Towards sustainable sanitation – the HAMBURG WATER Cycle in the settlement Jenfelder Au

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ABSTRACT

One of the largest urban development projects at present in Hamburg is the conversion of former military barracks into a new residential area for about 630 households, called Jenfelder Au. The urban design concept for this 35 ha area follows a high quality approach to develop a carbon-neutral, attractive neighbourhood for approx. 2,000 inhabitants abundant with green space and urban water. HAMBURG WASSER, Hamburg's water supply and wastewater utility, is rethinking the way of wastewater management by implementing an integrated concept for decentralised wastewater treatment and energy production – the so-called HAMBURG WATER Cycle® (HWC) – in this new residential area, based on source control of wastewater. Stormwater, greywater and blackwater are collected separately and then treated separately on site in Jenfelder Au. The realisation of the HWC will be the hitherto largest demonstration of a resource oriented sanitation concept working with vacuum technology for the collection of concentrated blackwater. This concept intends to establish synergy between wastewater management, waste management and energy production, and contributes to an improved local natural water cycle.

Key words | blackwater digestion, energy generation, HAMBURG WATER Cycle®, source separation

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INTRODUCTION

The need for higher energy and resource efficiency in the delivery of basic infrastructure services – drinking water supply, wastewater management, energy supply and solid waste management – becomes more and more urgent, as factors such as urbanisation, climate change and aging infrastructure facilities represent challenges for future service provision.

By 2020 about 56% of the world's population will live in urban areas (United Nations 2012) and the growth of these urban areas is expected to take place mainly in low- and middle-income countries (Satterthwaite 2007). Solutions for the provision of the above mentioned infrastructure services often have to cope with rapid development and scarce natural resources.

The effects of climate change, such as changes in precipitation patterns and the tendency towards heavier rainfalls, challenge and overburden existing drainage infrastructure (Funke 2007; Schramm 2009). In most cases, the enlargement of sewers as an adaptation to climate change is limited by both the available space in inner city grounds and economic factors.

The typical economics of existing centralised infrastructure turns out to be a serious dilemma since ageing infrastructure is a key challenge for most constructed infrastructure facilities (Jacobi & Sympher 2002; Ugarelli *et al.* 2008). Yet the traditional replacement of assets with again long lifetimes may not be an appropriate way to achieve future infrastructure service provision, which may need to be more resilient and adaptable to the impacts of urbanisation and climate change. (Hillenbrand & Hiessl 2006). The development of decentralised infrastructure systems

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seems to be a promising solution to this dilemma. However, the potential of decentralised 'island' solutions still needs to be demonstrated, evaluated and verified, especially when these systems do co-exist within centralised infrastructure.

In Hamburg, the second largest city in Germany, the water supply and wastewater utility company HAMBURG WASSER has achieved for the first time, a decentralised and integrated infrastructure concept, namely the HAMBURG WATER Cycle® (HWC), within its conventional centralised wastewater management infrastructure. This innovative infrastructure concept links wastewater management with energy production and aims at providing a carbon-neutral wastewater concept for cities of the future.

The HWC is part of the large urban development project 'Jenfelder Au' of the Free and Hanseatic City of Hamburg (FHH) in the district Hamburg-Wandsbek. The city stipulated ambitious development goals for the urban planning of this new settlement when conducting the urban development plan competition.

The integrated infrastructure concept, HWC, as well as the winning concept for the urban development plan, is widely considered as a promising, innovative and sustainable example of water sensitive city planning. The urban development plan for Jenfelder Au was awarded the 'Gold Award' in the 2009 International Urban Landscape Award (IULA) because of its outstanding architectural, social, economic and ecological elements. The quality of urban living is enhanced by energy-efficient and resource-optimised construction and the integrated approach regarding the multiple urban functions (e-architect 2010).

SUSTAINABILITY ASPECTS OF THE URBAN PLANNING IN JENFELDER AU

In the following sections the urban development project Jenfelder Au is presented, focussing on the urban planning and the infrastructure planning.

