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Areal View Haulander Weg Area (Source: IBA Hamburg – Google Earth)

THE EFFECTS OF URBAN WATER MANAGEMENT OPTIONS ON THE WATER BALANCE AND ENERGY USE IN A NEW URBAN DEVELOPMENT (HAULANDER WEG)

A FIELD RESEARCH IN HAMBURG, GERMANY

Roelf Steendam

MSc Thesis (MWI 09.02)
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Master of Science Thesis
by
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Abstract

Climate change, population growth and urbanisation are the major global change pressures having a negative impact on the sustainability of the natural systems. Water is becoming scarce in many parts of the world, fossil fuels (coal, oil and gas) are nearing depletion and an increased emission of greenhouse gasses are just a few examples to deal with these days. To protect the environment it is therefore necessary to use resources in a much more sustainable way. In this perspective, many cities around the world are becoming aware that the conventional approach to the provision of services like water supply, sanitation and drainage services, does not comply with these aspirations of ecological sustainable development. It is recognised that the different aspects of urban water systems should be viewed in relation to each other, which requires the adoption of an integrated approach to urban water system planning, provision, and management, which can be achieved only by a paradigm shift. This means operating in terms of cycles of source, usage, collection and treatment, recycling, resourcing, and reusing as much as possible.

In view of this context the SWITCH project proposed a study to investigate the effects of urban water management options on the water balance and on the energy use in a new development located within the city of Hamburg, one of the SWITCH demonstration cities, on the River Island Wilhemsburg.

A daily water balance model (Aquacycle) has been used to simulate the urban water cycle (water supply, wastewater disposal and stormwater drainage). A centralised approach (the baseline strategy) has been compared with a number of decentralised strategies applied on three different scales with respect to the water balance and energy consumption. These decentralised strategies imply the use and reuse of rainwater, wastewater and stormwater and also the implementation of water saving devices within the households, altogether with the aim to reduce on imported water as well as on energy consumption.

Keywords: Integrated Urban Water Management, Decentralised water and energy systems, Reclaimed water, Rainwater and stormwater harvesting, Dual plumbing systems, Aquacycle model, Water balance, Energy consumption

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List of abbreviations

BOD	Biochemical Oxygen Demand
BSU	Behörde für Stadtentwicklung und Umwelt, Hamburg
CD-ROM	Compact Disk - Read Only Memory
CHP	Combined Heat and Power
COD	Chemical Oxygen Demand
DE	Decentralised Energy
DeSaH	"Decentralised Sanitation and Reuse"
DST	Decision Support Tool
EGSB	Expanded Granular Sludge Blanket
EU	European Union
GC	Global Change
GSL	Gas, Sludge, Liquid
HSF	Horizontal Subsurface Flow
HWC	Hamburg Water Cycle
IBA	"International Building Exhibition", Hamburg
IUWM	Integrated Urban Water Management
IWU	Indoor Water Usage
HCU	Harbour City University
KWR	KIWA Water Research
MF	Micro Filtration
MS	Micro Soft
SUDS	Sustainable Urban Drainage System
TUHH	Technical University Hamburg-Harburg
UASB	Upflow Anaerobic Sludge Blanket
UK	United Kingdom
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNIDO	United Nations Industrial Development Organisation
UV	Ultra Violet
UWM	Urban Water Management
UWOT	Urban Water Optioneering Tool
UWS	Urban Water System
VFS	Vertical Flow system
WaND	Water Cycle Management for New Developments Project
WFD	Water Framework Directive
WUR	Wageningen University and Research Centre

1 Introduction

1.1 Background

With the demands from external water sources for many cities nearing supply capacity, there is an increasing interest in making more use of the total water resources available to urban areas. The emergent paradigm of integrated urban water management promotes the consideration of water supply, stormwater, and wastewater concurrently as components of the total urban water cycle. Quantifying the water balance of the whole urban water cycle is a way of moving towards this goal by providing greater understanding of various inputs of water into, and outputs of water from, an urban catchment (Mitchell et al., 2003).

Additionally, cities around the world face the challenge of managing their impact on the natural environment and the stresses on aging infrastructure. As a result, the sustainable cities concept is an international movement, with the major objective of making cities greener and healthier places for their inhabitants, with sustainability involving economic viability, social stability, and wise use of resources while protecting and nourishing the natural environment (Leitmann, 1999).

An important component of any urban area, be it a city or regional centre, is the water system, providing water supply, sanitation, and drainage services to its inhabitants. However, in many cases, the conventional approach to the provision of these services does not comply with the more recent aspirations of ecologically sustainable development. There is great interest in approaches to providing water systems that lower the impact on the natural environment and control expenses. In order to reorientate urban areas towards sustainability, it is recognised that the different aspects of urban water systems should be viewed in relation to each other, which requires the adoption of an integrated approach to urban water system planning, provision, and management. Integrated Urban Water Management (IUWM) takes a comprehensive approach to urban water services, viewing water supply, drainage, and sanitation as components of an integrated physical system, and recognises that the physical system sits within an organisational framework and a broader natural landscape (Mitchell, 2006).

Noticeable nowadays is an increasing need for sustainability and protection of the environment regarding urban water management; a necessity to re-evaluate the traditional approach in seeking ways to reduce the environmental impacts on water systems. This can be achieved only by a paradigm shift from fragmented towards integrated urban water management. This means operating in terms of cycles of source, usage, collection and treatment, recycling, resourcing, and reusing as much as possible (Karka et al., 2007).

With regard to sustainable sanitation systems it means closing of the water and nutrients cycles, taking into account that the main task of sanitation is to assure highest hygienic standards in a cost-effective, environmental sustainable way,

saving both water and energy and keeping soils fertile. This can be achieved by separating different qualities from human settlements: blackwater (toilet wastewater), greywater (washing, cleaning), stormwater runoff, biodegradable and non-biodegradable waste. Such sanitation reduces the freshwater consumption considerably and produces fertilizer for agriculture in stead of waste (Otterwasser, 2009).

On specific component to focus on within this integrated physical system is the use of energy, or better the reduction of it, especially in eras like now with strongly increased energy prices and with the depletion of fossil fuels. Water and energy are two highly interconnected sectors: energy is needed throughout the water system, from supplying (pressurising) water to its various users, including urban people, to collecting and treating wastewater. On the other hand, water is essential to producing energy, from hydropower to water cooling in power stations. In the context of a growing world population, leading to increasing demands and competition for water and energy, it is time to integrate the management of these resources (UNIDO, nd). As stated in the SWITCH (2008) water supply and wastewater management consume energy to the equivalent of about 5-10% of total domestic electricity consumption.

In another -just recently published- report (Kenway et al., 2008) it has been approximated that in some major cities of Australia and New Zealand the total energy use by water utilities is about 0.2% of the total urban energy consumption. The energy use for residential water heating represented 1.3% of the energy use in the total urban system. Residential hot water heating uses on average 6.5 times the energy that is used to deliver urban water services (this ratio is ranging from 4.7 in one city to 11.2 in another city).

The water sector can therefore not be ignored in initiatives to reduce overall energy consumption, such as the EU ambition to reduce energy consumption by 20% in 2020 as compared to its use in 1990 or the ambition of some cities to become ‘carbon neutral’.

According to Morrison et al (2001), the objectives of developing an urban water system are: (1) to preserve the quality of the raw water resources, (2) to allow for sustainable use of the raw water sources, (3) to supply the general population with safe drinking water in sufficient quantity, (4) to supply the general population with adequate sanitation and (5) to reduce the use of limited resources and energy to within the levels of sustainability.

In this perspective a proposed field research has been formulated within the SWITCH Demonstration City Hamburg, a greenfield area at the Haulander Weg, which has to be developed between 2008 and 2013 into the biggest ecological demonstration settlement with 500 to 700 living units and described as “a new benchmark for eco-housing”. Different partners are involved like HCU-The Harbour City University Hamburg, Water Utilities Hamburg, Technical University Hamburg-Harburg (TUHH), BSU Department Hamburg, all in cooperation with the International Building Exhibition (IBA_HAMBURG).

1.2 Problem identification

One of the demonstration projects within the SWITCH Project is the river island Wilhelmsburg -on which The Haulander Weg area is located- in Hamburg, Germany. Hamburg has an increasing population and is one of the fastest growing cities in Germany. An expected population growth of 60.000 by 2020 and the expanding harbour evoke a need for urban development. Hamburg has a central water supply system with several wells that tap large aquifers. Since the mid-1980s the average water consumption per capita has been reduced. Despite increasing population, there is no shortage expected in the future. Hamburg has a sewerage system that serves over 99% of all inhabitants. The sewerage system is connected to a central sewage treatment plant which ensures a progressive multi stage treatment of waste water (SWITCH, 2007; cited in Reid, 2008). The main area of the river island of Wilhelmsburg comprises of a future urban development of a range of 20.000 to 100.000 lot residential project that seeks to achieve the highest possible level of sustainability for urban development. The area also will be the scene of the International Building Exhibition (IBA) 2013 and the International Horticultural Exhibition (IGS) 2013. This area has to cope with several water management problems, such as flood risks caused by the river Elbe and the North Sea (due to its high ground water tables, the area is protected and controlled by a system of dikes and the surplus of water is constantly being pumped out), stormwater management (fluvial flooding, caused by stormwater and the coordination of the ditch-network), pollution of the surface waters caused by industries, agriculture and stormwater, limited additional capacity in the existing sewerage system and the high energy use for pumping, heating, transporting and discharging the water. Currently Wilhelmsburg is unsustainable regarding the urban water management. Therefore the overall ideal vision is to achieve a sustainable self-sufficient and balanced water system (Reid, 2008).

From the overall observation described above regarding the entire Island a step down can be made to focus on a more specific problem of integrated urban water management; how do different water management options influence the overall water balance and the correlated energy consumption? That is what will be projected on this relatively small part of the Island, the earlier mentioned new development Haulander Weg. Its location on the Island can be found in Figure 1.1.

Figure 1.1 **Study area: Haulander Weg, part of River Island Wilhelmsburg, Hamburg in Germany (Source: HCU)**

The Haulander Weg site is approximately 0.2 km^2 (20ha), or circa 0.5% of the total area of River Island Wilhelmsburg which measures about 40 km^2.

So far the intention of the International Building Exhibition (IBA_HAMBURG) is to divide the greenfield area into six sites or clusters and these will be developed one after the other and will consist of:

1. Double houses - DH (two homes under one roof)
2. Row houses - RH
3. Quatro - MFH (More Family Houses)
4. Mansions (block of flats, apartment houses)
5. Live & Work
6. Small Industries and Services

The final design phase of "Haulander Weg" will most probably start somewhere during the first half of 2009.

1.3 General objective

The general objective of this study is to investigate the effects of urban water management options on the water balance and on the energy use in the new development called Haulander Weg in Hamburg.

1.4 Specific objective

More particularly the study was carried out with the intention to meet the following specific objectives:

- To describe and model the water system of Haulander Weg - Hamburg with respect to water balance and energy use.
- To define different technological options for urban water management and to evaluate the options based on water and energy aspects, as well as other sustainability criteria.

2 Literature review

2.1 Urban water management: conventional versus integrated approach

According to Mitchell (2004) conventional urban water management considers water supply, wastewater and stormwater as separate entities, planning, delivering and operating these services with little reference to one another. Current urban water systems harvest large volumes of water from remote catchments and groundwater sources, deliver drinking quality water to all urban users and subsequently collect generated wastewater. This wastewater is removed, taken to treatment plants usually located on the fringe of the city or town, then discharged to the surrounding environment. Only 9% of this wastewater is currently reused (Radcliff, 2003; cited in Mitchell, 2004). Large volumes of stormwater are also generated within urban areas due to the increased imperviousness of urban catchments. The majority of this stormwater flows out of the urban area, with little management of its quality and even less of it being used. As a result, the adverse impact of conventional urban water management on the water balance of these areas is substantial (Mitchell et al, 1997; cited in Mitchell, 2004).

In comparison, Integrated Urban Water Management takes a comprehensive approach to urban water services, viewing water supply, stormwater and wastewater as components of an integrated physical system and recognises that the physical system sits within an organisational framework and a broader natural landscape (Mitchell, 2004).

In addition, there are a broad range of tools which are employed within Integrated Urban Water Management, including, but not limited to water

conservation and efficiency; water sensitive planning and design, including urban layout and landscaping; utilisation of non-conventional water sources including roof runoff, stormwater, greywater and wastewater; the application of fit-for-purpose principles; stormwater and wastewater source control and pollution prevention; stormwater flow and quality management; the use of mixtures of soft (ecological) and hard (infrastructure) technologies; and non-structural tools such as education, pricing incentives, regulations and restriction regimes.

Integrated Urban Water Management recognises that the whole urban region, down to the site scale, needs to be considered, as urban water systems are complex and inter-related. Changes to a system will have downstream or upstream impacts that will affect cost, sustainability or opportunities. Therefore, proposed changes to a particular aspect of the urban water system must include a comprehensive view of the other items and consider the influence on them.

The principles of Integrated Urban Water Management can be summarised as:

1. consider all parts of the water cycle, natural and constructed, surface and sub-surface, recognising them as an integrated system
2. consider all requirements for water, both anthropogenic and ecological
3. consider the local context, accounting for environmental, social, cultural and economic perspectives
4. include all stakeholders in the process
5. strive for sustainability, balancing environmental, social and economic needs in the short, medium and long term

2.2 Integrated urban water management and the SWITCH approach

The approach to (urban) water management has developed over time, with the Dublin Statement and the EU Water Framework Directive (WFD) as important milestones. SWITCH wants to build on ideas from the ‘Belagio Statement’ and the 3-Step Strategic Approach (developed by UNEP; see Figure 2.1), but wants to add a thorough and scientific ‘sustainable assessment’ of new approaches and new technologies. By doing this, the SWITCH approach will be developed. Models and Decision Support Systems will be used to evaluate (technological) innovations for IUWM under different future scenarios (SWITCH, 2006a).

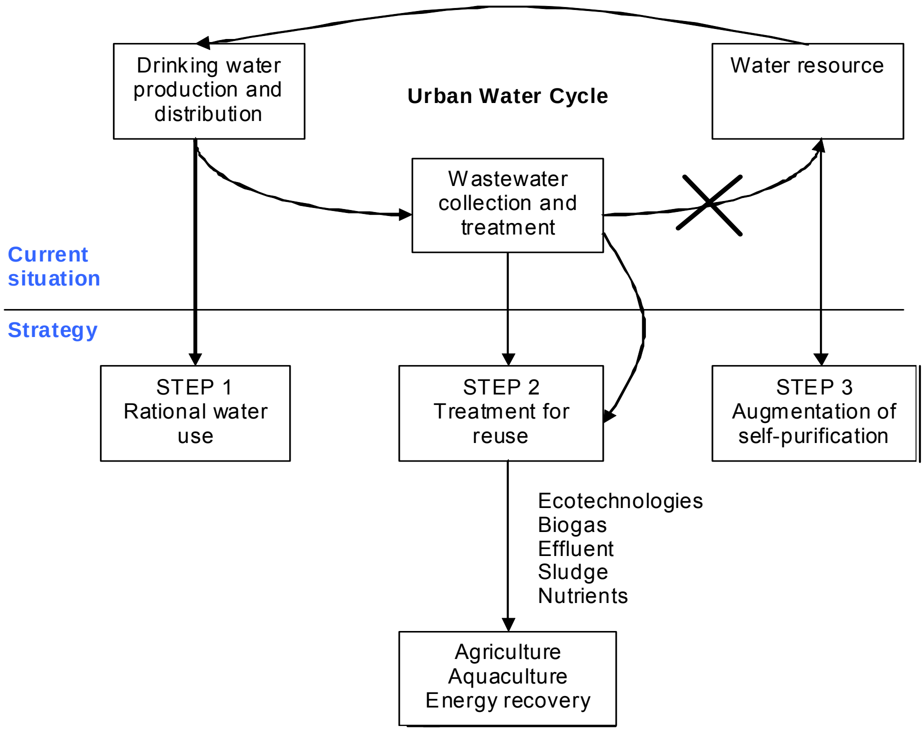

Figure 2.1 Application of the 3-Step Strategic Approach to the Urban Water Cycle (Nhapi and Gijzen, 2005; cited in SWITCH, 2008)

The SWITCH project wants to develop a new approach to Integrated Urban Water Management. This approach will have to result in new ways of planning the urban water system for the future, to address adjustments needed and to address global change (GC) pressures. The (integrated) planning for a sustainable urban water management (UWM) should be built on a foundation of scientifically driven, demand led approach. All this aimed at increasing the sustainability of the urban water system (UWS) and reducing the risks (SWITCH, 2006a).

As a consequent, the approach to urban water management should be done in a more holistic way. This new approach and shifting paradigm emphasis on demand and supply side management, utilization of non traditional water resources and the concept of fit-for-purposes and decentralized systems (Mitchell, 2004). The shifting paradigm has changed the 'old' one, from water disposal and treatment to conservation, recycling and resources (Vlachos and Braga, 2001). Through a decentralized system, water supply, treatment, sanitation, and runoff management systems would be highly integrated. This principle deem to collect, treat and reuse or dispose of wastewater at or near its point of generation and takes advantage of local hydrologic resources (e.g. urban rainwater/storm water harvesting and aquifer storage recovery systems) and uses all manner of wastewater treatment and reclamation/reuse systems. A combination of end-use efficiency, system efficiency, storm water harvesting, storage innovations, and reuse strategies would reduce water demand to levels below current demand. And problems raised by centralization of wastewater services (such as high investment and maintenance cost, overbuilt and resulting debt burdens for citizens, and affecting the hydrology of water shed) is resolved by this 'new' system (Pinkham, 1999). The Table 2.1 below shows some characteristics of the old and emerging paradigms.

Table 2.1 The old and emerging paradigms of urban water systems (adopted from Pinkham, 1999)

The Old Paradigm	The Emerging Paradigm
Human waste is a nuisance It should be disposed of after treatment.	**Human waste is a resource** It should be captured and processed effectively, used to nourish land and crops.
Stormwater is a nuisance Convey stormwater away from urban area as rapidly as possible.	**Stormwater is a resource** Harvest stormwater as a water supply, and infiltrate or retain it to support aquifers, waterways and vegetation.
Demand is a matter of quantity Amount of water required or produced by different end-users is the only parameter relevant to infrastructure choices. Treat all supply side water to potable quality and collect all wastewater for treatment.	**Demand is multi-faceted** Infrastructure choice should match the varying characteristics of water required or produced for different end-users in terms of quantity, quality, level of reliability, etc.
One use (throughput) Water follows one-way path from supply, to a single use, to treatment and disposal to the environment.	**Reuse and reclamation** Water can be used multiple times, by cascading from higher to lower quality needs, and reclamation treatment for return to the supply side of infrastructure.
Grey infrastructure Infrastructure is made of concrete, metal or plastic.	**Green infrastructure** Infrastructure includes not only pipes and treatment plants, made of concrete, metal and plastic, but also soils and vegetation.
Bigger/centralised Bigger/centralised is better for collection system and treatment plants.	**Small/decentralised** Small/decentralized is possible, often desirable for collection system and treatment plants.
Limit complexity and employ standard solutions Small number of technologies by urban water professionals defines water infrastructure.	**Allow diverse solutions** Decision makers are multidisciplinary. Allow new management strategies and technologies.
Integration by incident Water supply, wastewater and stormwater may be managed by the same agency as matter of historical happenstance. Physically, however, three systems are separated.	**Physical and institutional integration by design** Linkages must be made between water supply, wastewater and stormwater, which requires highly coordinated management.
Collaboration=public relations Approach other agencies and public when approval or pre-chosen solution is required.	**Collaboration=engagement** Enlist other agencies and public in search for effective solutions.

According to the SWITCH (2008), the current state of the SWITCH approach to UWM is aimed at solving the challenge of water management in the city of the future. This approach consists of the following elements:

- A description of the major global change (GC) pressures that affect the state of urban water systems
- An overview of the strategic issues that urban managers are confronted with now and in the next decades; and the concrete strategic questions that need an answer
- A description of the potential of strategic planning for urban water management under changing conditions and uncertainty
- A strategic planning approach based on a Learning Alliance (LA) process and directed at creative visioning, scenario identification and strategy development
- A method to implement strategic urban water management plans via the government and non-government sectors
- Recommendations to use a monitoring system of sustainability indicators (SIs) to measure the state of the urban water system, the results of which are to be used in a next cycle of strategic planning
- Recommendations to use a decision support tool (SWITCH to evaluate the effect of various strategies and options on overall system sustainability, prior to the implementation of these strategies and options
- Recommendations on the application of a number of innovative (technological) options in future urban water management schemes

Especially the last two above mentioned elements are associated with this research and will be (partly) addressed within the study theme in relation to water balance and energy use.

2.3 Modeling the urban water cycle with Aquacycle

2.3.1 The urban water cycle

The modeling programme Aquacycle can be applied to simulate the urban water cycle. It can be utilized to assess the relative merits of a range of water servicing alternatives for urban developments during the initial planning and preliminary design phases. The system boundary of the model is conceptualised as shown below in Figure 2.2. Within this hydrological system the water balance equation is:

Input (mm/year) = Output (mm/year)

Precipitation + Imported Water = Evapo[transpi]ration + Stormwater + Wastew.

Note: “Stormwater” is including Seepage

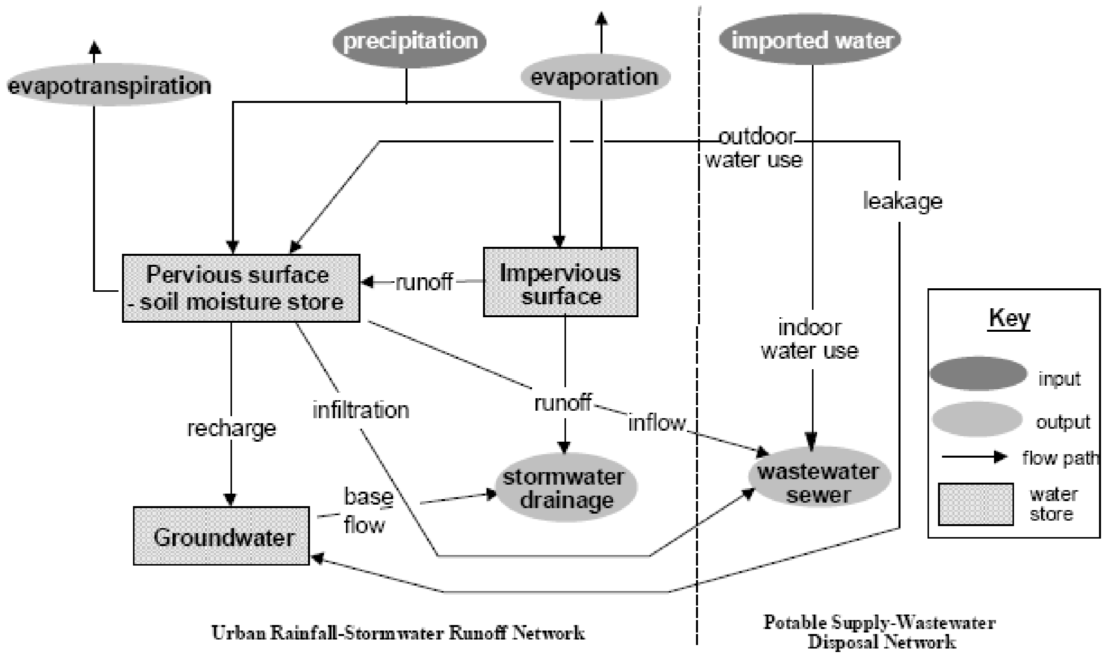

Figure 2.2 Urban water system as presented by Aquacycle

According to Karka et al (2007) there are a large number of models available for describing the urban water system. However, in the past, the interactions among the potable water supply, wastewater discharge and the rainfall-stormwater runoff networks were rarely considered within the same modeling framework, which could provide a more holistic view of the urban water system. Aquacycle, a quasi-distributed daily time step model, focuses on urban water balance aspects, estimating the volume of demand water and available stormwater and wastewater in different spatial scales. Aquacycle operates on a daily time step. It has been developed with the objective to simulate the urban water cycle as an integrated system and can be a powerful tool investigating the use of locally generated stormwater and wastewater as a substitute for imported (fresh)water in order to improve efficiency in water use. Three groups of input data are required by Aquacycle: indoor water usage, climate, and physical characteristic data (Mitchell et al, 2001).

2.3.2 Spatial scales: unit block, cluster and catchment

Aquacycle has been developed by Mitchell et al (2001) and operates on three nested spatial scales, namely (**1**) unit block, (**2**) cluster and (**3**) catchment scale, which makes it able to model a wide variety of schemes (see Figure 2.3).

The **unit block (ubl)** represents a single household, industrial site, institution, or commercial operation, and represents the smallest scale at which water supply and disposal operations can be managed. Modeling the unit block scale allows the cumulative effect of individuals' actions (i.e. stormwater and wastewater use at unit block scale) on the whole catchment to be determined. Therefore, it is the appropriate fundamental spatial scale for the modeling purpose.

A **cluster (clu)** represents a group of uniform unit blocks that form a local neighbourhood or suburb and the associated roads and public open space. The cluster can be used within the model to represent the spatial scale at which community supply and disposal operations may be managed.

A **catchment (ctm)** represents a group of clusters; these clusters may relate to the suburbs in the catchment or areas of single land use. Using catchments as a water resource planning unit has been promoted in the last few years, although, in urban areas, the provision of constructed water supply, stormwater drainage, and wastewater disposal infrastructure has led to the blurring of natural catchment boundaries. Even so, catchments are an appropriate planning unit for urban water resources.

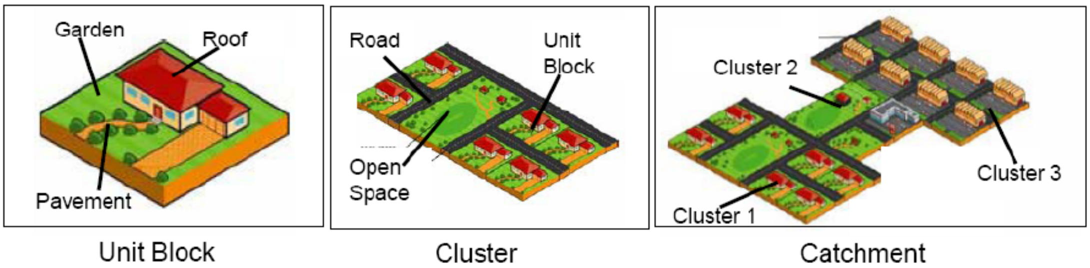

Figure 2.3 Spatial scales used in Aquacycle (Karka et al, 2007)

As has been further described by Karka et al (2007) water flows through different processes (stores) that are part of the urban water cycle. The urban water cycle is approached considering all water pathways in two main subsystems; the rain-fall runoff (i.e. the urban drainage system), and the water supply and wastewater system. In both subsystems the water balance is estimated taking also into account the interactions between them. The model receives input both from precipitation and imported water, as well as indoor water use requirements and evapotranspiration data. In Aquacycle, surfaces are divided into two categories: pervious and impervious. Impervious surfaces (roofs, road and paved areas) are represented as single stores that overflow when full. Pervious areas are divided into areas which produce runoff during a rainfall event and those that do not. Water evaporation from both pervious and impervious surfaces is calculated according to daily evaporation values. The amount of water imported into an area is the sum of indoor water use, irrigation, and leakage. The total wastewater discharged from the catchment is the sum of indoor use, infiltration and inflow from the stormwater drainage system.
The Aquacylce package also models a range of technologies which have the potential to provide alternative individual and community scale water service systems. At the unit block scale, options for stormwater and wastewater exploitation include the installation of rainwater tanks, on-site wastewater treatment units and sub-surface irrigation with greywater. At the cluster scale, methods include stormwater storage, wastewater treatment and storage and aquifer recharge and recovery. Finally, centralised options applicable at the catchment scale can also be examined, including wastewater reuse and strormwater storage in order to meet the needs of a particular or several clusters.

2.3.3 Limitations of Aquacycle

The software has been developed to assess the total quantity of water moving through the urban water cycle, and therefore, everything is expressed in daily time steps. In addition, according to SWITCH (2006b), there is no flow routing option within the model and as such is incapable of addressing any aspect of the flooding problems within a study area. Also, most of the critical urban hydrological processes such as wastewater overflows, inflow/infiltration, and exfiltration are not incorporated into the present version of Aquacycle. The lack of capabilities to address such important aspects is a major limitation of this software. In summary, this conceptual urban water balance model (Aquacycle) has been developed to provide a picture of the available water quantity values within an urban area and for any further analysis this software would need to be substantially enhanced.

Another limitation is the restricted approach on the reuse options for greywater, wastewater and stormwater as prescribed by the model and as mentioned in Table 3.3. For example: treated wastewater and stormwater can only be used for toilet flushing and irrigation and for treated greywater there is just one reuse option, namely unit block irrigation.

It should be noted that within the SWITCH project a model called SWITCH City Water is at the moment under construction and is expected to become available later on this year (2009). It is basically an upgrade of the Aquacycle model, with more possibilities and therefore with more potential.

2.5 Previous study on Haulander Weg (TUHH)

November last year Mr. Benjamin Görges (TUHH) completed an MSc research on energetic aspects of different treatment concepts within the frame of Haulander Weg. It focuses on the usage of water, the energy consumption and the project costs of the proposed technologies as has been described and calculated in four different concepts (decentralised) and a baseline strategy (centralised). E.g. by applying water saving technologies as well by reusing greywater and blackwater for respectively heat regeneration (heat exchanger and heat pump) and heat production (UASB - biogas production). The technologies just mentioned, like water saving technologies, USAB reactor and heat pump, will be described in more detail in respectively sub-subsection 2.8.7 and 2.9.5.

The main conclusions can be summarized as follow, where a distinction is drawn between ‘the double houses’ and ‘the row houses’ concepts:

Double houses
For double houses the most favourable variation is a combination of the reduction of hot water usage by means of water saving appliances together with heat regeneration from greywater by means of heat exchangers (see Figure 2.4). It is very favourable to separate the colder greywater (≤ 30 °C) from the warmer greywater (> 30 °C) by installing a temperature sensor (and regulated by a control system engineering device) in the greywater storage tank. In this way the average temperature in the storage tank can be kept relatively high so that it can

be used to heat water that will be used e.g. for the natural gas heating system within the house. As a result, less natural gas will be needed.
Especially for the treatment of blackwater from the double houses, it is very beneficial to apply vacuum toilets: just one system for two households. The solids from the greywater, being separated from the liquid in the greywater storage tank, can also be collected by this vacuum system. Subsequently it can be transported by truck to the nearby treatment plant, with relatively low costs, since it is located only about 8 km away from the Haulander Weg area. The relatively short distance to the treatment plant also makes it less profitable to construct a decentralised biogas unit. That is also the reason why for the row houses concept, further described below, the construction of such a plant will not be reviewed; instead the construction of solar systems for energy and heat generation will be taken into consideration.

