation

The differentiating sanitation concepts (fig. 4 and 5) for semicentral and decentral sanitation concepts are not all in practical use or tested. The demonstration of the possibilities is a proposal, for a few of these a test in a pilot project and a system optimisation is necessary. For two of these systems patent are claimed (not by the authors).

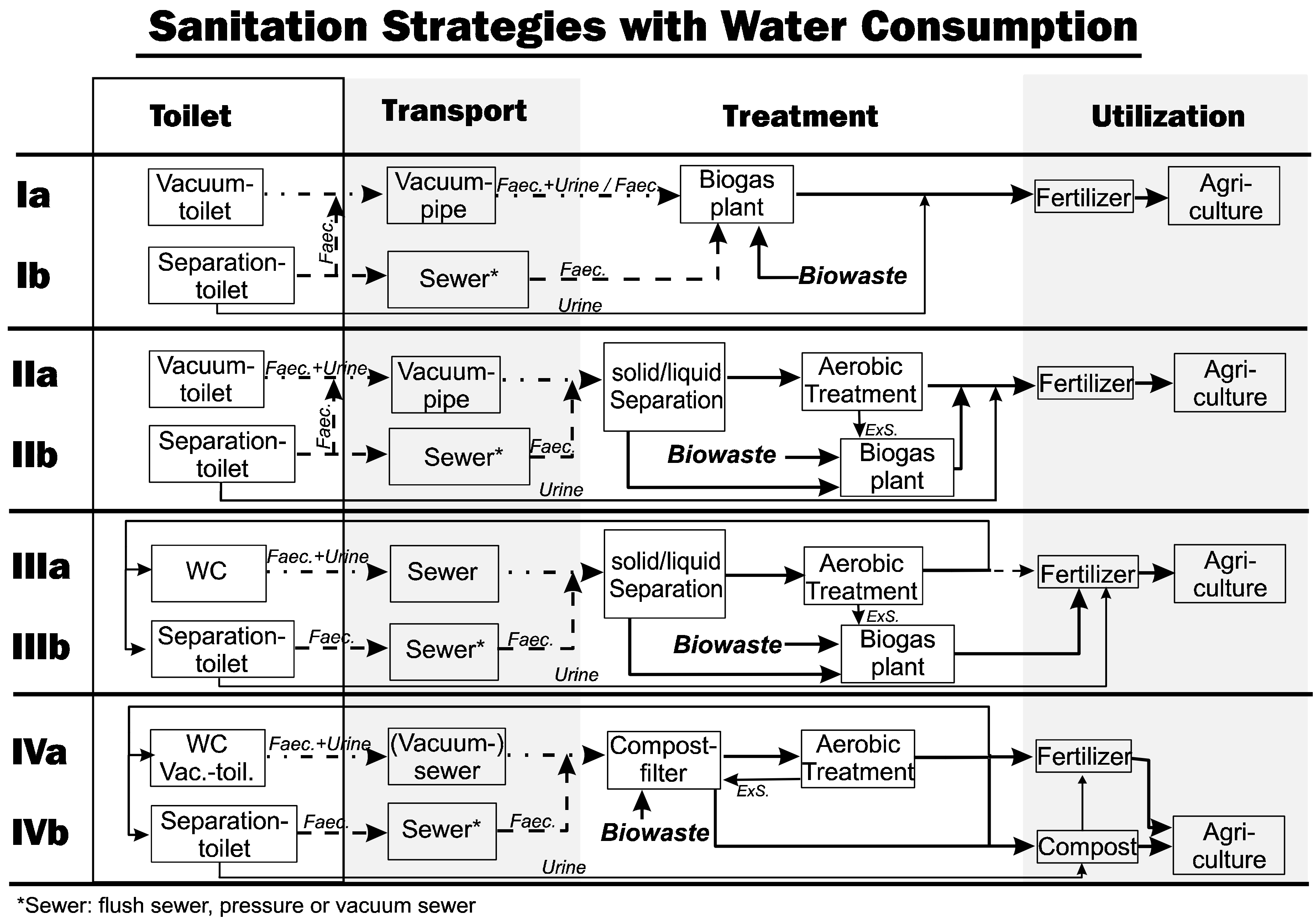


Figure 4: Options for sanitation with resources management - Part I

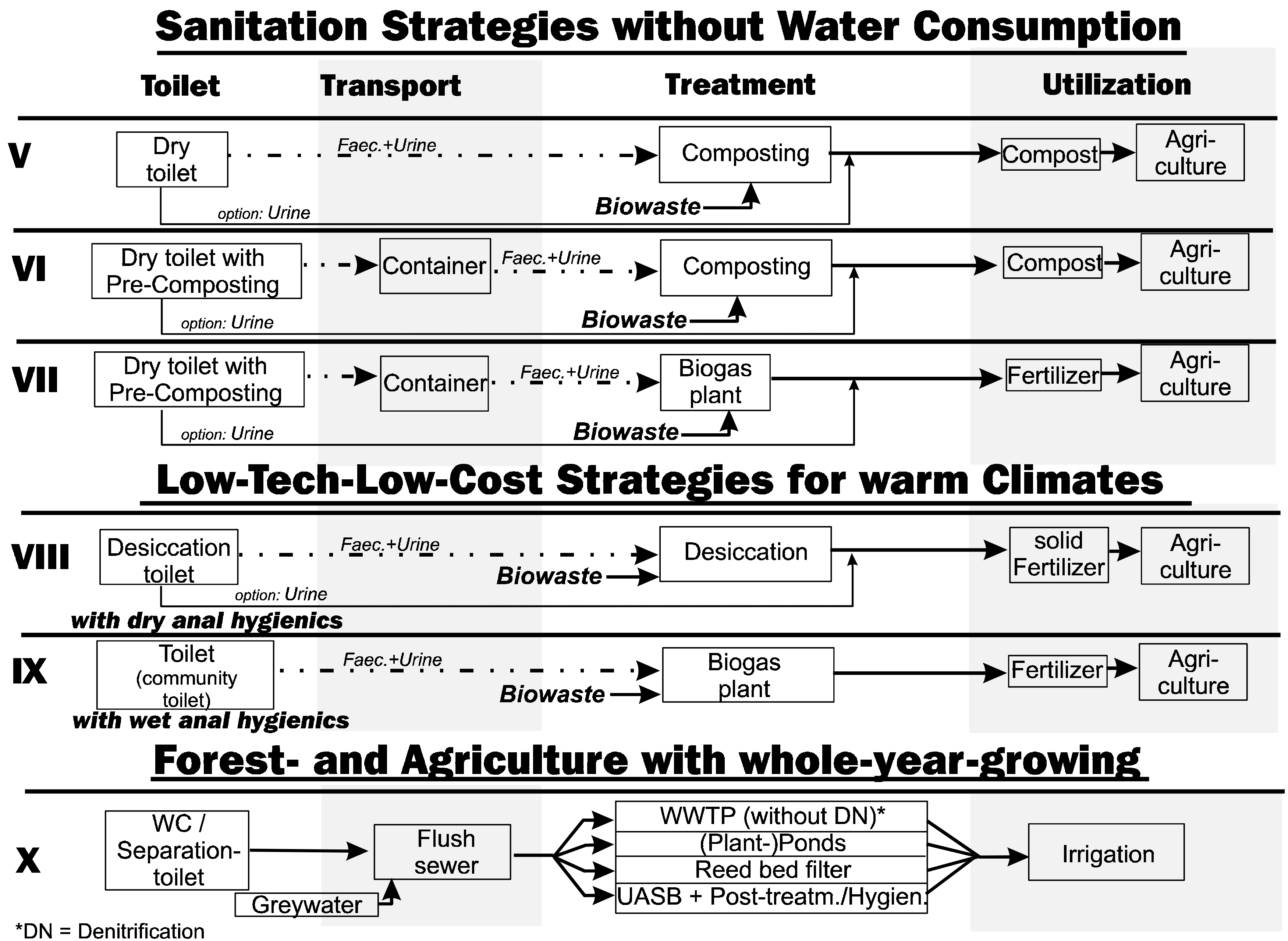


Figure 5: Options for sanitation with resources management - Part II

Concept Ia (Vacuum-Biogas-System)

Vacuum closets (VC) are well developed from some decades of installation on ships. They have a water consumption of 0,5 - 1,0 l per flush. This way a dilution of the blackwater is avoided and anaerobic treatment with hygienisation and co-treatment of organic household waste (biogas plant) is possible (Ia). Biowaste might be transported by the vacuum sewer system after passing a biowaste grinder, but technology has to be further developed for little water consumption. The more simple solution would be biowaste collection with sufficient frequency and central check-up and grinding at the biogas plant. The gas produced by digestion will be used in a power station, which produces thermic and electric energy for the settlement. The product of the treatment in the biogas plant is a liquid fertilizer with a relatively high nutrient level (P, N, K) including also calcium, magnesium and many important trace substances and may be used by the farmers in agriculture. The fertilizer could also be used for an agricultural energy production based on oilseeds (e.g. rape, flax, hamp) that also feeds cattle and cattle manure feeds the same digestor in the settlement. Native oil of these energy plants can also be used together with biogas for heat and energy production in special converted diesel engines.

