UNESCO-IHE
INSTITUTE FOR WATER EDUCATION

Application of a total urban water cycle and energy balance model to develop sustainable urban water systems, a case study in Hamburg, Germany

Julia Reid

MSc Thesis ES 08.27
April 2008

UNESCO-IHE
Institute for Water Education

Erata

This thesis evaluates different options for urban water management (rainwater harvesting, stormwater use and wastewater recycling) and the effects on the energy consumption in the system. It appeared that some of the calculations are not correct, especially the calculation of the energy consumption required for heating water and the energy required to pump water from rainwater storage tank into the house. The incorrect calculations were repaired.

- The specific heat content of water was corrected to 4.186 J/kg/K
- The energy consumption for pumping rainwater was estimated as 0.17 kWh/m3, (http://www.rainwater-harvesting.biz/acatalog/TAM105_1__230v_Centrifugal_Water_Pump_.html)

The result for the 1% increase in population per year is shown below (compare page 31 in the thesis). It shows that rainwater harvesting may reduce the energy consumption in the water system by 18%.

Peter van der Steen
Delft, May 2008

		1% Population Growth				
	Base Scenario	2020 Business-as-usual Scenario	2050 Business-as-usual Strategy	2050 Eco Strategy	2050 Moderate Strategy	2050 Conventional Strategy
OUTPUTS FROM AQUACYCLE						
water supply						
1. volume of imported water (m3/year)	1.558.000	1.805.000	2.413.000	608.000	741.000	1.064.000
2. volume of imported water (m3/day)	4.268	4.945	6.611	1.666	2.030	2.915
storm water						
3. Volume of storm water (m3/year)	8.037.000	7.961.000	9.766.000	8.398.000	8.132.000	8.455.500
4. Volume of storm water (m3/day)	22.019	21.811	26.756	23.008	22.279	23.166
wastewater						
5. Volume of wastewater (m3/year)	1.805.000	1.995.000	2.565.000	2.128.000	2.565.000	2.565.000
6. Volume of wastewater (m3/day)	4.945	5.466	7.027	5.830	7.027	7.027
Volume stormwater reused (m3/day)	0	0	0	781	781	
Volume wastewater reused (m3/day)	0	0	0	468		
Volume rainwater used (m3/day)	0	0	0	3.696	3.696	3.696
INPUT DATA - LITERATURE						
1. volume of imported water (m3/day)	5.635					
2. height of ground water table (m)	133	133	133	133	133	133
Inventory for Energy Balance (kWh/d)						
WATER SUPPLY						
1. Pumping ground water	2.225	2.578	3.447	868	1.058	1.520
2. Pumping water for distribution	190	220	294	74	90	129
Sum energy consumption water supply	2.415	2.798	3.740	942	1.149	1.649
3. Heating water at household level (volume after reuse)	121	138	186	186	186	186
STORMWATER						
4. Pumping storm water	562	557	683	587	569	591
WASTEWATER						
5. Collection of wastewater	5.095	5.632	7.241	6.007	7.241	7.241
6. Treatment of wastewater	4.105	4.537	5.833	4.839	5.833	5.833
Sum energy consumption wastewater	9.200	10.168	13.074	10.846	13.074	13.074
7. Biogas/Sludge incineration energy production	-6.164	-6.813	-8.759	-7.267	-8.759	-8.759
Total net energy consumption	6.134	6.848	8.923	5.295	6.217	6.741
REUSE STRATEGY CONSUMPTION						
8.Rain tanks energy				616	616	616
9. Stormwater reuse distribution				492	492	
10.Wastewater reuse – Treatment				583		
10.Wastewater reuse – Distribution				295		
Final net energy consumption	6.134	6.848	8.923	7.281	7.325	7.357

Application of a total urban water cycle and energy balance model to develop sustainable urban water systems, a case study in Hamburg, Germany

Master of Science Thesis
by
Julia Reid

Supervisors
N. Peter van der Steen, PhD, MSc (UNESCO-IHE)
Prof. P.N.L. Lens, PhD, MSc (UNESCO-IHE)

Examination committee
Prof. P.N.L. Lens, PhD, MSc (UNESCO-IHE), Chairman
N. Peter van der Steen, PhD, MSc (UNESCO-IHE)
Prof. R. Mackay (Birmingham University)

This research is done for the partial fulfilment of requirements for the Master of Science degree at the UNESCO-IHE Institute for Water Education, Delft, the Netherlands

Delft
April 2008

To my family and friends for all their support during this important journey

ABSTRACT

Nowadays, there is an increasing need for sustainability and protection of the environment regarding urban water management; a necessity to re-evaluate this 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.

Within this context, the present research demonstrates the utilization of storm water and wastewater as an urban water resource rather than a waste product offers an alternative to present approach to water supply and disposal. Also the rain water harvesting can be a great substitute for the imported water at the households.

As the main points of the results, this study demonstrates that large reductions on the urban water system can be achieved with imported water, storm water and wastewater reuse strategies. Also, it was found that even though the reuse options can increase the energy consumption, yet it was found reductions on energy consumption for the overall energy balance with the reuse options.

The direct conclusion of the research is that the utilization of storm water and wastewater as an urban water resource rather than a waste product offers an alternative to present approach to water supply and disposal. Such alternatives like; rainwater use, wastewater reuse and subsurface grey water irrigation hold the key to lessening environmental impacts in living towns. Less water being that is needed to be imported into cities means also less energy to spend on water transportation within the network distribution. In addition, when less wastewater and storm water are discharged, there is a reduction in energy for wastewater treatment and less flow of contaminants from the storm water.

Keywords: Urban water cycle, Aquacycle, water and energy balance

ACKNOWLEDGEMENTS

This report is the result of research to the MSc Programme in Environmental Science of UNESCO-IHE Institute for Water Education, financed by the Programme Alban – European Union Programme of High Level Scholarships for Latin America (no. E06M101672BR). This research is part of the SWITCH project.

I would like to thank for the great help for the data acquisition; the Switch consortium partners in Hamburg; Mr. Jochen Eckart, Mr. Matthias Weiner from the Freie und Hansestadt Hamburg and Mr. Dieter Ackermann from the Landesbetrieb Straßen, Brücken und Gewässer in Hamburg.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 BACKGROUND

Nowadays, the urban water management practices intend primarily to remove storm water and wastewater efficiently from urban areas. Recently the necessity for a more sustainable approach has been introduced, which considers storm water and wastewater as an alternative potential resource substitute for a portion of the water imported via the reticulated supply system. This means that the development the of current urban water systems towards a more sustainable one can be done only by improving the existing systems and developing alternative technologies (Lundin et al, 1997). The new approach to the water and wastewater system must consider not only the original objective that focuses mainly on human health, but also energy efficiency, resource use, environmental effects, access to service, service quality and other aspects of sustainable development. According to Morrison et al, (2001), the objectives of developing an urban water system are: (1) to preserve the quality of the raw water resource, (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.

This project is part of the Integrated Water Management Plan in Wilhelmsburg from the SWITCH project, which aims to change the way water is managed, towards a more sustainable urban water system. The SWITCH project was funded by the European Community and is aimed at contributing to the development of sustainable urban water management schemes in nine (9) demonstration cities in Europe and the South (Switch, 2007; Van der Steen, 2007). Within this project, a total urban water cycle model ("Aquacycle") was developed in order to evaluate different options for urban water management under different scenarios for the future. Currently there are only few tools to evaluate the feasibility of such alternative and management scenarios and still only on a very broad blush scale (Mitchell et al., 2001). The Aquacycle model can be used to evaluate the effect of different management measures on the city's water balance in a more holistic way.

1.2 CASE STUDY AND PROBLEM STATEMENT

One of the demonstration projects from the SWITCH project is on the river island of Wilhelmsburg in Hamburg, Germany (Fig. 1.1). With a population of about 1.7 million inhabitants, Hamburg has an increasing population and is one of the fastest growing cities in Germany. Expected population growths (of 60.000 people 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 reduced. Despite increasing population, there is no shortage of drinking water expected in future. Hamburg has a sewerage system that services over 99% of inhabitants. The sewerage system is connected to a central sewage treatment plant which ensures a progressive multi stage treatment of waste water (SWITCH, 2007).

This main area of the river island of Wilhelmsburg comprises of a future urban development in the range of about 6.000 lot residential project that seeks to achieve the highest possible level of sustainability for urban development. The area will also be

the scene of the International Building Exhibition (IBA) 2013 and the International Horticultural Exhibition 2013.