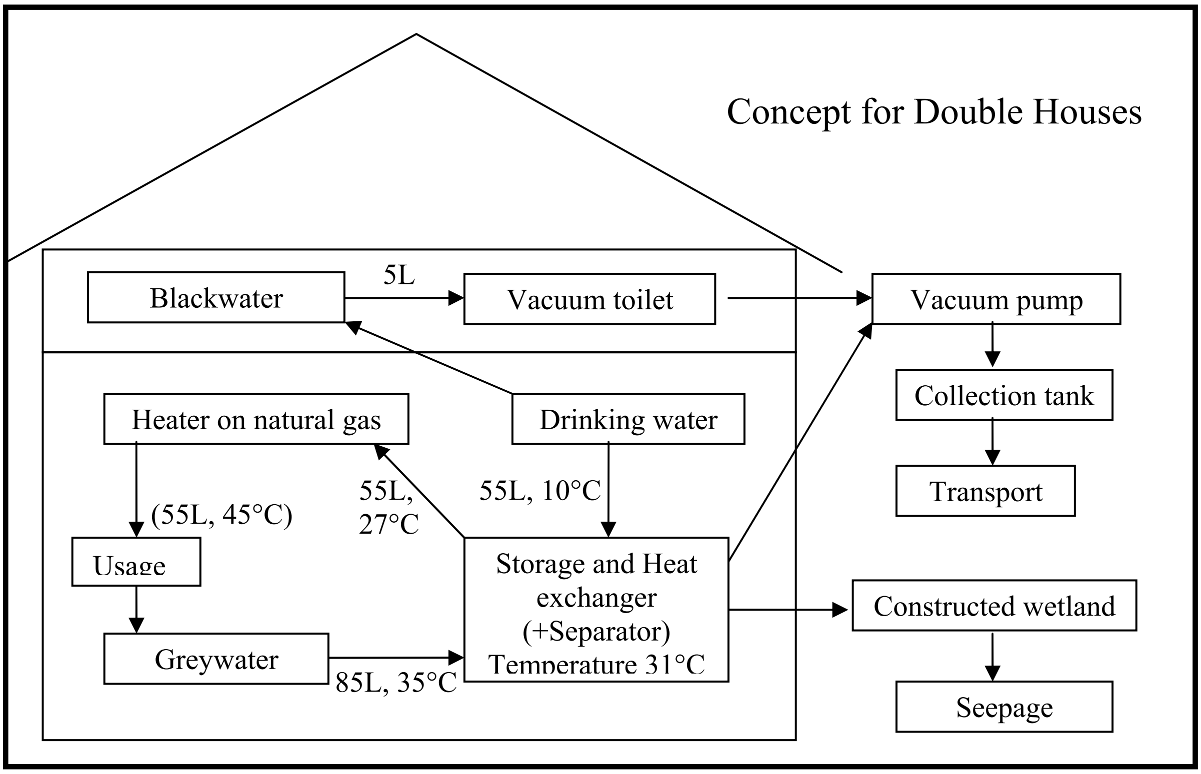

Figure 2.4 Water flow and temperature for double houses concept (Volumes in L/p/d) (Adopted from Görges, 2008)

Row houses
Like for the double houses the energy consumption for water heating can be reduced by the combination of two concepts: by means of water saving appliances and at the same time by biological pre-treatment of the warm greywater (e.g. with an UASB reactor) followed by the regeneration of the heat by the combination of a heat exchanger and heat pump (see Figure 2.5). It has two advantages: it will reduce the risk of clogging the tubes in the heat exchanger and -very important- the cold water will be heated by the heat pump up to 60 °C which will reduce the risk of legionella formation.
The quality of the water leaving the UASB reactor is not good enough to be discharged directly into surface water. For additional treatment it can be discharged in a (vertical) constructed wetland. It will be beneficial to discharge

the colder greywater (≤ 30 °C) directly into the constructed wetland, while the warmer greywater (> 30 °C) will be led through respectively the UASB reactor and heat pump. In this way the capacity of the heat regeneration devices can be reduced consequently.

The treatment of the blackwater in the row houses will be done through a blackwater cycle. Although this will imply extra pipes inside the houses for the reuse of treated blackwater (to flush toilets), on the other hand it means a pipe system as would be required for a vacuum system can be abandoned.

With the application of a heat pump and a blackwater cycle the energy need for heating has substantially reduced, though the electrical energy consumption - compared with the baseline strategy- has strongly increased. The construction of a solar system can compensate in the extra need of electrical energy and can make the installation of a central heating system on natural gas unnecessary.

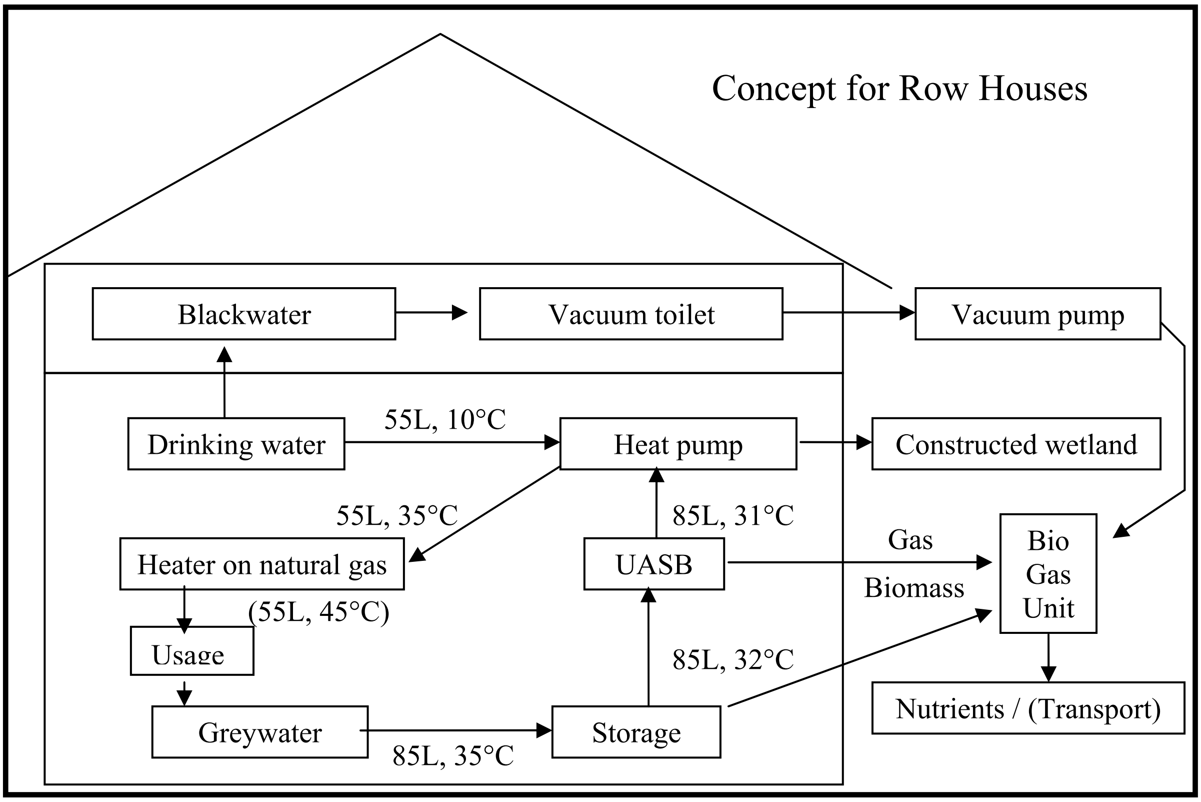

Figure 2.5 Water flow and temperature for row houses concept (Volumes in L/p/d) (Adapted from Görges, 2008)

Since the data applied in the research from Görges (2008) is from recent date, it has been used for this research as well.

Note: This section and the next section have been included to show what kind of research has been done recently within the Haulander Weg area and most probably in the future in Hamburg-Jenfeld.

2.6 Pilot Project Hamburg-Jenfeld

Beside "Haulander Weg" another new development will be constructed in Hamburg-Jenfeld under the auspices of HAMBURG WASSER and which will act as a Pilot Project. Hamburg Water Cycle® is a new town drainage concept build on basic known components, which can later on also be applied at a bigger town scale. It will focus on the development of resource saving technologies, and it is to demonstrate that an energy independent wastewater treatment system and at the same time the recovery of nutrients like phosphorous is also possible within the boundaries of a city (Schonlau et al., 2008).

The area of the pilot project measures about twice the size of the Haulander Weg study area. On some 35 ha of land of a former barracks in Hamburg-Jenfeld, 700 accommodation units will be constructed, i.e. detached houses, semi-detached houses, and apartment blocks. This is the first time that the Hamburg Water Cycle® (HWC) will be implemented in an urban environment. The HWC system is based on the separate treatment of local material flows. Thus domestic wastewaters are separated at source into black water (toilet water) and greywater (other domestic sewage). Grey water is treated in a decentralized plant with relatively little effort and then discharged locally into the receiving waters. Black water is enriched with additional biomass and then fermented. Stormwater is discharged via open flumes (cascades) into a pond that serves as a stormwater retention tank, and from there into the receiving waters.

In contrast with this study is that in the pilot project of Jenfeld potential sources like rainwater, greywater and stormwater won't be further utilised within the households: their greywater will either be used to restore the natural water level during dry periods or be applied as servicewater for planned small industries and services. The blackwater in this pilot project -enriched with additional biomass- will be fermented and subsequently generating biogas. The biogas will be exploited in a combined heat and power (CHP) system (co-generation) for the production of energy and heat (see sub-subsection 2.9.4). In this way the wastewater treatment system can be energy independent. Later on also the recovery of the nutrients nitrogen and phosphorus will be accomplished.

2.7 Classification of different (waste)water flows in households

For better understanding it is worth to stipulate the various components of water within the urban water cycle. They are introduced explicitly to allow for the conceptualisation of interactions between these components. An overview is shown below in Figure 2.6. In Figure 2.7 the three main wastewater flows in a household are shown.

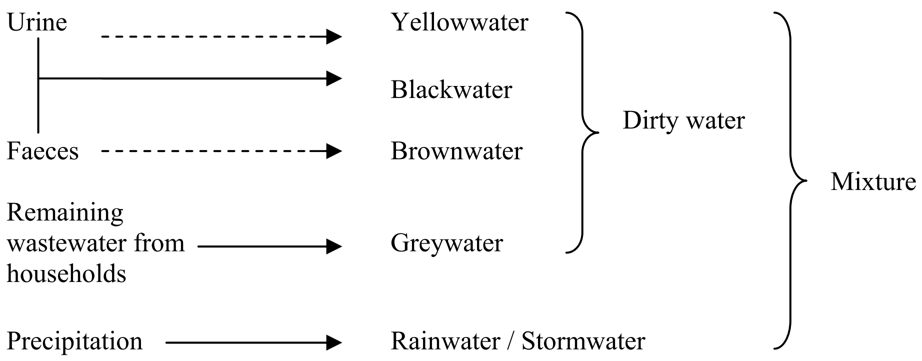

Figure 2.6 Overview of the various components of water within households (Source: HWC)

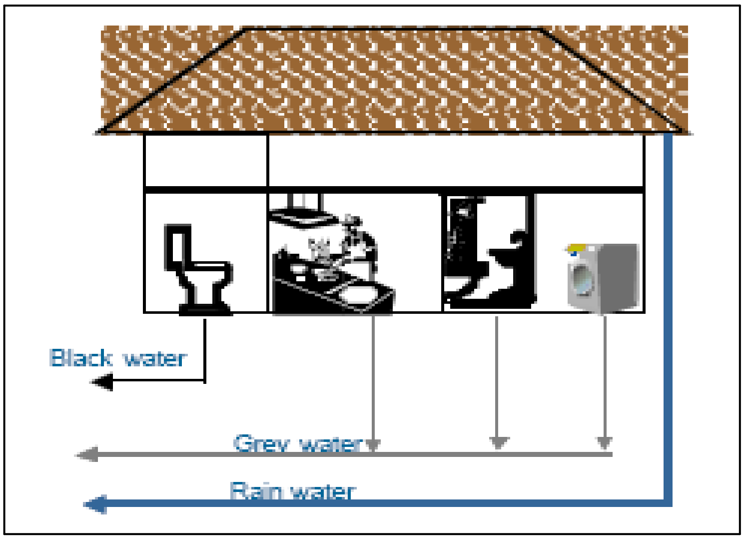

Figure 2.7 Picture showing the three main wastewater flows in a household (Source: LeAF)

A brief description of five streams of urban water adapted from Makropoulos et al. (2008) is given in the next sub-subsections.

2.7.1 Potable water (or: imported water)

Potable water is by definition water whose quality meets drinking water standards. Treating water to potable standards is an expensive and energy consuming process. However only a small proportion (approximately 15-20%) of in-house water demand is actually used for purposes requiring drinking water quality (including water used for drinking, cooking and cleaning dishes). Water consumption patterns can vary significantly from house to house, depending on the household occupancy, the social and cultural conditions as well as on the type of the water consuming appliances installed in the houses (Butler and Davies, 2004; cited in Makropoulos et al., 2008).

2.7.2 Greywater

Greywater is the dilute wastewater stream originating from domestic activities

such as showering, bathing, washing hands, tooth brushing, dishwashing, washing clothes, cleaning and food preparation. The water contains some organic material, for example, food remains, with pathogens, and inorganic material, such as detergents, sand and salt (Balkema, 2003; cited in Makropoulos et al., 2008). The advantage of reusing greywater is that the supply is regular and not dependent on external phenomena (such as rain). As a result, the storage space required could be substantially smaller than in the case of rainwater systems. Moreover, the substitution of potable water with greywater used for purposes other than drinking, e.g., toilet flushing and garden irrigation, reduces demand and thus assists the preservation of valuable water resources (Nolde, 2000; cited in Makropoulos et al., 2008).
The main issues, relevant to the applicability of greywater systems include social acceptability and water quality. A freshly produced greywater usually does not have any objectionable odour. However, it requires early treatment after collection. If stored untreated for long periods, oxygen deficient conditions will develop and scum will be formed that can float or sink in the collection tank (Memon and Butler, 2005; cited in Makropoulos et al., 2008). Moreover, the bacterial population tends to increase with increased storage duration (Dixon et al., 1999; cited in Makropoulos et al., 2008). In general, treating greywater prior to recycling is more socially acceptable, and renders it suitable for more uses. It should be noted, however, that water quality standards for in-house greywater use (or indeed greenwater - see below) have yet to be defined in the UK.

Summarised:
Greywater: washing from kitchen, bathrooms, laundry, without faeces and urine.

2.7.3 Greenwater (or: servicewater)

Greenwater is a term used in this work to denote treated rainwater and treated greywater.

- Rainwater usually carries small pollutant loads (depended inter alia on location, roof building materials and collection system construction) and its harvesting system consists of three basic elements: the collection system, the conveyance system and the storage system. The main disadvantage is the unpredictable and often irregular supply which results in large storage space requirements (Dixon et al., 1999; cited in Makropoulos et al., 2008). Light treatment and disinfection is generally adequate for rainwater treatment to non-potable standards.
- Greywater requires more treatment than rainwater to reach an acceptable standard. The level of treatment required depends on the scale and purpose of use. At small scale, a two-stage treatment consisting of filtration of coarse pollutants (hair and suspended impurities) followed by disinfection with chlorine, bromine or UV may be sufficient (Memon and Butler, 2005; cited in Makropoulos et al., 2008). Greywater recycling at medium to large scales may be more viable but requires more complex treatment. Options include biological aerated filters, membranes, bioreactors, UV treatment, Titanium Dioxide (TiO_2) dosing, membrane aeration bioreactors and coagulation/flocculation with alum or ferric (Memon and Butler, 2005; cited in Makropoulos et al., 2008).

Greenwater, regardless of the scale of the recycling scheme or origin, could be a viable alternative water supply, and can potentially substitute potable water in some water uses within the house, with the obvious exception of drinking water or food preparation. Studies have shown (Nolde, 2000; cited in Makropoulos et al., 2008) that service (green) water made available from rainwater or greywater systems can be cost effective and with proper operation presents no hygienic risk or comfort loss for the consumer. The unavailability of water quality standards for greenwater in-house use, however, is an obvious barrier to its adoption as an alternative form of supply, at least in the UK.

2.7.4 Wastewater

In conventional water supply and drainage systems, the whole volume of delivered drinking water becomes wastewater requiring treatment before being released to the environment. Increasing water demand also means that additional wastewater will have to be disposed of, often in areas where existing sewage treatment works may be at capacity or in areas where discharge potential to local watercourse is limited by environmental concerns (beyond the self purification capacity of the eco-system). If recycling schemes are implemented the volume of wastewater produced can be significantly reduced. In Figure 2.8 the volume percentages of the fractions in household wastewater are given: about two-third of the volume is greywater.

Additionally blackwater can be divided into brownwater (faeces or solid water) and yellowwater (urine or liquid waste).

Summarised:

Blackwater (Excreta):	wastewater from toilets (faeces and urine, with or without flush water).
Brownwater:	faeces without urine, with or without flush water.
Yellowwater:	urine from separation toilets and urinals (with or without flush water).

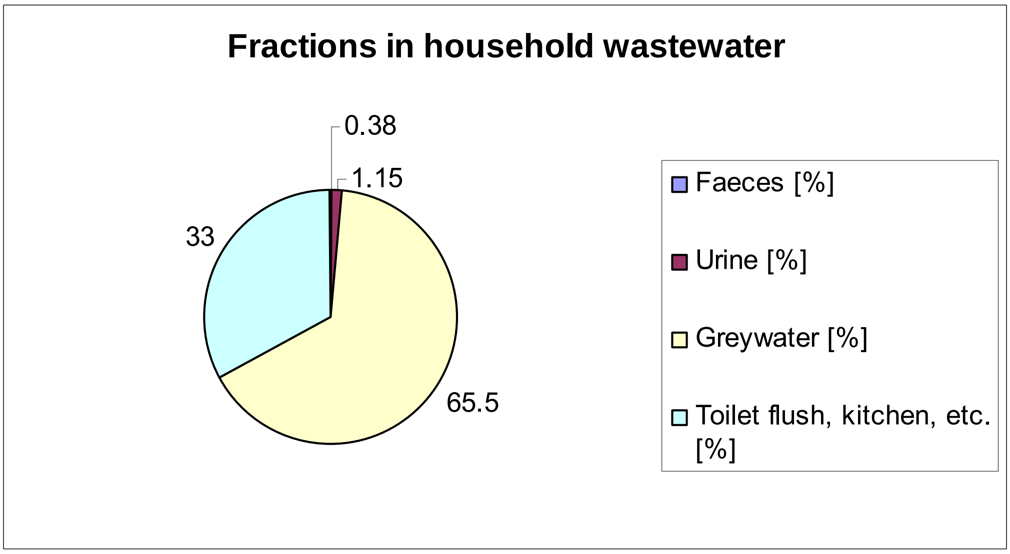

Figure 2.8 Fractions in household wastewater (Source: TUHH)

2.7.5 Runoff

New developments have a direct impact on existing drainage infrastructure and the surrounding environment (Butler and Maksimovic, 2001; cited in Makropoulos et al., 2008). It increases the area of paved surfaces, thus reducing infiltration, while causing surface runoff to exhibit higher peak flows, larger volumes, shorter times to peak and accelerated transport of pollutants and sediment from urban areas. (Niemczynowicz, 1999: Makropoulos et al., 1999; cited in Makropoulos et al., 2008). This results in pollution of the receiving watercourses and increased flood risk within the development. Controlling surface runoff thus becomes a key element in working towards urban sustainability. Surface runoff can be reduced either by collecting rainwater for recycling (through harvesting) -with the additional advantage of the reduced potable water demand- or by the installation of non-piped solutions to urban drainage (known as ‘‘sustainable urban drainage systems’’ (SUDSs) in the UK (Butler and Parkinson, 1997; Butler and Davies, 2004; Makropoulos et al, 2006a,b; cited in Makropoulos et al., 2008).

2.7.6 Composition of wastewaters and quality standards for treated wastewater

In “Neuartige Sanitärsysteme” (2008) a comprehensive overview with detailed descriptions can be found on all kind of modern sanitation systems, including the composition of e.g. rainwater, greywater and also the required quality standards for treated (waste)waters that will be reused for a certain purpose (known as “fit-for-purpose”). In this study it will be assumed that the different types of reusable waters are treated in such a way that they meet with these standards, in order to be fit-for-purpose.

In Table 2.2 below an overview is shown of the various water types as described previously, the so called “wastewater rainbow”.

Table 2.2 The wastewater rainbow (adopted from Kujawa-Roeleveld et al., nd)

Water Colour	Source	Composition of relevant compounds
Total Domestic	All streams mixed	All contaminants, moderate concentrations
Black water	Toilet wastewater	COD, nutrients, pathogens, pharmaceuticals, hormones
Yellow water	Separated urine	Nutrients, pharmaceuticals, hormones
Brown water	Faeces with flush water	COD, pathogens, hormones, nutrients
Kitchen waste	Food left-over	COD
Grey water	Other than toilet	COD, personal care use
Light grey water	Personal hygiene	Personal care products
Kitchen wastewater	Washing-up, food preparation	COD

2.8 A selection of innovative technologies

To develop the strategies as described in the next Chapter 3, an investigation on a variety of innovative technologies has been carried out that can be applied within the new development. With a literature search on innovative technologies, the typical figures of water use and the energy efficiency for each technology have been determined. Besides a literature search, a number of water technology centres and recently implemented urban (eco-)sites provided with (decentralised) innovative technologies have been visited with the same intension.

Emphasis will be put as much as possible on innovative technologies which have 'potential' for the future rather than those "well known" and already on the market for a while. Another condition is that they should fit within the new development, taking into account the function of the Haulander Weg: an ecological demonstration site.

In the following sub-sections some interesting 'potentials' for unit block, cluster and/or catchment scale are described in more detail. Out of them a selection will be made for the strategies being developed later on.

2.8.1 The shower head with vortex ('WOLF')

"Wolf Umwelttechnologie" (2008) developed a shower head which seems currently one of the most innovative water saving shower heads (shown in Figure 2.9). It came just recently available on the market. Due to its vortex technology and the mixture with air, which enters through a hole in the centre of the shower head, the water drops do not only consist of water but have an air bubble inside. It can be described as hollow water drops leaving the shower head and as a result it uses only 6 Litres of water per minute. According to the supplier it therefore saves about 200 Euro per year on warm water usage. The price is still relatively high, it costs about 80 Euro. Another advantages of the vortex technology applied in the WOLF shower head is it reduces the risk of Legionela: no formation of aerosols (very tiny drops), which can easily penetrate into the lungs, but creating relatively big drops filled with an air bubble inside (Görges, 2008).

Figure 2.9 WOLF shower head with vortex, 6 L/min (Source: WOLF Umwelttechnologie)

"De 12 Ambachten Foundation" (2009) in Boxtel - The Netherlands, also developed a water saving shower head: it uses 4.5 L/min and it costs 35.70 Euro. The difference between a conventional shower head and the water saving one can be clearly noticed in Figure 2.10.

Figure 2.10 Shower heads: 11-13 L/min (l) versus 4.5 L/min (r) (Source: De 12 Ambachten Foundation)

It is important to realise that the water pressure in the pipe system has a significant effect on the water usage of appliances like shower heads. In The Netherlands shower heads are divided into six classes according the NEN-EN 1112 standard. An increase of the pressure by 200 KPa (2 bar) may in some cases result in a doubled water flow, as can be noticed in the following Table 2.3. Therefore, the above mentioned figures for the "WOLF" and "The 12 Ambachten" shower heads should be considered as average values.

Table 2.3 Water flow for shower heads at different pressures (acc. NEN-EN 1112)

Class	Water flow at 100 KPa (L/min)	Water flow at 300 KPa (L/min)
Z	4.2-6.9	7.2-12
A	>6.9-8.7	>12-15
S	>8.7-11.5	>15-20
B	>11.5-14.4	>20-25
C	>14.4-17.3	>25-30
D	>17.3-21.9	>30-38

(Source: TVVL Magazine 2/2008) *Note*: 100 KPa = 1 bar

2.8.2 The propelair toilet

Propelair Limited (2008), built on an ingenious toilet -the Propelair- as shown in Figure 2.11, which combines the convenience of a conventional toilet with the water saving and performance benefits of air assisted flushing. The technology is currently still at prototype stage and is undergoing trials with the Water Research Centre (UK). By using a unique application of Boyles Law, atmospheric air is displaced into the bowl to create the flush instead of precious water. This reduces the flushing volume to just 1.5 Liters -an 84% saving compared with an average toilet- and the poor performance associated with other reduced flushing volume toilets is avoided.

Figure 2.11 The Propelair toilet (Source: Propelair Limited)

How it works
The lid is closed before flushing, which forms an air seal with the bowl. A small quantity of water enters the bowl to wash it, followed by displaced air. As the air can't exit the bowl, it acts to efficiently and effectively expel the contents of the bowl without water, pumps or maceration. After flushing, sufficient water replenishes the water trap seal, and the propelair toilet is ready for the next user. The entire flushing cycle takes around three seconds to complete.

Installation
The system looks like, and is used in the same way as, a conventional toilet, and is very convenient to install. Significantly, the propelair toilet connects onto existing drains and requires no special pipes, yet it's unique performance also allows it to transport wastewater without gradients if required, making difficult drainage runs easy to tackle through flexible, smaller-bore waste-pipes that fit between joints. The propelair toilet is a self-contained system and requires no ancillary equipment. It uses fresh air to flush and compressors are not required. The small amount of water that it does use for washing and providing a water trap seal can be provided from any water supply, including gravity tanks, so a pressurized water supply is also unnecessary.

Hygiene
Laboratory testing over the past year has indicated substantial hygiene benefits of propelair toilets. Not only is the rimless, side-hinge pan design very easy to clean, but a 99.8% contaminant removal rate and a 95% reduction in formation of bacterial aerosols makes it a very tough act to follow when it comes to toilet hygiene.

2.8.3 The shower base with heat-exchanger ('RECOH-TRAY')

"Hei-tech Energiesystemen" (2008) has brought a fairly unknown but highly

efficient shower base on the market -at least in The Netherlands-, which incorporates a heat-exchanger. It is shown in Figure 2.12 and energy savings of about 50% can be achieved.

How it works

The hot waste water (greywater) from the shower passes the heat-exchanger on its way down the drain. The heat is exchanged with the water from the mains water en route (instantaneously), to both the water heater and the shower. It is also possible to just preheat the fresh water going directly to the shower. The efficiency will in that case be slightly lower.

The greywater, which has a temperature of about 40 °C, flows across a spherical copper shell from the centre to the outside. Underneath the shell approximately 20 meters of copper pipe is connected to the shell. The fresh water, of about 10 °C, flows through this pipe and is thereby preheated to about 25 °C and can be connected with the cold water tap of the shower as well as with the warm water heater. Through this the heater can operate at less than half of the normally required capacity, which will -according to the supplier- save about 200 m^3 of natural gas per year per living unit. There is a double wall between the greywater and the fresh water, in accordance with Dutch KIWA (KWR) requirements. This is compulsory in most countries.

The heat-exchanger holds less than one litre. This means the heat-exchanger starts working almost immediately after starting showering. The maximum flow is 12 L/min depending on the local mains pressure.
The efficiency of the Recoh-tray was measured by the Dutch KIWA/Gastec Certification and is 47% with a fresh water flow of 7.5 L/min. Due to this efficiency the pay-back time it therefore relatively short, only 4-7 years.

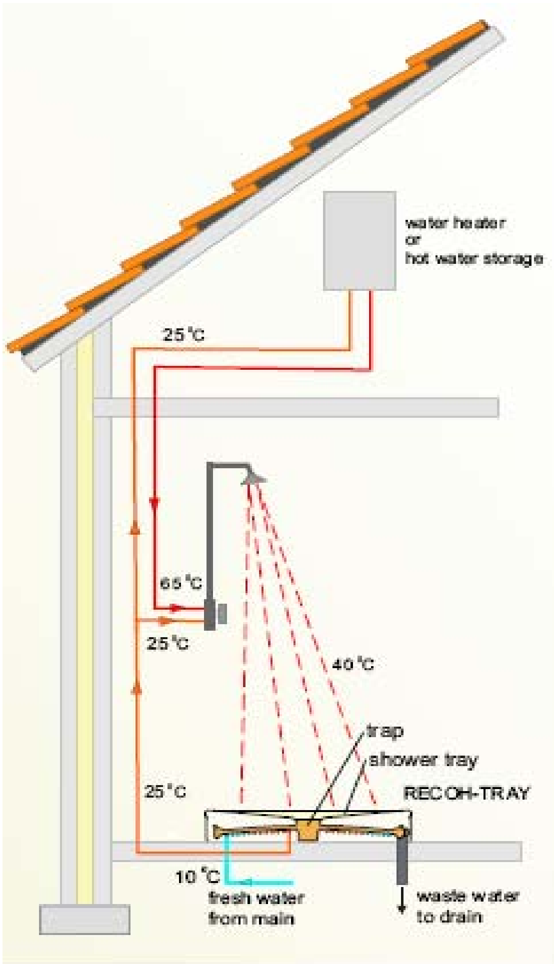

Figure 2.12 **Shower base with heat exchanger (Source: Hei-tech Energiesystemen)**

Note: The following calculation will not be further integrated in the study, but is just to demonstrate its effectiveness on saving energy.

Energy consumption for heating up water

Water has a specific heat capacity of 4.186 kJ/(kg.K). The heat energy to raise water's temperature one Kelvin can be calculated as follows:

$$E_{eff,1m^3} = \rho_{H_2O} \cdot c_{H_2O} \cdot \Delta T = 998 \frac{kg}{m^3} \cdot 4.186 \frac{kJ}{kg \cdot K} = 1.16 \frac{kWh}{m^3 K}$$

With: ρ_{H_2O} : specific density of water (kg/m^3)

c_{H_2O} : specific heat capacity of water {kJ/(kg.K)}

ΔT : the difference in temperature (K)

Note: 1kWh = 3600 kJ

The device, e.g. a gas fuelled water heater has a certain efficiency of an estimated 80%. Therefore the energy required for heating the water increases:

$$E_{Warm-water,1m^3} = \frac{E_{Eff,1m^3}}{\eta} = \frac{1{,}16\frac{kWh}{m^3K}}{0{,}8} = 1{,}45\frac{kWh}{m^3K}$$

Conventional: baseline strategy [1], 30 L/p/d for showering:
The energy to heat -on a daily basis- 30 L (baseline strategy) of cold water (10°C) to comfortable warm water of 45 °C for showering is:

$$E_{Eff,1m^3} = 1{,}45\frac{kWh}{m^3K}\cdot(45-10)K = 50{,}75\frac{kWh}{m^3}$$

The total energy required to heat 30 L water for showering per person per year is:

$$E_{Warm-water} = 50{,}75\frac{kWh}{m^3}\cdot 0{,}030\frac{m^3}{p\cdot day}\cdot 365.25\frac{day}{y} = 556\frac{kWh}{p\cdot y}$$

With a low flow shower head: applied in strategy[1] S0ws up to S4Wz, 18 L/p/d:
The total energy required to heat 18 L water for showering per person per year is:

$$E_{Warm-water} = 50{,}75\frac{kWh}{m^3}\cdot 0{,}018\frac{m^3}{p\cdot day}\cdot 365.25\frac{day}{y} = 334\frac{kWh}{p\cdot y}$$

It results in an energy reduction of almost 40%, just by making use of a low flow shower head.