As an alternative to VC separation toilets could be used as well (Ib). The different flushing volumes for faeces and urine of e.g. 6 l and 0.2 l result in a similarly low dilution as with vacuum toilets making anaerobic digestion with biowaste possible. The pipes could simply be connected behind the toilet and the problem with urine pipes (crystallisation may occur) is avoided. It is a sort of ‘misuse’ of this type of toilet, but it also avoids the weak part in urine separation: transport in pipes and storage. Even a first step installation in order to save water can make very much sense and pays within a couple of month or years depending on the respective water and wastewater prices. Later, with an eventual renovation of the sewers the shift to separating transport and treatment can be done. The usage of separating toilets makes the system described above much simpler as no vacuum pumping station is needed. However separate transport of the blackwater will require a considerable gradient in the sewer. If urine is collected separately it could be added to the liquid fertilizer after the digestor. This can reduce reactor sizes and avoids too high ammoniac concentrations that can inhibit the digestion. Of cause urine can be stored and treated separately if this is of advantage in the special situation. Storage and treatment of urine have traditionally been a normal way to recover valuable substances also for industrial usage (e.g. leather treatment). For large scale application more research with pilot studies has to be carried out. There are several installations in Sweden, where urine separating and reusing concepts are getting more and more attention (Hellström, 1998). Ironically the usage or toilet paper after urinating as it is a habit for most women and many men is the greatest obstacle to acceptance. There are even reports about higher water consumption by separating toilets than conventional ones because of an extra flush for disposal of the paper. A paper bin can be used and in case of non acceptance by users paper disposal could be organised in a way that the following feaces flush will transport the paper without being visible before. Care for future generations comes down to dealing with strange problems, indeed.

The subsequent installation of urine separating toilets can be used for implementing the ANS system as described by Larsen and Gujer (1997). Urine is collected in decentral tanks which are equipped with remote control for starting the emptying. Timing considers lowest flows in the sewerage system and flowtimes from the respective location in order to get a concentrated ‘urine-wave’. This wave shall be caught at the influent of the treatment plant directing it to further processing and usage.

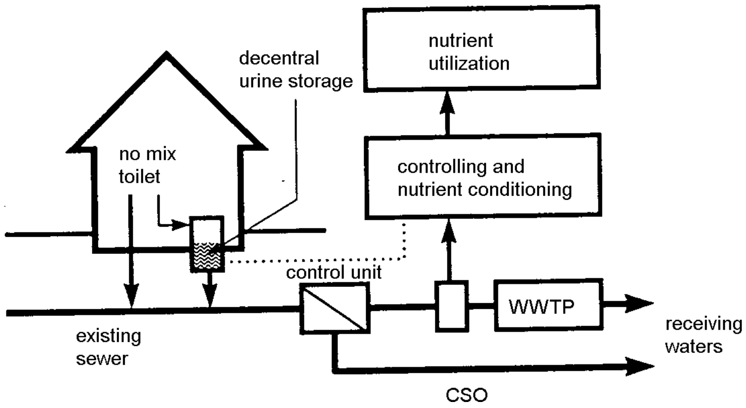


Figure 6: The ANS-system (Gujer and Larsen, 1998; translated)

The main advantage of this system is the applicability in existing infrastructure, what can not be done as easily with many of the other options. A restriction can be found in sewerage systems with a low gradient, where the flow often never comes down enough and deposits will be eroded by the yellow wave. Planning work of the authors of this paper indicates clear advantages of this system on the level of a subcatchment especially on the level of a new or renovated settlement. Pilot projects are well possible with a minimum risk - in the worst case storage is skipped and the systems works like a normal sanitation but with good water savings.

Concept II (Blackwater Pre-treatment)

Concept II (Braun, 1998) is additionally equipped with solids separation in order to limit the capacity necessary for the digestor. An aerobic treatment with nitrification (no denitrification) of the liquid phase of the blackwater produces a flow containing most of the nutrients. This flow can be mixed with the effluent of the digestor (biowaste and solids from blackwater) or stored separately and be reused as fertilizer. Liquid fertilizer containing nitrate has to be applied with greater precaution as nitrate may easily be washed down to the groundwater.