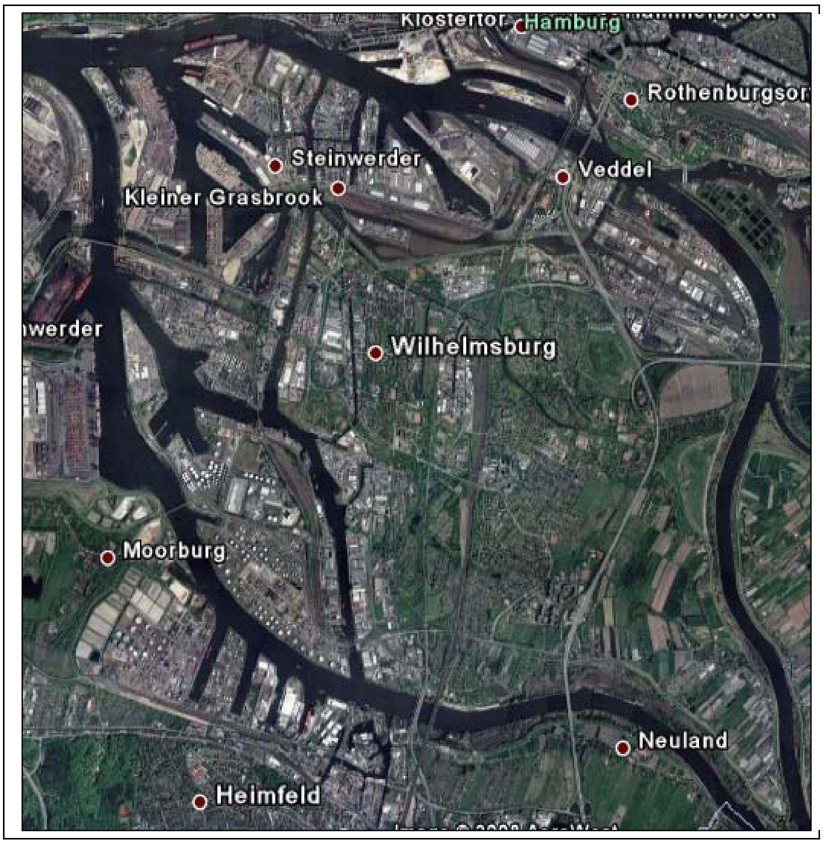

Figure 1.1 Study area; the river island of Wilhelmsburg, Hamburg in Germany

This area is under several water management problems, such as flood risks caused by the river Elbe and the North Sea (the area is also under a system of dikes due to the high ground water tables; the water in the island is constantly being pumped out), storm water management (fluvial flooding in the inland, caused by storm water and coordination ditch network and storm water management) energy intensive (pumping, heating transporting and discharging the water), pollution of the surface waters caused by industries, agriculture and storm water, and limited additional capacity in the existing sewerage system.

The area also has lacked urban planning. This means water can be used as an element to develop attractive locations for living and visible to people. Wilhelmsburg is currently unsustainable regarding the urban water management; therefore the overall ideal vision is to achieve a sustainable self-sufficient and balanced water system through different management interventions (such as rainwater harvesting, storm water collection and use, decentralized wastewater treatment and reuse).

Increasing demands and pressure on its water systems and associated environmental impacts of its present water use and management schemes, there is a need to assess and make recommendations for improvement and sustainability of the water management system in Wilhelmsburg, hence the necessity for this research.

2 RESEARCH OBJECTIVES

2.1 GENERAL OBJECTIVE

To investigate how different management interventions (such as rainwater harvesting, storm water collection and use, decentralized wastewater treatment and reuse) will affect the water and energy balance in a SWITCH demonstration city; Wilhelmsburg, Hamburg, Germany.

2.2 SPECIFIC OBJECTIVES

- ✓ To formulate future scenarios, such as water use, wastewater production, and storm water production and applying a preliminary integrated urban water management model (Aquacycle) for those schemes.

- ✓ To estimate the impacts of alternatives in reuse/recycling schemes on fresh water withdrawals, wastewater discharge, and storm water drainage, energy reductions.

- ✓ To facilitate decision making by permitting the analysis of diverse, more decentralized solutions on urban water management.

2.3 RESEARCH QUESTIONS

- ✓ How do the specific changes in water use change the water balance and energy consumption, and pollution within the urban water management at Wilhelmsburg?

- ✓ What is the efficiency in water use when using locally generated storm water and wastewater as substitute for imported (fresh) water?

3 LITERATURE REVIEW

3.1 URBAN WATER MANAGEMENT, PAST, PRESENT AND CURRENT APPROACHES

Freshwater resources are coming under increasing pressure as a result of population growth and degradation of resources. With the continuous population growth in urban areas it becomes evident that the present management of urban water resources and system will not be suitable models for service provision for the near future (Eiswirth et al., 2003).

For over 100 years, the urban water cycle has been managed as separate centralized water supply, wastewater and storm water disposal processes. In the traditional approach, throughout the world water systems and planning of water services operate on once-through, linear terms; ones that deliver potable water and dispose of sewage separately to the provision of storm water drainage (Karka, et al., 2007; Mitchell, et al., 2001). The urban water cycle begins with extraction of water from water reservoirs and then delivery through an extensive pipe system to residential, commercial and industrial developments after previous quality treatment. The treated water is also used for recreational purposes like irrigation of parks and gardens. A portion of this water is then used to transport waste through a network of sewers to treatment plants which discharge effluent into receiving waters bodies. Precipitation on paved urban areas contributes to the urban catchment's storm water that is collected by an extensive drainage system for disposal into receiving waters (Coombes, undated).

In addition to the centralized urban water cycle problems, large volumes of storm water and wastewater are discharged from cities; while these wastes could be reused as a resource. Also, the amount of storm water and wastewater discharged typically exceeds the amount of water imported for water supply into to the area. This means that on average, three quarters of the water imported into urban areas is discharged as wastewater effluent. In some cities the wastewater is treated before being discharged to the receiving waters, though most storm water flows into the receiving waters without any previous treatment or quality improvement (Mitchell, 1999).

Nowadays, there is an increasing need for sustainability and protection of the environment regarding urban water management; a necessity to re-evaluate this 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).

According to Hellstrom et al., 2000, ideally urban water and wastewater system should without harming the environment provide clean water for a variety of users, and remove wastewater to avoid flooding. In addition it should exhibit an optimum for water efficiency for the site, pollution control, deliver recreational and cultural benefits, and effective capital and recurrent costs for the developers and householders (Hunt et al, 2004).

In addition to this need for a more sustainable urban water management, it is observed that some regions in Europe are already facing shortages of treated water resources and there is a tendency to this pattern to increase in the near future due to climate

change and population growth. Therefore, the increase in demands for water supply and sanitation services due to population growth cannot be fully met by the traditional sources and current technologies (Water Supply and Sanitation Technology Platform, 2005).

In the view of this more sustainable approach, new alternatives to the traditional water supply and disposal methods can be very beneficial. If this more sustainable approach is put in practice, decreases in imported water resources and wastewater and storm water discharges on urban systems can be achieved, consequently a decrease in water related energy consumption. This more holistic approach in urban planning and sustainable development can be provided if the water service provision is added to the traditional equation that includes components such as transport, energy, housing and employment (Mitchell, 2004). Therefore, storm water and wastewater are being re-evaluated as an alternative source to be reutilised and not as a waste to be disposed.

3.2 SWITCH VISION

The main vision consists of achieving a truly integrated management of the urban water system. A vision is a concise description of a desired future, how it is visualized to be in the future in terms of water resources and services.

The formulation of the new strategies for the new city and the description of the general vision is part of the process of the SWITCH demonstration cities. First of all, the vision and a set of sustainable indicators are established, and a number of future scenarios will be formulated. The scenarios are “stories” about the way the world might be in the future, a description of a possible future situation which is determined by the most uncertain factors, like climate change. The next step is to work out different strategies that are aimed to reach the vision under the conditions of a certain scenario.

Cities that are aiming to achieve the SWITCH vision could follow the following general objectives:

- ✓ To have citizens that are aware of “water and sustainability” and where authorities will involve the public in decision making.
- ✓ To manage its urban water system in an integrated way; integrating aspects of water supply, storm water management, wastewater collection, wastewater treatment and wastewater reuse.
- ✓ To use a set of sustainability indicators for decision making and planning.
- ✓ To have a strong scientific basis for decision making concerning the management of its urban water system.
- ✓ To ensure equity in the access to water, as well as to irrigated green areas.
- ✓ To minimize the energy consumption in the urban water cycle.

First of all, the vision and a set of sustainable indicators are established, and a number of future scenarios will be formulated. The scenarios are “stories” about the way the world might be in the future, a description of a possible future situation which is determined by the most uncertain factors, like climate change. The next step is to work out different strategies that are aimed to reach the vision under the conditions of a certain scenario. An example of this process is described below in Fig. 3.1.

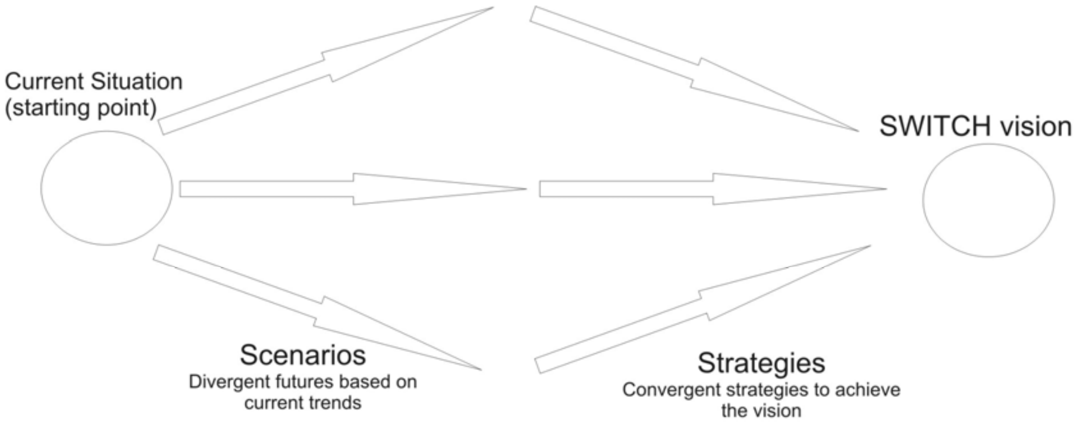

Figure 3.1 Scenario analysis and strategy development in the SWITCH planning process.