According to the data of the supplier another 47% on energy will be saved due to the heat exchanger in the shower base: 334 x 0.47 = 157 kWh

This results in a total energy reduction of: 556 – (334-157) / 556 x 100 = 68%

1) Reference is made to the strategies developed in Aquacyle: see sub-section 4.2.

2.8.4 The Ecoplay toilet

For the user, the intelligent Ecoplay system from Ecoplay (2008) works in exactly the same way as a standard toilet (see Figure 2.13). Greywater from the bath and shower is collected in the Ecoplay cleaning tank where a skimmer removes surface debris such as foam, hairs and soap. Heavier waste particles sink to the bottom and are flushed away to waste. The remaining 'clean' greywater is then transferred to a storage tank ready for use in toilet flushing. The storage capacity of the system is 100 liters - sufficient for approximately 20 flushes. It has an intelligent operation:

- If the toilets are not flushed within 24 hours after a period of regular use, (e.g. when the house is empty) the system purges any retained water to

waste. The Ecoplay keeps the retained water young and in motion, preventing legionella from developing.

- This also cleans the system and prevents retained water becoming stale
- The system then draws in a minimal amount of fresh mains water to allow toilet flushing.
- A power failure causes all stored water to be drained off immediately
- Occasional operating noise levels from Ecoplay are lower than the sound of a normal toilet flushing (according CME test data), therefore existing building legislation is sufficient to provide the required levels of sound insulation.

The Ecoplay micro greywater recycling unit reduces the consumption of mains water and drainage by up to 30% and up to 50% of the energy consumption due to a build-in heat exchanger (to pre-heat cold water that flows to the warm water heater). It can save all the water required for toilet flushing, assumed to be 22.40 L/day in case a Dual Flush Toilet 6/4 will be used.

There will be no energy consumption in case only one Ecoplay toilet will be used, assumed that the it will be installed on the ground floor while the bath and shower cabin are on the first floor, so that the greywater will flow into the Ecoplay by gravity. An option can be to install a second Ecoplay toilet on the first floor; in that case a small magnetic driven pump, with an electrical capacity of **0.4 W**, will pump flush water from the storage tank of the Ecoplay on the ground floor to the one on the first floor. Ecoplay keeps the retained water young and in motion, preventing Legionella from developing.

Figure 2.13 Ecoplay toilet (Source: Ecoplay)

Ecoplay helps the environment by reducing mains water consumption, energy usage and sewage treatment requirements.

2.8.5 The eco-tube

EcoTube Service GmbH (2009) developed an ecological friendly tube, the eco-tube; a porous low pressure tube. It is a new innovation for the distribution of wastewater for sub-surface garden irrigation. It saves about 80% of irrigation water compared to the more conventional drip-systems. It has a steady out-flow when a specific pressure is applied and it interacts with the soil. This makes it is less suitable for sandy soil: the microscopic holes in the tube can be blocked.

In addition it is completely safe for human beings even when untreated wastewater will be used for irrigation: it flows safely through the tube just under the surface (sub-surface) and therefore no chance to become in contact with the liquid. The tube has to be laid at a depth ranging from 10-70 cm, with a distance between the tubes of about 20-50 cm and with lengths of maximum 150 m. At the moment at least two sizes of diameter are available. Furthermore it is an eco-friendly product: it is made of recycled car tires and enforced with Poly Ethylene (PE), and it saves about 50% on energy.

2.8.6 The Busse MF (on-site wastewater treatment unit)

"Busse IS GmbH" (2009) developed a wastewater treatment unit for a single household: the Busse MF domestic sewage treatment system uses microfiltration, eliminating even bacteria and germs (see Figure 2.14). This restores wastewater to hygienic condition fit for use as servicewater, for example, to water the garden or flushing the toilet. It is estimated that the consumption of drinking water in a household can be reduced by about one third. The constantly high level of water treatment in the Busse MF system ensures that the discharged water is considerably cleaner than the law requires and therefore can be discharged in sensitive areas and water protection zones. Other advantages of this new compact technology are the small footprint and the fact that it can be installed without expensive earth-moving work. The system, which consists of a double-walled safety tank, is installed within a few hours and is immediately ready for operation.

How it works

The Busse MF Small Size Sewage Treatment System is designed on the basis of DIN 4261 part 2 and comprises two treatment steps, namely pre-treatment (1) and aeration (2) (see Figure 2.14). At the pre-treatment step, which also serves as wastewater store, biologically degradable coarse material such as, e.g., faeces, toilet paper, is dissolved and the non-dissolving components separated from the wastewater by an aerated sieve (3). A pump (4) pumps the water, from which the coarse material has been separated, to the aeration section. At this step the organic matter in the waste water is degraded biologically by microorganisms and oxygen (5). In addition to this, the wastewater is treated physically by microfiltration membranes (6) (ultrafine filter with 0.4 µm pore size). These membrane filters eliminate suspended material, even bacteria and germs, ensuring that only absolutely clear, odorless, hygienically harmless water (filtrate) leaves the system.

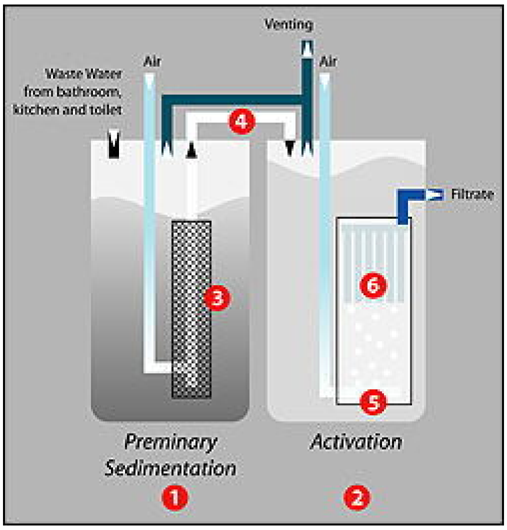

Figure 2.14 Functional principle of Busse MF microfiltration technology (Source: Busse IS GmbH)

The Busse MF system was tested successfully by the University of Hannover and the Technical University in Berlin and the water by the system in practical service is more than significantly better than the limits set by DIBt Berlin* (Z-55.3-60) and the applicable law. Due to the immersed microfiltration membranes, in combination with a technology which requires a high concentration of biomass, the COD level in the discharged water can be reduced to under 30 mg/l* and the BOD_5 value to under 5 mg/l*.

* Design qualification approval of DIBt Z-55.3-60
24-h-trial run

COD	≤ 75 mg/l
BOD_5	≤ 15 mg/l
NH_4-N	≤ 10 mg/l

The smallest type MF-HKA4 is suitable for 1 to 4 people and can therefore be used on unit block scale. The specifications related to treatment capacity and power consumption read as follows:

Maximum daily wastewater volume:	0.60 m^3/d
Power consumption (min-max)	1.8 – 3.0 kWh/d
Average power consumption per volume of wastewater	**4.0 kWh/m^3**

2.8.7 The UASB reactor

According “Waterandwastewater.com” (2009) anaerobic treatment is becoming a popular treatment method for industrial as well as domestic wastewater, because of its effectiveness in treating high strength wastewater and because of its economic advantages.

Developed in The Netherlands in the late seventies (1976-1980) by Prof. Gatze Lettinga - Wageningen University and Research Centre (WUR), the UASB (Upflow Anaerobic Sludge Blanket) reactor was originally used for treating

wastewater from sugar refining, breweries and beverage industry, distilleries and fermentation industry, food industry, pulp and paper industry. The essential components are shown below, in Figure 2.15.

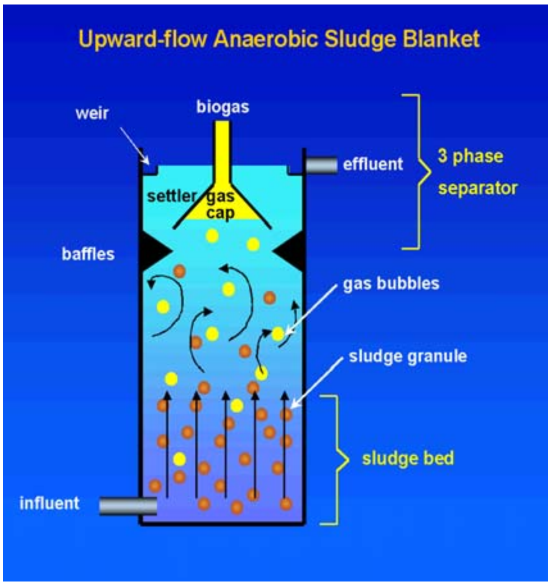

Figure 2.15 Essential Components of an UASB Reactor (Source: Waterandwastewater.com)

In recent times the applications for this technology are expanding to include treatment of chemical and petrochemical industry effluents, textile industry wastewater, landfill leachates, as well as applications directed at conversions in the sulfur cycle and removal of metals. Furthermore, in warm climates the UASB concept is also suitable for treatment of domestic wastewater. This also counts for colder climates, but in that case the UASB should be installed indoors where a temperature can be maintained of at least 15 °C.

In recent years, the number of anaerobic reactors in the world is increasing rapidly and about 72% consist of reactors based on the UASB and EGSB technologies. EGSB stands for Expanded Granular Sludge Bed, which is a variant of the UASB concept.

Specifics of the UASB reactor: When comparing with other anaerobic reactors, it can be concluded that the differences as well as the specifics of an UASB are existence of granules sludge and internal three-phase GSL device (Gas / Sludge / Liquid separator system).

Granules sludge: (see Figure 2.16): In an UASB reactor, anaerobic sludge has or acquires good sedimentation properties, and is mechanically mixed by the up-flow forces of the incoming wastewater and the gas bubbles being generated in the reactor. For that reason mechanical mixing can be omitted from an UASB reactor thus reducing capital and maintenance costs. This mixing process also encourages the formation of sludge granules.

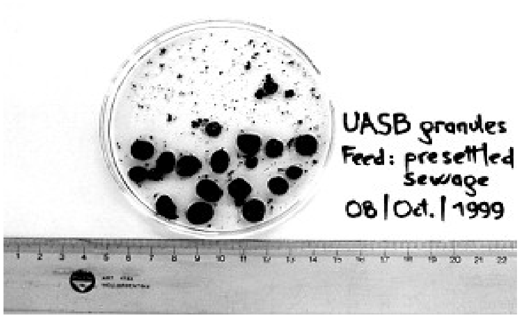

Figure 2.16 Shape and size of granules sludge
(Source: Waterandwastewater.com)

The sludge granules have many advantages over conventional sludge flocs:

- Dense compact bio-film
- High settle-ability (30-80 m/h)
- High mechanical strength
- Balanced microbial community
- Syntrophic partners closely associated
- High methanogenic activity (0.5 to 2.0 g COD/g VSS.d)
- Resistance to toxic shock

Internal three-phase GSL device: Installed at the top of the tank, the GSL device constitutes an essential part of an UASB reactor with following functions:

- To collect, separate and discharge the biogas formed
- To reduce liquid turbulences, resulting from the gas production, in the settling compartment
- To allow sludge particles to separate by sedimentation, flocculation or entrapment in the sludge blanket
- To limit expansion of the sludge bed in the digester compartment
- To reduce or prevent the carry-over of sludge particles from the system

2.8.8 Treatment through wetlands

Greywater and wastewater can be treated and further reused with simple and low cost processes: a wetland is considered as an accepted technology for water pollution control (Malisie, 2008).

There are two types of wetlands: (1) Natural wetlands and (2) Constructed wetlands and the constructed wetlands are divided into two types: (1) Free water surface and (2) Subsurface flow systems, and for the latter two different flow patterns can be distinguished: (1) Horizontal Subsurface Flow (HSF) and (2) Vertical Flow System (VFS).

Constructed wetlands are inundated land areas that support the growth of emergent plants. These plants provide surfaces for the attachment of bacteria films, aid in the filtration and adsorption of wastewater constituents, transfer oxygen into the water column and control the growth of algae by restricting the penetration of sunlight (Metcalf and Eddy, 1991; cited in Malisie, 2008).

Successful case studies indicate that constructed wetlands significantly reduce suspended solids (SS), biological oxygen demand (BOD), pathogens, heavy metals and excessive nutrients from wastewater (Gersberg et al., 1984, Rogers et al., 1991, Mashauri and Mulungu, 2000; cited in Malisie, 2008). By using constructed wetlands, besides treating the water, a green space is created (Van der Vleuten-Balkema, 2003; cited in Malisie, 2008).

The vertical flow constructed wetland requires only half or less area than the horizontal one and has better treatment qualities (Sasse, 1998; cited in Malisie, 2008). It may be assumed that for this reason this type is "commonly" used in Germany, as for the eco-sites Allermöhe and Lübeck-Flintenbreite. In Figure 2.17 a part of the constructed wetland can be seen (right side), including the greywater collection chamber and power supply unit to supply the electricity to the (small) pumps.

Figure 2.17 Vertical flow constructed wetland at Allermöhe, Germany (Source: Author)

Note: The application of vertical flow constructed wetlands is the proposed option by IBA_HAMBURG for the treatment of greywater within the new development Haulander Weg (however, not with the intention to be reused in the households, but being drained into the surface water).

2.8.9 Green-roofs

For those strategies without rainwater and stormwater reuse a worthy option is to construct houses with green roofs; a helpful way to store water during periods of heavy rain and therefore one of the options to tackle water storage issues (and much heavier rains are already noticeable due to climate change!). It reduces peak run-off, improves the air quality (adsorbs fine dust), isolates (also noise), protects the roof cover (bitumen), enhances the biodiversity (it attracts e.g. insects and birds) and it provides a nice "natural green look", especially during the spring and summer time in an urban environment. Furthermore it is one of the measures to reduce the 'urban heat island' effect. Due to the evaporation of

water, heat will be withdrawn from its surroundings and thus lowering the temperature. Only for those people who are allergic from tussocks of grasses for example, may be less pleased to live with a growing number of green-roofs. Figure 2.18 shows an example of a green-roof.

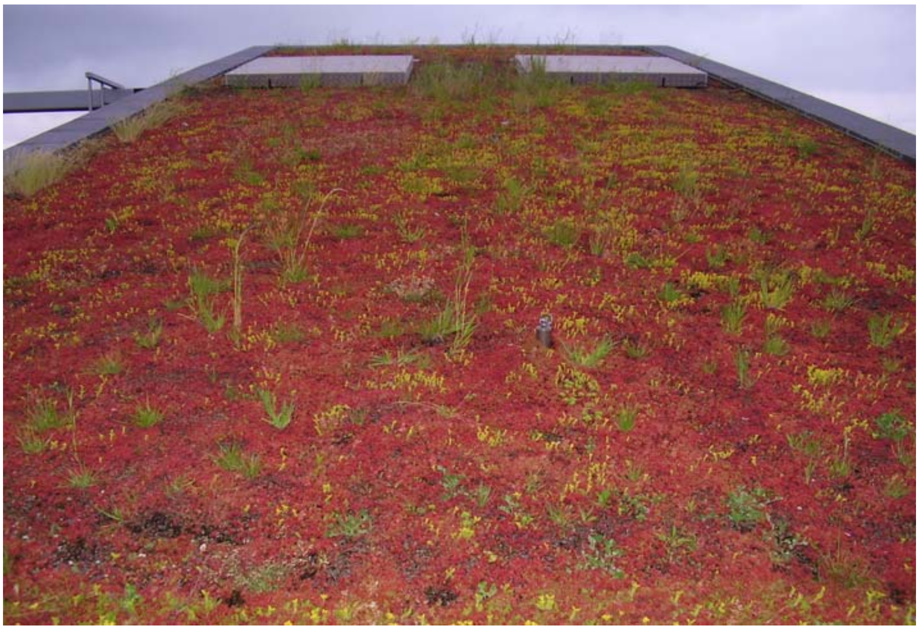

Figure 2.18 An example of a green-roof (Source: Author)

2.9 Renewable energy technologies and decentralised energy

2.9.1 Introduction

Although all developed strategies in this study seems to require less energy than the baseline strategy, it is in line with the study to at least mention some of the most appropriate technologies that can compensate for the relatively high energy consumption related to water use and reuse. They can either save on electrical energy or on natural gas used for a central heating system to produce warm water (thermal energy).

From UNIDO (nd) it can be learned, a distinction should be made between energy intensity and total energy use: energy intensity measures the amount of energy used per unit of water (kWh/m^3). Some water sources are more energy intensive than others; for instance, desalination requires more energy than wastewater recycling. Water conservation technologies may either increase or decrease energy intensity. Yet when water planners make decisions, they should look not just at energy intensity, but also at the total energy used from source to tap and back to the source. In the case of water conservation, some programmes may consume a lot of energy at one stage in the energy-water use cycle, but still decrease the amount of energy used overall.

2.9.2 Photovoltaic panels

The use of electrical energy can be compensated by the installation of photovoltaic panels, most commonly installed on roofs. When the electricity

production from the panels is higher than the consumption the surplus can be discharged to the electricity grid and for which the supplier will be compensated.

2.9.3 Solar hot water systems

Water can be heated by solar hot water systems. These systems are generally composed of solar thermal collectors, a fluid system to transport the heat from the collector to its point of usage. The system may require some electricity for pumping the fluid, and has a reservoir or tank for heat storage and subsequent use. On average saving up to 50% of the energy consumption needed for the production of warm water. Also, it can e.g. effectively be used in combination with a washing machine or dish washer that has a hot-fill connection: the electric heater of the device needs less time to heat this pre-heated water and therefore will save on electrical energy. Another crucial point is the fact that warm water from a solar hot water heater has been heated in a much more efficient way than by the electric heat element of the washing machine and dish washer. It also counts for warm water heated by a high efficient water heater or by combined heat and power (CHP) and are therefore other efficient alternatives to supply a hot-fill connection. Furthermore, a solar hot water system can also be combined with a high efficiency water heater.

2.9.4 Combined heat and power (CHP)

In sub-section 2.6 “co-generation” or “combined heat and power (CHP)” was already mentioned. In short it means that the excess of heat developed during power production will not be wasted (like in a conventional power plant) but used for other applications. Co-generation plants are commonly found in district heating systems of big towns, hospitals, prisons oil refineries, paper mills, wastewater treatment plants, thermal enhanced oil recovery wells and industrial plants with large heating needs. CHP plants, although often fuelled by fossil, are much more efficient than large centralized power stations, because the heat is used either as process heat in industries or distributed around buildings via a district heating system.

2.9.5 Heat pumps

A heat pump is a device that moves heat from one location (the 'source') to another location (the 'sink' or 'heat sink') by mechanical labour. The purpose of a heat pump is to absorb heat in one place where it is plentiful, then to transport and release it in another location where it can be used for space or water heating. This requires energy, but the energy gained from the heat pump is much higher than the energy to be invested (about 4:1) and therefore quite efficient. Common examples are food refrigerators and freezers, air conditioners, and reversible-cycle heat pumps for providing thermal comfort. Useful heat can be found in the air outdoors, in the ground, and is present in water, rivers, lakes and the sea. A heat pump may produce (some) noise, which is a disadvantage: insulation measures are required.

2.9.6 Windmill power

Another way to generate electrical energy is by installing windmills. Household types like ‘double houses’ and ‘row houses’ can be provided with their own small windmill. Other types like ‘the mansions’ (block of flats, apartment-

houses) or ‘live & work’ can have bigger ones installed on top of the roofs (see Figure 2.19; an example of a Vertical Axis Wind Turbine - VAWT). An assessment in advance would be necessary to investigate whether it can be efficient or not to install windmills: is the area open enough, what is the average annual wind speed, are there any restrictions in the law and legislation, etc.

Figure 2.19 Example of a VAWT (5 kW rated power) (Source: PacWind, 2009)

2.9.7 Decentralised energy

According the “Decentralised Energy Knowledge Base” (2009), the developed world’s electricity is generated by an outdated, technologically obsolete, centralised system which wastes around 65% of the energy used to fuel it. If this can be replaced with systems which make use of the heat wasted by producing electricity, in tandem with locally generated renewable energy, which is (1) better for the climate, (2) more secure and (3) gives better value for money. This is Decentralised Energy (DE).

Local energy generation with DE promotes a cultural change in our attitude to the use of energy, which can be integrated into our communities, thereby stimulating energy-use efficiency at local level. The share of new generation taken by decentralised power globally is on the increase. National governments around the world need to remove policy and regulatory barriers to encourage the utilisation of DE as one of the key solutions to tackling climate change.

Background

Climate change has thrust energy production to the top of the political agenda. The developed world is currently dominated by a centralised electricity generating system, which is the embodiment of technological inertia, performing little better today than it did in the 1970s. This centralised system is hugely wasteful and environmentally damaging.

Within the (pre-2007) 25 European Union nations, for example, the electricity sector is responsible for releasing more than 1.2 billion tonnes of carbon dioxide and over 2600 tonnes of dangerous radioactive waste every year. What's more, only 0.6% of the oil, 2% of the gas, 7.3% of the coal and almost none of the world's uranium lie within EU, so there is limited security of supply. At the same time more than half of Europe's power plants are more than 20 years old, and will need to be replaced over the next decade or so, offering an opportunity to move towards a more sustainable decentralised system which protects the climate and provides future generations with secure energy.

Big centralised electricity generating stations waste around two thirds of the energy in the fuels they use by throwing away waste heat in cooling water, up the cooling towers and then in the electricity transmission wires. So 65% of the energy is lost before it even reaches consumers. If we could make use of this waste heat it would make a very large contribution to tackling climate change and improving security of supply.

By seeing the energy system as a whole and locating energy production close to where it is used, it is possible to use both the heat and electricity generated and more than double the efficiency of power stations. This system would work hand-in-hand with renewable energy sources and gives more efficient end use. This highly efficient, decentralised, approach is better for the climate, more secure and gives better value for money than investment in a centralised system.

Decentralised energy
A Decentralised Energy (DE) system produces heat as well as electricity at or near the point of consumption. It includes high efficiency co-generation or combined heat and power (CHP); on-site renewable energy systems and energy recycling systems. CHP plants, although often fuelled by fossil fuels, are much more efficient than in large centralised power stations, because the heat is used either as process heat in industry or distributed around buildings via a district heating system. The availability of a local district energy network connected to the DE generation plant means the CHP plant can be integrated with other fuels/technologies such as biomass, geothermal energy, or solar collectors.

Importantly once a DE scheme has been constructed with its associated district energy network, as new technologies mature, such as fuel cells, they can easily be integrated. This is not the case where a development has been constructed with many localised heat plants and grid electricity supplies.

3 Methodology

3.1 Data collection on Haulander Weg

The proposed methodology for the field research is to first describe and formulate a baseline strategy -to allow for a common basis for comparison- of the three main components of the urban water cycle (water supply, wastewater disposal and stormwater drainage) with respect to water and energy use for the

new development Haulander Weg, assuming that it will be served with a conventional infrastructure that delivers potable water, separately from the infrastructure that disposes of wastewater and separately to the provision of drainage for stormwater.

To develop the baseline strategy related information and data have been collected from the stakeholders in Hamburg. For this reason Hamburg has been visited twice during the study period and during the first visit, besides the stakeholders, also two eco-demonstration sites have been visited: Allermöhe and Lübeck-Flintenbreite.

The following data -among others- has been collected to provide for the baseline strategy:

- Required energy (kWh/m^3) to treat and to pump potable water to the 598 households.
- Required energy (kWh/m^3) for the treatment of wastewater (tertiary treatment).
- Required energy (kWh/m^3) to pump the excess of stormwater out of the area into the river Elbe.
- Infiltration rate of the area.
- Precipitation rate of the area.
- Imperviousness of the area.
- Soil condition of the area.
- Groundwater level of the area.
- Size of the area.
- Topography of the area.
- The (preliminary) design of the new development.
- Water use data; end-use categories.
- Leakage percentage of the water supply system.
- Stormwater data; infiltration, runoff and evaporation.

With this data and with lacking data obtained from literature and a number of visits (and telephone calls) of relevant projects and companies in Germany as well as in The Netherlands, the water balance and typical figures for the energy consumption have been calculated and/or estimated for -in first instance- the development of the baseline strategy.

Once the baseline strategy has been put in place, a number of strategies can be developed through the introduction of water managing technologies within the various scales, respectively **unit block (ubl)**, **cluster (clu)** and **catchment (ctm)** (see sub-section 4.2). For instance, on unit block scale the replacement of a conventional toilet for a low-flow toilet, on cluster scale the utilization of collected rainwater for e.g. toilet flushing, and on catchment scale the introduction of stormwater collection and usage. These strategies have their impact on the water balance and as a result on the volume of imported water and generated wastewater and also -as it is directly related- on the energy consumption. The propounded strategies will be compared with the baseline strategy, but also with each other.

In Figure 3.1 a schematic representation of a development is shown. The system

boundary is illustrated with the dotted bold line, representing a **cluster** of houses.

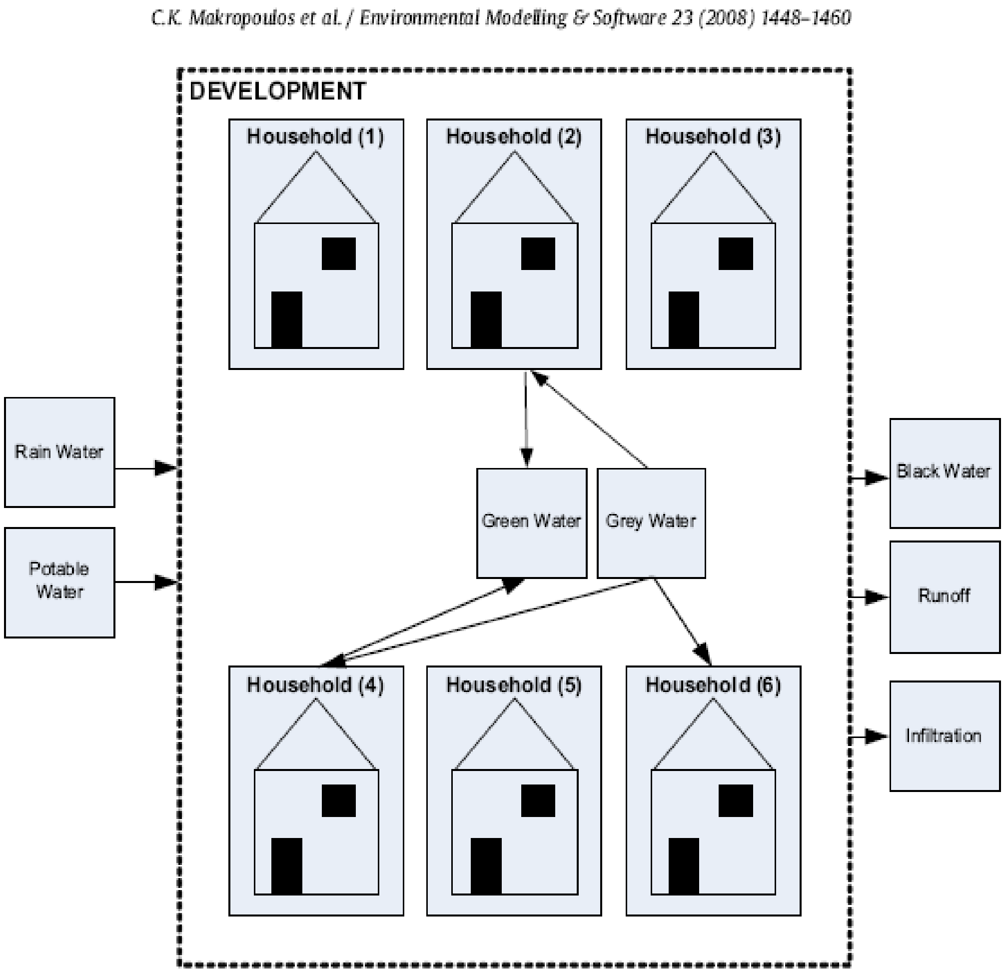

Figure 3.1 Schematic representation of a development at cluster scale (Makropoulos et al, 2008)

The baseline strategy as well as the other strategies for the water balance has been developed in Aquacycle (and two strategies in UWOT for comparison). The methodology of "Aquacycle" and "UWOT" are described below. Further calculations, including related energy consumption patterns, are done in an MS Excel spreadsheet and visualised with graphs and bar diagrams.

3.2 The Aquacycle model

3.2.1 Aquacycle input files

There are a total of six input files required to run Aquacycle. These six files are listed in Table 3.1 below.

Table 3.1 Aquacycle Input Files

Input File Type	File Suffix
1. Indoor water usage profile	.wpf
2. Climate data	.clm
3. Unit Block	.ubl
4. Cluster	.clu
5. Catchment	.cmt
6. Parameter & initial values	.prm

3.2.1.1 Indoor water usage profile (IWU-profile)

It provides data on domestic water use for a particular urban area and period of time. It is important to realise that the same water usage profile is used for all clusters. The breakdown of the domestic water use is in Litres per household (unit block) per day.
The order used is:
- household occupancy,
- kitchen water use,
- bathroom water use,
- toilet water use,
- laundry water use,

and it has to be specified for an occupancy of 1 up to 7. Furthermore the proportion of hot water use to total water use in kitchen, bathroom and laundry has to be specified.

It is assumed that all in-house water use becomes wastewater with no consumptive losses as such losses are in the order of 2% of indoor water use (Mitchell, 2001).

The data on domestic water use in this study has been adopted from Görges (2008), since it is from a recent date and related to the same study area.

3.2.1.2 Climate file

The climate data file contains historic daily rainfall and potential evaporation data series, in units of millimetres. For Hamburg historical data is available, ranging from 01-01-1991 up to 31-12-2007 (17 years in total) and in the following format: date, rainfall and potential evaporation.

3.2.1.3 Unit block file

The unit block file contains details on the options for the unit blocks within each cluster being simulated. All unit blocks within the cluster have the same arrangements but these arrangements may differ significantly between clusters. With thirty three (33) comma separated numeric values, the type of arrangements selected are indicated for each cluster in turn.