Concept III (Blackwater Reuse Circle)

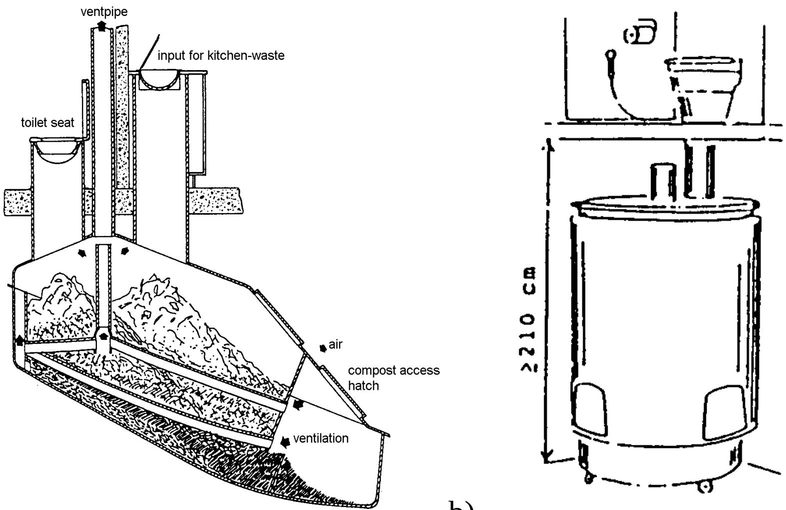
Similar to concept II concept III (Braun, 1998) uses the liquid phase to be circulated back to toilet flushing after hygienisation (e.g. UV-unit). This way the concentrations of nitrogen (but also P, K) can be rising up to concentrations of several thousand mg nitrate per liter. A compensation for the loss of alkalinity due to nitrificaton may be necessary. This concept has to be further tested in pilot installations, however from a theoretical point of view it should work. Nitrate does not inhibit the process and will not evaporate. The frequency of water reuse has jet to be found. Any type of flushing toilet can be used, provided the circle does work. Control of the addition of water might be done at the decentral treatment plant measuring useful indicators (e.g. nitrate concentration, overall flow).

Concept IV (Composting Blackwater Solids)

Another option is the use of a composting filter for the solids contained in blackwater. There are two basic principles for the composting filter: it has to be kept in aerobic conditions (water level below filter material) and the feeding has to be switched between two or more compartments allowing composting with less moisture. The liquid phase will contain most of the nutrients and can be treated aerobically in any high- or low-tech process. The treated effluent should be used as fertilizer as the the long treated compost.

Concepts V to VII: Waterless sanitation and reuse concepts

Dry toilets are usually combined with composting, often in combination with biowaste (kitchen and garden waste). There are many systems with a complete decentral composter in the cellar of the house. In this case the transport works simply by gravity without contact to the pipes (see figure x). This requires installation vertically below the toilets and limits the height to about 3 storeys. The composter for a family of 4 needs room of a total space around 8 m³. Some maintenance is basic for good functioning (30 min per month) and rich soil can be produced. If the process goes well the hygienic quality can be excellent due to temporary high temperatures and a mean residential time of two to four years. The production is only around 40 l per person per year (Lorenz-Ladener, 1992) and therefore easy to handle. A special question is the possible waste of energy in cold climates due to the airflow that is necessary to keep smells out of the house and the compost aerobic. This flow has to be taken into account especially in eco-houses with extremely good isolation.



a) b)

Figure 7: Schematic view of a composter for feaces and biowaste (a) Lorenz-Ladener, 1992 b) Ekolet)

If space for a composter is not available the installation of a pre-composting dry toilet can be taken into account. Models for colder climates that are heated with electricity should be avoided due to the large waste of energy. However there are several models available that use not more than a small motor for ventilation. The principle of these models is to keep the compost dry enough to prevent anaerobic conditions. A small container collects excess compost that can be taken out without manual contact. This has to be done about once a month and disposal will usually be any kind of outdoors compost together with biowaste. Two adjacent heaps with yearly change are recommended to assure composting times with a one year minimum. Alternatively this compost could be fed to a biogas plant (VII) with a loss of gas production due to precomposting (jet to be tested).