Wilhelmsburg is currently unsustainable regarding the urban water management; therefore the overall ideal vision is to achieve a sustainable self-sufficient and balanced water system. The specific visions for Wilhelmsburg are:

- ✓ To reduce imported water from outside the island.
- ✓ To achieve an independent system as much as possible on terms of imported water, by reuse of its own water (storm water, wastewater, surface waters).
- ✓ To reduce the energy consumption on the urban water cycle by 50%.

3.3 AQUACYCLE MODEL FOR URBAN WATER CYCLE

Basically a model is a description of the reality; it has to be adjusted and compared to the available measured data (calibration), and to be able to reproduce independently in a satisfactory way another set of observed data (validation). In this way the model can be used as a research tool to investigate the urban water balance. A good model is one that is properly validated; where it is possible to make the use of another set of measured data in another city for example, in the case of modelling urban water balance for example, and the group of observed data or output is well reproduced.

The aim of modelling the urban water cycles is to understand and predict the behaviour and performance of all components in the integrated water system. The models can be a powerful tool to derive solutions to structural and operational problems in order to be evaluated by the relevant stakeholders (SWITCH, 2006). In addition, models can be very useful in the design and turning of control strategies, since the possibilities to evaluate a strategy in practice are usually very limited (Vanrolleghem, 2005).

There are a variety of models available for describing the urban water system. Those models are mostly based on simple generic total water balance. Only recently a more holistic view of the urban water system is being taken into account; where the interactions among the potable water supply, wastewater discharge and the rainfall storm water runoff networks are being considered within the same modelling framework.

Aquacycle is a model for the simulation of the urban water cycle that considers the interactions among potable water supply, wastewater discharge, and the rainfall storm water runoff networks in a holistic way. The Aquacycle model focuses on urban water balance aspects, estimating the volume of water demand and available storm water and wastewater in different spatial scales. It can be a tool for investigating the use of locally generated storm water and wastewater as a substitute for imported water.
The model takes into account all stages in the passage of water through the urban water cycle. Basically the "cycle" starts with water entering as precipitation or (fresh) water imported in order to meet indoor and outdoor water use requirements. It then passes through the urban water system and exits in the form of evapotranspiration, storm water and wastewater (Fig. 3.2).

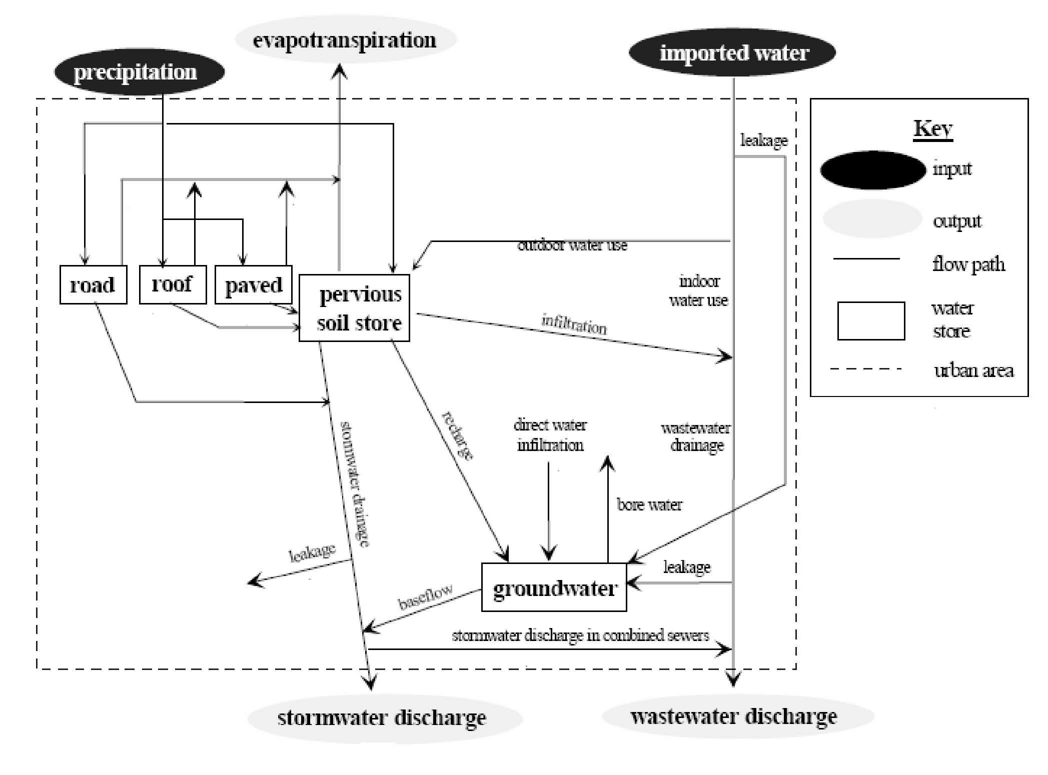

Figure 3.2 Schematic urban water cycle (Eiswirth, 2003)

The definition of the boundaries for the model includes the spatial dimensions and the time scale of the evaluation. The Aquacycle model operates on three spatial scales in order to be able to model a wide variety of schemes; (1) the unit blocks, (2) cluster, and (3) catchments (Mitchell, et al., 2001).

The unit block refers to a single household, industrial site, or public or commercial facility. This scale represents the smallest unit for the management of water supply, disposal and recycle-reuse operations, and is spatially divided into roof, garden and pavement areas. A cluster represents a group of uniform unit blocks that can form a local neighbourhood or suburb. It includes roads and public open spaces, and is used to represent the spatial scale at which community water servicing operations are managed. The catchment is made up of a group of clusters, which represents a uniform group of clusters that can form a local neighbourhood or suburb (Fig. 3.3).

In Aquacycle, 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 rainfall-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 processes of interception, storage, infiltration, inflow, and drainage are modelled using conceptual stores with parameters that can either be calibrated or introduced by the user. Those parameters include the percentage area of water stores, roof area initial losses, effective area and initial losses for roof, pavement and road areas, the base flow index and the base flow recession constant, the percentage of surface run off that inflows into the wastewater system, the infiltration index and the infiltration store recession constant, and the trigger-to-irrigate ratios for gardens and open spaces (*"The trigger to irrigate represents the level of soil wetness that the irrigator wants to maintain")*. The model receives input both from precipitation and imported water, as well as indoor water use requirements and evapotranspiration data.

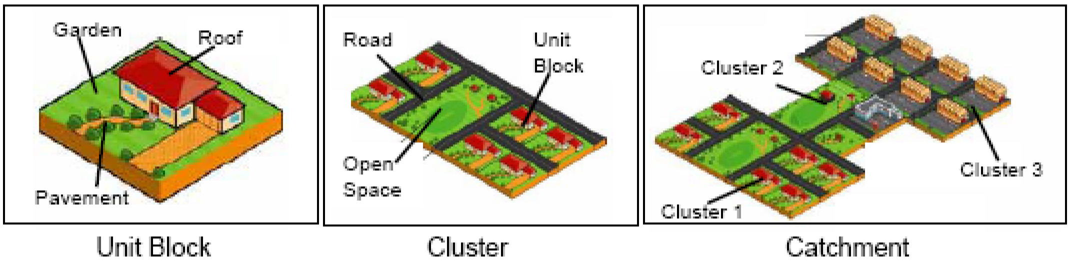

Figure 3.3 Spatial scales used in Aquacycle (Karka, et al., 2007).

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 evapotranspiration 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 water use, infiltration and inflow from the storm water drainage system.

The Aquacycle input data requirements are related to physical characteristics of the modelled catchment. A distinction is made between measured and calibrated parameters. Measured parameters are related to physical catchment characteristics and their values are determined through measurement, observation or local experience, whereas calibrated parameters are used in the estimation of water use, wastewater production and storm water drainage.

The Aquacycle can also simulate 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 storm water and wastewater exploitation include the installation of rainwater tanks, on-site wastewater treatment units and subsurface irrigation with grey water. At the cluster scale, methods include storm water storage, wastewater treatment and storage and aquifer recharge and recovery. Finally, centralized options applicable at the catchment scale can also be examined, including wastewater reuse and storm water storage in order to meet the needs of a particular or several clusters.

3.4 ENERGY BALANCE ON URBAN WATER SYSTEMS

Urban water usage has increased steadily to reflect more concentrated populations and intensified economic activities around urban areas. It can be said that the social and economic importance of water dedicated to urban use is enormous even though its

volume is less than that used by agriculture and other sectors. The usage of water at the urban system has gradually increased in order to cope with population growth and economic activities within the urban areas. The availability of water has decreased, due to intensified groundwater and surface water as a consequence to urbanization and economic development. To treat, pump, transport water from original sources for portable use becomes even more difficult, with the diminishing of freshwater resources. The current trend is for increasingly energy intensive water projects to store excess water in wet years, since most of the accessible water sources have already been depleted. In addition, the processes required to supply potable water often consume energy.

At the urban water systems there is a consumption of energy along the whole cycle at different levels, mainly at the extraction of supply water (from pumping to transportation), storm water collection and wastewater treatment. Also the heating of water at the household level can be included in this system, as it consumes a considerable amount of energy (Fig. 3.4). Water energy use is expected to increase due to a growing population, increasing reuse of wastewater, the remoteness or lower quality of alternative water sources, and increasingly severe treatment requirements due to a variety of water quality and environmental protection concerns.

The utilization of storm water and wastewater as an urban water resource rather than a waste product offers many benefits, including reductions of quantity of storm water and wastewater discharged from urban areas, reduction of quantity of imported water. Consequently, less water imported into cities means also less energy consumption on water transportation and a reduction in energy for wastewater treatment. On the other hand, some source substitution and reuse options can increase energy consumption by 500 to 1,000 kWh per ML. Storm water and wastewater reuse require extra energy to the traditional urban water system, as well as the rain water harvesting tanks. For example a treatment method such as reverse osmosis can increase energy consumption by around 4,000 kWh/ML (White et al, 2003).