3.2.1.4 Cluster file

The cluster file contains details on the water options selected for each cluster

within a catchment being simulated. All clusters within the catchment have the same water arrangements, but these arrangements may differ significantly between clusters. With nineteen (19) comma separated numeric values, the type of arrangements selected are indicated for each cluster in turn.

3.2.1.5 Catchment file

The catchment scale file contains details on the water options selected for the catchment being simulated. With eight (8) comma separated numeric values, the type of arrangements selected are indicated for the catchment.

3.2.1.6 Parameter and initial value file

The parameter and initial value file contains details on the "measured parameters", "calibrated parameters" and "initial storage level values" for each cluster in the catchment being simulated. The file is structured in three blocks. The **first block** contains the "measured parameters" for each cluster, and due to its importance will be listed down in Table 3.2.

Table 3.2 Measured parameters file

1	No. of blocks in cluster, ≥0
2	Average household occupancy, ≥0
3	Area of unit block in m^2, ≥0
4	Area of unit block garden in m^2, ≥0
5	Area of unit block roof in m^2, ≥0
6	Area of unit block pavement in m^2, ≥0
7	Per cent of unit block garden irrigated as a %
8	Total area of cluster in hectares, ≥0
9	Road area in hectares, ≥0
10	Area of public open space in hectares, ≥0
11	Per cent of public open space irrigated as a %
12	Water supply leakage rate as a %
13	Cluster stormwater output flows into Cluster No.? specific cluster number or 0
14	Cluster wastewater output flows into Cluster No.? specific cluster number or 0

The values of the different areas asked for in the **first block** ("measured parameters") have been determined for each cluster and can be found in sub-section 5.1.

The **second block** contains the "calibrated parameters" for each cluster, related to Stormwater, Wastewater and Water Use. The study area does not exist yet, which means there is no observed data available, necessary for calibration. And because it is quite complicated to estimate the values of these parameters, default values have been used as mentioned in an example on page 44 of the Aquacycle User Guide (Mitchell, 2005).

The **third block** contains the "initial storage level values" for each cluster. These are assumed to be zero: in a time range of 17 years (climate data), the values of the initial storage levels are of minor importance (levelled out).

3.2.2 Using rainwater, stormwater and wastewater

A range of small to medium scale technologies exist that have the potential to provide individual or community scale water service systems (Clark, 1990; cited in Mitchell, 2005). The common element of all these technologies is the collection, storage, and subsequent distribution of the water.

The sources, from which the water is collected and the locations, to which it is subsequently distributed, vary. Treatment may or may not be required depending on the water source and purpose for which it is intended. Rather than attempt to simulate the operation of a large number of different stormwater and wastewater utilization schemes in detail, a smaller number of generic methods can be modelled, representing the common elements of the different schemes.

A number of stormwater and wastewater use methods have been selected within Aquacycle to represent a range of approaches to stormwater and wastewater utilization and are listed in Table 3.3. They relate to the different spatial scales at which water can be managed; all result in the beneficial use of the stormwater or wastewater. Combining several of these schemes can result in both stormwater and wastewater being used within a particular catchment, allowing the maximum exploitation of these resources. The only consideration of water quality relates to the selection of appropriate applications for stormwater and wastewater. Potable reuse, as opposed to sub-potable reuse of stormwater and wastewater, is discussed within the water industry (Anderson (1995), Law (1997); cited in Mitchell, 2005). However, it may well be a number of years before potable reuse is accepted (if ever) allowing for such schemes to be installed in urban areas. See also the discussion on dual plumbing systems in Chapter 6.

Table 3.3 Methods for stormwater and wastewater reuse available in Aquacycle

Scale	Method	Source(s) of water*	Uses*	Comments
Unit Block	Rain Tank	Roof runoff	All indoor and outdoor unit block uses	May have a first flush device. Can only supply the unit block that the rain tank is located within.
	Sub-Surface irrigation of greywater	Greywater flows: kitchen, bathroom, laundry	Unit block irrigation	Distributes greywater directly to the garden through a sub-surface drainage field according to the daily irrigation requirements.
	On-site wastewater treatment unit	Wastewater flows: kitchen, bathroom, laundry, toilet.	Unit block toilet flushing. Irrigation.	Can store treated effluent. Can only supply the unit block that it is located within. Option of disposing of effluent to stormwater or wastewater system.
Cluster	Stormwater store	Unit block runoff. Road runoff. Public open space runoff. Stormwater from other clusters.	Unit block toilet flushing. Irrigation.	May divert a first flush to wastewater system. Any unit block or cluster can be supplied by any cluster stormwater store in catchment.
	Wastewater treatment and storage	Unit block wastewater. Wastewater from other clusters(s).	Unit block toilet flushing. Irrigation.	Any unit block or cluster can be supplied by any cluster wastewater store in catchment. Option of disposing of effluent to stormwater or wastewater system.
	Aquifer storage and recovery	Unit block runoff. Road runoff. Public open space runoff. Stormwater from other cluster(s).	Unit block toilet flushing. Irrigation.	Recharge and recovery is limited by rate at which water can be injected and pumped.
Catchment	Stormwater store	Catchment stormwater Runoff.	Unit block toilet flushing. Irrigation.	May divert a first flush. Any unit block or cluster can be supplied by catchment stormwater store.
	Wastewater treatment and storage	Catchment wastewater discharge.	Unit block toilet flushing. Irrigation.	Any unit block or cluster can be supplied by catchment wastewater store. Option of disposing of effluent to stormwater or wastewater system.

* Where more than one source or use is listed, any or all of the different sources/uses can be selected by the user.

3.2.3 Preferences in satisfying a demand from multiple available sources

According to Mitchell (2005) it is important to realise that if there is more than one source selected to supply a particular demand (e.g. both rain tank and on-site wastewater treatment unit) then there is a set order in which these sources will be used to meet that demand (see Table 3.4).

The rules used to determine the priorities for each demand are as follows:

1. Use the lowest quality water source available which meets the requirements of the demand first
2. Supply indoor water demands before outdoor demands
3. Use the water sources within the unit block before cluster sources
4. Use cluster scale water sources before catchment scale water sources
5. Use all local sources of water before importing water (reticulated water)
6. If a particular potential source of water has not been selected by the user, then the next highest priority source is used instead.

Table 3.4 Preferences in satisfying a demand from multiple available sources

Water Supply Source	Water Demand					
	Unit Block					*Cluster*
	Kitchen	Bathroom	Laundry	Toilet	Irrigation	Public Open Space Irrigation
Unit block direct sub-surface greywater irrigation (kitchen and/or bathroom and/or laundry)					1	
Unit block treated wastewater				1	2	
Unit block rain tank	1	1	1	2	3	
Cluster wastewater store (located in own cluster or another cluster)				3	4	1
Cluster stormwater store (located in own cluster or another cluster)				4*	5*	2*
Aquifer storage and recovery (via cluster stormwater store)				4	5	2
Catchment wastewater store				5	6	3
Catchment stormwater store				6	7	4
Reticulation (imported water)	2**	2**	2**	7**	8	5

*Aquifer storage and recovery operates in conjunction with a cluster scale stormwater store (see section on Aquifier storage and recovery).
**Reticulated water is automatically supplied to unit block indoor water demands if there is a shortfall in supply from higher priority sources.

4 Vision, scenarios and strategies

4.1 Introduction on vision, scenarios and strategies

In general a strategic planning can have three subsequent phases. It starts with the creation of a **vision** -a concise description of a desired future-, i.e. a shared idea or “picture” of the future organisation of the urban water system. It is followed by the development of a number of conceivable **scenarios**, i.e. a qualitative and quantitative description of the future external situation that the city and its inhabitants will face and which can be described as developments in the future which are uncertain and “out of your hands” (the unpredictability of the future), like climate change, drought, (peak) oil prices, economical and financial crisis’s etc. Scenarios can be considered as the corrections of the actions to achieve the vision. Finally, **strategies** are developed which describe the various general strategic approaches that could be followed under certain

scenarios to achieve the vision. For each scenario a strategic plan can be developed. It may happen that the original vision cannot be realised due to unrealistic strategies. In that case another scenario should be followed to achieve the original vision. It may even be necessary to adjust the vision. An illustration of it can be found in Figure 4.1.

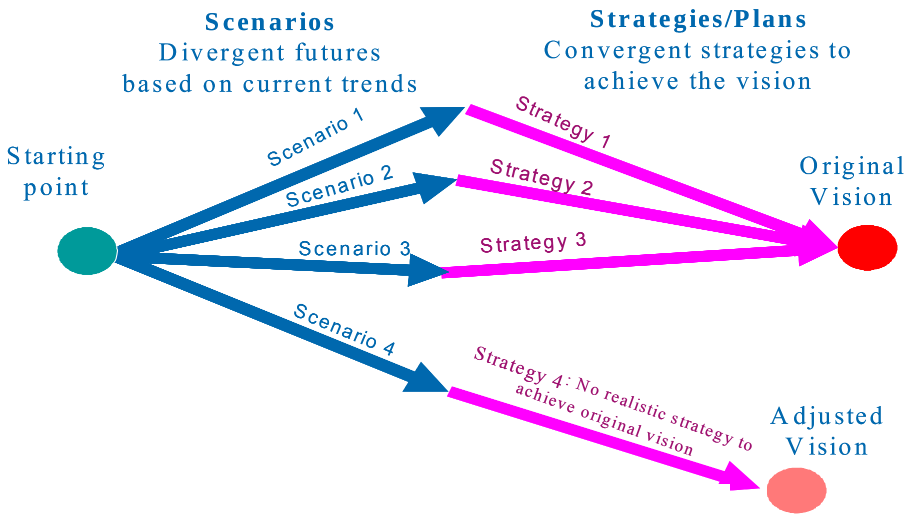

Figure 4.1 Visioning, scenario analysis and strategy development (SWITCH, 2008)

The vision for this study can be described as:
The development of an ecological site within the boundaries of the Haulander Weg area, with the aim to consume a minimum of water and energy.

As mentioned before, a decentralised approach will be followed and therefore a number of decentralised innovative technological measures will be proposed that can possibly be implemented in the new development to accomplish the vision. These are the strategies, and they could have been developed and evaluated by a tool like “SWITCH City Water”; a tool which is in particular suitable to evaluate different strategies (down to the level of technical options and innovative financing methods) under certain defined scenarios, in terms of their effect on overall urban water system sustainability. However “SWITCH City Water” is still under development and will become available later on this year and for that reason another modeling programmes have been applied in this study (Aquacycle).

4.2 Aquacycle strategies

The focus will be put on the development and evaluation of a number of water management strategies from a sustainability perspective. Therefore, a selection of innovative technologies has been put forward for the three known scales (unit block, cluster and catchment) as described in sub-section 2.8. The outcome of the strategies are processed in a MS Excel data sheet, providing water and

energy consumption patterns for each strategy and with which insight can be gained on how innovative technologies have their impact with respect to water and energy use. An overview is shown in Figure 4.2.

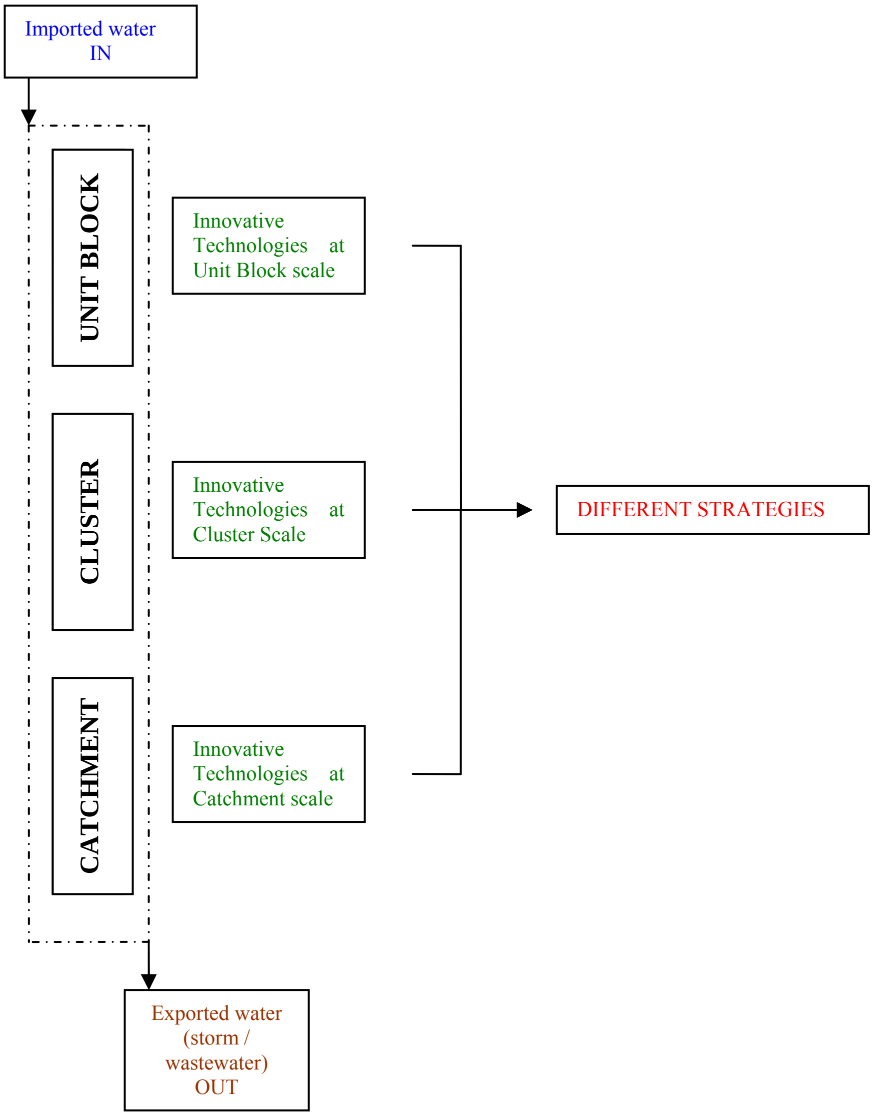

Figure 4.2 Overview Aquacycle strategies

In the Table 4.1 below an overview is shown of the strategies which will be further developed in Aquacycle with regard to water (re)use and energy consumption or in one case even energy production (strategy S3Wz).

Table 4.1 Overview different strategies

(Re)use of / Strategy	wst (*	rain water ulb	grey water ubl	waste water ubl	waste water clu	waste water ctm	storm water clu	storm water ctm
Baseline: Sbl	-							
S0ws	X							
S1Rx	X	X						
S2Gx	X		X					
S3Wx	X			X				
S3Wy	X				X			
S3Wz	X					X		
S4Sy	X						X	
S4Sz	X							X

*) wst = water saving technologies

The "coding system" for the strategies reads as follows:

Sbl	Baseline strategy
S0ws	Strategy zero, water saving technologies
S1Rx	Strategy one, rainwater harvesting and treatment at scale x
S2Gx	Strategy two, greywater collection and treatment at scale x
S3Wx	Strategy three, wastewater collection and treatment at scale x
S3Wy	Strategy three, wastewater collection and treatment at scale y
S3Wz	Strategy three, wastewater collection and treatment at scale z
S4Sy	Strategy three, stormwater collection and treatment at scale y
S4Sz	Strategy three, stormwater collection and treatment at scale z
x	unit block (household) scale (ubl)
y	cluster (neighbourhood) scale (clu)
z	catchment scale (ctm)

Note: The Aquacycle input data and output data (results) files of the below mentioned strategies can be found in respectively Appendix 1 and 2 (on CD-ROM).

4.2.1 Strategy Sbl: Baseline strategy

As mentioned in Chapter 3 (Methodology) first a baseline strategy has to be described and formulated -to allow for a common base for comparison- of the three main components of the urban water cycle: water supply, wastewater disposal and stormwater drainage. It means the new development will be regarded as "conventional" (centralised): wastewater will not be treated and/or reused within the catchment, but will be disposed of at a central wastewater treatment plant. Also the (re)use of rainwater, greywater, stormwater and wastewater is not included and the appliances and fixtures, like toilets, taps and shower head are considered to be of conventional types. In other words, there is no question of demand management. The water required for garden irrigation at unit block (household) scale and public open space irrigation at cluster scale will be supplied from imported water. The corresponding 'switches' have been

‘switched on’ in the unit block file (.ubl file) and cluster file (.clu file). In the parameter and initial value file (.prm) the percentage of the total garden area of ‘public open space irrigated’ has been set at 40% and the percentage of the total garden area of ‘unit block garden irrigated’ at 65%. This percentage determines the volume of water required to meet the irrigation demand, which depends on the weather conditions (e.g. rainfall pattern, fixed in the climate file [.clm]). These percentages remain the same for the other strategies.

A crucial file to be developed is the indoor water usage file, since it will be used for each cluster and it will also be the same for each cluster. According to the Aquacycle User Guide (Mitchell, 2005) a typical pattern can be developed which provides a reasonable representation of household water use, despite the variation in residential indoor water use from household to household. This typical pattern is based on the different indoor water use components, kitchen, bathroom, laundry, and toilet. The resultant water use profile can be constructed and used to predict indoor water use.

For the study area the indoor water usage profile for the baseline strategy is based on data that can be found in Görges (2008). It has been developed as follows: the average daily water usage is 110 L/d and the average household occupancy is three (3), resulting in an average daily water usage of 330 L/d, the sum of 30+165+75+60. These figures can be specified as follows (in L/d):

Kitchen:	3x (5 dishwasher + 2 cooking + 3 cleaning)	= 30 L/d
Bathroom:	3x (30 shower + 15 bath + 10 sink)	= 165 L/d
Toilet:	3x 25	= 75 L/d
Laundry:	3x 20	= 60 L/d

Table 4.2 Indoor water usage profile, Baseline Strategy (Sbl)

No. of occupants	Kitchen (L/d)	Bathroom (L/d)	Toilet (L/d)	Laundry (L/d)	Total (L/d)
1	15	75	35	19	144
2	23	122	57	35	237
3	30	165	75	60	330
4	35	195	92	75	397
5	37	215	102	86	440
6	45	244	115	99	503
7	52	272	128	111	563

The other values in the Table 4.2 have been calculated by determining the proportion ratios from two existing tables mentioned in the following user guide and paper respectively:

1. Aquacycle User Guide, page 28-29 (Mitchell, 2005)
2. Modeling the urban water cycle, page 619 (Mitchell et al., 2001)

Although the water usage values in these two tables are different, it appeared that the proportion ratios were identical. To estimate the water usage values for the other occupancy numbers these proportion ratios have been used for this

study.

In Appendix 3 (on CD-ROM), the two tables and calculated proportion ratios are presented.

Energy consumption

The energy requirements for (1) the production (extraction and treatment) and distribution of drinking water, (2) the conveyance and treatment of wastewater and (3) the collection and pumping of stormwater into the river Elbe are well being estimated in the reports of Görgers (2008) and Reid (2008). These values will be applied for the calculations of the baseline strategy (Sbl) and strategy S0ws (conventional, centralised systems).

Energy consumption (1):	**0.54 kWh/m^3**	(imported water: drinking quality)
Energy consumption (2):	**0.60 kWh/m^3**	(wastewater)
Energy consumption (3):	**0.03 kWh/m^3**	(stormwater)

4.2.2 Strategy S0ws: Water saving technologies

This strategy can be seen as an intermediate one: it is in between the baseline strategy and the remaining strategies S1Rx to S4Wz, and just to demonstrate the reduction in water usage due to the application of water saving technologies only.

The water usage profile for this strategy has been modified due to the water saving technologies, however only for the columns 'Bathroom' and 'Toilet' since no water savings for 'Kitchen' and 'Laundry' has been applied. It is assumed that the future inhabitants will all use 'less water using' or so called A labelled washing machines and dishwashers, since these devices are nowadays commonly used. Such economical washing machines use about 42.5% less water than an average one and for dishwashers this figure is about 28% (SenterNovem, 2008). In this study emphasis will be put on less commonly known and applied technologies which can make a difference. These earlier described water saving appliances and fixtures are: the 1.5 L/flush toilet (Propelair), the 6 L/min shower head (WOLF) and the flow-reducer installed on the tap in the bathroom (50% reduction). The figures in the Table 4.3 below have been developed as follows:

Bathroom:	Shower:	3 min/p/d x 6 L/min	= 18 L/p/d
	Bath:	no change	= 15 L/p/d
	Sink:	50% of 10 L/p/d	= 5 L/p/d
	Total:		= 38 L/p/d x 3 p = 114 L/d
Toilet:	on average 5 toilet visits per day		= 5 x 1.5 x 3 p ≈ 23 L/d

Table 4.3 Indoor water usage profile (applied for S0ws up to S4Sz)

No. of occupants	Kitchen (L/d)	Bathroom (L/d)	Toilet (L/d)	Laundry (L/d)	Total (L/d)
1	15	52	10	19	96
2	23	84	17	35	159
3	30	114	23	60	227
4	35	135	27	75	272
5	37	149	31	86	303
6	45	168	35	99	347
7	52	188	39	111	390

Note: The following strategies S1Rx up to S4Sz have all been calculated with the low indoor water usage profile of strategy zero.

Energy consumption

The same values are applicable as being described under the baseline strategy (sub-subsection 4.2.1).

4.2.3 Strategy S1Rx: On-site rainwater use

Strategy one is similar to strategy zero, but it includes the harvesting and use of rainwater at unit block scale. This has been realised by adapting some of the settings in the unit block input files (.ubl files) for each cluster:

- The harvesting of rainwater: each household provided with a rainwater tank. The size of the tanks for a certain house-type within each cluster have been estimated by applying graphs from The Department of Water, Land and Biodiversity Conservation - South Australia (2008) indicating the tank size related to the parameters “annual rainfall” (mm/y) and “roof size” (m^2). The tank sizes are listed below and have been set in the .ubl file of each cluster.

Cluster 1 – DH: 2 m^3
Cluster 2 – RH: 4 m^3
Cluster 3 – Quatro MFH: 3 m^3
Cluster 4 – Mansions: 4 m^3
Cluster 5 – Live & work: 2 m^3
Cluster 6 – “Small Ind. & Services”: 2 m^3

- The first litres of contaminated rainwater from the roofs will be flushed. The amount to be flushed according to the Rainwater Harvesting Guide (2008) in case of a “constant volume tank” is 5 gallons of water per 500 sq.feet of catchment area, which is about 22.75 L per 46.5 m^2 of roof area. Since each cluster is composed of houses of a specific type and consequently with a specific roof size, the amount of first flush will differ accordingly. The calculated values are as follows and these have been set in the .ubl files of each cluster:

Cluster 1 – DH: 38 L
Cluster 2 – RH: 20 L
Cluster 3 – Quatro MFH: 30 L

Cluster 4 – Mansions: 18 L
Cluster 5 – Live & work: 42 L
Cluster 6 – "Small Ind. & Services": 50 L

- Within Aquacycle, harvested rainwater will be applied for:
  - domestic hot water
  - domestic kitchen cold water
  - domestic bathroom cold water
  - domestic laundry cold water
  - domestic toilet water
  - domestic garden irrigation

Energy consumption
The location of the rainwater tank will determine whether electrical energy is required or not. With the tank located just under the roof the collected rainwater can be distributed by gravity, free of energy consumption. However, in this study it has been assumed having the tanks located on the ground floor (or even under the ground), requiring an estimated energy consumption of **0.17 kWh/m^3** for pressurising the water through a filter with a relatively small pump (adapted from Reid, 2008).

4.2.4 Strategy S2Gx: Greywater reuse

In this strategy, again combined with the water saving technologies, the reuse of greywater from the unit blocks (households) supplied from kitchen, bathroom and laundry for sub-surface irrigation has been introduced and are 'switched on' in the unit block input files (.ubl files) for each cluster. In the Aquacycle modeling programme the reuse of greywater is limited to sub-surface irrigation only.

There are two options to utilise the greywater:
- Without treatment, directly drained to the garden for irrigation/infiltration, e.g. by making use of the "eco-tube" as described in sub-subsection 2.8.5.
- After treatment through a vertical flow constructed wetland (see sub-subsection 2.8.8) it will be reused for its defined purpose by Aquacycle, so for garden irrigation (sub-surface) only. The remaining treated greywater, the "spillage" (in Aquacycle terms) can be further applied for e.g. toilet flushing and the laundry (washing machine) in stead of being discharged into the surface water.

It should be noted that the greywater will be drained, collected and treated at cluster scale but reused at household scale. It means each cluster will have its own vertical flow constructed wetland. According Otterpohl et al. (1997) the size of such a wetland should be about 2.0 m^2 per person. For the clusters one to six this means respectively: 234, 1884, 240, 516, 264 and 450 m^2.

Alternatively this can be done at catchment scale by one semi-decentralised vertical flow constructed wetland for all 598 households of about 3588 m2 (approximately 60 x 60 m), but will not be considered in this study.

Energy consumption
The energy required up to the treatment part of the greywater has been done

through determining a real case situation, which is the ecological site Allermöhe in Hamburg, Germany. A description and the calculations can be found in Appendix 4. From the calculations it appears the energy consumption for the treatment of 10.64 m^3 greywater per day is about 2.3 kWh/d, which is: 2.3 / 10.64 = **0.21 kWh/m^3**

There is however one dilemma: the treated water in Allermöhe is not pumped back to the houses for reuse opportunities, but discharged into the surface water. Therefore, that remaining part -to pump the treated water collected in cluster storage tanks back to the houses- has been estimated to be about 50% higher than for a conventional, centralised system like applied for the baseline strategy (due to economy of scale effect). However, the figure (0.54 kWh/m^3) mentioned under the baseline strategy includes the total energy consumption of (1) water collection (extraction), (2) treatment and (3) pumping into the distribution network. It may be reasonable to assume that about 40% to 50% of this total is required for pumping (to be on the safe side, assume 50%), finally resulting in: 0.54 x 1.50 x 0.50 ≈ **0.4 kWh/m^3**

Therefore, the total energy consumption for (a) the treatment part and (b) the part to pump the collected and treated greywater from a cluster storage tank back to the households will be: 0.21 + 0.4 = **0.61 kWh/m^3**

4.2.5 Strategy 3: Wastewater reuse at unit block, cluster and catchment scale

4.2.5.1 Strategy S3Wx: On-site wastewater reuse

In this strategy the on-site collection and reuse of wastewater from the kitchen, bathroom, laundry and toilet has been ‘switched on’ in the unit block input files (.ubl files). In the Aquacycle modeling programme the reuse of wastewater is limited to <u>toilet flushing and garden irrigation</u>. Each unit block (household) will be provided with a wastewater treatment unit, the Busse MF-HKA4 for 1 to 4 persons, as described in sub-subsection 2.8.6. It has a maximum daily storage capacity of 0.6 m^3.

Energy consumption
It is assumed the Busse MF-HKA4 treatment unit will produce the amount of reusable water as being calculated by the model. The treated water will be reused for its defined purpose by Aquacycle, which is toilet flushing and garden irrigation, and the remaining or the “spillage’ can be applied for e.g. the laundry (washing machine) and the dishwasher. From the calculation in sub-subsection 2.8.6 it can be seen that the Busse MF-HKA4 uses on average **4.0 kWh/m^3**. To pressurise the treated water for further usage within the household another **0.17 kWh/m^3** would be required, similar to strategy 1 (rainwater use). It means a total energy consumption of: 4.0 + 0.17 = **4.17 kWh/m^3**.

4.2.5.2 Strategy S3Wy: Wastewater reuse at cluster scale

In strategy S3Wy the wastewater from the unit blocks will be drained into cluster wastewater stores in stead of being drained and treated at unit block (household) scale. Each cluster has its own wastewater storage tank and their estimated sizes are (for a maximum of four days storage):

Cluster 1 – DH: 35 m^3
Cluster 2 – RH: 285 m^3
Cluster 3 – Quatro MFH: 36 m^3
Cluster 4 – Mansions: 78 m^3
Cluster 5 – Live & work: 40 m^3
Cluster 6 – "Small Ind. & Services": 68 m^3

The treatment will take place through vertical flow constructed wetlands, similar to strategy 2 (greywater treatment) preceded by some form of pre-treatment, e.g. by means of a septic tank. As prescribed in the modeling program, treated wastewater can only be reused at unit block (household) scale for toilet flushing and garden irrigation, and at cluster scale only for public open space irrigation. So the amount of "spillage" can be applied for e.g. the laundry (washing machine).

Energy consumption
As can be read under sub-subsection 4.2.4 (strategy S2Gx, greywater reuse) the total energy consumption for (a) the treatment part and (b) the part to pump the treated and collected greywater, or in this case wastewater, from a cluster storage tank back to the households will be: 0.21 + 0.4 = **0.61 kWh/m^3**

4.2.5.3 Strategy S3Wz: Wastewater reuse at catchment scale

This strategy is regarding the collection of wastewater at catchment scale, where it will not only be treated for reuse but also for the production of energy. Within the Aquacycle input files the settings will be in such a way that treated wastewater will be used for toilet flushing and garden & public open space irrigation. Again the "spillage" can be used for other applications, like for the washing machine. The size of the storage tank is about 542 m^3 (the sum of the cluster tank sizes of strategy S3Wy), making it able to store a volume that can be produced by 598 households during four consecutive days.

Energy consumption
For the estimation of the energy consumption, design data has been used of a new development "Noorderhoek" in Sneek (The Netherlands) of 250 households with 575 inhabitants in total. The most crucial component is the USAB reactor as described in sub-subsection 2.8.7. The treatment system not only requires energy but will also produce energy (biogas), resulting in a net energy production of **-1.87 kWh/m^3**. A description and the calculations can be found in Appendix 5.

Like with the previous calculations, again there is one dilemma: the treated water in Noorderhoek will not be pumped back to the houses for reuse opportunities, but discharged into the surface water. Therefore, that part -to pump the treated water collected in a catchment storage tank back to the houses- has been estimated to be about 30% higher than for a conventional, centralised system, like applied for the baseline strategy (due to economy of scale effect). However, the figure mentioned under the baseline strategy of 0.54 kWh/m^3 includes the total energy consumption of (1) water collection (extraction), (2)

treatment and (3) pumping into the distribution network. It may be reasonable to assume that about 40% to 50% of this total is required for pumping (to be on the safe side, assume 50%), finally resulting in: 0.54 x 1.30 x 0.50 = **0.35 kWh/m^3**.

The economy of scale effect has relatively less influence on a catchment scale supply system compared to a cluster scale supply system. That is the reason why an increase of only 30% has been considered in stead of 50% as was estimated for a cluster scale supply system (see strategy S2Gx, sub-subsection 4.2.4).