Jenfelder Au – the urban development plan for integrating social and ecological sustainability

The FHH decided to develop a former military barracks area in the district Hamburg–Wandsbek into a new housing area. The surrounding neighbourhood of Jenfeld has a high proportion of subsidised housing and a diverse socio-economic mix. The built environment is dominated by an anonymous, uniform appearance with monotonous residential high-rise buildings. The FHH conducted an urban development plan competition for the conversion of the former barracks in 2005/2006, which was intended to also improve the image of the neighbourhood Jenfeld. The winning concept was offered by *West 8 Urban Design & Landscape Architecture* and focussed on a high-quality approach to developing a sustainable and attractive neighbourhood with abundant green spaces and water bodies.

The urban development plan features a range of diverse building types and a variety of public spaces. Three major design principles, which are 'Partial Collectivity', 'Clear Individuality' and 'Sustainability' are dominating West 8's design for Jenfelder Au. This refers to a strong emphasis on social sustainability, which is of particular importance in areas such as the Jenfeld neighbourhood that have been neglected by urban planning processes in the past. The urban design with different housing types therefore aims to attract a wide variety of different residents ranging from lower to upper middle class and an urban mix of younger and older people. Plot sizes are compact and provide for attractive and affordable townhouses with gardens.

The housing area is improved by incorporating an interesting mix of space for living and working, as well as various other functions such as small businesses, services, municipal facilities, restaurants and cafes, retail and day-care centres. These functions, integrated into the urban development plan, turn Jenfeld into a 'city of social sustainability'. The area is planned to be urban, yet green, which is reinforced by the incorporation of water and green areas into the public space. Water bodies (i.e. the Cascade Park and the Kuehnbachteich, which is a water body located in the centre of the area), greened places, avenues and garden plots are incorporated into the entire area. Figure 1 shows the new plan for Jenfelder Au and highlights the mix of living and working as well as the green elements in the urban layout.

A main square at the centre of the area, where small businesses, services and cafes are located next to public green spaces and dwellings, provides for a good mix of cultural, social and public functions. The green spaces are

Figure 1 | Bird's eye view of the attractive town houses with gardens and PV panels on the roofs (FHH, West 8 & BRW 2006).

closely connected to the semi-natural use of rainwater within the urban landscape. The rainwater will be collected in small ditches and will feed the water cascade in the main green area ('Cascade Park'). The cascade then discharges into the central pond called Kuehnbachteich, which is in fact a rainwater retention basin (see Figure 2). This basin has a retention volume of 5,000 m^3, and is designed for rainfall events with a return period of 30 years. In Jenfelder Au, urban design functions, such as providing public recreational space, are merged with rainwater infrastructure provision.

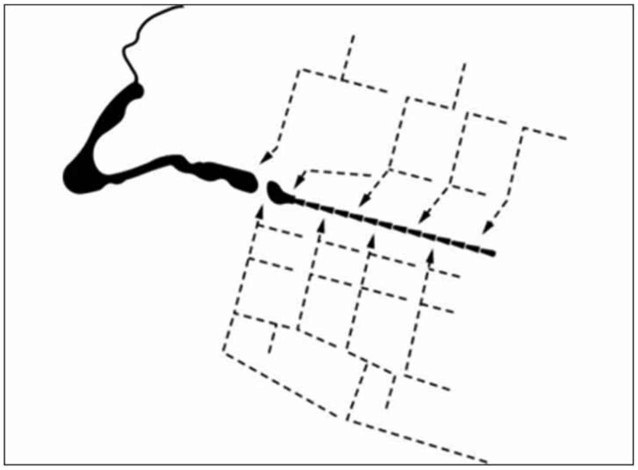

Figure 2 | Rainwater management in Jenfelder Au (FHH, West 8 & BRW 2006).

Some existing buildings of the former barracks are going to be refurbished and integrated into the housing concept. A parade ground is going to be maintained as an historic monument and upgraded by the integration of private gardens. However, military ornaments are going to be covered to reflect the future peaceful use. North of the new development area is designated as a commercial area for various low emission uses such as stores, small trade and offices.