The process of composting has some clear restrictions. The moisture has to be kept in a range between about 30 and 50 %, above this range the composting will turn to digestion with production of smells. This applies to households without any kitchen- or garden waste and also for cultures using water for anal cleaning. In regions with warmer climates the compost will easily become too dry for the micro-organisms in the compost. The latter case gave rise to the development of desiccation toilets (VIII, Winblad, 1996) that are solar heated for example with a black sheet of metal.

Two compartments changed anually care for hygienisation with resident times exceeding a year and frequently heated. The end product has only a small quantity and will be usable as fertilizer, soil improver or firing material. There are very old traditional sanitation concepts based on desiccation existing in some hot climates (Winblad and Kilama, 1985).

Concept IX: Low-tech biogas sanitation

A relatively simple low-tech sanitation concept is applied in many countries around the world, especially in India and China. This concept is also usable where wet anal hygiene is used. The most simple solution are toilets for a neighbourhood located directly above or besides a biogas plant (IX). The limited usage of water is necessary to restrict reactor sizes. The codigestion of biowaste, manure and clean organic waste from food industry is advantageous for gas production and financial feasibility. The operation by trained personnel is of major importance, a small usage fee my be necessary to cover costs. Gas usage is usually only accepted if there are not frequent shortages.

Concept X: Conventional or low-tech treatment plants with irrigation in agriculture

In regions without winter climates and with all year round growth periods concept X can be applied. In many cases this can mean the usage of the effluent of an existing treatment plant without nutrient removal as irrigation water that carries also fertiliser. Hygienization of the effluent or crop restrictions will be necessary. Digested sludge can be used in addition provided it is not too polluted. The sources for pollution are widespread in the mix-it-all concepts, as industrial wastewater can carry high loads of heavy metals and non-biodegradable organic chemicals. The treatment according to X can also be done by constructed wetland as wastewater lagoons or sandfilters with reed. The usage of lagoons can provide storage in addition to treatment, too. The main aspect of concept X besides avoiding pollution are the geographical possibilities for water usage.

Usually the dilution of a mixed wastewater prohibits the use of anaerobic treatment. An exception is the UASB (upflow anaerobic sludge blanket) reactor, where solids have a much longer retention time than soluble substances (Zeeman and Lettinga, 1998). This technology can produce energy and can be much easier in operation in low income countries. This technology can also play an important role in separating sanitation systems.

The combination of treatment and agriculture has been applied with the system of energy forests (Hasselgren, 1995). In cases with winter seasons there is a lack of treatment in Winter, what might make the combination with one of the above concepts advisable.

GENERAL REMARKS CONCERNING ALL SYSTEMS

Fertiliser application has to make sure that hygienic aspects are respected. Furthermore the utilisation has to consider good agricultural practices in order to prevent an overload of nutrients. Area requirements may be around 200 to 500 m² per person depending on the local soil quality and the respective crops. In order to take most care the reuse cycle for human nutrition should be prolonged for example by preference for industrial crops. Composting provides with long-term fertiliser and soil improper while biogas-systems or aerobic wastewater treatment produces fertiliser that should be applied during the growth periods only. A seasonal storage will be necessary in climates with winter seasons. If a further dilution shall be prevented a simple cover should be built in humid regions. A higher concentration of the liquid fertilisers might be achieved by floating reeds or other swamp plants put into the storage tank.

GREYWATER TREATMENT

The above concepts from I to IX are based on separate greywater treatment. Besides further usage of existing treatment plants activated sludge processes should be avoided. Due to the risk of a lack of nutrients the sludge may deteriorate and lose the capability of floc-formation. Sessile biomass systems like trickling filters, rotating disk or sandfilters (technical or as constructed wetland) can reuse nutrients released by lysis of biomass should be preferred. A very competitive option for decentral greywater are constructed wetlands in the form of sandfilters planted with reeds. Extensive experience with many different construction leaves only one principle: Vertical filters which are fed in intervals with a water level at the bottom. These require less than 2m²/person for greywater. Filter-material should not be too fine in order to take up and mineralise excess sludge over 50 years. After the filters are filled the sand can be washed and refilled. If technical plants are chosen the warmth from greywater can be used with heat pumps for warm water supply.

Greywater can relatively easy be treated to a standard according to EC bathing water guidelines. This opens many ways of reuse, too.