With the energy required to pump the treated water back to the households included, the overall net energy production will be:
-1.87 + 0.35 = **-1.52 kWh/m^3**

4.2.6 Strategy 4: Stormwater use at cluster and catchment scale

4.2.6.1 Strategy S4Sy: Stormwater use cluster scale:

Strategy S4Sy involves the collection of stormwater into cluster stormwater stores and its use. Unit block (household) runoff as well as road runoff will be collected into the cluster stores. Treated stormwater will and can only be used within the modeling program for toilet flushing and garden & public open space irrigation. The "spillage" can be used for other applications. Each cluster has its own stormwater storage tank and their estimated sizes are (four days storage):

Cluster 1 – DH:	130 m^3
Cluster 2 – RH:	340 m^3
Cluster 3 – Quatro MFH:	80 m^3
Cluster 4 – Mansions:	65 m^3
Cluster 5 – Live & work:	105 m^3
Cluster 6 – "Small Ind. & Services":	165 m^3

The cluster stormwater store can -at least for the majority of the clusters- be located in the basement of the building. Only for the clusters 'Double Houses' and 'Row Houses' this option won't be applicable. For these an underground storage tank can be constructed within the cluster.

Energy consumption
The stormwater will flow by gravity force into the cluster stores, so that part will not need energy. The next part however, to treat the water and to pump it back to the households requires energy. The pumping part will be similar to the estimation in strategy S2Gx (greywater reuse) and the treatment part is estimated to be 0.25 kWh/m^3. Finally the estimated energy consumption will be: 0.25 (treatment) + 0.4 (pumping) = **0.65 kWh/m^3**

4.2.6.2 Strategy S4Sz: Stormwater use at catchment scale:

Instead of collecting the stormwater in separate cluster storage tanks it can also be drained into one big tank in the heart of the new development, e.g. in between the row houses of cluster number two (see sketch in Figure 4.3). Since it should be avoided to damage the clay layer (at a depth of 1.2 - 3.0 m), the storage tank

can be constructed partly under and partly above the ground and be covered with earth and grass. This artificial hill can be integrated in a green park area, giving a special effect within the flat adjacent areas. The water from the storage tank should be treated and pumped to the households for further usage.

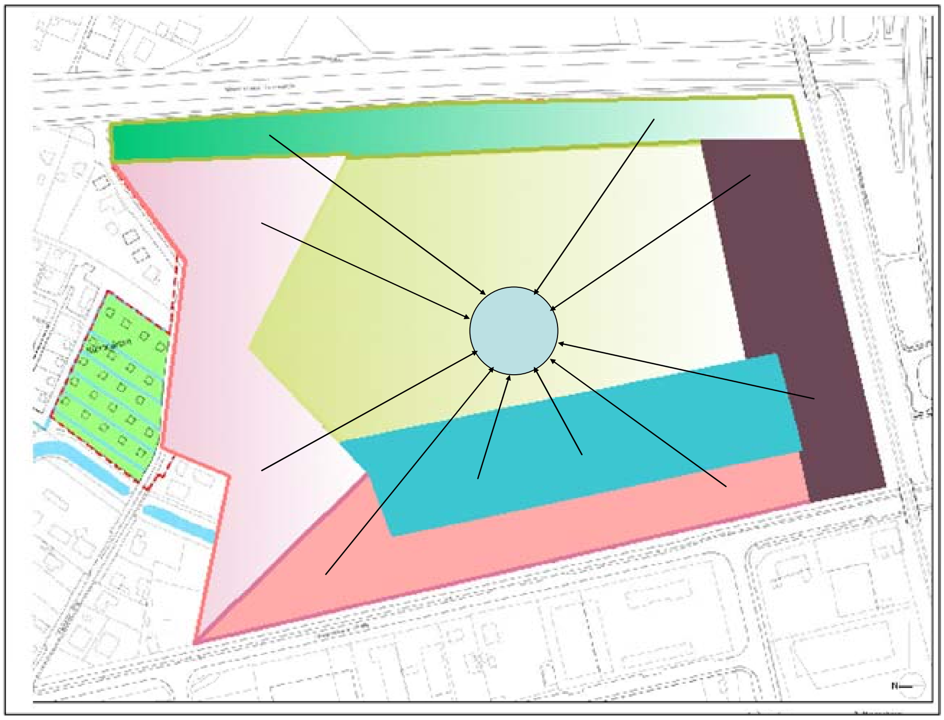

Figure 4.3 **Cluster stormwater drained to a catchment storage tank (or pond)**

Another option is to drain and temporary store the stormwater into an artificial lake or pond before reusing it. It also can be dug in between the row houses of cluster number two. Also in this case the clay layer should not be damaged: with a total storage capacity of about 885 m^3 (the sum of the cluster storage tank sizes of strategy S4Wy) and a depth of 1.0 meter, the diameter of an -assumed-circular pond should be circa 35 meter. An art impression is shown in Figure 4.4.

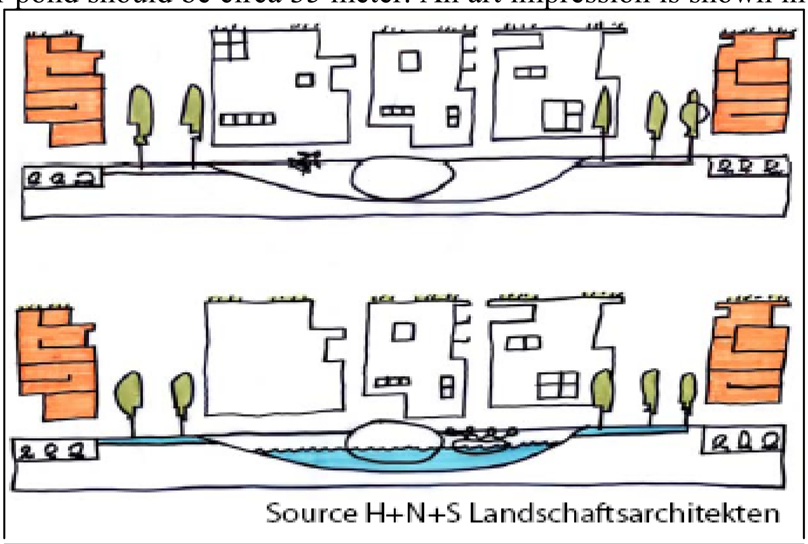

Figure 4.4 **Temporary retention of stormwater (Source: HCU)**

There are two options to filter this water prior to being pumped to the households:

1. The water can be filtered through a filter bed made of gravel and/or sand constructed along the bank of the pond seeping into perforated pipes and collected in a vertical standpipe, from which it can be pumped. This has been applied in a new development called De Schooten in the city Den Helder, The Netherlands. The filtered water is used to flush toilets and it is expected to save about 30% on imported water.
   The toilets should also be connected with the reticulated system, in case of water shortage or when a defined minimum water level in the pond has been reached (SenterNovem, 2008).

2. The second option is by applying bank filtration: a shallow well can be constructed about 100 to 150 meters away from the pond and channel. The distance of 100 to 150 meters will result in a travel time of about 60 days, which is necessary for adequate treatment.

Through the implementation of an open stormwater drainage system (swales) and a pond within the new development, water becomes visible and will enhance the identification of the inhabitants with their environment. Furthermore it will improve in particular the biodiversity. To keep water level fluctuations between limits there should be enough open water for buffering: e.g. for the new development Leidsche Rijn in The Netherlands it was calculated that 10% of the total area has to be open water. However, it should be realised that “Leidsche Rijn” is a semi-closed systems: only during extreme events water will be pumped out or led in to balance the situation between minimum and maximum fluctuation levels.

Energy consumption

The stormwater will flow by gravity force into the catchment store, so that part will not consume energy. The next part however, to treat the water and to pump it back to the households requires energy. The pumping part will be similar to the estimation in strategy S3Wz (wastewater reuse at catchment scale) and the treatment part is estimated to be 0.2 kWh/m^3. Finally the estimated energy consumption will be: 0.2 (treatment) + 0.35 (pumping)) = **0.55 kWh/m^3**

5 Results

5.1 Formation of six clusters for Aquacycle

The preliminary design and data available for the Haulander Weg area have been used to create the earlier mentioned baseline strategy and other strategies. The total area -or the catchment in Aquacycle terms- has been divided into six so called clusters or “neighbourhoods”. Within each cluster, unit blocks or “households” of the same type can be found. Minor adaptations had been made in the plan or lay-out to “cluster” these similar unit blocks; e.g. the two small

"Infrastructure" areas with its main function of Kindergarten have been erased completely and the Row Houses have been brought together and therefore it was necessary to shift the Quatro-MFH a bit westwards. Below are shown two lay-outs: Figure 5.1 showing the original (preliminary) plan and Figure 5.2 showing the plan divided in the six clusters.

It should also be noted that cluster number six (small industries & services) was not further specified in the data and for that reason it has been assumed it will consist of 75 unit blocks (scrutinised in Table 5.1).

According to the preliminary design the following numbers will be considered to be constructed within each cluster:

Cluster 1: DH; Double Houses (two homes under one roof)	39
Cluster 2: RH; Row Houses	314
Cluster 3: Quatro-MFH; Quatro-More Family Houses	40
Cluster 4: Mansions; block of flats (apartment houses)	86
Cluster 5: Live & work units	44
Cluster 6: Small industries and services	75 (assumed)
Total number of units	598

According to Görges (2008) the occupancy for each and every household is assumed to be three. This number will also be regarded in this study.

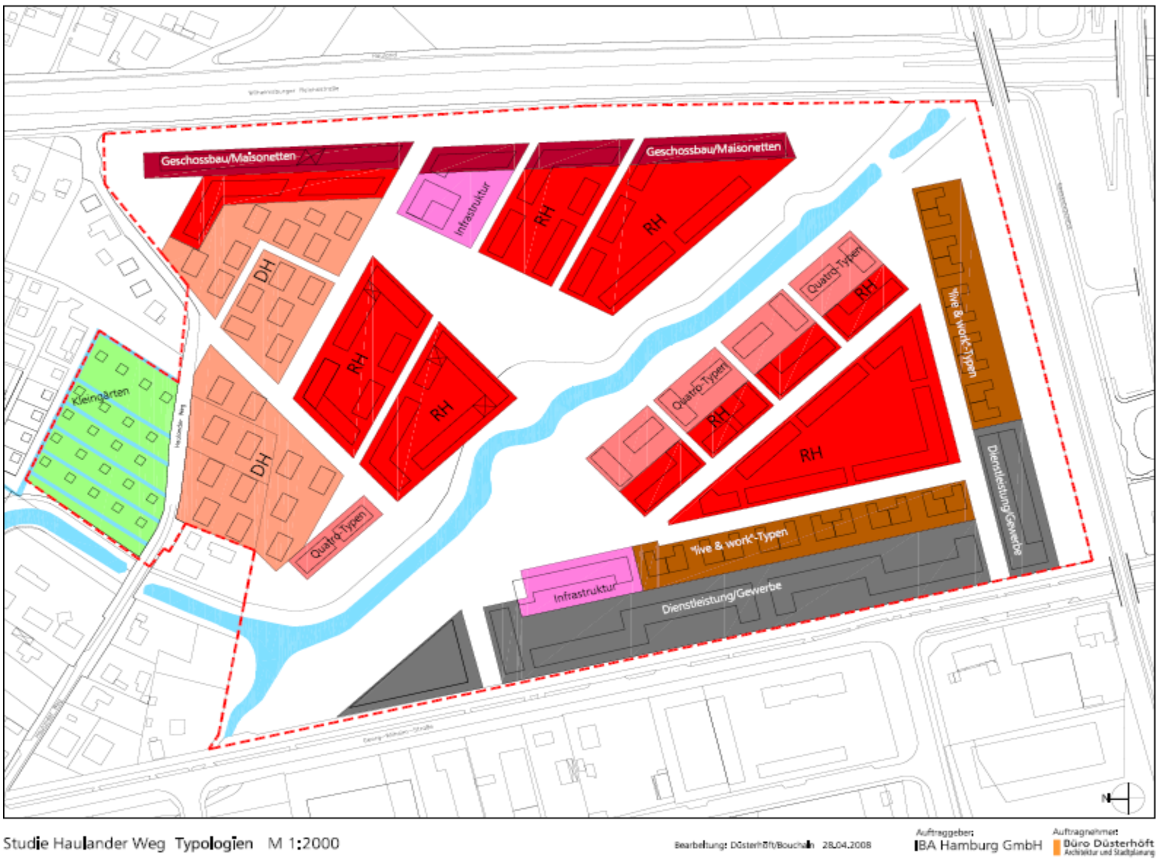

Figure 5.1 The original preliminary plan of the study area (Source: IBA, Hamburg)

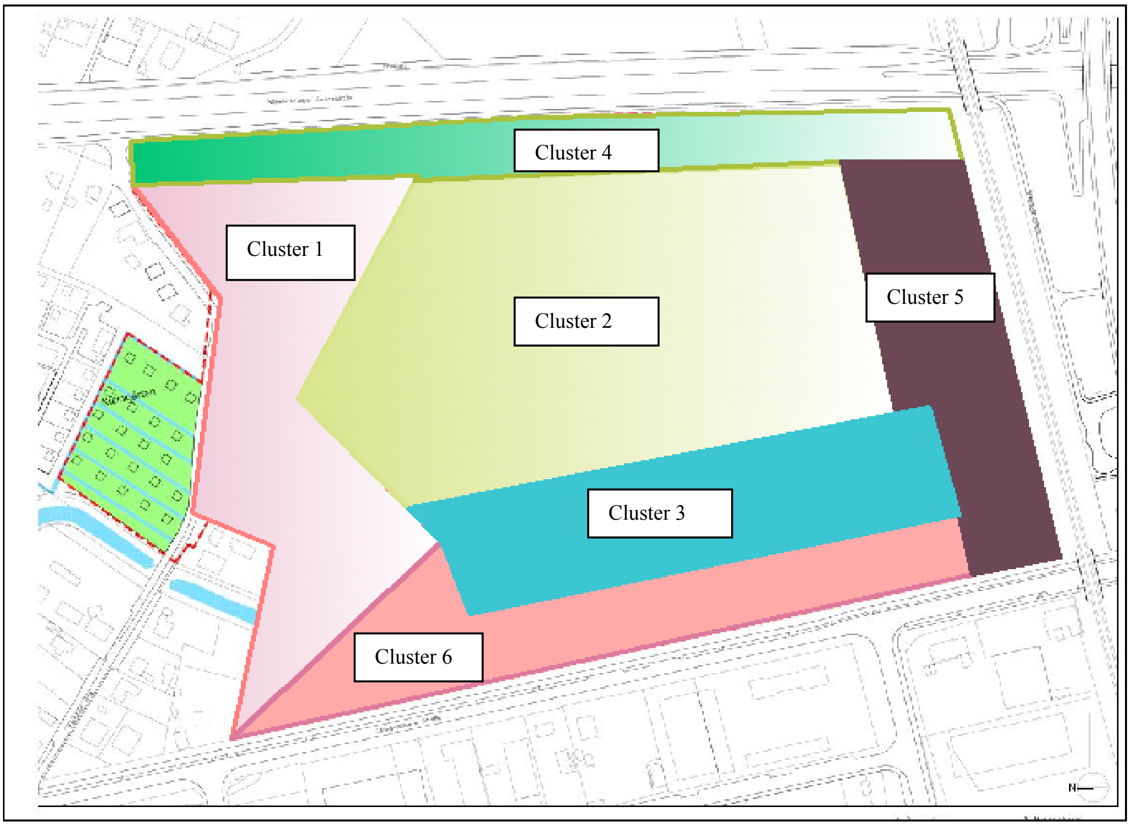

Figure 5.2 **The six developed cluster areas within the study area (Adapted from: IBA, Hamburg)**

With the data provided by IBA_HAMBURG a ratio of the distribution of the areas could be estimated in such a way that it could fit in the input file format of the modeling program Aquacyle. It was done by measuring the sizes of the various areas with a ruler from the plan. For the Double Houses and Row Houses this could be done straightforward, but for the remaining unit block (household) types it was a bit more complicated. The size of garden and pavement were estimated with a certain ratio, e.g. 4:1 for Double Houses, 3:1 for Row Houses and Quatro-MFH, and 0.5:1 for Live & Work. An overview can be found in the Table 5.1 below.

Table 5.1 Overview distribution of areas within the six clusters

No. Living Units	Unit Block area [m²]	Garden area [m²]	Roof area [m²]	Pavement area [m²]	Total living area [m²]	Road area [m²]	Public open space area [m²]	Total cluster area [m²]	Ratio Garden : Pavement
Cluster 1 – DH: Double Houses (two homes under one roof)									
39	468	314.4	75	78.6	18252	2380	10000	30632	4:1
Cluster 2 – RH: Row Houses									
314	122	62.7	38.4	20.9	38308	5050	32000	75358	3:1
Cluster 3 – Quatro MFH: Quatro-More Family Houses									
40	180	90	60	30	7200	2020	8000	17220	3:1
Cluster 4 – Mansions (block of flats, apartment houses)									
86	38.4	1.4	34.5	2.5	3302.4	2020	7500	12822.4	0.56:1
Cluster 5 – Live & work									
44	235.2	50.9	82.5	101.8	10348.8	1370	5000	16718.8	0.5:1
Cluster 6 – "Small Industries, Services": ***substituted by 75 houses***									
75	240	47.1	98.7	94.2	18000	1660	2500	22160	0.5:1
TOTAL									
598	95411.2	41441.9	31382.1	22587.2	95411.2	14500	65000	174911.2	-

It appeared a correction had to be made for the scale (1:2000) of the plan: for areas [m²] the measured value to be multiplied with a factor 2.5 and consequently for distances [m] with the square root of 2.5. Also, two areas have been excluded: the allotment (garden) area and the so called "infrastructure area" (mainly used for kindergarten). In other words only those areas used for (**1**) the construction of houses and small industries and services, (**2**) the roads and (**3**) public open space have been considered. And lastly the reserved area for "small industries and services" has been modified in an area or cluster with an estimated 75 houses, for the reason that no further details where specified regarding this area, just only the size (18000 m²). The garden / pavement ratio for this area was chosen 0.5 : 1, the total roof area was measured from the plan (7405 m²) and the roof size per unit block estimated to be about 100 m² (after calculations: 98.7 m²) and thus resulting in 75 living units. It rather well fits with the latest information from IBA_HAMBURG that most probably no small industries and services will be build at all, but houses instead. In this way it also does not affect the Aquacycle "indoor water usage profile", which is predominately designed for domestic water use.

The other data, not related to area sizes, have been set as follows and are shown in the following Table 5.2 (they are identical for all six clusters):

Table 5.2 Part of measured parameters file

7	Per cent of unit block garden irrigated as a %:	65%
11	Per cent of public open space irrigated as a %:	40%
12	Water supply leakage rate as a %:	9%, acc. to Reid (2008)
13	Cluster stormwater output flows into Cluster No.?:	0
14	Cluster wastewater output flows into Cluster No.?:	0

5.2 Aquacycle strategies: a summary and graphs

For an overview of the strategies reference is made to the Table 4.1 in sub-section 4.2.

Although the strategies have been described in detail in sub-section 4.2, they again will be briefly portrayed in the next sub-subsections: a summary of the technologies selected for the treatment of the different water types with the aim to be reused within the households, as well as its impact on the energy consumption. Each strategy was run in Aquacycle, calculating the water balances and with the results directly shown in graphs and the most important values given in output data files. Not the graphs, but only the output data files (in tables) are presented in an Appendix (Appendix 6, on CD-ROM).

The point is Aquacycle only reuses treated water for a limited number of options, e.g. the reuse of greywater will only be applied for sub-surface irrigation (see Table 3.3). For this reason the output data values of the so called "spillage" have also been considered as a useful resource that can be utilized for e.g. toilet flushing, the laundry and -assumed the amount is sufficient and the quality according to prescribed standards- even for the dishwasher. In the following sub-subsections two words will be used to make distinction between the (limited) reuse options -and their values- as generated by the model (**USE**) and those that has the potential to be reused but was not given "a function" by the model (**SPILLAGE**).

Graphs from the amount of spillage for the catchment strategy (shown below) as well as for the cluster strategies, were made in MS Excel to check whether the amount is sufficient for a reuse option, or even for more than one option. The total number of graphs can be found in Appendix 7 (on CD-ROM). However, to avoid too microscopic graphs, the catchment-strategy-graphs below are just ranging from 1998 to 2007 (ten years in total) in stead of the full range of seventeen years (1991-2007) as shown in Appendix 7. But it gives a rather good impression.

For some of the strategies the red line, showing the amount of spillage that will be reused, crosses the blue line (the total amount of spillage) a couple of times (see the graphs below). It indicates that during certain periods there is a (minor) deficit, but that will be supplemented with imported water. Since it incorporates only small fractions, it has been neglected in the subsequent calculations.

After having calculated (and decided) on how much spillage can be reused and for which purposes, this particular amount of spillage has been deducted from the amount of imported water (in mm/y), as can been seen in another MS Excel file (Appendix 8, on CD-ROM): in first instance two water consumption calculations -one "excluding use of spillage" and one "including use of spillage"- in combination with the energy consumption calculations were developed. The calculations are per strategy for the catchment as well as for each cluster.

The creation and usage of data and tables described above is presented in a data flow diagram (Figure 5.3).

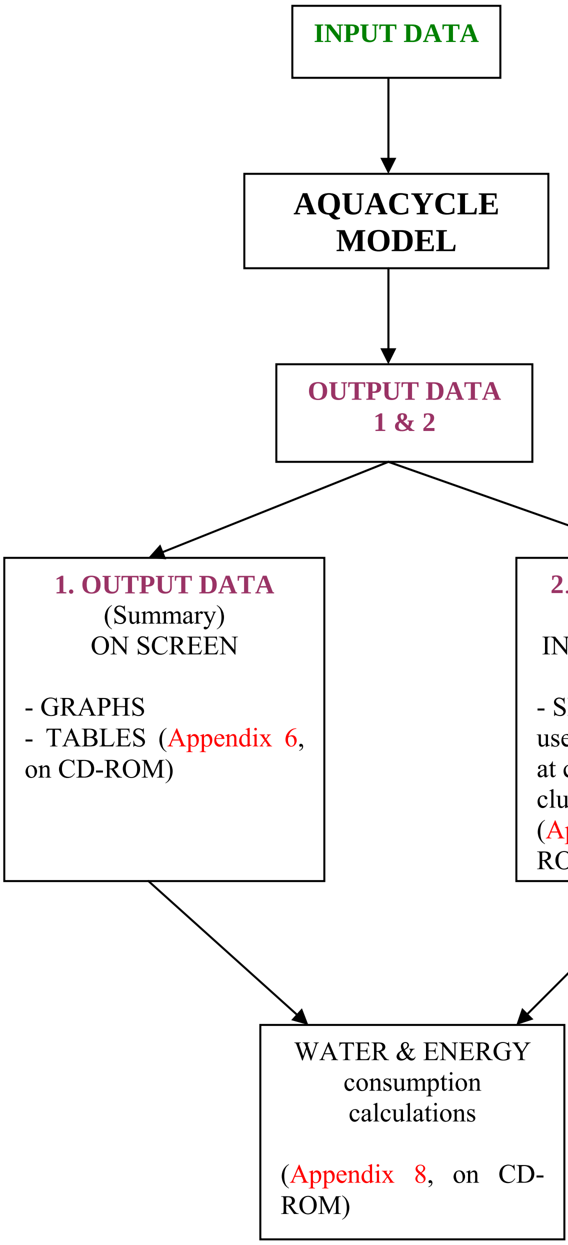

Figure 5.3 Overview data flow Aquacycle

5.2.1 Sbl: Baseline strategy

Conventional (centralised) systems for imported water, treatment of wastewater and pumping of stormwater into river Elbe.

Energy consumption
Conventional, centralised systems:
Water supply: **0.54 kWh/m^3**
Waste water: **0.60 kWh/m^3**
Stormwater: **0.03 kWh/m^3**

5.2.2 S0ws: Water saving technologies

Reduced amount of imported water just due to the application of water saving technologies.

Energy consumption
Same as mentioned under 5.2.1

5.2.3 S1Rx: On-site rainwater use

Like S0ws, including rainwater collection and USE at unit block scale (see Figure 5.4).

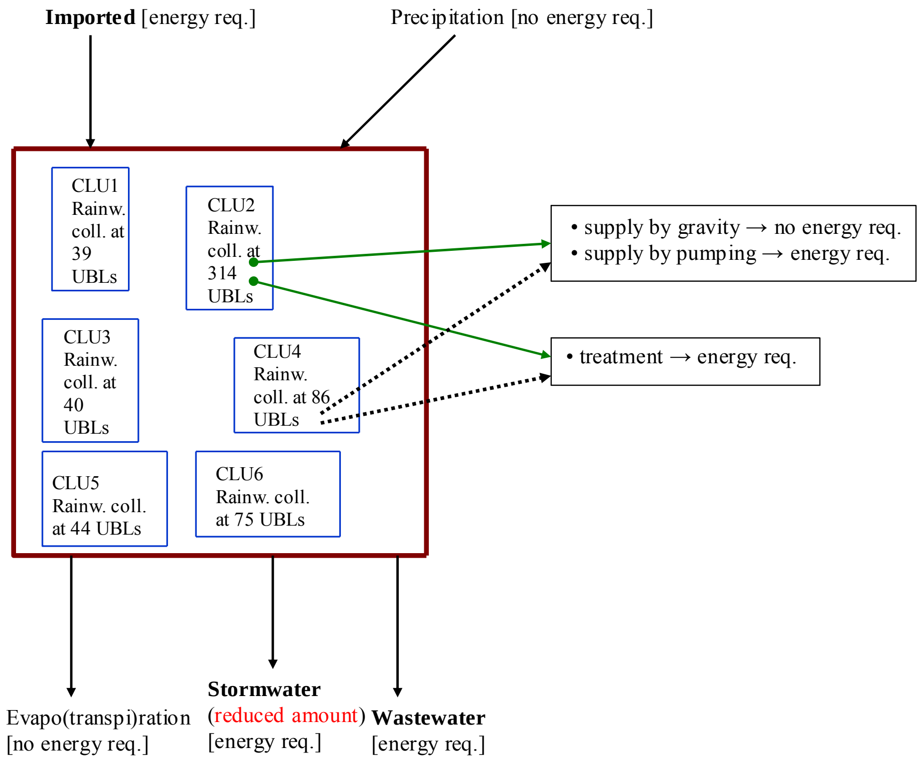

Figure 5.4 Overview use of rainwater at unit block scale

Different tank sizes selected for each house type within a cluster; respectively 2, 4, 3, 4, 2 and 2 m^3 and the first flush proportional to the size of the roof.

Rainwater USED for all indoor and outdoor unit block uses:

- Domestic hot water
- Domestic kitchen cold water
- Domestic bathroom cold water
- Domestic laundry cold water
- Domestic toilet water
- Domestic garden irrigation

Average SPLILLAGE of raintank water: 2454 m^3/y ≈ 6.7 m^3/d ≈ 11.2 L/hh/d ≈ 4.1 kL/hh/y (see Table 5.3)

Table 5.3 Raintank system performance

Component	Catchm	Clu 1	Clu 2	Clu 3	Clu 4	Clu 5	Clu 6
Average annual values	kL	kL/hh	kL/hh	kL/hh	kL/hh	kL/hh	kL/hh
USE of raintank water	21628	48	28	44	26	50	55
SPILLAGE of raintank water	2454	8	0	1	0	11	19

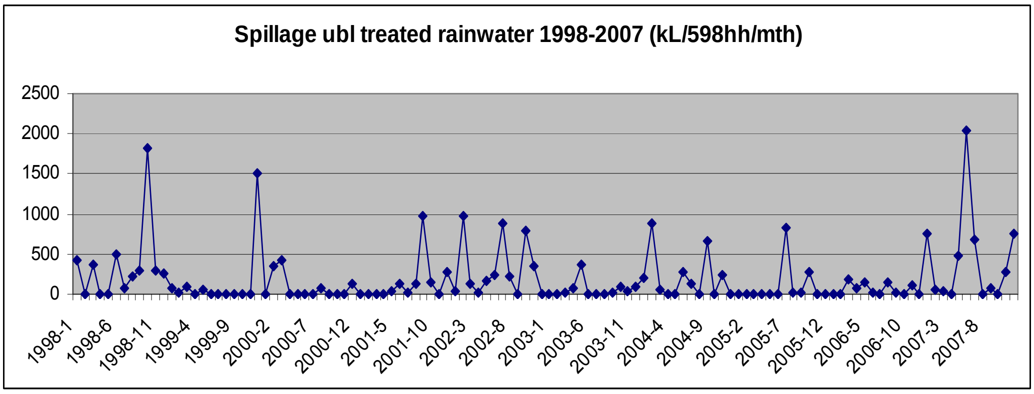

Figure 5.5 Spillage unit block treated rainwater 1998-2007 (kL/598hh/mth)

The SPILLAGE is not sufficient for further usage on a regular base (see Figure 5.5).

Energy consumption

The estimated energy consumption for pressurising the water through a filter with a small pump (each household to be provided with its own pump) is:
0.17 kWh/m^3 (adapted from Reid, 2008).

5.2.4 S2Gx: Greywater reuse

Like S0ws, including collection of greywater from kitchen, bathroom and laundry at cluster scale and the reUSE of treated greywater for sub-surface irrigation at unit block scale (see Figure 5.6).