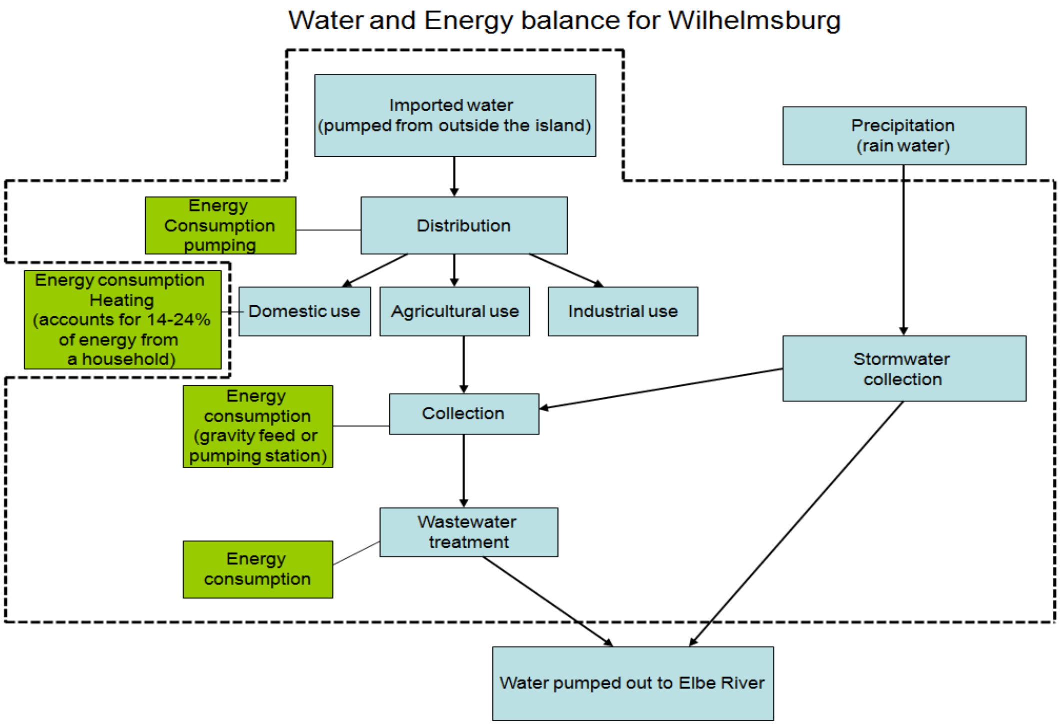

Figure 3.4 Water and energy balance for the urban water system of Wilhelmsburg.

4 METHODOLOGY

The proposed methodology for the case study consisted of two phases. The first phase is based on the application of an urban water balance model (Aquacycle) through the formulation of scenarios, like climate change and population growth and alternative strategies such as water use, wastewater production, and storm water production. After the application of the water balance model its outputs from the baseline scenario and future scenarios were inserted on a spreadsheet based model to calculate an inventory of energy balance at the urban water cycle. After the completion of the water and energy balance at the urban water cycle a matrix of scenarios and strategies was elaborated so it can be used as a tool as from each scenario the decision makers can decide the most likely strategy, and according to the scenario it can be switched from one strategy to other (Fig. 4.1).

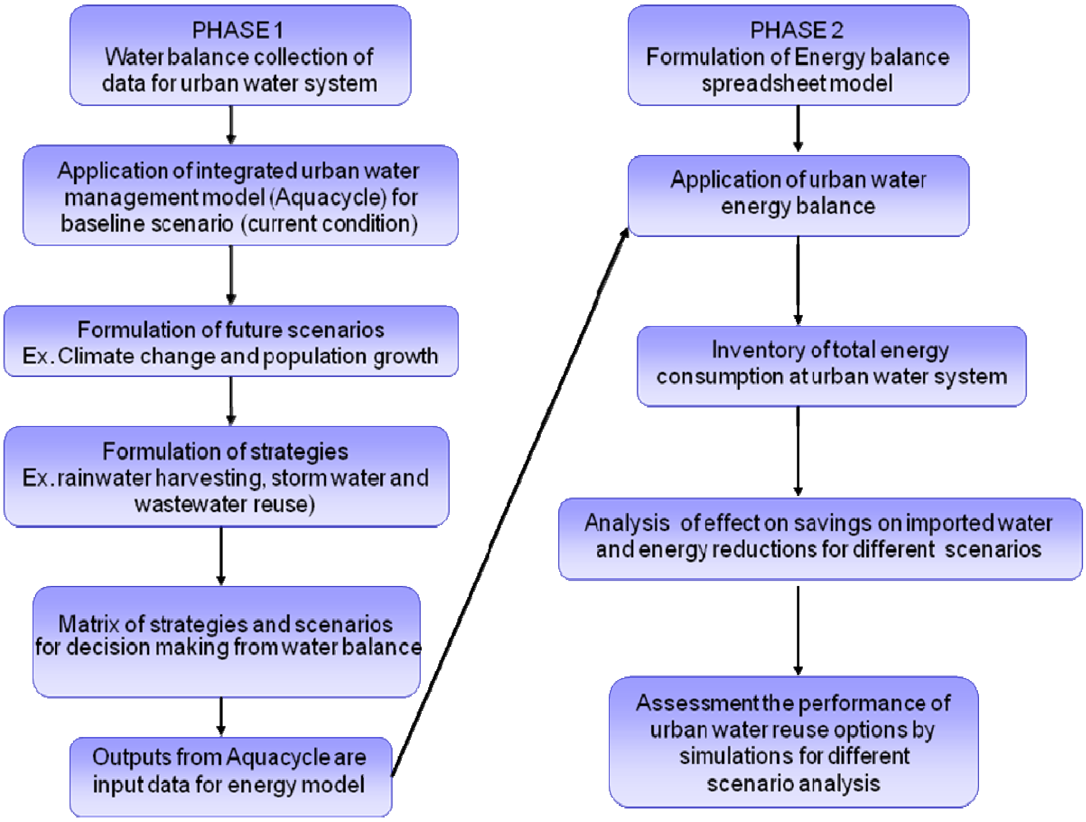

Figure 4.1 Diagram of methodology setup and its two phases; the urban water balance and the urban energy balance.

4.1 MODELLING OF THE URBAN WATER CYCLE AND ENERGY BALANCE FOR WILHELMSBURG

As a primary tool to estimate water balance on the urban water cycle from different sources the Aquacycle model was used. To meet the Aquacycle model requirements a vast input data needs to be acquired and processed. This water balance model requires specific information on the physical characteristics, such as distribution of houses, garden, paved area of a residential property, open space, roads, etc). Additionally it required demographic data (inhabitants per house) and information about water consumption behaviour of the population. Aquacycle also needs as input daily

based climate data, like precipitation and potential evaporation. The climatic time series range from 1991 to 2007 was derived from Deutscher Wetterdienst, 2008.

For this research, default initial parameters from Aquacycle are used. Consequently, this means that the model will not be calibrated. It is assumed that the default parameters from Aquacycle are satisfactory for this case study, as the aim of the application of this the model is to be used for strategic decisions and planning to evaluate different scenarios for the future. Uncertainties in the future scenarios are probably much higher than the uncertainties found in the model itself. In sum, the calibration will not be very precise as the main goal of the model is to make predictions for the future scenarios which already have many factors which are uncertain.

For the model setup, five (5) clusters were selected based on different spatial characteristics for the boundary conditions for the model, according to Figure 4.2. Those clusters were drawn on Google Earth by producing polygons so the areas could be calculated.