A PILOT PROJECT FOR THE VACUUM-BIOGAS SYSTEM FOR URBAN AREAS

An integrated sanitation concept with vacuum toilets, vacuum sewers and a biogas plant for blackwater will be implemented for the new settlement ‘Flintenbreite’ within the city of Lübeck (Baltic Sea, Germany). The area with a total of 3.5 ha will not be connected to the central sewerage system. The system is planned by the authors of this paper for the local construction company, which develops this area in co-operation with the city of Lübeck. The settlement will be inhabited by about 300 inhabitants and is meant as a pilot project to demonstrate the concept in practice. However, 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, aeroplanes and trains. There are already some implementations in flat buildings for saving water. Unified vacuum sewerage serves hundreds of communities. Anaerobic treatment is in use in industrial wastewater treatment, biowaste treatment, on many farms and for faeces in tenthousands of applications in South East Asia and elsewhere. The system that will be build in Lübeck consists mainly of:

- vacuum closets (VC) with collection and anaerobic treatment with co-treatment of organic household waste in decentralised/semicentralised biogas-plants, 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 digestor) in addition to other fuel (here: natural gas).
- decentralised treatment of grey wastewater in constructed wetlands (very energy efficient)
- stormwater collection for reuse, collection of excess-stormwater in a through and drain trench for retention and infiltration (Grotehusmann 1993)

The heat for the settlement will be produced by a combined heat and power generating engine which is switched to use biogas when the storage is filled. It will also be used to heat the biogas plant. In addition there will be passive solar systems to support heating of the houses and active solar systems for warm water production. A sketch of such a system is presented in figure 4. The figure is not meant for showing all the details but shall give an idea of the concept with collection and treatment of faeces.

At the digestor a vacuum pumping station will be installed. The pumps have an extra unit for the case of failure. Pressure in the system is 0.3 bar operating both the vacuum toilets and the vacuum pipes. Pipes are dimensioned 50 mm to allow good transport by the air. They have to lie deep enough to be protected against freezing and must have down-bows about every 30 meters to create plugs of the transported matter. Noise is a concern with vacuum toilets but modern units are not louder than flushing toilets and give only a short noise.

Faeces mixed with the shredded biowaste (only blackwater for mixing) will be hygienised by heating the feed to 70°C for 30 minutes. The energy is reused by a heat exchanger that preheats the incoming flow. The digestor shall be operated termophilically at around 55°C with a capacity of 35 m^3, what is half of the size compared to mesophilic operation (around 37°C). However, problems may occur in operation arising from high concentrations of NH_4/NH_3 which are predicted to be around 2000 mg/l. In case of difficulties operation will be switched to mesophilic conditions, where the proportion of NH_3 is lower at the same pH-value with an additional tank. Another concern is the amount of sulphur in the biogas. This can be minimised by controlled input of oxygen into the digestor or into the gas flow.

The biogas plant is meant to be a production unit for liquid fertiliser as well. It is important to consider pathways of pollutants from the beginning. One important source for heavy metals are copper or zincplated pipes for drinking water. These materials will be avoided and polyethylene pipes will be used. The sludge will not be dewatered for having a good composition of the fertiliser and for not having to treat the sludgewater. The relatively small amount of water added to the blackwater keeps the volumes small enough for transportation. There will be a 2 weeks storage tank for the collection of the digestor effluent. Biogas will be stored in the same tank within a balloon what gives more flexibility in operation. The fertiliser will be pumped off by a truck and transported to a farm that has a storage tank for 8 month. These tanks are often available anyway or can be build with little investment.

Decentralised treatment of grey wastewater should be done by biofilm processes. Appropriate technologies with very limited space are aerated sandfilters, rotating disk plants and trickling filters (Nolde 1995) with infiltration of treated greywater within the stormwater storage- and infiltration system. Constructed wetlands are also a possible solution for urban areas - they can be integrated in gardens and parks. Greywater is relatively easy to treat because it has low contents of nutrients. There may even be a lack of nutrients for incorporation during the start-up of the greywater treatment system. As soon as there is a sufficient biofilm the micro-organisms can reuse nutrients released by lysis. Several projects on technical scale have demonstrated the feasibility and good to excellent performance of decentralised greywater treatment. These plants allow reuse of the water in toilet flushing, what is not economically feasible in the Lübeck project because of the low water consumption of the vacuum toilets. Greywater in Flintenbreite will be treated in decentralised vertically fed constructed wetlands with sizes of 2 m^2 per inhabitant. These are relatively cheap in construction and especially in operation. The pumping wells will serve as a grit chamber, for grease control and will have filters for larger particles above the waterline. The effluent will preferably be infiltrated in the drain trench system for stormwater.