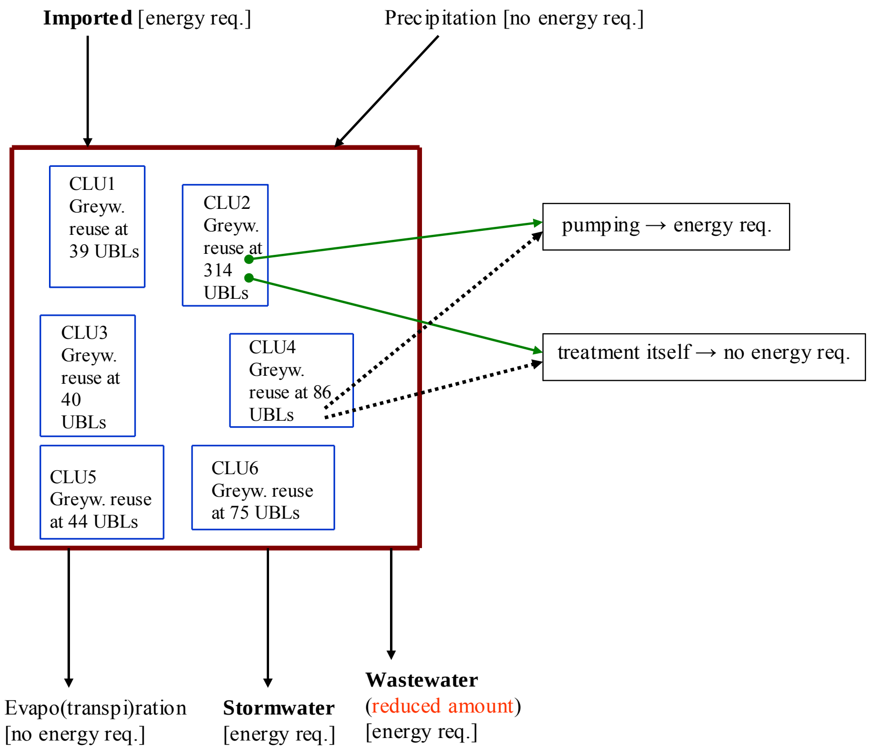

Figure 5.6 Overview reuse of greywater at unit block scale

Average SPILLAGE of greywater: 42402 $m^3/y \approx 116\ m^3/d \approx 194$ L/hh/d ≈ 71 kL//hh/y (see Table 5.4)

Table 5.4 Sub-surface greywater system performance

Component	Catchm	Clu 1	Clu 2	Clu 3	Clu 4	Clu 5	Clu 6
Average annual values	kL	kL/hh	kL/hh	kL/hh	kL/hh	kL/hh	kL/hh
USE of greywater	2154	10	3	4	0	2	2
SPILLAGE of greywater	42402	63	70	68	74	71	71

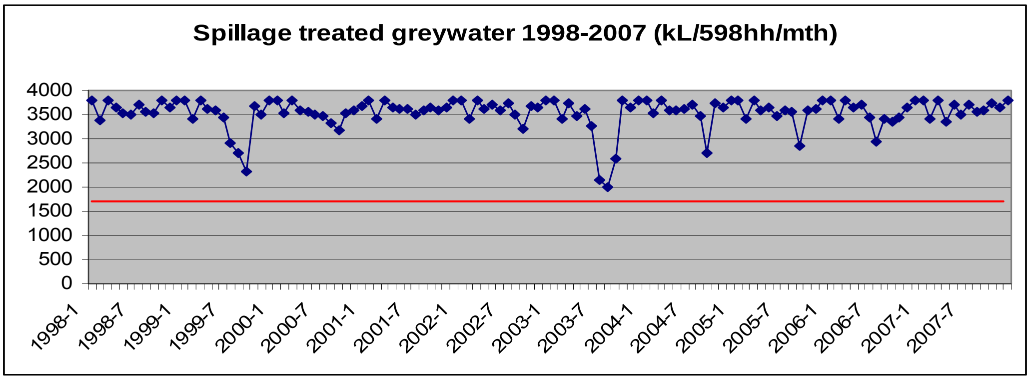

Figure 5.7 Spillage treated greywater 1998-2007 (kL/598hh/mth)

The SPILLAGE is sufficient to cover the needs for toilet flushing, the washing machine and the dishwasher; saving 122 mm/y or 1784 kL/598hh/mth on imported water (see Figure 5.7).

Energy consumption

The total energy consumption for (a) the treatment part and (b) the part to pump the collected and treated greywater from a cluster storage tank back to the households will be: 0.21 + 0.4 = **0.61 kWh/m^3**

5.2.5 S3: Wastewater reuse at unit block, cluster and catchment scale

5.2.5.1 S3Wx: On-site wastewater reuse

Like S0ws, including collection of wastewater at unit block scale from kitchen, bathroom, laundry and toilet and the reUSE of treated wastewater for toilet flushing and garden irrigation at unit block scale (see Figure 5.8).

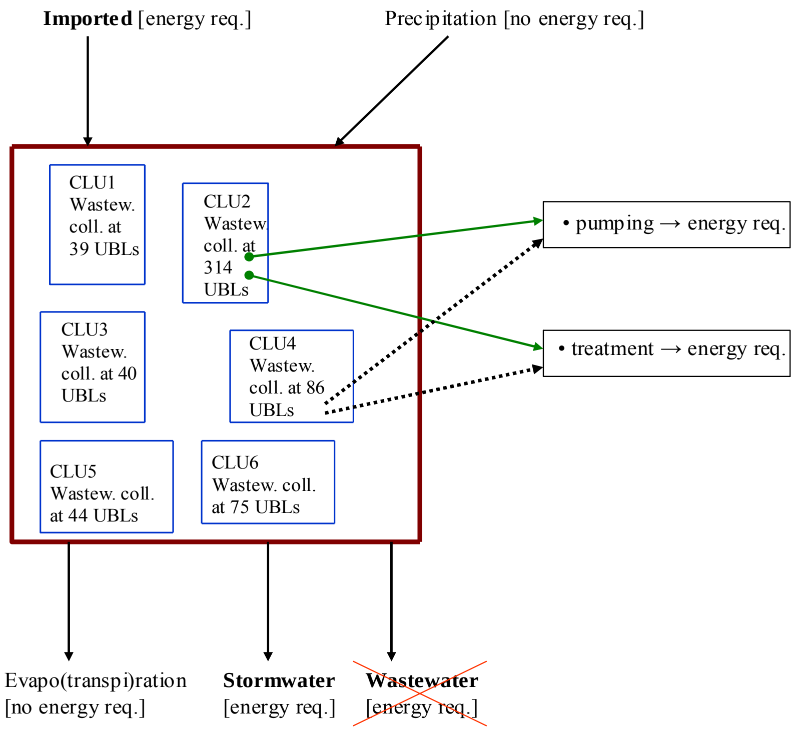

Figure 5.8 Overview reuse of wastewater at unit block scale

The maximum daily storage capacity of the Busse MF treatment unit is 0.6 m^3.

Chosen and set in Aquacycle: "wastewater overflow to stormwater". For this reason, the amount of wastewater discharged is negligible.

Average SPILLAGE of treated wastewater: 42340 m^3/y ≈ 115.9 m^3/d ≈ 194 L/hh/d ≈ 71 kL/hh/y (see Table 5.5).

Table 5.5 On-site wastewater treatment system performance

Component	Catchm	Clu 1	Clu 2	Clu 3	Clu 4	Clu 5	Clu 6
Average annual values	kL	kL/hh	kL/hh	kL/hh	kL/hh	kL/hh	kL/hh
USE of treated wastewater	7219	1920	11	13	8	10	10
SPILLAGE of tr. wastewater	42340	62	70	68	73	71	71

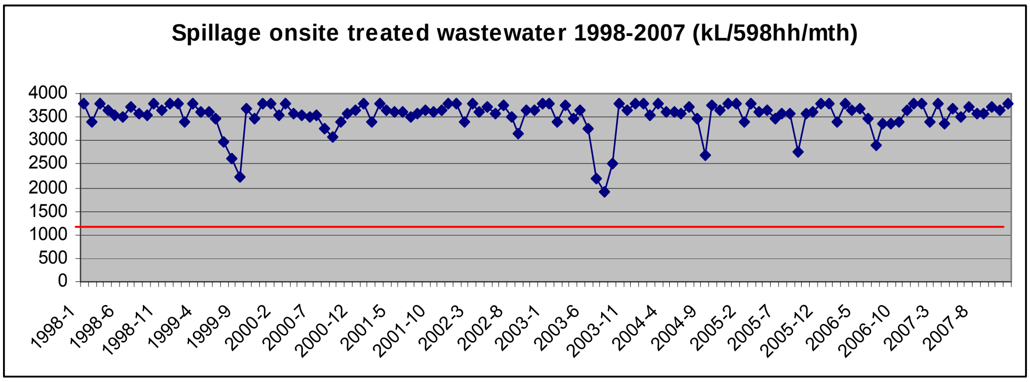

Figure 5.9 Spillage on-site treated wastewater 1998-2007 (kL/598hh/mth)

The SPILLAGE is sufficient to cover the needs for the washing machine and the dishwasher; saving 94 mm/y or 1365 kL/598hh/mth on imported water (see Figure 5.9).

Energy consumption
Each household will be provided with a Busse MF-HKA4 wastewater treatment unit for 1 to 4 persons, which will consume on average of 4.0 kWh/m^3. With 0.17 kWh/m^3 for pressuring the treated water for reuse within the household, it becomes in total: 4.0 + 0.17 = **4.17 kWh/m^3**

5.2.5.2 S3Wy: Wastewater reuse at cluster scale

Like S0ws, including unit block wastewater drained to cluster wastewater stores. Treated wastewater USEd for toilet flushing and garden irrigation (unit block scale) & public open space irrigation (cluster scale). See Figure 5.10 below.

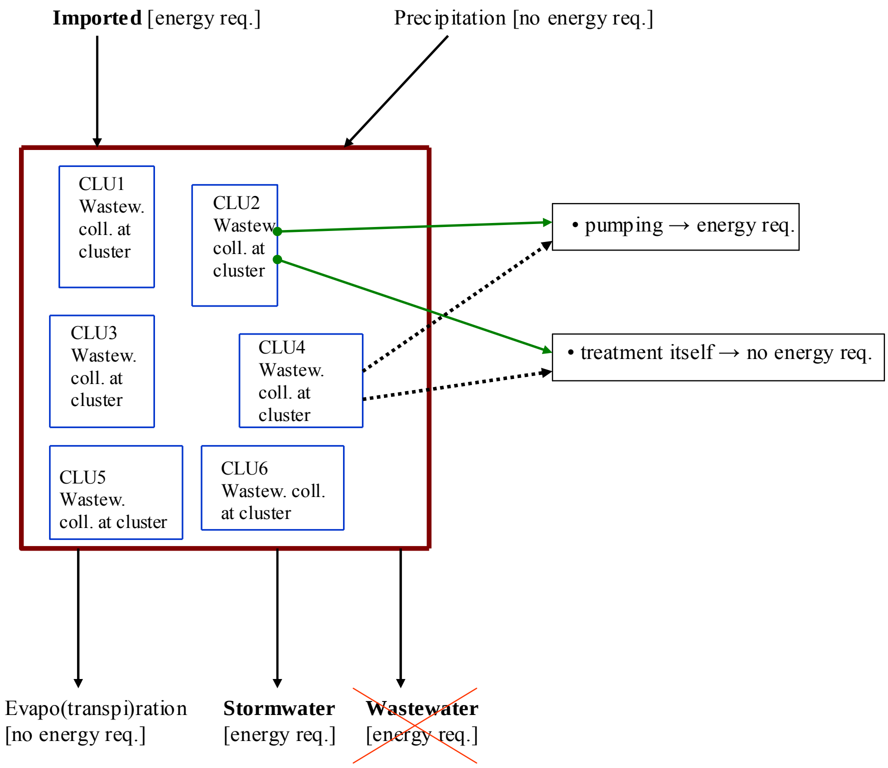

Figure 5.10 Overview reuse of wastewater at cluster scale

Storage capacity for four days, respectively 35, 285, 36, 78, 40 and 68 m^3.

Chosen and set in Aquacycle: "cluster scale wastewater overflow to stormwater". For this reason, the amount of wastewater discharged is negligible.

Average SPILLAGE of treated wastewater: 40547 $m^3/y \approx 111$ $m^3/d \approx 186$ L/hh/d ≈ 68 kL/hh/y (see Table 5.6).

Table 5.6 Cluster wastewater treatment system performance

Component	Catchm	Clu 1	Clu 2	Clu 3	Clu 4	Clu 5	Clu 6
Average annual values	kL	kL	kL	kL	kL	kL	kL
USE of treated wastewater	9001	935	4792	720	970	660	919
SPILLAGE of tr. wastewater	40547	2295	21223	2593	6154	2984	5293

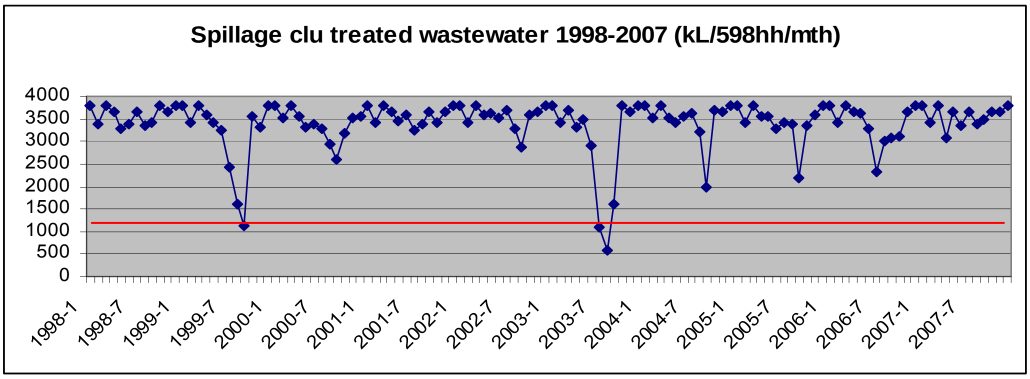

Figure 5.11 Spillage cluster treated wastewater 1998-2007 (kL/598hh/mth)

The SPILLAGE is sufficient to cover the needs for the washing machine and the dishwasher; saving 94 mm/y or 1365 kL/598hh/mth on imported water (see Figure 5.11).

Energy consumption
Similar to the treatment of greywater (strategy S2Gx), including a septic tank: the total energy consumption for (a) the treatment part and (b) the part to pump the collected and treated greywater from a cluster storage tank back to the households will be: 0.21 + 0.4 = **0.61 kWh/m^3**

5.2.5.3 S3Wz: Wastewater reuse at catchment scale

Like S0ws, including unit block wastewater drained to catchment wastewater stores. Treated wastewater USEd for toilet flushing and garden irrigation (unit block scale) & public open space irrigation (cluster scale). See Figure 5.12 below.

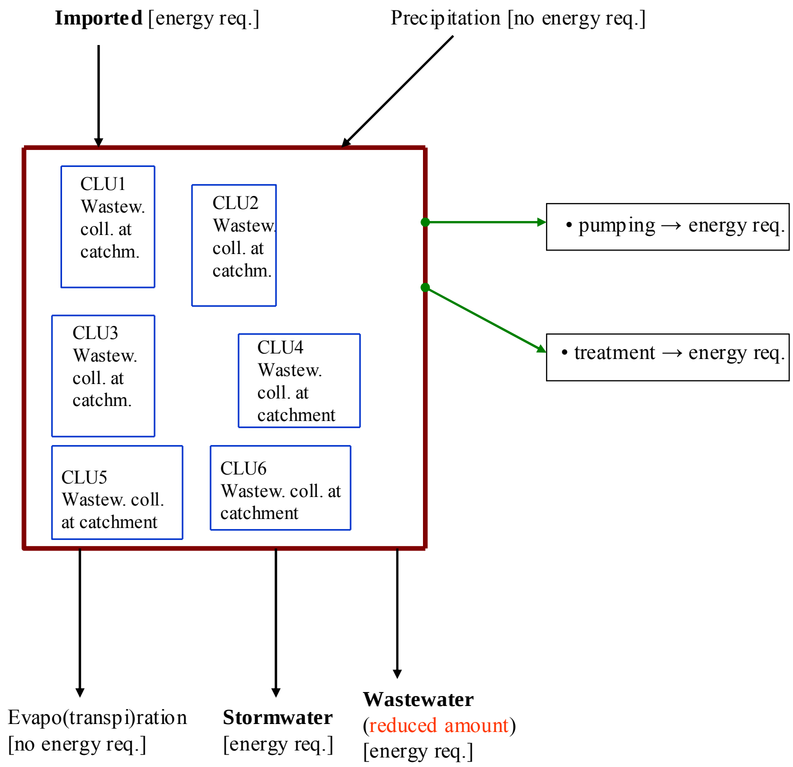

Figure 5.12 Overview reuse of wastewater at catchment scale

Catchment storage capacity for four days, which is the sum of the cluster tank sizes of strategy S3Wy = 542 m^3

Average SPILLAGE of treated wastewater: 44360 m^3/y ≈ 121 m^3/d ≈ 203 L/hh/d ≈ 74 kL/hh/y (see Table 5.7). For the calculations, this amount has been distributed proportionally over the six clusters.

Table 5.7 Catchment wastewater treatment system performance

Component	Catchm	Clu 1	Clu 2	Clu 3	Clu 4	Clu 5	Clu 6
Average annual values	kL	kL	kL	kL	kL	kL	kL
USE of treated wastewater	9377	-	-	-	-	-	-
SPILLAGE of tr. wastewater	44360	-	-	-	-	-	-

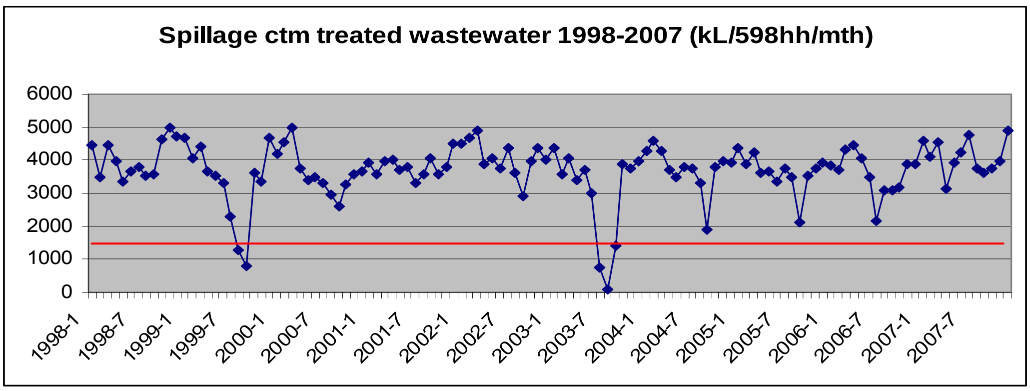

Figure 5.13 Spillage catchment treated wasterwater 1998-2007(kL/598hh/mth)

The SPILLAGE is sufficient to cover the needs for the washing machine and the dishwasher; saving 94 mm/y or 1365 kL/598hh/mth on imported water (see Figure 5.13).

Energy consumption
The wastewater treated with an UASB reactor according the DeSaH Project Noordhoek in Sneek (The Netherlands) will result in a net energy production of -1.87 kWh/m^3. The overall net energy production will be less due to the energy required (0.35 kWh/m^3) to pump the treated wastewater back to the houses, so: -1.87 + 0.35 = **-1.52 kWh/m^3** (overall net production).

5.2.6 S4: Stormwater use at cluster and catchment scale

5.2.6.1 S4Sy: Stormwater use at cluster scale

Like S0ws, including stormwater from "unit block runoff", "road runoff and "stormwater runoff" (the latter from excess public open space irrigation) drained to cluster stormwater stores. Treated stormwater USEd for toilet flushing and garden irrigation (unit block scale) & public open space irrigation (cluster scale). See Figure 5.14 below.

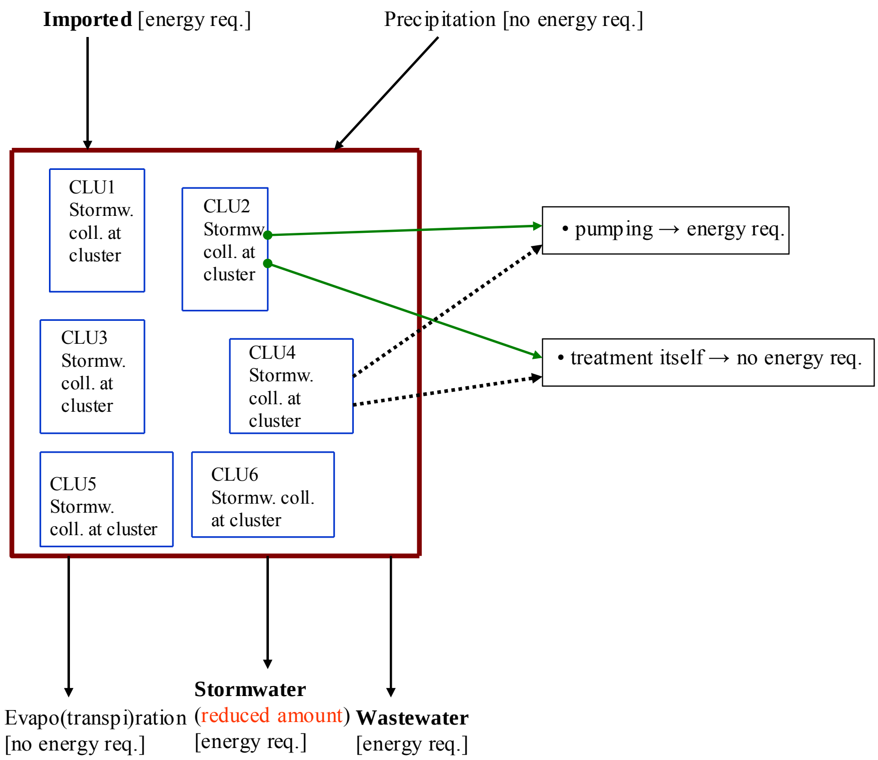

Figure 5.14 Overview use of stormwater at cluster scale

Storage capacity for four days, respectively 130, 340, 80, 65, 105 and 165 m^3.

Average SPILLAGE of stormwater: 60136 m^3/y ≈ 165 m^3/d ≈ 275 L/hh/d ≈ 101 kL/hh/y (see Table 5.8).

Table 5.8 Cluster stormwater system performance

Component	Catchm	Clu 1	Clu 2	Clu 3	Clu 4	Clu 5	Clu 6
Average annual values	kL	kL	kL	kL	kL	kL	kL
USE of stormwater	7679	897	3790	618	864	608	897
SPILLAGE of stormwater	60136	8187	20978	5206	4264	8117	13378

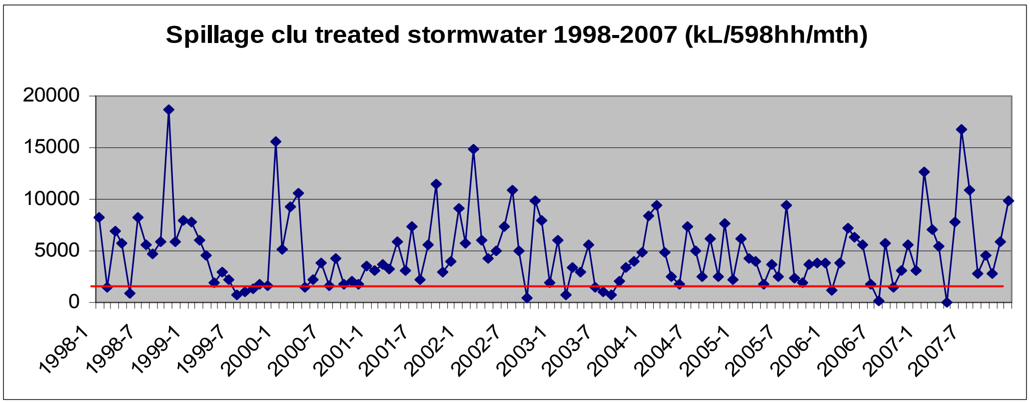

Figure 5.15 Spillage cluster treated stormwater 1998-2007 (kL/598hh/mth)

The SPILLAGE is (almost) sufficient to cover the needs for the washing machine and the dishwasher; saving 94 mm/y or 1365 kL/598hh/mth on imported water (see Figure 5.15).

Energy consumption

As the stormwater will be drained into the cluster storage tanks, there is only energy required for some treatment (filters) and to pump it back to the households: 0.25 + 0.4 = **0.65 kWh/m^3**

5.2.6.2 S4Sz: Stormwater use at catchment scale

Like S0, including stormwater drained to a catchment stormwater store. Treated stormwater USEd for <u>toilet flushing</u> and <u>garden irrigation</u> (unit block scale) & <u>public open space irrigation</u> (cluster scale). See Figure 5.16 below.

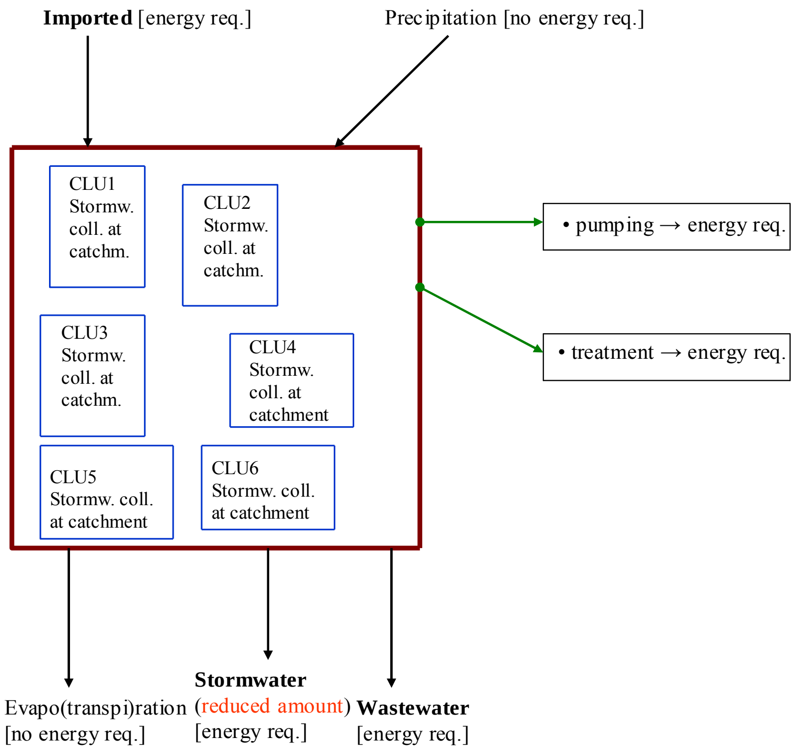

Figure 5.16 Overview stormwater use at catchment scale

Catchment storage capacity for four days, which is the sum of the cluster tank sizes of strategy S4Sy = 885 m^3

Average SPILLAGE of stormwater: 58338 m^3/y ≈ 160 m^3/d ≈ 267 L/hh/d ≈ 98 kL/hh/y (see Table 5.9). For the calculations, this amount has been distributed proportionally over the six clusters.

Table 5.9 Catchment stormwater system performance

Component	Catchm	Clu 1	Clu 2	Clu 3	Clu 4	Clu 5	Clu 6
Average annual values	kL	kL	kL	kL	kL	kL	kL
USE of stormwater	7812	-	-	-	-	-	-
SPILLAGE of stormwater	58338	-	-	-	-	-	-

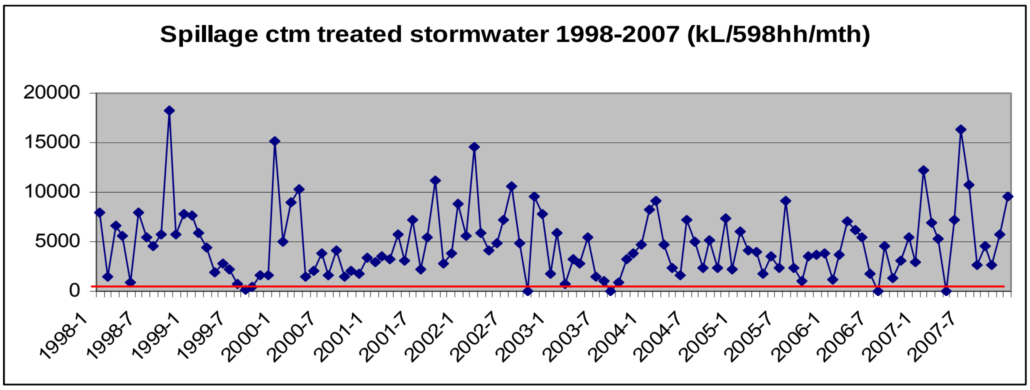

Figure 5.17 **Spillage catchment treated stormwater 1998-2007 (kL/598hh/mth)**

The SPILLAGE is sufficient to cover the needs for the washing machine and the dishwasher; saving 94 mm/y or 1365 kL/598hh/mth on imported water (see Figure 5.17).

Energy consumption

As the stormwater will be drained into the catchment storage tank, there is only energy required for some treatment (filters) and to pump it back to the households: 0.2 + 0.35 = **0.55 kWh/m^3**

For a quick reference, an overview of the energy consumption per strategy for the treatment of wastewater to be reused and for pumping it back to households is given in the following Table 5.10.

Table 5.10 **Overview energy consumption per strategy for treatment and pumping**

		ENERGY CONSUMPTION		
Strategy	**Description**	**Treatment [kWh/m^3]**	**Pumping after treatment [kWh/m^3]**	**Total [kWh/m^3]**
BL&S0ws	Water supply	(incl. in total)	(incl. in total)	0.54
BL&S0ws	Wastewater	(incl. in total)	(incl. in total)	0.60
BL&S0ws	Stormwater	-	(only pumping)	0.03
S1Rx	Rainwater use, ubl	(incl. in total)	(incl. in total)	0.17
S2Gx	Greywater reuse, ubl	0.21	0.40	0.61
S3Wx	Wastewater reuse, ubl	4.00	0.17	4.17
S3Wy	Wastewater reuse, clu	0.21	0.40	0.61
S3Wz	Wastewater reuse, ctm	-1.87	0.35	-1.52
S4Sy	Stormwater use, clu	0.25	0.40	0.65
S4Sz	Stormwater use, ctm	0.20	0.35	0.55

5.3 Results Aquacycle: water and energy consumption patterns at catchment and cluster scale for different strategies

From the calculations made in the MS Excel sheets (see Appendix 9) a number of bar diagrams could be developed presenting the water consumption in relation to the energy requirements for the different strategies at catchment scale as well as at the six cluster scales. In Figure 5.18, the plan of the area has been projected showing the diagrams "including the use of spillage" at cluster scale.

In addition, diagrams at catchment scale are displayed in triples:

- one showing the results in case "the spillage" is not included (Figure 5.19)
- the following "including the use of spillage" (Figure 5.20)
- and the third one "including the use of spillage and rainwater" (rainwater applied for bathroom needs only) (Figure 5.21)

Triple-bar diagrams have been developed for each cluster as well and can be found in Appendix 8.

The most remarkable observations and trends are mentioned and discussed below.