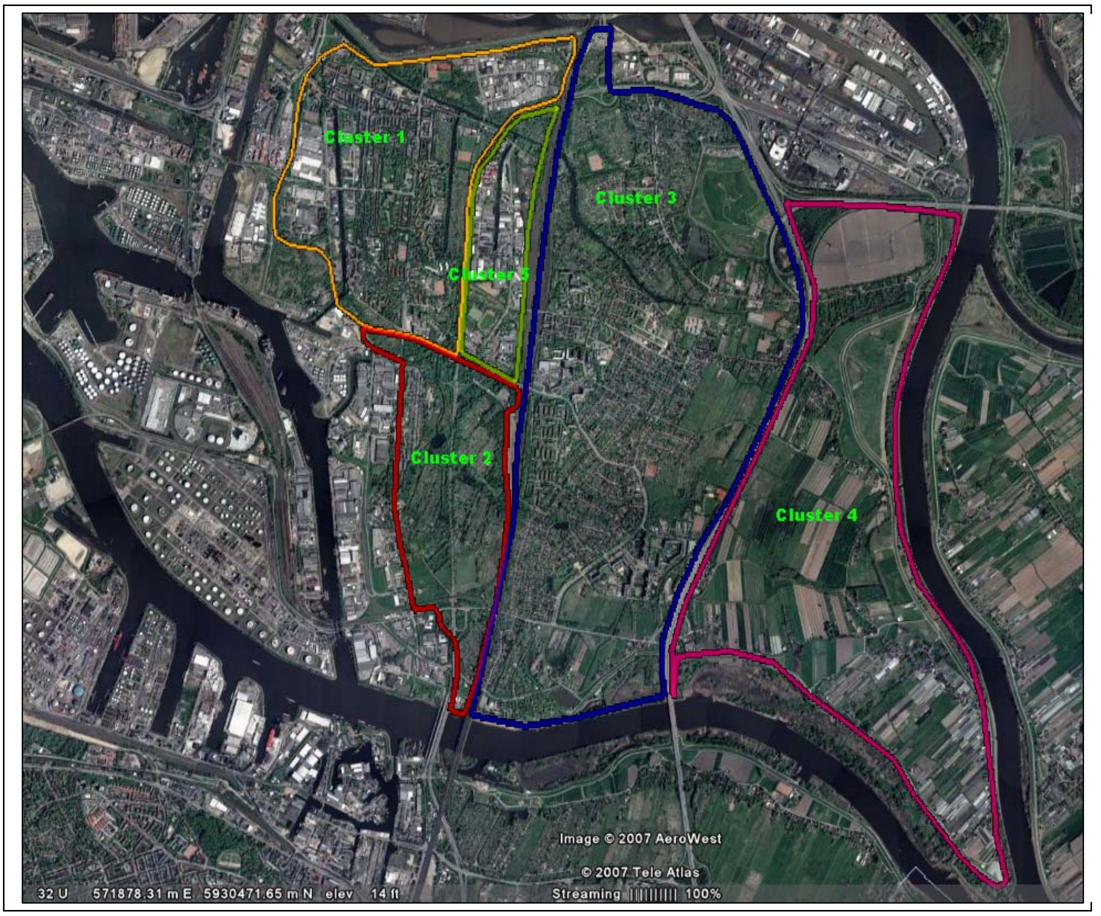

Figure 4.2 Google Earth with polygons representing the five different clusters of total area of 19 km².

- ✓ Cluster 1: Total area of approximately 3.1 km^2 (Highly populated area, smaller unit blocks)
- ✓ Cluster 2: Total area of approximately 1.7 km^2 (Low density, small unit blocks, area of International Year Exhibition in 2013, where about 6.000 new houses will be built)
- ✓ Cluster 3: Total area of approximately 7.8 km^2 (Sparse and bigger unit blocks)

- ✓ Cluster 4: Total area of approximately 5.7 km^2 (Agriculture, few and small unit blocks)
- ✓ Cluster 5: Total area of approximately 0.7 km^2 (Industries, few and big unit blocks)

4.2 DATA ANALYSIS AND PROCESSING

Both water volumes and energy consumption on the different components of the urban water cycle were collected for the area of interest. The data for the model was collected through data collection checklists and observation, as well as information from the SWITCH consortium partners in Hamburg; HafenCity University and the Municipality of Hamburg.

The baseline scenario consists of the actual situation of the river island of Wilhelmsburg, in this way the data below is necessary for the model setup. The measured parameters are shown on Appendix 3. The following data are required for the model Aquacycle as well as parameters required for the energy balance analysis. In addition this data, a field inspection to the study area as well as interviews with local operators was carried out in order to set up the models.

Climate data

- ✓ Precipitation and temperature data from Deutscher Wetterdienst, 2008

Water quantity parameters

- ✓ **Quantities of water delivered by Hamburg Wasser to Wilhelmsburg**

The amount of water imported into an area corresponds to the sum of indoor water use, irrigation, and leakage. These values are important as it helps to validate the model and for comparisons of savings on imported water according to different strategies.

- ✓ **Water distribution system map: division in zones?**

The distribution of water is important for the water balance analysis, the mobility of water in the island. Also in the model the wastewater and storm water can be transferred between clusters for reuse.

- ✓ **Storm water runoff**

The storm water runoff is the water that leaves the system flowing across impervious surfaces. It would be important to have the map of discharge of the storm water, where the pipes are, how it is arranged; is the storm water being discharged from houses to canals or it is all discharged straight to the rivers?

- ✓ **Quantity of wastewater arriving at wastewater treatment plant**

The total wastewater discharged from the catchment is the sum of indoor water use, infiltration and inflow from the storm water drainage system. It is likely that the wastewater arriving at the WWTP is from the whole city of Hamburg, in this way the useful information instead would be based on the values of production of wastewater at each household or the volumes arriving at the wastewater pumping stations at Wilhelmsburg for example.

- ✓ **Quantity of water pumped in/out of the polder**

Important factor to quantify the water balance for the island; also information on where those pumps are would be useful. Also it would be interesting to know about the energy that is being brought to the island.

<u>Energy quantity parameters</u>

- ✓ **Electricity consumption at the wastewater treatment plant**

- ✓ **Energy requirements for Hamburg Wasser to deliver water to Wilhelmsburg and for the distribution system – pumping stations**

Important data for evaluation on energy balance for the island. The possible savings on water can also minimize the costs on transport on water. This parameter can be used to calculate possible savings on energy related to water.
If this data is unknown, it would be useful to know the distances for the water to be delivered water to Wilhelmsburg and for the distribution. Another useful information would be the depth of the groundwater table where the water is extracted, so it can be calculated the energy consumption.

Simulations were performed for different scenario analysis, which are factors that will be influencing the system structure over time, to assess the performance of urban water reuse options. Those simulations of scenarios were used to identify possible improvements in the urban system.

The model has some limitations; from others works it can be learned that the model has a limited capacity in analyzing long term scenarios on population growth, urban expansion and climate change (Karka et al., 2007). An experienced practitioner can achieve the integration of models fairly simply with the aid of a spreadsheet. In this way a spreadsheet was developed to forecast climate change and population growth so this data could be later used on Aquacycle.

Strategic for decision making in the future:

As mentioned previously, the scenarios are developments in the future that are not controlled by urban water managers, for example, parameters which are beyond manager's control, like population growth, climate change and economic situation. For this case study examples of scenarios could be the number of people living the river island and climate change.

The strategies are actions that urban water managers can adopt in order to reach scenarios. The development of scenarios will lead towards the vision; they are the corrections of the actions to achieve the visions. Examples of strategies are storm water collection at the catchment scale, rainwater collection at household scale, or no storm water collection (conventional).

For this study, strategies and scenarios were formulated and for each scenario there will be calculated an output (Table 4.1). The outputs can be as examples; percentage of reduction of water supply needed to be transported from outside the island area and reduction in energy use. This matrix can be used as a tool as from each scenario the decision makers can decide the most likely strategy, and according to the scenario it can be switched from one strategy to other. The renewable technologies can be compared, aiming at providing independent viewpoint for decision makers when considering which technologies to adopt.

Table 4.1 Example of scenarios and strategies matrix for decision making.

	Scenario 1 Population growth	**Scenario 2** Climate change	**Scenario 3** Economic changes
Strategy A Green-Eco strategy	Model outputs: energy use, water reuse		
Strategy B Moderate strategy		X	
Strategy C Conventional			X

5 DESCRIPTION OF STUDY AREA

Wilhelmsburg is the biggest district of Hamburg with an area comprising of 35.3 km² and has about 49,000 inhabitants in 2006 (Wikipedia, 2008). It is situated on an island between the Northern and Southern branches of the Elbe river (*Norderelbe* and *Süderelbe*), together with the other districts of Steinwerder, Veddel and Kleiner Grasbrook (Fig. 5.1). The latter almost exclusively consists of facilities of the Hamburg Harbour. The other districts are technically all islands of their own, as they are all separated by their own dams.

Figure 5.1 Wilhelmsburg and neighbours districts. Source: Wikipedia (2008)

The average water consumption in Hamburg is 115 litres per capita per day (Hamburg for 2002). It is consumed as 40 litres per capita per day for the toilet, 25 litres per capita per day for the bath and shower, 20 litres per capita per day for the laundry and 20 litres per capita per day for cooking.

6 FORMULATION OF SCENARIOS AND STRATEGIES

6.1 INTRODUCTION

Scenarios and alternative strategies were formulated. The strategies are actions that urban water managers can adopt in order to reach scenarios. The development of scenarios will lead towards the vision; they are the corrections of the actions to achieve the visions. Examples of strategies are storm water collection at the catchment scale, rainwater collection at household scale, or no storm water collection (conventional).

6.2 SCENARIOS

Climate change

a) Precipitation and temperature trends:

The last decade in Germany has been the warmest of the century. According to the IPCC reports, there has been a small trend, just over two per cent, towards a wetter climate over Germany during spring and autumn seasons. There is a slight increase in expected annual precipitation over Germany in the future - between 5 and 10 per cent by the 2050s. These increases in precipitation occur in winter, spring and autumn, but summers become drier over all of Germany (Fig. 6.1).

The evaporation will be also influenced by the temperature change. According to the IPCC for Hamburg there will be an increase of 1.4°C for 2020, 2.6°C for 2050 and 3.9°C degrees for 2080 (Hulme, 1999).

The changes in the precipitation pattern depending on its magnitude can affect dramatically. the overall water balance for the island of Wilhelmsburg, more precipitation means more storm water runoff and more water available for the whole system, while the dry summers can have a negative effect on the water balance; a deficit of water.