The infrastructure for Flintenbreite including the integrated sanitation concept will be pre-financed by the construction company and a private company where participating companies, planners and later the house- and flat-owners are financially integrated and will have the right to vote on decisions. Parts of the investment are covered by a connection fee, just like in the traditional system. Money saved by not having to construct a flushing sewerage system, by smaller freshwater consumption and by co-ordinated construction of all pipes and lines (vacuum sewers, local heat and power distribution, water supply, phone- and TV-lines) are essential for the economical feasibility of this concept. The fees for wastewater and biowaste charged later will cover operation, interest rates on additional investment and rehabilitation of the system. A part of the operation costs has to be paid for a part-time operator, but this also 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 communications system.

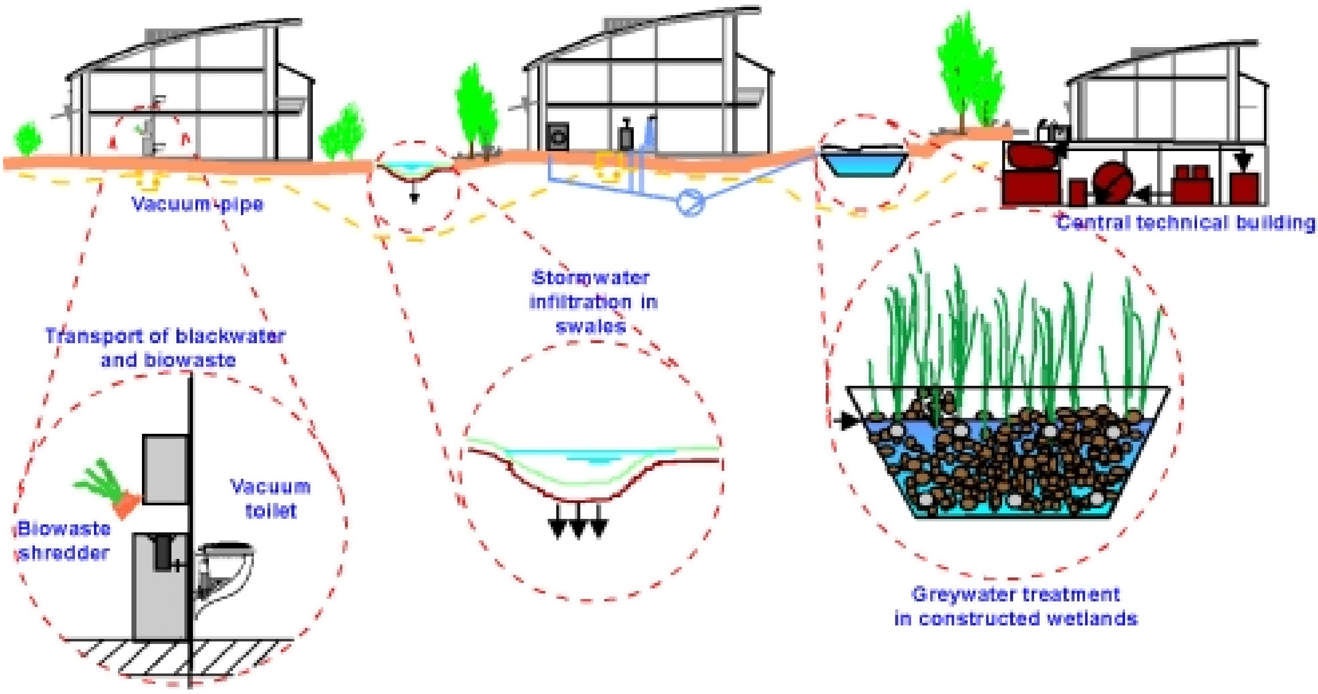


Figure 4: Vacuum - biogas system integrated in a new settlement

The material and energy intensity of the structure is presently studied with the MIPS-method in comparison to a traditional system at the Wuppertal Institute in Germany (Reckerzügl, 1997). 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 table 3). For the central system most of the material intensity results from the construction of the sewerage system. The predicted effluent values are based on averages of measurements of greywater effluent qualities are presented in comparison to average values of a modern treatment plant with an advanced nutrient removal and good performance.