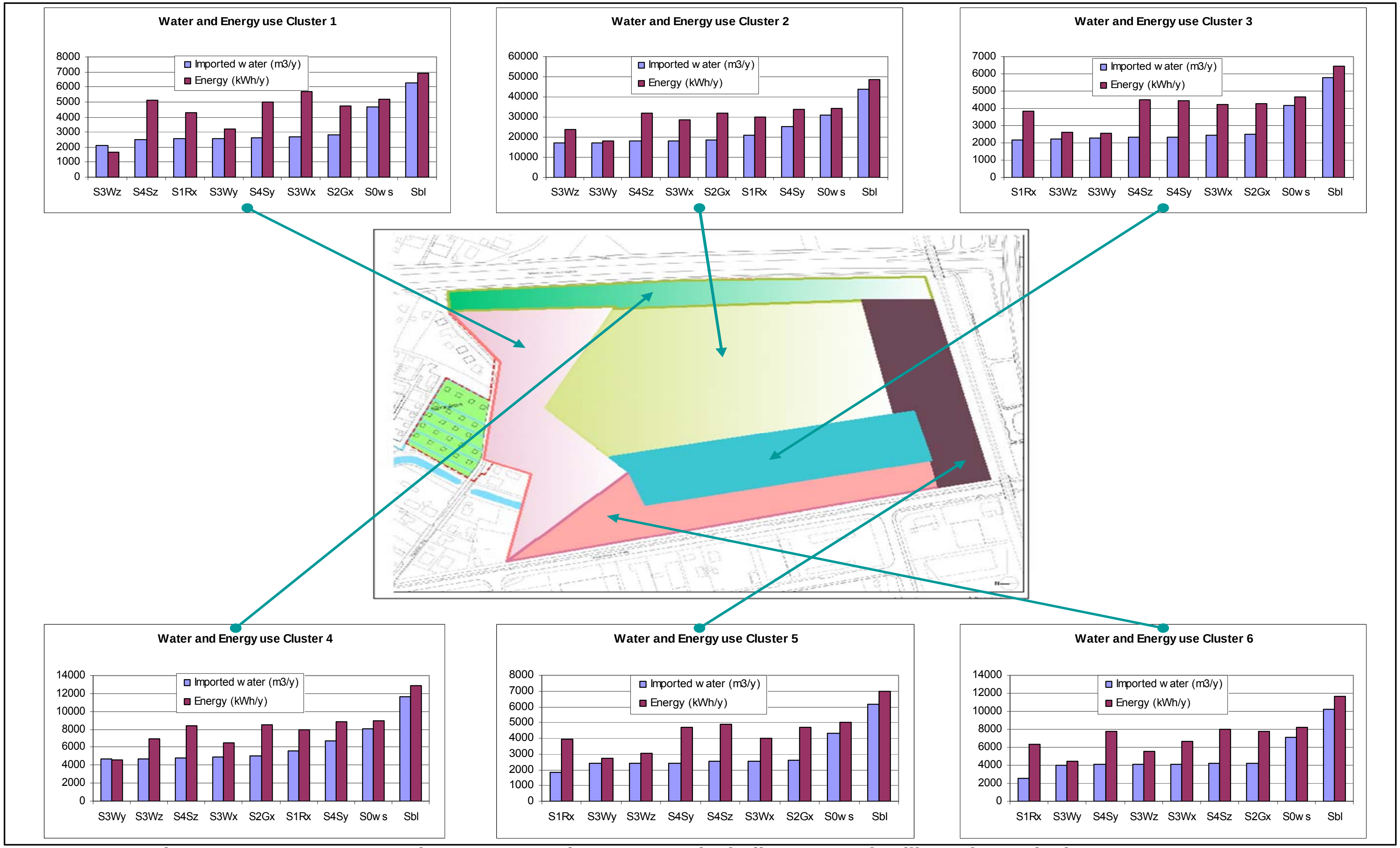

Figure 5.18 **Graphs on water and energy use -including reuse of spillage- for each cluster**

BAR DIAGRAMS AT CATCHMENT SCALE:

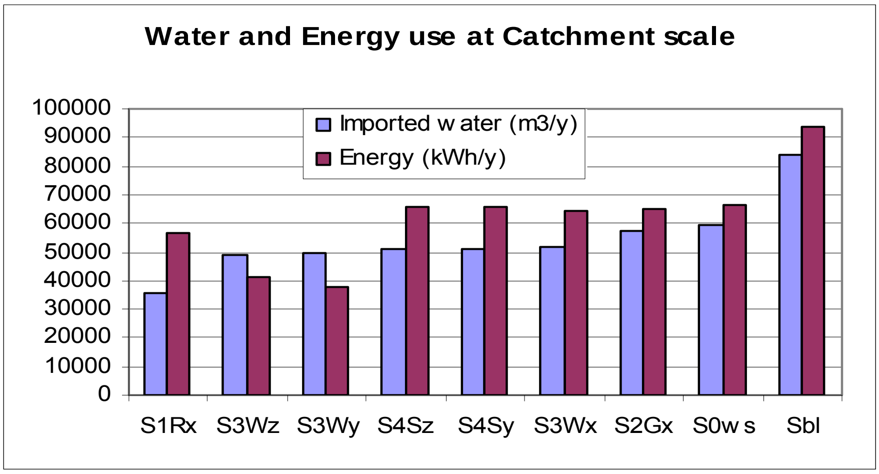

Figure 5.19 **Imported water and energy use at catchment scale, EXCL. use of spillage**

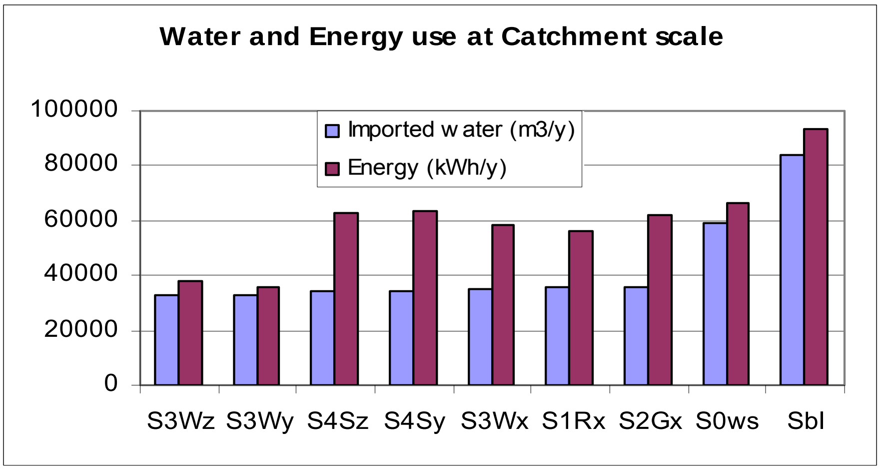

Figure 5.20 **Imported water and energy use at catchment scale, INCL. use of spillage**

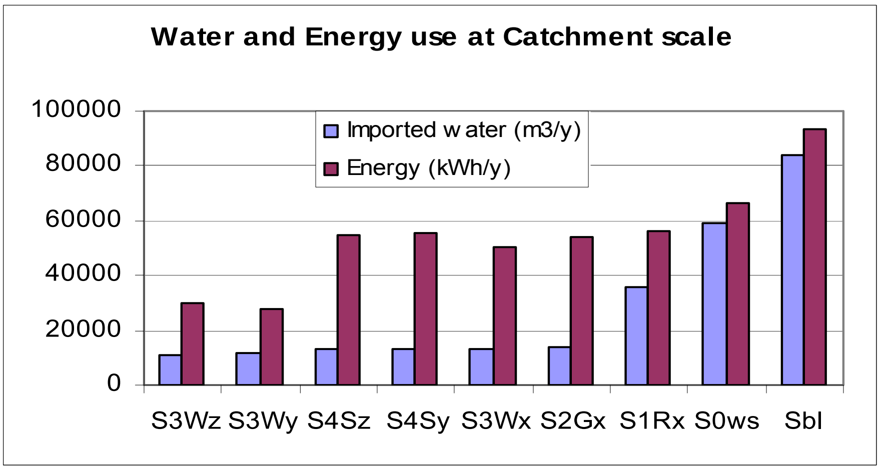

Figure 5.21 **Imported water and energy use at catchment scale, INCL. use of spillage and rainwater (rainwater for bathroom only)**

With the utilization of harvested rainwater, another reduction on imported water could be achieved. It was calculated how much it could provide for in the needs of the bathroom (the amount of spillage had not been sufficient for that purpose). The next Table 5.11 shows it can cover those needs up to 100 percent for the clusters 1, 3, 5 and 6.

Table 5.11 Harvested rainwater providing for the water needs of bathroom

	Catchm	Clu 1	Clu 2	Clu 3	Clu 4	Clu 5	Clu 6
Rainwater harvesting at unit blocks covering bathroom requirements	87%	100%	68%	100%	62%	100%	100%

Since the cluster bar diagrams show similar trends to the catchment bar diagrams, only the latter will be analysed in more detail and read as follows:

Imported water:
- The baseline strategy (Sbl) compared with S0ws shows that due to a number of water saving measures, a reduction of almost 30% can be accomplished.
- Since there is no deduction of "use of spillage" and "use of rainwater' for both Sbl and S0ws, the values for Sbl and S0ws are exactly the same in the diagrams.
- In Figure 5.21 another reduction of imported water is realised by also subtracting the use of rainwater applied for the needs in the bathroom, saving in total almost two-third (63.5%) of imported water for the strategies S2Gx, S3Wx, S3Wy, S3Wz, S4Sy and S4Sz.

Energy consumption:
- In Figure 5.20 and 5.21, the energy consumption is dependent on how much spillage was available and for which and for how many applications it could be used. Since the more spillage available and useful to cover certain needs, the more energy required to pump the spillage back to the households.
- It should be noted that for two strategies less energy is required for pumping, due to and as being set in the Aquacycle input files:
  - S3Wx: "wastewater overflow to stormwater"; because there is less energy required to pump stormwater into the river Elbe (only an estimated 0.03 kWh/m^3) than for discharging the wastewater (estimated: 0.60 kWh/m^3).
  - S3Wy: "cluster scale wastewater overflow to stormwater"; same as just mentioned above: there is less energy required to pump stormwater into the river Elbe (only an estimated 0.03 kWh/m^3) than for discharging the wastewater (estimated: 0.60 kWh/m^3).

- As could be expected the energy consumption for strategy S3Wz is one of the lowest in Figure 5.20 and 5.21, due to the fact that the wastewater treatment method (UASB) produces energy.
- Like mentioned under "imported water", it will be obvious there is no difference for the baseline strategy (Sbl) and S0ws in the three Figures with regard to the energy consumption.
- In both Figures (5.20 and 5.21) it can be noticed that the energy consumption of the various strategies is about the same or even less than of S0ws.

In the following Table 5.12 the baseline (Sbl) and S0ws strategies are compared at catchment and at cluster scale on the reduction (in %) of imported water and energy consumption, from the calculations "including the use of spillage".

Table 5.12 Sbl compared with S0ws on imported water (including use of spillage) and on energy consumption

	Imported water [m^3/y]			Energy [kWh/y]		
	Sbl	S0ws	Reduction [%]	Sbl	S0ws	Reduction [%]
Catchment	84132	59470	29.3	93403	66493	28.8
Cluster 1	6280	4687	25.4	6936	5209	24.9
Cluster 2	43934	30972	29.5	48384	34257	29.2
Cluster 3	5803	4150	28.5	6450	4654	27.8
Cluster 4	11656	8104	30.5	12858	8994	30.1
Cluster 5	6136	4313	29.7	6977	4996	28.4
Cluster 6	10238	7136	30.3	11654	8270	29.0

From Table 5.12 above, it can be noticed an average reduction of about 30% can be accomplished on water as well as on energy consumption due to the application of water saving technologies within the households.

Optimal strategies for clusters

In the next Table 5.13 the population density has been calculated and the most favourable strategies are determined with regard to imported water and energy consumption. For two clusters, namely cluster 1 and 4, the optimal strategy for imported water is also the optimal strategy for the energy consumption; respectively strategies S3Wz (wastewater collection and treatment at catchment scale) and S3Wy (wastewater collection and treatment at cluster scale).

Due to a chosen setting in the Aquacycle input file ("wastewater overflow to stormwater"), strategy S3Wx and S3Wy are becoming more favourable than the other strategies with regard to energy consumption (see above, under "Energy consumption"). This can explain why for five out of six clusters, strategy S3Wy is the optimal one. Only for cluster one "the energy producing wastewater treatment process of S3Wz" is still prevailing.

Furthermore, it appears the highest reduction on imported water can be achieved by (1) utilizing harvested rainwater (strategy S1Rx) and (2) reuse of wastewater at catchment scale (strategy S3Wz).

Table 5.13 **Optimal strategies for clusters on imported water (including use of spillage) and on energy consumption**

	Description			Optimal Strategy	
Cluster	# of people (# HHs x inhabitants)	Cluster area [km^2]	Pop. density [p/km^2]	Imported water consumption [m^3/y]	Energy consumption [kWh/m^3]
1: DH	39x3= 117	0.030632	3820	**S3Wz**: 2114	**S3Wz**: 1696
2: RH	314x3= 942	0.075358	12500	**S3Wz**: 17031	**S3Wy**: 18016
3: MFH	40x3= 120	0.01722	6969	**S1Rx**: 2187	**S3Wy**: 2582
4: Mans.	86x3= 258	0.0128224	20121	**S3Wy**: 4667	**S3Wy**: 4543
5: L&W	44x3= 132	0.0167188	7895	**S1Rx**: 1839	**S3Wy**: 2730
6: Ind&S	75x3= 225	0.02216	10153	**S1Rx**: 2548	**S3Wy**: 4402

6 Discussion

Methodology

According the methodology and also due to the character of the study, data has been obtained from different kind of sources. Not only from the stakeholders in Hamburg and from literature reviews, but also from visits of demonstration sites in Hamburg (Allermöhe and Lübeck-Flintenbreite) and in the Netherlands (Sneek project, new development Leidsche Rijn) and by contacting and visiting companies and foundations. The plan, the preliminary design and associated data of the new development Haulander Weg seemed comprehensive enough to feed the Aquacycle model to execute the calculations for the water balances. From a number of applicable innovative technologies a selection is made to develop strategies, taking into account the function of the Haulander Weg development: an ecological demonstration site. The water balances for the various strategies could rather be developed straightforward, although the modeling programme has some limitations in view of the "desired" output data. The most influencing ones to be dealt with during the execution of the study and worth to mention are:

- The Aquacycle model, a useful tool to assess the merits of a range of water servicing alternatives for urban developments during the initial planning and design phase, has some limitations: (1) the indoor water use profile is rigid as it is the same for all clusters and therefore showing similar trends in the graphs and bar diagrams, (2) the (re)use options for e.g. treated rainwater, greywater, wastewater and stormwater are fixed and therefore limited and (3) the multiple available sources are supplied according a preference list (see Table 3.4), which makes it impossible to develop "an ideal combination of available sources strategy".
- Some assumptions and estimations are made in order to at least come up with figures, required to compare and evaluate the strategies. E.g. for the development of the clusters, estimations regarding roof-, garden and pavement areas and the ratios between garden and pavement are necessary. The same applies for the estimations of the sizes of storage tanks.
- It also appeared that reliable energy consumption figures of the applied

technologies (e.g. treatment facilities, pumps) are not always easy to determine. Mostly data from previous and pilot project studies and also from literature research could provide in this. However, it should be noted that the aim of this study is mainly to show what kind of technologies can be implemented in combination with indicative values rather than to give precise estimations.

Note: In addition to Aquacycle another model has been applied, called UWOT, developed within the Water Cycle Management for New Developments (WaND) Project. UWOT is a Decision Support Tool and its abbreviation stands for Urban Water Optioneering Tool. UWOT can be run in two modes: the "assessment mode" and the "optimisation mode". A number of strategies have been assessed with the "assessment mode", but it appeared the output data (results) could not easily be compared with those from Aquacycle and therefore "UWOT" is not included in this study.

Objectives

In compliances with the specific objectives, the water system of the study area has been modeled for a number of strategies with respect to the water balance and the energy consumption. For the strategies earlier defined, innovative technology options for the urban water management are chosen and applied on different scales (unit block, cluster and catchment). For better understanding and for the evaluation of the options regarding water use (and reuse possibilities) and linked energy consumption, calculations are executed and visualised in a number of graphs and bar diagrams as shown and evaluated in the previous Chapter 5.

Baseline strategy compared with the other strategies

Important but relatively easy measures to be taken to save on potable water as well as on energy consumption are to apply all kind of water saving devices, like (very) low flush toilets, water saving shower heads, tap aerators, etc. The water saving devices -proposed in this study- alone saving almost 30% on potable water. When reuse technologies for rainwater, wastewater and/or stormwater are also included, savings up to almost two-third (63.5%) can be reached.

Electricity consumption

From the bar diagrams, at catchment scale as well as at cluster scale, it can be observed that the reuse strategies do not necessarily lead to an increased energy consumption as might have been expected. Only in a few cases it is a bit more, but in most cases about the same or even less compared to strategy S0ws.

Energy consumption for indoor water heating systems

In this study only the energy consumption required for treatment and distribution (pumping) has been looked at. The energy consumption for indoor water heating systems has not been taken into account, although it is estimated that it is responsible for about 50% of the total natural gas consumption within a household. It seems to be a point of discussion within the water sector; should it be included or not? In this study a calculation was done on a shower base with an integrated heat exchanger, just to demonstrate how much on energy can be saved (it has an efficiency of 47%) and a number of renewable energy technologies have been portrayed that may reduce significantly on the energy consumption.

Cost aspects
The cost aspects of the strategies have not been looked at, however, a remark can be that some of the selected technologies could be quite expensive (high initial costs) and it can be assumed that regular maintenance is required, which should also be accounted for. It is expected that the rainwater harvesting strategy SR1x is most probably the cheapest solution, followed by the strategies with the vertical flow constructed wetlands (S2Gx and S3Wy). However, even constructed wetlands will not operate properly without maintenance: once a year the reed bed has to be cut and a caretaker should be appointed to at least check the functioning of it a couple of times a week.

General aspects
Theoretically the precipitation (853 mm/y) is sufficient to cover the water demand needs of all 598 households. Generally speaking, it should be noted that the strategies which utilise a combination of rainwater and stormwater may jeopardise the environment in the longer run, due to insufficiently recharging the groundwater table (aquifer replenishment). However, that will not be the case in Hamburg, which has a relatively high groundwater level. Green-roofs and strategy S4Sz (construction of a pond for collecting stormwater) will have a positive effect on the environment: it enhances the biodiversity and reduces the urban heat island effect: due to the evaporation of water, heat will be withdrawn from its surroundings and thus lowering the temperature.

The proposed strategies should be approached in a very broad and non-conservative way to make a move from the old paradigm to the emerging paradigm. Not only in relation to water supply but also to energy supply: as could be read in sub-subsection 2.9.7 a similar way of thinking is taking place within the energy sector.

In addition to the application of innovative technological appliances others measures can and should be taken as well to reduce on water and energy consumption, like awareness building among the consumers and water demand management.

Dual plumbing system
A matter of concern may be the need of dual plumbing systems required for the reuse options in this study:
For many of the uses of water, potable water is not necessary and appropriately treated and disinfected reclaimed water can be used safely. Reclaimed water can replace potable water for non-potable applications. Thus, potable water can be conserved and used for essential human health purposes such as drinking, cooking and bathing. However, it implies two independent plumbing systems are required: one for distributing potable water and one for reclaimed water (known as “dual plumbing system”). To establish such a system it is very important to ensure that applicable health and safety regulations have been met. In many cases interior use for toilet flushing in households is restricted, generally because modifications of the plumbing system may result in possible cross-connections between potable and non-potable water systems. With the production of increasingly higher quality reclaimed water and applications, other interior uses of reclaimed water may find greater acceptance (Metcalf & Eddy, 2006).

The legislation in The Netherlands regarding dual plumbing systems was changed quite abruptly in 2003 due to an incident. A pilot project with a dual plumbing system was implemented within a new development and it seems because of an un-removed cross-connection, a small number of people started to feel a bit unwell. Very unfortunate, but from that moment dual plumbing systems are not allowed anymore for a cluster of houses. For small scale applications however, these rules are not so strictly maintained; e.g. within a household or an office rainwater can be harvested and used for toilet flushing or a sprinkler installation, or greywater can be reused for toilet flushing (like for the Ecoplay toilet, described in sub-subsection 2.8.4). However, safeguards can and have to be implemented to reduce the risk of cross-connection: like backflow prevention devices; pipe separation; colour coding of piping, tanks, and appurtenances; reduced pressure of reclaimed water systems; signage; and outlets of pipes provided with special adapters or couplings.

In the future, however, as treatment technologies improve and regulatory requirements are revised, it may not be necessary to use dual plumbing systems if reclaimed water is returned to water supply reservoirs for blending with other surface water and long-term storage, followed by water treatment (Metcalf & Eddy, 2006).

A look into the future

Due to the ongoing development on innovative and appropriate technologies that can be applied efficiently on decentralised scale, households will become more and more and in the far away future probably completely self-sufficient or autarkic in terms of energy production and consumption (e.g. PV panels, windmill power, solar hot water systems, heat pumps, combined heat power) and subsequently also in terms of water production, consumption and treatment (e.g. reuse through vertical flow constructed wetlands / reed bed filters for pre-treatment in combination with membrane filtration).

Most easy to develop, environmental friendly and enhancing the natural environment, assumed there is enough space, are the vertical flow constructed wetlands like applied in Allermöhe and Lübeck-Flintenbreite, Germany. Promising are technologies, although much more complex (and assumingly more costly), like the pilot project in Sneek, which will soon be implemented on a bigger scale. It will save on imported water and produce energy -in stead of consuming- from the treatment of the wastewaters and kitchen waste (biomass). The Figures 5.22 and 5.23 showing an impression of how it might be in the future.

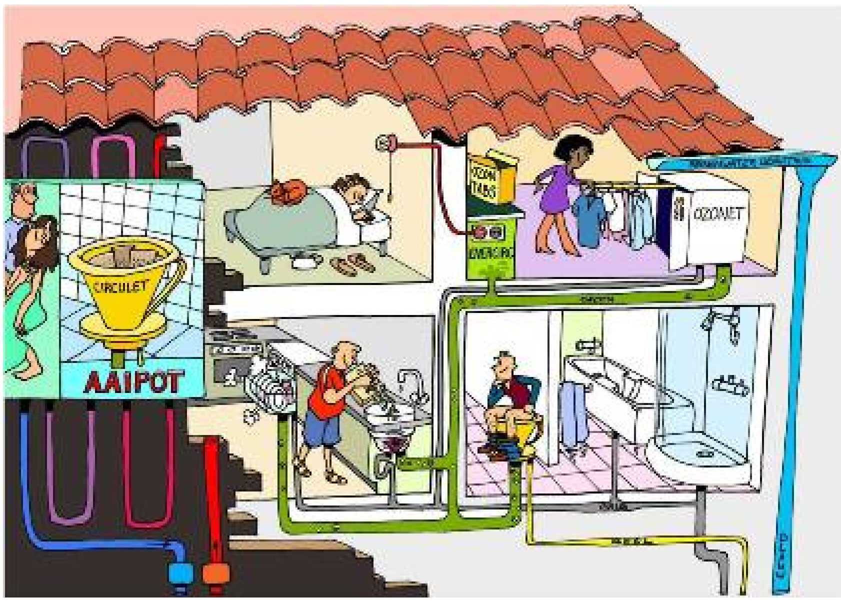

Figure 5.22 **Future scenario of the water system within a household: different types of wastewaters discharged separately (Source: VNG)**

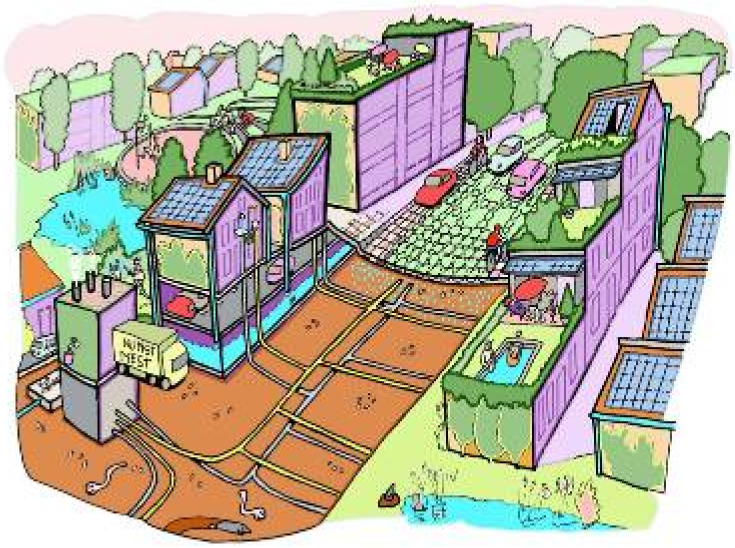

Figure 5.23 **A predicted piping system for different wastewater types, anno 2050 (Source: VNG)**

7 Conclusions

In this study a number of strategies have been developed with the aim to save on water and energy consumption, to estimate how much can be saved and to see which strategies are most promising. From the analyses of the results the following conclusions can be made.

- The baseline strategy (Sbl) compared with S0ws shows that due to a number of water saving measures, a reduction on imported water of almost 30% can be accomplished.
- By utilizing reclaimed water (including harvested rainwater) in combination with a number of water saving measures, a total reduction on imported water of almost two-third (63.5%) can be achieved.
- A decentralised approach, with the (re)use of the different types of (waste)waters, does not necessarily imply an increase of the energy consumption: the energy consumption of the various strategies is in a few cases a bit more, but in most cases about the same or even less compared to S0ws.
- S3Wz, a strategy with a wastewater treatment method (UASB) that produces energy, can be considered as one of the most favourable strategies with regard to energy consumption.
- The highest reduction on imported water can be achieved by (1) utilizing harvested rainwater and (2) reuse of wastewater at catchment scale.
- Sufficient data became available to feed and to run the model (Aquacycle), although a (limited) number of estimations had to be made.
- Aquacycle has its limitations, affecting the simulation and reducing the analyzing capacity. The most influencing ones for this study are: (1) the "indoor water use profile" is fixed and therefore the same for different types of clusters resulting in similar trends for all clusters and (2) the (re)use options of the different type of (waste)waters are fixed and therefore limited.
- The renewable energy technologies described in this study may significantly reduce the total energy consumption within a household, including the energy required for water heating (which accounts for an estimated 50% of the natural gas consumption).
- A relatively simple innovative technology like the shower base with an integrated heat exchanger is really promising. In combination with a low flow shower head it can reduce in total 68% on energy.
- Not only the water sector but also the energy sector seems to go through a similar process with regard to "decentralisation": moving from an old to an emerging paradigm.
- For reuse options dual plumping systems are required, which is not always allowed (rules and legislation).

8 Recommendations

In case further research will be executed on the water and energy balance for the new development Haulander Weg or on similar studies, the following recommendation can be suggested:

- Further research can be done on more than two indicators; not only water and energy consumption, but also e.g. capital and initial costs, reliability, risk to human health, land use, social acceptability, wastewater produced and runoff.
- The model “SWITCH City Water” is expected to become available soonest. It seems to be an improved version of Aquacycle and thus recommendable to be applied for studies (more or less) similar to this one.
- As shown in the 3-Step Strategic Approach (Figure 2.1), recovery and reuse (as fertilizer) of nutrients in wastewaters, like Magnesium, Nitrogen and Phosphorous, can be looked at.
- Energy required for household water heating systems can be included in the energy balance calculations.
- To get insight on the environmental impact of the strategies a Life Cycle Assessment can be executed.

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APPENDICES

Note: Appendices 1, 2, 3, 6, 7 and 8 can be found on the CD-ROM attached to the document.

APPENDIX 4

Calculations for Strategy S2Gx: Greywater reuse
Calculation energy consumption vertical flow constructed wetland, based on the ecological site Allermöhe – Hamburg, Germany:

The layout of the greywater collecting chambers, including the pumps, the vertical flow constructed wetlands and pond in Allermöhe is shown in the following Figure A 4.1:

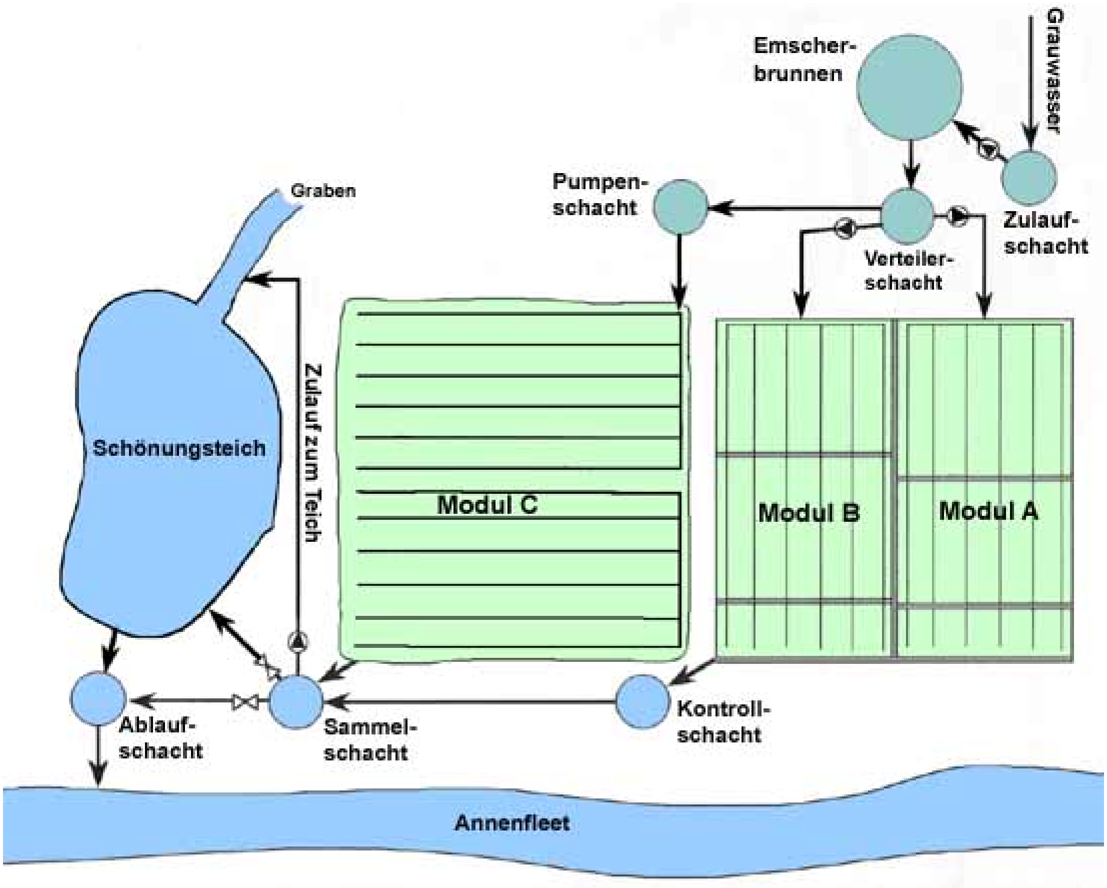

Figure A 4.1 Overview vertical flow constructed wetland Allermöhe, Hamburg – Germany (Source: www.oeko-siedlung-allermoehe.de/Home.htm., retrieved on 18-11-2008)

Translation of the text mentioned in above Figure A 4.1:

Grauwasser:	greywater
Zulaufschacht:	”inflow” well
Emscher brunnen:	oxygen-limited detention tank

Verteilerschacht:	distribution well
Module A, B, C:	vertical flow constructed wetlands A, B, C
Pumpenschacht:	pump well
Kontrollschacht:	monitor well
Sammelschacht:	collection well
Zulauf zum Teich:	drain to pond
Graben:	ditch
Schönungsteich:	purification pond
Ablaufschacht:	"outflow" well
Annenfleet:	(name of the channel)

The greywater treatment calculation

Allermöhe can be considered as a cluster with 34 household and 140 inhabitants in total. The average water consumption at eco-site Allermöhe is 76 L/p/d x 140 p = 10640 L/d = 10.64 m^3/d and will become the greywater volume, since all households are equipped with dry toilets.