Townhouse architecture

Not only the urban development plan, but also the suggested architectural housing types, reflect the modernity and high quality of living space that is planned in Jenfelder Au. The design principles 'Partial Collectivity' and 'Clear Individuality' are mainly transported in the development of townhouses. According to West 8's design concept, townhouses are a combination of row houses and freestanding family homes. Gardens are also important elements, and they provide attractive alternatives to the often monotonous suburban developments. The townhouse type covers a variety of housing types that help residents to express their personal lifestyle and individuality. Yet, a certain unity (a 'common canon of design') contributes to the feeling of identity and security across the diverse social and cultural mix (e-architect 2010).

According to West 8 the housing architecture of Jenfelder Au is characterised as follows (e-architect 2010):

> 'One of the most important aspects of the design is the individual unity of each building. This means that the buildings can stand alone, but also can be attached to each other, which will intensify the lively urban atmosphere of the neighborhood. The buildings are close together, their proportions are relatively narrow and high, and the corresponding plots are very compact. The combination of these characteristics enables the realization of affordable housing units with a strong expression. Due to the relatively high density, a quarter of small-scale, yet urbanized, can arise. Although each building will have its individual character, it is possible to develop a large number of houses at once: the developer offers potential buyers an architectural variety of housing types, and each individual house can then have its own façade design. This makes a natural architectural mix possible.'

The design principle 'Sustainability' means that a neighbourhood will be built which is future-oriented, ecological and carbon neutral. This is accomplished by incorporating renewable energy generation and achieving self-sufficiency in terms of energy use. The roofs of the residential buildings offer the potential to generate renewable energy by being equipped with photovoltaic and solar thermal systems. The design of the townhouses supports the technical systems by using the technical conditions for photovoltaic systems as a design element for the roof slope and orientation (see Figure 1). In addition to the consideration of generation of renewable energy, Jenfelder Au will also see a new approach to urban wastewater management. For the first time on a large scale the HWC developed by HAMBURG WASSER will be implemented and adapted to the local conditions in Jenfeld.

THE HAMBURG WATER CYCLE – AN INTEGRATED INFRASTRUCTURE CONCEPT (NOT ONLY) FOR THE NEW SETTLEMENT JENFELDER AU

The HWC combines sustainable sanitation with on-site energy generation and delivers heating energy directly to the neighbourhood. The following sections highlight the key characteristics of the HWC and its implementation in Jenfelder Au. A more detailed description of the planning process and the technical design can be found in Augustin *et al.* (2011).

Source separation of household wastewater flows

Wastewater systems with source control offer a higher potential to combine infrastructure services (water, energy, waste) in a more efficient way than the conventional sewerage system working with flushing toilets, mixed sewers and end-of-pipe treatment (Otterpohl *et al.* 1999). Based on the different characteristics of wastewater flows, different treatment processes can be applied. The main differentiation of household wastewater flows concerns the toilet wastewater (blackwater, i.e. urine and faeces with or without toilet paper), which is rich in organic matter and nutrients, and the water from kitchens and bathrooms (greywater), which produces larger volumes with lower concentrations of pollutants.

Based on this understanding, HAMBURG WASSER developed an innovative and integrated concept for wastewater treatment and energy production – the so-called HWC and adapted it for the new settlement Jenfelder Au (Schonlau *et al.* 2008). The HWC concept is based on following characteristics:

- Separation of different household wastewater flows at their source: blackwater, greywater and rainwater.
- Collection of concentrated blackwater by means of vacuum technology, i.e. with vacuum toilets and vacuum pipe network.
- Utilisation of blackwater and additional biomass (e.g. organic waste or grease) in a district anaerobic digester for the generation of heat and electricity in a combined heat and power plant (CHP).
- Decentralised treatment of separated greywater from showers, sinks, etc.
- On-site management of rainwater to close local natural water cycles.