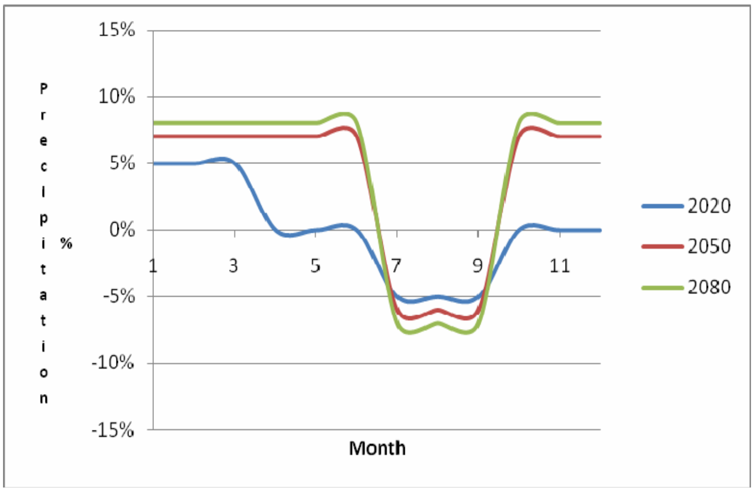

Figure 6.1 Precipitation forecast for the years of 2020, 2050 and 2080 according to IPCC data (Adapted from Hulme, 1999).

b) Sea level rise and temperature rise:

Global-mean temperatures increase by between 1.3º and 4.6ºC by 2100, representing global warming rates of between 0.1º and 0.4ºC per decade. This is comparable to an observed global warming rate of 0.15ºC per decade since the 1970s. One of the most remarkable consequences of a warming climate will be the sea-level rise. It is suggested a future global-mean sea-level rise of between 2cm and 10cm per decade, compared to an observed rise over the last century of between 1cm and 2cm per decade. The largest contribution to this rise in sea-level comes from the expansion of warmer ocean water, a slow inexorable process that will ensure that the world's sea-level continues to rise for centuries to come.

The North Sea and the Baltic coasts of Germany are at risk from sea-level rise and other consequences of climate change, such as an increase in the frequency and severity of storms, and an increase in salinity of fresh river waters (Hulme, 1999). The area of Wilhelmsburg is under the influence of the North Sea which is connected to the long River Elbe. The river island of Wilhelmsburg is surrounded by the River Elbe and the cannels in the island are constantly being pumped in or out to the River Elbe depending on the levels of the canals. Much of the water for the agriculture area of the island is coming from the River Elbe by keeping the water at the right levels.

With extreme scenarios of sea level the water of the River Elbe can become slightly brackish and can no longer be used for the agriculture; an additional supply of water for this purpose will have to be implemented, like groundwater, consequently increasing the demand of water.

Population Growth

In line with the policy to increase Hamburg´s population from 1,7m to 2m by 2010, Wilhelmsburg is engaged in planning and substantial capital investment. Hamburg has an area of 755.3 km^2 and a population of about 1.7 million, while Wilhelmsburg comprises of an area of 35.5 km^2 and a population of about 49.000 inhabitants. There is a plan of around 6.000 to 7.000 new homes to be constructed (Arkell, 2005).

As no data on population growth was found for Wilhelmsburg, it was estimated based on the population from the years of 2004 to 2006; where it was found a growth rate of approximately 1%. Though, if considered the construction of the 6.000 new houses on cluster 2, this rate is already above the expected 1% going up to 3%. In this way, for the population growth scenario it was simulated both populations' growths of 1% and 3%; where it is considered the new houses.

Extreme changes in water use (more or less use)

Regarding the household water consumption, the main driving forces of water consumption are economic and demographic growth, as well as changes in lifestyles that are more water intense. On the other hand, technological innovations (water efficient appliances and devices) and responsible household water use patterns can help to reduce water consumption. Some governments have design a policy package with a mix of policy instruments to move towards sustainable water consumption (*e.g.* water pricing and metering, stricter environmental regulation, taxes, diffusion of technology, information and environmental education), some OECD countries have succeeded in de-coupling economic growth from water consumption. However, in other countries water subsidies are still one of the main obstacles for the efficient and sustainable use and management of water. Urban water use constitutes about 20

percent of the water used in California, or 8.8 million acre-feet per year. Water delivered to a municipal water supplier has two additional energy requirements before it can become available to the customer: treatment and pressurization. Water delivered through municipal systems generally must be pressurized, using pumps to store water in aboveground tanks or to pressurize water mains directly for distribution and for water pressure for the customer (Organization for Economic Co-operation and Development, 2002).

For Hamburg it is shown that currently there is a decrease in water consumption by the population, though an opposite pattern should also be considered. Due to climate change an increase of water consumption could occur; it is known that in warmer climates there is an increase of drinking water consumption at the residential sector for example. This could cause a higher demand of water for future scenarios where it is expected an increase in temperatures.

In Germany, 99% of households are connected to water supply networks, and 98% to sewage systems. Water consumption is decreasing in Germany, while water supply decreased 15% from 1991 to 1998. In Germany, water losses due to leaking water pipes represent 9%, (OECD, 1999 at Organization for Economic Co-operation and Development, 2002). Various factors influence water demand at the household level. Though they are all interrelated, some have strong influences on reducing water consumption, whereas others result in increased water demand. Pressure on water supply is mainly due to economic growth both at the national and household level and to demographic changes (increases in population as well as more single households). In some OECD countries there has been a de-coupling of economic growth from water consumption. In these countries, technology and environmental awareness, and to some extent water pricing (taxes), have been key contributors to reducing water consumption. In some countries, however, changes in behaviour are related more due to environmental awareness than to economic incentives (Organization for Economic Co-operation and Development, 2002).

Changes in land use – cluster 4 (agricultural to urban use)

The area that has mainly agriculture land use in Wilhelmsburg may be used in the future for urban settlement, where that space is given for new houses. This shift of land uses may alter completely the demand of water supply for the island, for this case from agricultural use to urban domestic use. Consequently the water and energy balance for the whole catchment area will change.

Oil price x energy price

Many regions of the world are facing formidable freshwater scarcity. Although there is substantial scope for economizing on the consumption of water without affecting its service level, the main response to water scarcity has been to increase the supply. To a large extent, this is done by transporting water from places where it is abundant to places where it is scarce. The transport costs are closely related to the oil price; the higher the oil price, the higher the costs for transporting the water and consequently the water price (Zhou et al., 2004). The transportation of water is directly related to costs and oil price in this way influencing the costs with water related energy consumption. The increase in oil prices and consequently the costs for transportation of water will have an impact on water demand, which may decrease.

Kyoto protocol energy reduction

The need to reduce greenhouse gas emissions has driven a number of countries to address household consumption patterns through climate protection policies. The

German government has target 25% reduction of carbon dioxide emissions by 2005 compared with 1990 levels (BMU, 2000-Climate Protection Programme at Organization for Economic Co-operation and Development, 2002). Corresponding reduction targets for households were established at 13-20 million tonnes (Mio t) of CO^2 from buildings and a further 5 Mio t from private households. In one reduction scenario, household CO^2 emissions could drop from 158 Mio t in 1990 to 72 Mio t in 2020. This means that with the targets to reduce the emissions, the energy water related consumptions have to decrease not only at the household level but also the demand of water resources and urban wastewater treatment.

6.3 STRATEGIES

Rainwater harvesting

Rainwater tanks can aid self-sufficiency, providing a back-up supply in case of water restrictions caused by drought, peak supply shortages, or water quality problems. The rainwater tanks can also provide cost-effective on-site detention of storm water. The water use can be reduced by 50 to 100 percent in urban areas. This can consequently; (1) reduce the need for new dam construction, (2) protect remaining environmental flows in rivers (3) reduce infrastructure operating costs, and (4) reduce the energy used in pumping water, thereby lowering greenhouse gas emissions (Australian Government by the Australian Greenhouse Office, within the Department of the Environment and Heritage, 2005).

Decentralized wastewater treatment plant at household and cluster level

“The decentralized concept is based on a simple premise: Wastewater should be treated (and reused, if possible) as close to where it is generated as is practical” (Anh et al, 2002).
With decentralized and smaller wastewater treatment plants (at household or cluster scale) the wastewater can be managed on a better way and the costs reduced with less transportation and leakages on the network. A wastewater treatment at cluster scale is a more realistic practice as it involves fewer units. According to White et al, 2003, if compared to decentralized wastewater systems, the more centralized systems do not necessarily reduce the cost per lot over the whole life cycle.

Wastewater reuse

Wastewater can be used as a resource rather than a waste product; it can be used to flush toilets, water gardens and even to wash clothes. By reusing the wastewater it is possible to; (1) reduce water resources use, (2) cut down the amount of pollution going into our waterways and (3) help save money on new infrastructure for water provision and wastewater treatment. The Wastewater re-use decreases effluent volumes, reducing the stress on existing centralised wastewater disposal systems, which will work better and last longer. Greywater can be re-used indoors for toilet flushing and clothes washing. Toilets and clothes washers are two of the biggest users of water in an average household. Reusing wastewater for toilet flushing will save approximately 65 litres of potable water in an average household every day. Reusing wastewater in your clothes washer will save approximately 90 litres of potable water in an average household every day. Greywater can be directly diverted from the shower or bathroom sink drains for re-use in the toilet only. However, it should not be stored for more than a couple of hours before re-use or disposal to sewer (Australian Government by the Australian Greenhouse Office, within the Department of the Environment and Heritage, 2005).

Reduction in water use and consequent energy

The relationship between water and energy used in wastewater treatment and water reclamation is a complex one. When water is used only once, then treated and discharged to the environment, for instance through an ocean outfall as is still the practice in most coastal cities worldwide, the result is minimal resource utility, minimal resource recovery, and maximum compounded energy use. When water is reclaimed through advanced wastewater treatment and is then reused to offset the use of potable water for non-potable purposes such as irrigation and fire protection, water utility is increased. Moreover, the per-unit volume energy intensity associated with water collection, potable treatment, and distribution followed by wastewater collection, treatment, and reuse is decreased. In short, water reclamation and recycling save water and energy, while single-pass water use wastes water and energy. Matching water quality with its intended use achieves the greatest water and energy utility and efficiency, thereby minimizing depletion of these scarce resources. By offsetting the demand for new water resources, water reclamation and recycling reduce water consumption and the energy used in providing potable water.