Assumed this volume will be pumped in five sequences per day, at 20 minutes per sequence: 10.64 m^3 / 5 ≈ 2 m^3 per sequence → 2m^3 / 20min = 2000 L / 20 min = 100 L/min = 6000 L/h

Pump 1: Pump selected: 0.5 kW, 10000 L/h
(source Herco Pools: http://hercopools.com/files_mce/pump_consumption_1.pdf, retrieved on 21-03-2009)

Energy consumption per day: 5 x 20 min = 100 min
= 1.67 h x 0.5 kW = 0.83 kWh/d

The volumes to be pumped to module A, B and C is estimated according to the size: module C is about twice as big as module A and module B:

Module A: 0.25 x 10.64 m^3 = 2.66 m^3 = 2660 L
Module B: 0.25 x 10.64 m^3 = 2.66 m^3 = 2660 L
Module C: 0.5 x 10.64 m^3 = 5.32 m^3 = 5320 L

Pump 2: Same pump selected: 0.5 kW, 10000 L/h
To be pumped to module A: 5 x (20 min. x 0.25) = 25 min = 0.42 h → 0.42 h x 0.5 kW = 0.21 kWh/d

Pump 3: Same pump selected: 0.5 kW, 10000 L/h
To be pumped to module B: 5 x (20 min. x 0.25) = 25 min = 0.42 h → 0.42 h x 0.5 kW = 0.21 kWh/d

Pump 4: Pump is not shown in the layout; it's pumping from the "Pumpenschacht" (pump well) to module C.
Same pump selected: 0.5 kW, 10000 L/h
To be pumped to module C: 5 x (20 min. x 0.5) = 50 min = 0.83 h → 0.83 h x 0.5 kW = 0.42 kWh/d

Pump 5: Assumed is that 2/3 of the influent will become effluent, which is

0.67 x 10640 L/d ≈ 7130 L/d
Effluent to be pumped to the pond in 5 sequences per day, at 15 minutes per sequence: means about 7130 L / 5 ≈ 1426 L per sequence → 1426 / 15min = 95 L/min = 5700 L/h
Same pump selected: 0.5 kW, 10000 L/h
Energy consumption per day: 5 x 15 min = 75 min = 1.25 h
= 1.25 h x 0.5 kW = 0.63 kWh/d

In total it is: 0.83 + 0.21 + 0.21 + 0.42 + 0.63 = 2.3 kWh/d

So, the energy consumption for the treatment of 10.64 m^3 greywater per day is about 2.3 kWh/d, which is: 2.3 / 10.64 = **0.21 kWh/m^3**

Therefore, the total energy consumption for (a) the treatment part and (b) the part to pump the treated and collected greywater from a cluster storage tank back to the households will be: 0.21 + 0.4 = **0.61 kWh/m3**

On 24-03-2009 at the Praxis shop in Delft, a number of submersible pumps (and one centrifugal pump) ranging from 3200 L/h to 7500 L/h with an electrical power capacity between 250 W to 800 W were investigated (see Table A 4.1). It shows that the 500W used above for the calculations is a rather good estimation (on the safe side).

Table A 4.1

Pump brand	Pump type	Q_{max} (L/h)	$Head_{max}$ (m)	Energy (W)	Remarks
Garden Master (*subm.*)	SP 250 3C	**5000**	6	**250**	Clean water pump
BaseLine (*submersible*)	-	**6000**	7	**350**	Clean water pump
BaseLine (*submersible*)	-	**7500**	5	**400**	Muddy water pump, max 35 mm
BaseLine (*submersible*)	- (Inox)	**7500**	5	**400**	Muddy water pump, max 5 mm
BaseLine (*centrifugal*)	-	**3200**	40	**800**	Garden pump, max 35 mm

Another, though lighter pump (laboratory pump) than the ones mentioned above, also shows that the estimated capacity of 500 W is within the range:
Laboratory pump, type MD-100R-5(M): 100 L/min @ Head = 6 m → e-motor capacity **365** W (Source: CD-ROM "CD-07April2007-WTD1", Prof. Nemanja Trifunovic). And finally, the constructed wetland for a single household at "De 12 Ambachten" in Boxtel (The Netherlands) is also equipped with a pump within the range, i.e. **800** W.

APPENDIX 5

Calculations for Strategy S3Wz: Wastewater reuse at catchment scale

Calculation energy consumption and production, based on design data of the DeSaH Project Noordhoek in Sneek (Friesland), The Netherlands. The most crucial component is the USAB reactor as described in sub-subsection 2.8.7. The treatment system not only requires energy but will also produce energy (biogas). The calculations read as follows:

Influent (grey- and blackwater incl. bio-waste from kitchen):
51800 + 3565 + 287.5 = 55652.5 L/d = 96.8 L/p/d = 20327 m^3/y

Effluent: 55600 L/d = 96.7 L/p/d = 20308 m^3/y

Energy consumption:
Energy (electricity): 32328 kWh/y
Energy (thermal): 7596 kWh/y

Energy production:
Energy (electricity): 27269 kWh/y
Energy (thermal): 50642 kWh/y

Energy net (production – consumption):
Energy (electricity): 27269 – 32328 = - 5059 kWh/y (**consumption**)
Energy (thermal): 50642 – 7596 = 43046 kWh/y (**production**)

Results in a net energy production of:
(5059 – 43046) / 20327 = - 37987 / 20327 = **- 1.87 kWh/m3** (**net production**)

APPENDIX 9

Bar diagrams at cluster scale:

AT CLUSTER 1 SCALE (double houses: two homes under one roof):

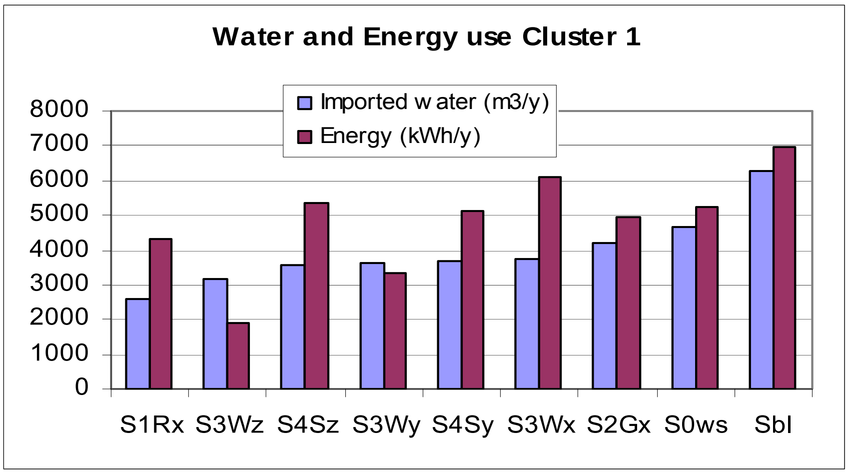

Figure A 8.1 Imported water and energy use at cluster 1, excl. use of spillage

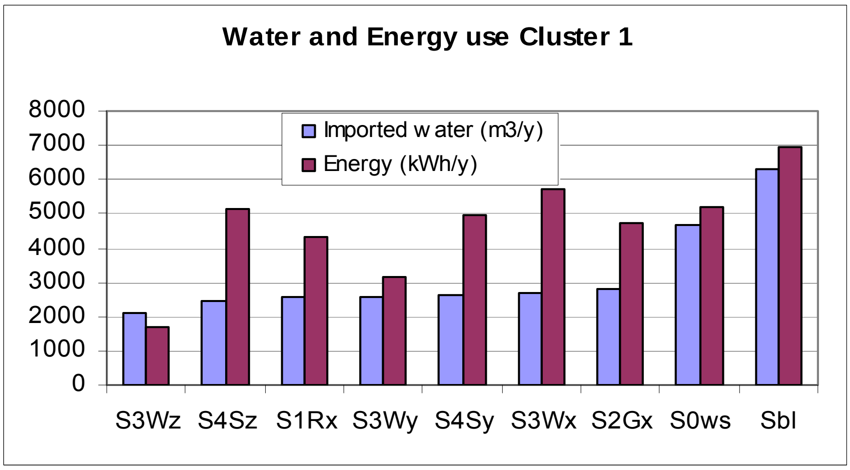

Figure A 8.2 Imported water and energy use at cluster 1, incl. use of spillage

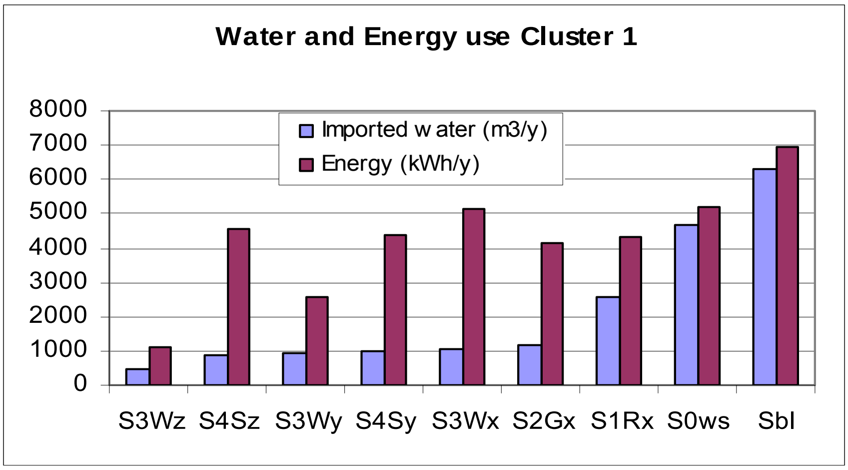

Figure A 8.3 **Imported water and energy use at cluster 1, incl. use of spillage and rainwater (rainwater for bathroom only)**

AT CLUSTER 2 SCALE (row houses):

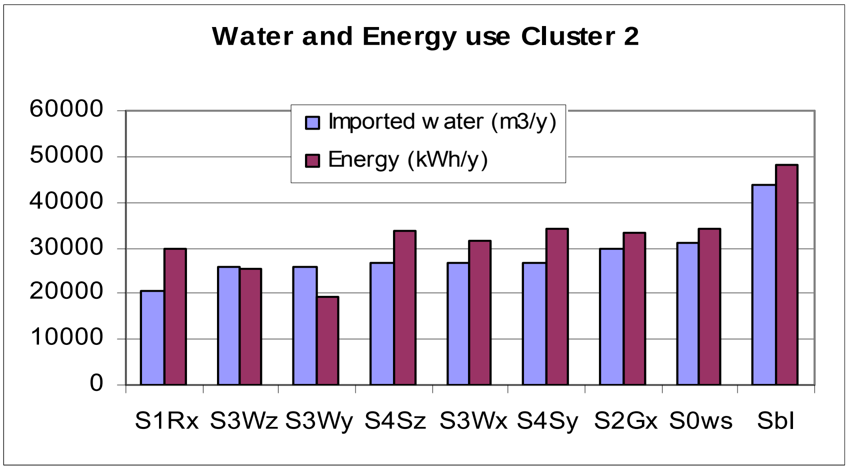

Figure A 8.4 **Imported water and energy use at cluster 2, excl. use of spillage**

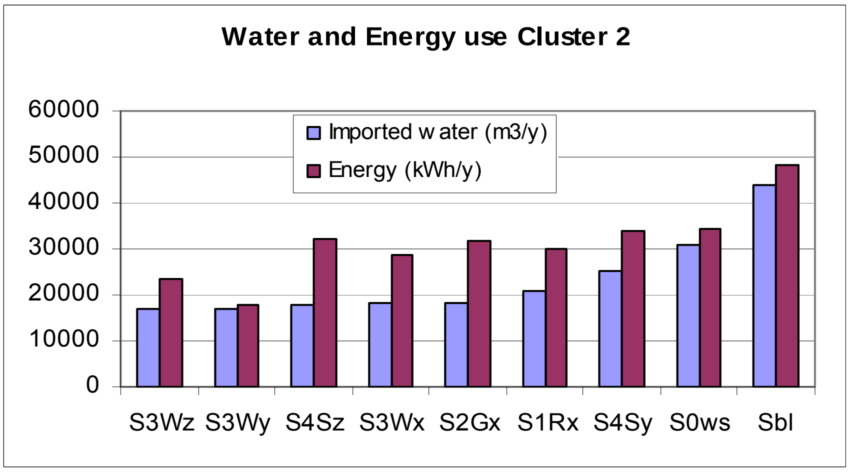

Figure A 8.5 **Imported water and energy use at cluster 2, incl. use of spillage**

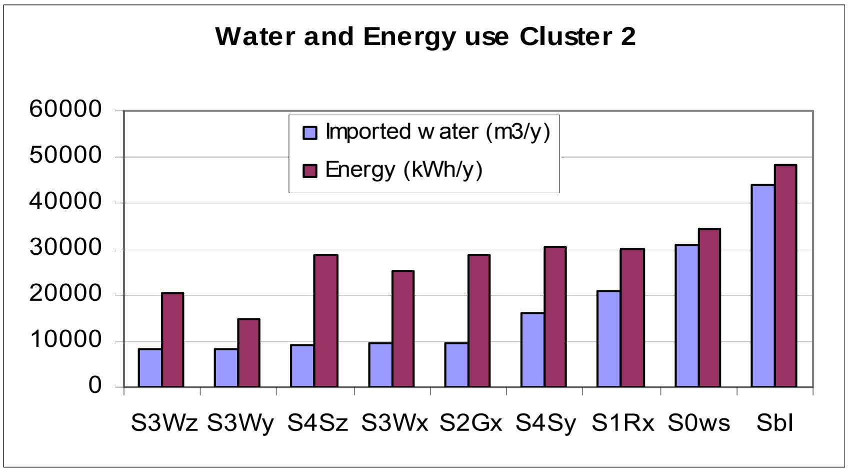

Figure A 8.6 Imported water and energy use at cluster 2, incl. use of spillage and rainwater (rainwater for bathroom only)

AT CLUSTER 3 SCALE (quatro-more family houses):

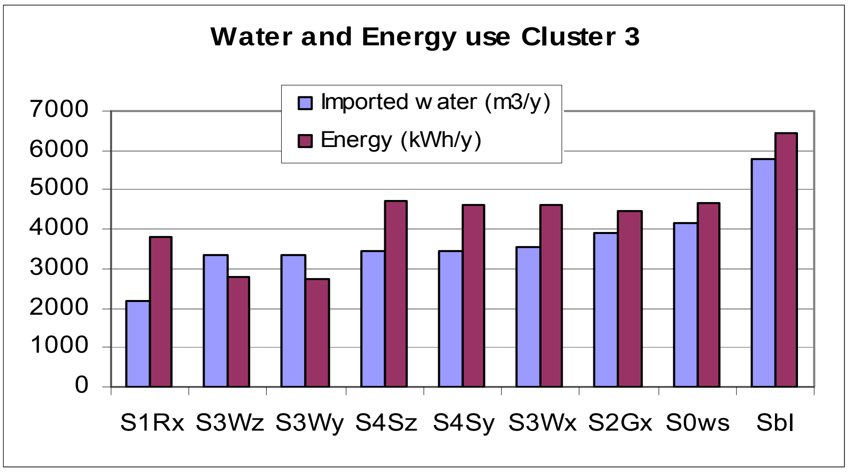

Figure A 8.7 Imported water and energy use at cluster 3, excl. use of spillage

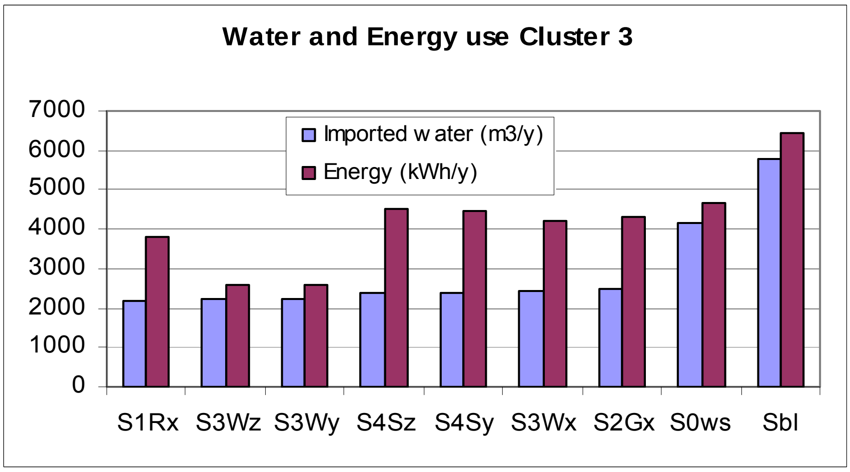

Figure A 8.8 Imported water and energy use at cluster 3, incl. use of spillage

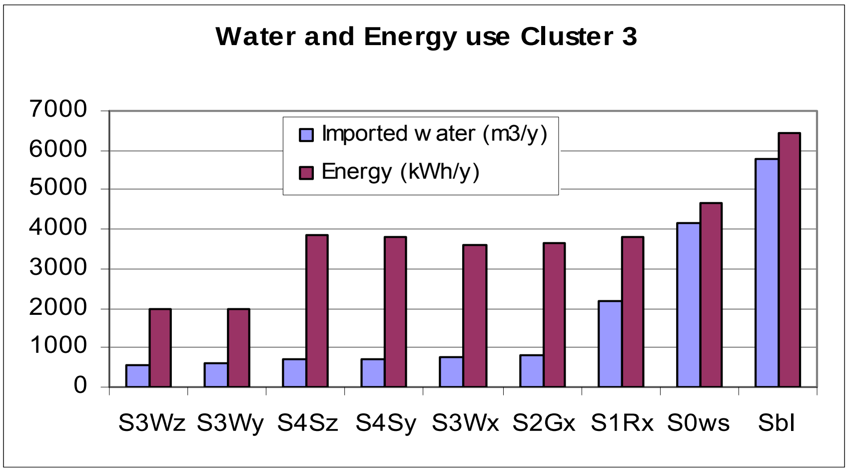

Figure A 8.9 **Imported water and energy use at cluster 3, incl. use of spillage and rainwater (rainwater for bathroom only)**

AT CLUSTER 4 SCALE (mansions: block of flats, apartment houses):

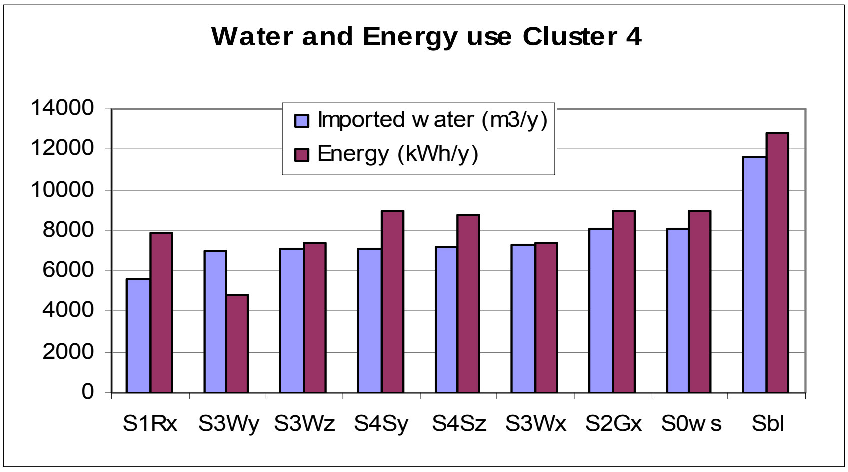

Figure A 8.10 **Imported water and energy use at cluster 4, excl. use of spillage**

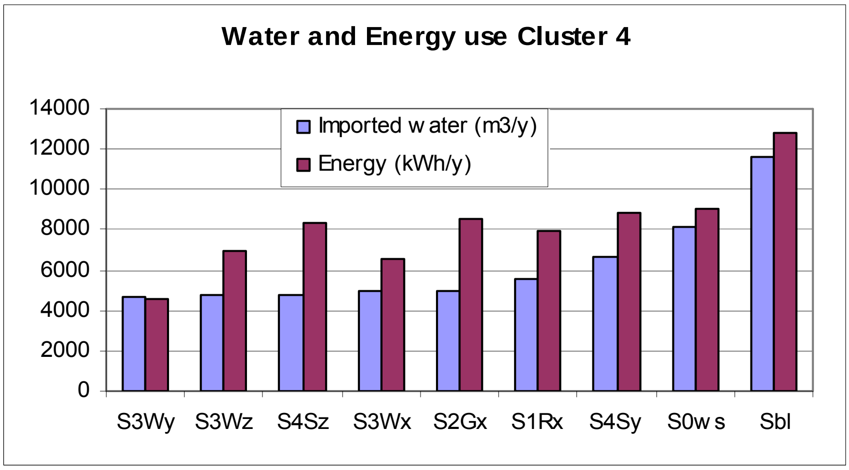

Figure A 8.11 **Imported water and energy use at cluster 4, incl. use of spillage**

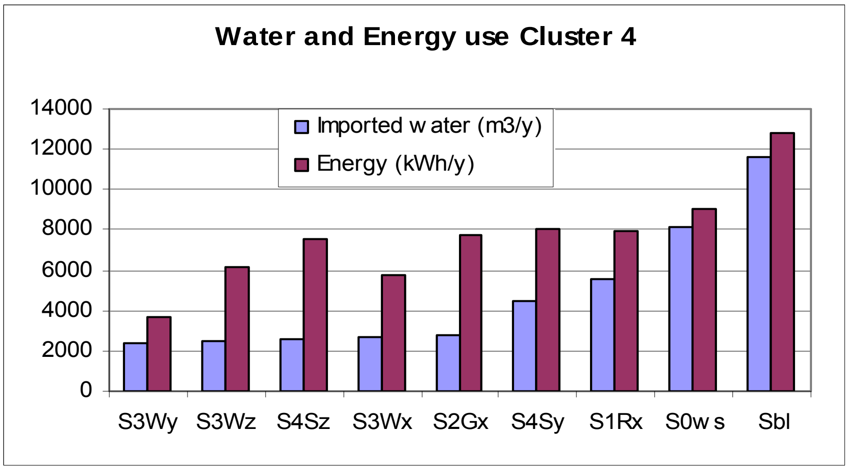

Figure A 8.12 **Imported water and energy use at cluster 4, incl. use of spillage and rainwater (rainwater for bathroom only)**

AT CLUSTER 5 SCALE (live & work):

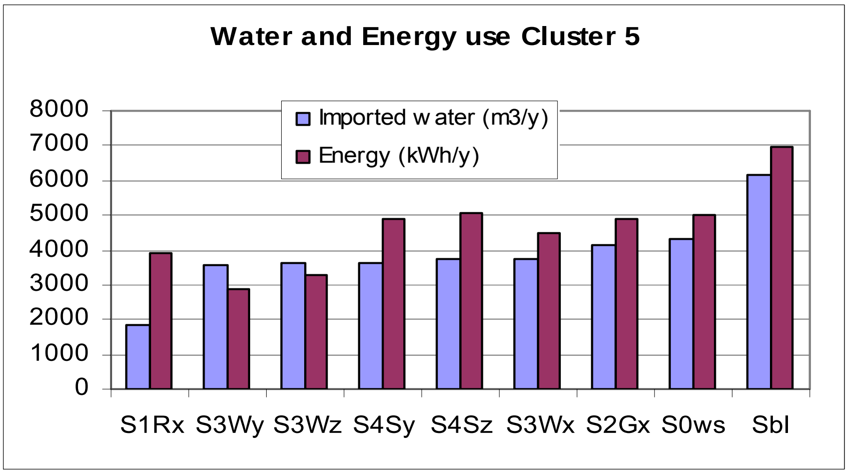

Figure A 8.13 **Imported water and energy use at cluster 5, excl. use of spillage**

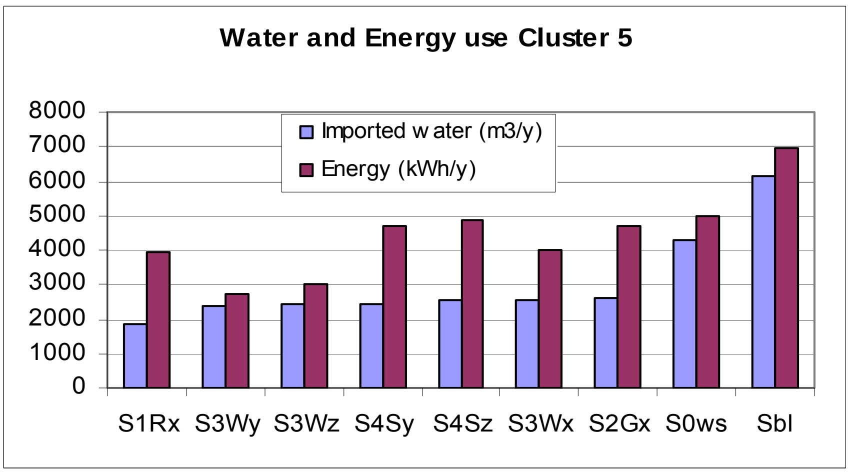

Figure A 8.14 Imported water and energy use at cluster 5, incl. use of spillage

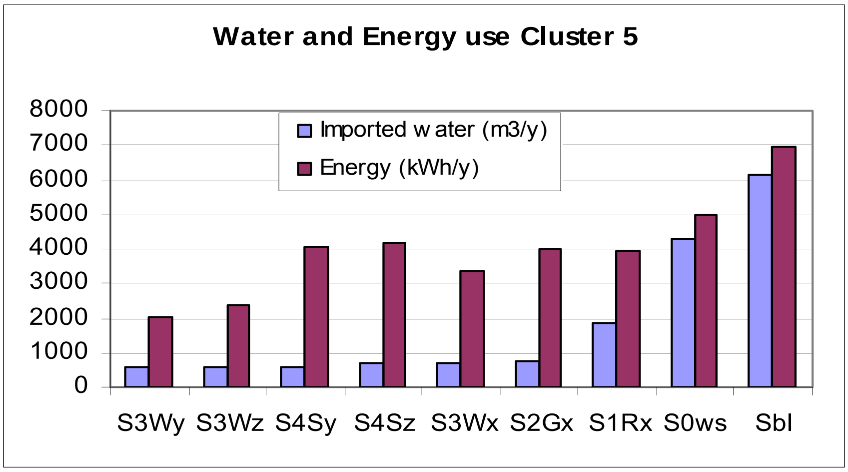

Figure A 8.15 Imported water and energy use at cluster 5, incl. use of spillage and rainwater (rainwater for bathroom only)

AT CLUSTER 6 SCALE (“small industries, services”: substituted by 75 houses):

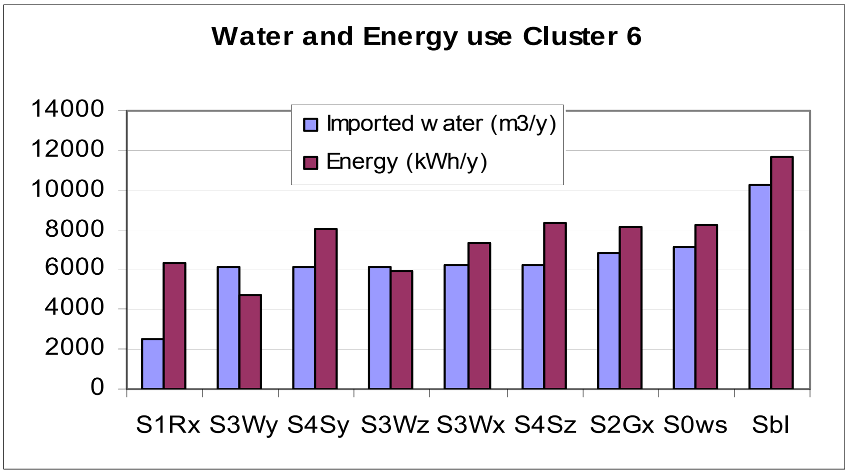

Figure A 8.16 Imported water and energy use at cluster 6, excl. use of spillage

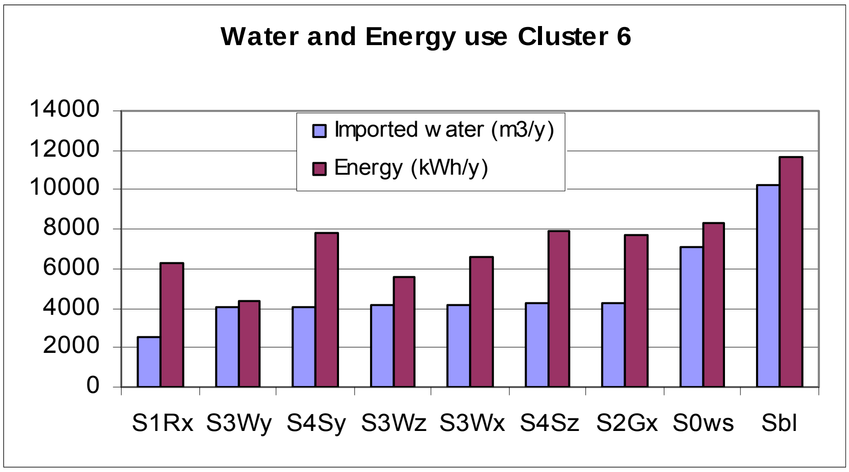

Figure A 8.17 Imported water and energy use at cluster 6, incl. use of spillage

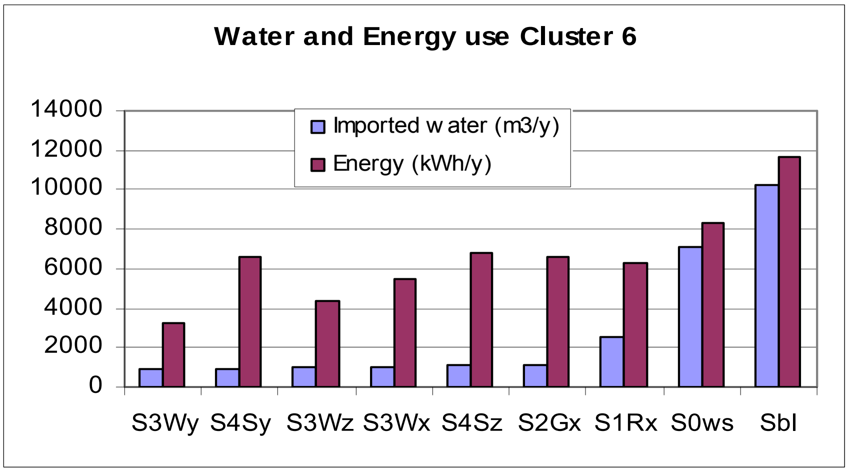

Figure A 8.18 Imported water and energy use at cluster 6, incl. use of spillage and rainwater (rainwater for bathroom only)