Figure 3 illustrates the basic flows of the HWC concept as it will be implemented in Jenfelder Au. The primary objectives of this first implementation of its kind on a

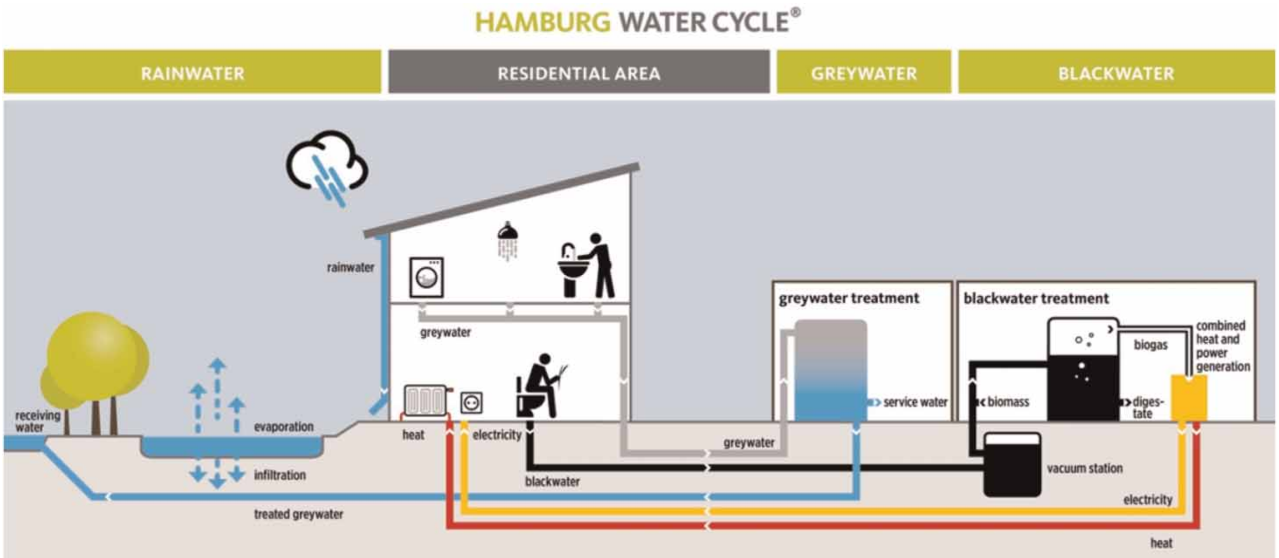

Figure 3 | HAMBURG WATER Cycle® – wastewater concept.

larger scale are to gain more experience in terms of the general aspects of the economic feasibility and the operation and maintenance as well as measuring actual data to compare to the predicted benefits. The main focus for the time being is on energy generation from the digested blackwater. Other benefits such as nutrient recovery or water recycling are going to be investigated for their basic feasibility but are not currently implemented in Jenfelder Au, since their economic rate of return under present conditions (e.g. current mineral fertiliser prices and water prices) is too low.

Energy from wastewater

When completed the HWC concept will demonstrate a minimisation of the need of non-renewable energy sources and will highlight the potential energy generation based on the separation of blackwater. In contrast to conventional wastewater treatment of mixed wastewater, aerobic and thus energy-intensive treatment of the blackwater is not required. Instead, anaerobic processes are used to treat the blackwater and to generate biogas. There will be one facility for the entire neighbourhood, which will be located in the Northern part of the area designated for commercial land use. In addition to the blackwater from the households of Jenfelder Au the plant will be fed with other organic waste such as organic household waste or contents of grease traps, e.g. from restaurants.

In a feasibility study regarding renewable energy supply HAMBURG WASSER showed that the whole heat demand of Jenfelder Au could be covered by locally generated biogas from blackwater and organic waste together with geothermal energy and solar heat. The heat supply of the 630 households (ca. 4.5 MWh per household and year) could be covered by three local, regenerative energy sources:

1. Biogas generated from the digestion of blackwater and organic waste. The treatment plant is designed to feed a CHP with a capacity of 100 kW_{el} and 135 kW_{th}. The generated heat is fed into a heat network serving the residents of Jenfelder Au and partially used to heat up the fermentation unit. The generated electricity is used to run heat pumps at affiliated decentralised geothermal plants. Energy from blackwater and organic waste is covering about 30% of the settlement's heat energy demand – this share can be further increased by an increased amount of digested high caloric waste, such as grease trap residues.
2. Solar heat can be generated on lean-to roofs of the settlement. About 10% of the settlement's heat energy demand can be covered by solar heat.