Storm water harvesting and reuse

Storm water is pure rainwater plus anything the rain carries along with it. In urban areas storm water is generated by rain runoff from roof, roads, driveways, and footpaths and other impervious areas.

Storm water can be a valuable resource. It’s re-use leads to water savings and reduced environmental impact; storm water is a useful resource that can replace imported water for uses where high quality water is not required, such as garden watering, toilet, kitchen, and bathroom use.

Use of surface water for drinking water instead of groundwater, like membrane filtration or desalinization

It is an alternative that in the future the treatment of surface waters will be done by the membrane filtration method. Reverse osmosis can increase energy consumption by around 4,000kWh/ML. Though nowadays the costs for this technique are quite high, the costs will continue to decline in the future as technology progresses.

Desalting brackish groundwater, as well as some surface water, agricultural and municipal wastewater, and seawater is the other emerging source of new water in the State. DWR expects that over the next twenty years it will not account for much more than a few tenths of a percent of all the water used in California. The primary desalination technology in use today is reverse osmosis, accounting for 90 percent of the water desalted in California. Reverse osmosis filters salty water under pressure through a semi-permeable membrane, leaving the salts behind. Currently, energy constitutes about 50 percent of the costs of reverse osmosis desalination, and energy costs alone can exceed $1,000/acre-foot. By comparison, it costs the Metropolitan Water District of Southern California an average of $115-$135 for one acre-foot of treated SWP water. There are numerous research efforts underway to develop more effective and less costly desalination methods. Recent developments in low-pressure membranes show promise for reducing energy requirements of desalination, and significant opportunities remain for further technology improvements (California Energy Commission, 2004).

7 AVAILABLE DATA

7.1 INTRODUCTION

The data used to setup the water and energy balance for the study area of Wilhelmsburg was gathered through literature studies, data acquisition in the city of Hamburg at the SWITCH consortium partners in Hamburg, at the Freie und Hansestadt Hamburg and at the Landesbetrieb Straßen, Brücken und Gewässerin Hamburg.

Both models for the water and energy balance accounts for all compartments in the urban water cycle, though not all the data was available to meet the model requirements. In this chapter the data available is discussed and when needed assumptions were formulated and explained in order to fill the data gaps.

7.2 WATER QUANTITY PARAMETERS

7.2.1 Water supply

For the public water supply, approximately 122,000,000m^3 active water was delivered in Hamburg in 2004. The entire water supply originates from groundwater.
For the area of Wilhelmsburg there are two (2) groundwater supply works, the Water Company on the Elbinsel and Suederelbmarsch (Fig 7.1). The first one which is situated in Wilhelmsburg is responsible for a small supply of the area of the same name is expected to be inactive by the end of August this year. Therefore, the only responsible supply work for Wilhelmsburg area will be Suederelbmarsch.

Wilhelmsburg, Water Company on the Elbinsel: Since 1911 the existing groundwater supply of Wilhelmsburg has delivered its fresh water with five wells, from 220 to 295 meters deep of sand and gravel layers. Submerged pumps transport the water to degassing and oxygenation. After filtering in eight closed pressure filters three centrifugal pumps ensure that the drinking water arrives at the consumers within the range of Wilhelmsburg (Hamburg Wasser, 2008). The continuous duty of the work is of 4,000 cubic meter per day, or more specifically a supply of 1,340,000m^3/year (Weiner, personal communication).

Suederelbmarsch: Central Water Company in the Elbmarsch the groundwater work Suederelbmarsch supplies water since 1956 (Fig.7.10). Two horizontal filter wells, nine deep and four flat wells extract groundwater from depths between 17 and 363 meters. The water is filtered before it arrives into three purified water tanks with a total volume of 10.000 cubic meters at a temperature of 11º C. From there five pumps transport approximately 38,000 cubic meters of drinking water daily to the supply network for the area of **Suederelbmarsch** water supply districts (Hamburg Wasser, 2008).

Figure 7.1 Map of water supply for the region of Hamburg and vicinity, the Suederelbmarsch water supply work supplies water for the 11 districts in the area in dark green, which includes Wilhelmsburg. [Source: adopted from Hamburg Wasser, 2008]

The total volume extracted for the water supply for Suederelbmarsch is estimated in 38,000m^3 for an area of 47.2 km^2 and a total population of about 73,000 inhabitants (Table 7.1). Considering the proportion between the population of the different zones in the Suederelbmarsch water supply area and water supply quantities, it is estimated that for Wilhelmsburg the daily water supply is around 25,500m^3. If the average water consumption in Wilhelmsburg is 115 litres per person per day and a total population of 49,140 inhabitants is taken in to account, it can be calculated that a total residential daily water supply is 5,557m^3. In this way it can be calculated that the daily water supply of 25,500m^3 subtracted from the residential use of 5,557m^3 equals to 19,800 m^3 which corresponds to the water supply for commercial and industrial use.

Table 7.1 The districts and the number of inhabitants of the Suederelbmarsch water supply network.

	Inhabitants
Alterwerder	784
Cranz	833
Finkenwerder	11689
Francop	704
Kleiner Grasbrook	1410
Moorburg	708
Neuenfelde	4870
Neuland	1636
Steinwerder	744
Waltershof	800
Wilhelmsburg	**49140**
Total	73318

7.2.2 Wastewater

The Free and Hanseatic City of Hamburg currently has a population of 1.7 million. For the treatment of the municipal wastewater in the Hamburg Metropolitan area, public entity Hamburg Wasser (represented by member company HSE) operates two WWTPs with a total treatment capacity of 2,100,000 PE. Koehlbrandhoeft WWTP, which is the bigger one of the two plants, is situated on the river island of Wilhelmsburg adjacent to the famous port of Hamburg (Fig. 7.2). According to the legal requirements for treatment of urban wastewater in Europe, the plant comprises mechanical and biological wastewater treatment stages with full nitrogen and phosphorous removal.

The amount of wastewater arriving at the local waste water treatment plant in the year of 2004 was approximately 145,000,000m^3. The amount of total wastewater corresponds to 105,000,000 m^3, the amount of precipitation water a volume of 23,000,000m^3 as well as a volume of 16,000,000 m^3 for the other remaining types of water (Consulaqua, 2006).

For 2005 the wastewater treatment wastewater treatment plants received an amount of 4 to 5 m^3/s of wastewater with a peak of 17m^3/s during rainy events. The maximum load of the two (2) wastewater treatment plants was 440,000m^3 of wastewater per day, while both Koehlbrandhoeft and Dradenau together treat 160,000,000 m^3 per day, with a total amount of 25,000,000 m^3 of storm water per year. The total energy consumption of the wastewater treatment plants was of 121,150,000 kWh. (Hamburger Stadtentwässerung, 2006).

The daily wastewater flow in 2008 is approximately 400,000m^3/d, while the daily BOD-load is approx. 120,000 kg/d. In addition, annually about 25 million m3 of rain water arrive at the plant (Hamburg Wasser, 2008).

Additionally, Koehlbrandhoeft WWTP comprises the central sludge treatment system for both WWTPs to be operated by HSE in Hamburg. The biogas produced amounts to 65,000 m^3/d. Since 1992 about 27 million kWh of electricity had been generated annually in a combined heating and power station. Waste heat had been used internally. Meanwhile digestion gas mainly serves to dry digested sludge in the KETA, the sewage sludge dewatering and drying system. Since 1997 the dried sludge is thermally utilized in the incineration plant for residues from the sewage treatment (VERA). The sludge and residual substance are extracted in the different steps of the

waste water treatment and are separated accounting for about 1.4 million cubic meter of sludge in one year. There is a reduction of the sewage sludge from originally 1.4 million on approximately 101,000 cubic meters, which is more than 90 per cent (Cegelec, undated).

7.2.3 Storm water

There are three (3) pumping stations at Wilhelmsburg to pump the storm water out of the island into the River Elbe (Fig. 7.2). The total amount of water pumped in the year of 2007 was of 9,603,110m^3, while for each station the volume of water pumped was; for Kuckuckshorn it was 2,017,656.00m^3 for Finkenriek it was 4,093,588.80 m^3 and for Sperlsdeich it was 3,491,866.80 m^3 (Appendix 2).