Table 3 indicates some major advantages for the new system which justify further research. The cumulated savings of emissions to the seas and of energy- and material usage for an average lifetime of 70 years for one person would be: about 700 m^3 of freshwater, 200 kg of COD, 4.2 kg of P, 37 kg N, 91 kg of K, 15.000 KWh of energy and about 160 tons of material usage. The saved emissions can replace fertiliser production from fossil resources and synthesis of nitrogen, too. This can be calculated as another 7.000 KWh of energy saved (Boisen, 1996); other references quote energy demands up to ten times this value for production of mineral fertilizer. These numbers are important with respect to a large world population and decreasing fossil resources.

TABLE 3: ESTIMATED EMISSIONS, ENERGY CONSUMPTION AND MATERIAL INTENSITY OF THE PROPOSED SYSTEM COMPARED TO A TRADITIONAL SYSTEM

Advanced traditional sanitation (WC-S-WWTP) concept		New sanitation system	
Emissions		**Emissions** *)	
COD	3,6 kg/(P*a)	COD	0,8 kg/(P*a)
BOD_5	0,4 kg/(P*a)	BOD_5	0,1 kg/(P*a)
Total N	0,73 kg/(P*a)	Total N	0,2 kg/(P*a)
Total P	0,07 kg/(P*a)	Total P	0,01 kg/(P*a)
Total K **)	(>1,7 kg/(P*a))	Total K **)	(< 0,4 kg/(P*a))
Energy		**Energy**	

water supply (wide variation)	-25	kWh/(P*a)	water supply (20 % water savings)	-20	kWh(P*a)
wastewater treatment (typical demand)	-85	kWh/(P*a)	Vacuum system	-25	kWh/(P*a)
Consumption			Greywater treatment	- 2	kWh/(P*a)
			Transport of sludge (2/month, 50 return)	-20	kWh/(P*a)
Consumption	*-110*	*kWh/P*a)*	*Consumption*	*-67*	*kWh/(P*a)*
			Biogas	110	kWh/(P*a)
			substition of fertilizer	60	kWh/(P*a)
			Win	*170*	*kWh/(P*a)*
Total	**-110**	**kWh/(P*a)**	**Total**	**103**	**kWh/(P*a)**
Material intensity***)	3,6	t/(P*a)	Material intensity***)	1,3	t/(P*a)

*) measurements HH-Allermöhe
**) assumption, no data
***) MIPS-Study (Reckerzügl]

FURTHER OPTIONS FOR INTEGRATED SANITATION CONCEPTS BASED ON BIOGAS PLANTS

The interest in the integrated concept described above has dramatically increased since the first publication (Otterpohl and Naumann, 1993) and the beginning of the planning for the project in Lübeck. There are other projects where this type of concept shall be built. The system in general can well be cheaper all in all than the traditional system. This depends on the possibility to infiltrate stormwater locally what is just becoming the standard approach. It also depends on the size of the area that is served and on the number of inhabitants. An optimum size may be an urban area with around 500 to 2000 inhabitants. Smaller units are feasible if the blackwater and biowaste mixture is only collected and transported to a larger biogas plant that would preferably be situated on a farm. The treatment of greywater can be done in an existing wastewater treatment plant if the sewerage system is nearby. In some cases this is the most economical way. If a certain percentage of the population is served by separate blackwater treatment nutrient removal can be improved. At a certain proportion nitrification would be obsolete.

The size of cities is of concern because of the transport distances. However even in metropolitan areas there would be possibilities to deal with this problem. The liquid fertiliser or the raw blackwater-biowaste mixture can either be pumped or transported by rail out of peak load times for passenger transportation. These are questions of long-term planning in close connection to city planning. From the point of view of sustainable sanitation, for food production and transport and for a closer contact of city dwellers to nature cities of the future should be developed in the shape of stars with rural areas in between.

The proposed system is based on vacuum toilets, but there are other ways to collect blackwater. Urine separation toilets and a type of pressure flush toilet with a lid instead of a water siphon to prevent smells (Lange and Otterpohl, 1997) that are both developed in Sweden can be used as well. The latter type needs a pipe gradient above 5% at least to a collection pit. Further transport could be done by a vacuum or a pressure system. Systems based on biogas plants should have a heat and power generator if there is a demand of heat around the plant, typically in the settlement served by the system (colder climates). A charming concept could be the production of biodiesel with fertiliser from the digestor. There are engines that can be run with a mixture of biodiesel and biogas.

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