3. Geothermal energy can generate up to 40% of the settlement's heat energy demand. This share is limited by the available space for the drillings in the public greens and the geological conditions on site.

The peak load heat energy, which constitutes about 20% of the total heat demand, can be covered in various ways, e.g. using a gas boiler, a wood pellet boiler or a connection to a nearby district heating network. In addition a high share of the electricity demand of Jenfelder Au could be generated locally by solar panels on rooftops and surplus electricity from the CHP. This energy concept based on local regenerative energy sources and the HWC is a great step towards energy self-sufficient cities of the future.

In 2012 the FHH started a tender procedure for the heat supply procurement contract in the settlement based on the above presented integrated wastewater and energy concept of the HWC. The outcome of the tender will define the energy concept which is in any case based on the 'HWC biogas' from separated blackwater.

BENEFITS OF THE HWC CONCEPT

The realisation of the HWC in Jenfelder Au will be the largest working demonstration of a resource oriented sanitation concept within an urban environment in Europe. It will also be the largest installation of vacuum technology for separate collection of blackwater in a residential area, although this technology has been widely applied in cruise ships, aircrafts and trains. The approach makes it feasible to combine the infrastructure services of wastewater management and energy generation and to contribute to increased resource efficiency. However, even if the HWC concept offers synergy effects between different infrastructure services, several utilities will provide these services in Jenfelder Au: HAMBURG WASSER is in charge of the wastewater management, an energy contractor is in charge of providing the heat supply and Hamburger Stadtreinigung is in charge of the waste disposal. The technical linkages of the HWC concept must find their way to transcend traditional organisational boundaries to make use of the full potential of the integrated concept.

Although the main focus is on renewable energy generation, the HWC also provides for wise management of other resources. In particular, sustainable water use is an important aspect of the concept. Since the vacuum toilets only need about a quarter of the usual flush water volume (about 1–1.5 l per flush), this saves large amounts of valuable drinking water. In Jenfelder Au more than 12,500 m^3 drinking water will be saved annually that would be otherwise flushed down the toilets.

Since the greywater is separately collected and treated, appropriate technologies can be used ranging from high-tech treatment to allow water reuse for various purposes to low-tech natural treatment technologies such as planted soil filters and ponds resulting in water fit for irrigation purposes. Due to the relatively low pollution of the greywater these extensive treatment processes can be designed in such a way that land use is minimised and costs are saved. Since in Hamburg water reuse is not required due to the good availability of water resources, these aspects of the HWC are not incorporated in Jenfelder Au, but the aim is to implement greywater treatment processes with high flexibility and robustness. According to current planning status, a trickling filter will be used for greywater treatment.

Rainwater in Germany is often mixed with domestic and industrial wastewater, which can result in combined sewer overflows leading to the pollution of receiving water bodies. The HWC concept integrates separate and on-site management of rainwater and uses the rainwater runoff as landscape shaping elements, for example in rainwater cascades or in the semi-natural retention pond.

Other resources that the HWC aims to address are nutrients that can be found in domestic wastewater and that can be used as plant fertilisers. The macronutrients nitrogen and phosphorus are of particular interest due to their energy-intensive production (nitrogen) and their limited availability in terms of finiteness, natural pollution and skewed global distribution (phosphorus). Both nutrients can be found in wastewater and are particularly present in urine or blackwater (Meinzinger & Oldenburg 2009). The separate collection and low dilution of these flows is therefore very beneficial for the recovery of nutrients. Beside the direct use of these separated wastewater flows in agriculture after sufficient treatment to reduce pathogen contents, there are currently several processes under consideration to extract the nutrients and make them available in a more concentrated form (Balmer 2004; Maurer *et al.* 2006; Alp 2010). However, these are pilot investigations and still uneconomical. Yet, several authors suggest that future prices for mineral fertiliser may rise significantly and therefore options for nutrient recovery such as provided by the HWC will become increasingly important.

Overall, the HWC will contribute significantly to making the area Jenfelder Au a low carbon neighbourhood. In contrast to conventional wastewater collection with maximum concentrations of about 900 mgCOD/l the collection of blackwater in vacuum toilets yields about 10 times higher concentrations of organic matter of approximately 10,000 mgCOD/l. This is a prerequisite for the efficient anaerobic treatment of the wastewater.

CONCLUSION

The HWC is an innovative wastewater concept based on source separation of domestic wastewater flows and their efficient treatment and use. The concept contributes significantly to the sustainable profile of Jenfelder Au by combining urban water and waste infrastructures with local energy production. Concentrated blackwater is anaerobically digested, thereby generating energy, whereas greywater and rainwater are separately collected, treated according to their specific characteristics, and returned to the local natural water cycle. The use of vacuum toilets instead of conventional gravity-driven toilets will save annually more than 12,500 m^3 of water. Recovery of nutrients and water recycling are further options for improved resource management.

The concept will be implemented for the first time in Jenfelder Au in Hamburg, Germany. Jenfelder Au is an outstanding example of sustainable urban planning and will provide affordable housing for more than 600 households. After the first construction phases finishes in 2013, the first inhabitants are expected to populate the new quarter in 2014. So far the new concept gets positive feedback from current property developers, who are in charge to construct the separate blackwater and greywater drainage systems within the houses. The future benefits of the HWC concept are expected to make up for the higher investment costs during the construction. The community in the neighbourhood particularly appreciates the well-balanced functional and spatial mix set in West 8's urban planning concept and the people show interest in the new technologies used in the HWC such as the vacuum toilets.

HAMBURG WASSER is the first German water and wastewater company that is integrating a decentralised, source separating concept into its operational structures. The projection of investment costs for this new infrastructure concept indicates higher costs than for a conventional wastewater disposal concept. These additional costs are covered by HAMBURG WASSER and by external funds such as the EU LIFE+ programme. LIFE is the EU's financial instrument supporting environmental and nature conservation pilot or demonstration projects with European added value (European Commission 2013). Operating a decentralised system such as HWC will require new operating structures to be implemented within HAMBURG WASSER. However, the biggest challenge is the implementation of a new technology for wastewater transport and its technical and legal implications; so far HAMBURG WASSER operates gravity flow sewers as well as pressure sewers. The vacuum technology for Jenfelder Au is an innovation with relevance for the networks operation department as well as for the planning department and the legal department. Lacking experience with the vacuum technology so far, HAMBURG WASSER was dependent on external facilities as reference for the planning and the future operation. Several technical details of the vacuum network in Jenfelder Au are tailor-made in-house developments, which were subject to extensive planning and testing (Skambraks *et al.* 2012). Furthermore, the legal department introduced the new technology for wastewater transport to the current legal framework of HAMBURG WASSER by an amendment to the wastewater law of Hamburg (HmbAbwG). This amendment process started early in 2010 and is still ongoing (Skambraks *et al.* 2012).

Despite the additional costs and the special challenges of the vacuum technology, the implementation of the HWC in the settlement will also generate benefits. Residents will save on their water bills due to reduced water consumption. The provision of energy from decentralised sources allows a decreased dependency on external energy suppliers and their pricing policies. Other benefits such as water recycling or nutrient recovery will not yet be financially exploited in this first implementation in Jenfelder Au, but present promising options particularly from a global perspective as a response to diminishing and deteriorating natural resources such as phosphate rock (Cordell *et al.* 2009).

The implementation of the HWC in Jenfelder Au will present a valuable opportunity for more detailed research in the field of source separation of wastewater and improved resource efficiency. HAMBURG WASSER intends to carry out more research to improve robustness and efficiency of blackwater and greywater treatment. Furthermore, challenges such as the elimination of pharmaceutical residues from wastewater or the further use of the digester effluent as fertiliser or soil conditioner can also be addressed by the HWC and will be further investigated in an extensive research project funded by the German Federal Ministry of Education and Research (BMBF). First results of these supporting research activities are expected for the year 2013.

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