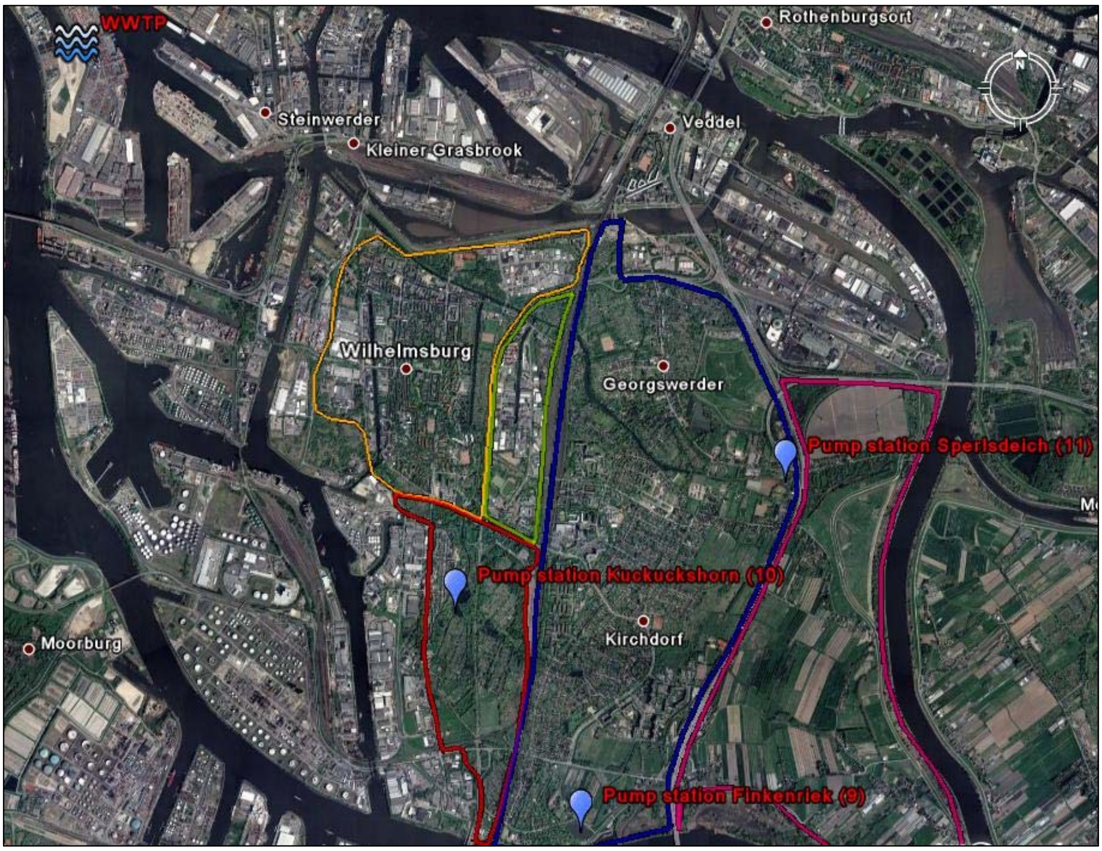

Figure 7.2 Location of the three pumping stations (Kuckuckshorn, Finkenriek and Sperlsdeich) and waste water treatment plant for Wilhelmsburg.

7.3 ENERGY REQUIREMENTS PARAMETERS

7.3.1 Water supply

The water supply system consists basically of the energy consumed in pumping, treating, storm water drainage and water heating. Generally groundwater must be pumped to be put to use, requiring energy to lift it to the surface.
Urban water usage has increased steadily to reflect more concentrated populations and intensified economic activities around urban areas. Although the volume of water

dedicated to urban use is less than that used by agriculture and other sectors, its social and economic importance is enormous. Urban water system has high energy consumption, between 1,100 and 20,100 kilowatt-hours per 3785.41 m^3 (million gallons) (California Energy Commission, 6/2005). For Hamburg and vicinity there is a daily supply of water of 312,523m^3 and an energy consumption of 65,529 MWh for the whole abstraction process. If an estimation is done for Wilhelmsburg based on a daily water consumption of 4,268 m^3 (according to the water balance outputs from Aquacycle) the daily energy consumption will be about 2,415 kWh.

7.3.2 Wastewater

The sewage sludge resulting during the waste water purification are stabilized, drained and dried then in the KETA ("Klaerschlammentwaesserungs" and drying unit). It is carefully thermally used afterwards in the VERA. Only the heavy metal sludge in the year 2006 about 360 tons) must be deposited as special refuse; the resulting residual substances such as burn ash and gypsum are reused. Current consumption and generation in the VERA achieved the best value with 81 million KWh since 2001. With a current consumption of the sewage purification plant group of approximately 97 millions a KWh and an internal requirement of the VERA of 24 millions a KWh the own production ratio for 2006 was of 67 % as opposed to 58 to % in the previous year. Without considering the VERA own generation ratio amounts to still 59% in 2006 and 49% in 2005.

The current consumption of the sewage purification plant Dradenau annually is 97 million kWh, and the portion VERA consumption of 24 million kWh, in a total of 122 million kWh for both WWTP portions. The energy production from the sludge accounts for 82 million kWh and the gas digester production of 32 million kWh.

7.3.3 Storm water

There are three (3) pumping stations at Wilhelmsburg to pump the storm water out of the island into the River Elbe. The energy spent for each of the stations for last year for Kuckuckshorn was 68,700 kWh, for Finkenriek was 85,915 kWh, and for Sperlsdeich was 42,685 kWh (Appendix 2).

An interesting fact seen when comparing the three (3) stations is that there are differences in quantities in water pumped and energy consumption between stations. The pattern where the more water being pumped more energy is consumed is not followed; like the station of Kuckuckshorn shows to pump lower volumes of water per year when compared to other stations and the higher energy consumption. This could be due to several factors, like due to technical characteristics of the pumps used stations (more efficient and newer pumps) and/or a difference among the pumping station on the pumping head levels.

8 RESULTS

8.1 APPLICATION OF AQUACYCLE MODEL FOR URBAN WATER BALANCE

8.1.1 Scenarios

For the application of the urban water balance model, several scenarios were simulated: a baseline scenario, which is the current condition, and different future scenarios for the years of 2013, 2020 and 2050 (Table 8.1). For those future scenarios a population growth forecast of 1% and 3% and the precipitation forecast for the respective years were also simulated (for the year of 2013 the precipitation considered was the same as for the baseline scenario, the year 2007). The growth rate of 1% is an estimation of the growth rate based on an average of the years of 2004 to 2006. Though the population growth of 1% is more realistic, a population growth rate of 3% was also simulated as it is a more extreme rate and it follows the growth of population if the new housing plan is accomplished, where the 6,000 new houses are built in. The precipitation data used in the simulations consists of daily precipitation for 17 years; from 1991 to 2007. The precipitation forecast was based on the IPCC scenarios as described previously.

Table 8.1 Setup of scenarios

Scenarios	Precipitation forecast	Temperature	Sea level rise	Population (1% growth)	Population (3% growth)
Baseline	-	-	-	49,000	49,000
2013	-	-	-	52,719	60,387 (6,000 houses in cluster 2)
2020	+5% in winter and -5% in summer	increase of 1.4°C	38 cm	56,522	74,117
2050	+7% all seasons and -6% in summer	increase of 2.6°C	68 cm	75,852	179,901

8.1.2 Strategies

Four types of strategies were simulated, a green-eco strategy, a moderate, a conventional strategy and the business-a- usual strategy for 2050. The strategies were simulated for the two different populations' growths of 1% and 3%, where on the latter it is considered also the scenario on the year of 2013 where the 6000 new housing units will be constructed.

1) 2013 strategy:

In this case a strategy of rain tanks is tested for the new housing development at only the cluster number 2 (only for the 3% population growth).

- ✓ Unit block scale: Use of rain tanks at all clusters with capacities of $0.3m^3$ for the clusters 1, 2 and 3 and 0.25 m^3 for clusters 4 and 5. The water from the rain tanks are used for kitchen, bathroom, laundry and toilet.

2) Green-Eco strategy:

This strategy includes all the possible ranges of reuse strategies at the unit block, cluster and catchment scales for the urban system like:

- ✓ Unit block scale: Use of rain tanks at all clusters with capacities of $0.3m^3$ for the clusters 1, 2 and 3 and 0.25 m^3 for clusters 4 and 5. The water from the rain tanks are used for kitchen, bathroom, laundry and toilet.
- ✓ Wastewater storage at cluster scale: of $4{,}000m^3$ for clusters 1 and 3 and $3{,}000m^3$ for clusters 2 and 4, and for cluster 5 of $1{,}000m^3$. The unit blocks have the wastewater being drained to the wastewater storage (at the clusters storage) and all the unit blocks receive a supply to toilet from a cluster store. The waste water storage overflow to storm water.
- ✓ Storm water storage at cluster scale: storage capacity of $4{,}000m^3$ for clusters 1 and 3, $3{,}000m^3$ for clusters 2, $2{,}000m^3$ for clusters 4, and for cluster 5 of $1{,}000m^3$. The road runoff goes to the storm water store. The storm water will supply toilets from a cluster storm water store.

3) Moderate strategy:

- ✓ Unit block scale: Use of rain tanks at all clusters with capacities of $0.3m^3$ for the clusters 1, 2 and 3 and 0.25 m^3 for clusters 4 and 5. The water from the rain tanks are used for laundry and toilet.
- ✓ Storm water storage at cluster scale: storage capacity of $4{,}000m^3$ for clusters 1 and 3, $3{,}000m^3$ for clusters 2, $2{,}000m^3$ for clusters 4, and for cluster 5 of $1{,}000m^3$. The road runoff goes to the storm water store. The storm water will supply toilets from a cluster storm water store.

4) Conventional strategy:

- ✓ Unit block scale: Use of rain tanks at all clusters with capacities of $0.3m^3$ for the clusters 1, 2 and 3 and 0.25 m^3 for clusters 4 and 5. The water from the rain tanks are used for kitchen, bathroom, laundry and toilet.

5) Business-as-usual strategy:

- ✓ That is the situation were no strategy is adopted, where there is no intervention. It only pre-supposes continuation of existing trends and paradigms into the future.

For the selection of the volume of storm water storage at cluster scale it was simulated the performance of a series of different sizes of storage capacity and its effects on reductions on water imported to the system. That was done in order to optimize the size water storage; it is not necessary to have large water storage if there are no significant reductions in imported water and there still are costs related to it. Volumes between $2{,}000m^3$ and $26{,}000m^3$ were simulated for storm water storage and the effects on reduction on imported water. Also included were the simulation of no storm water storage and its needed volume of imported water. It was found that for bigger capacities of storage the greater it was the reduction on water imported, but at a certain point the reductions are not very significant, where the curve in the graph shows stabilization. The point found where the curve starts to stabilize is when the volume of

storm water storage should be optimal, that is with a storm water storage of 14,000 m^3 (Fig. 8.1).

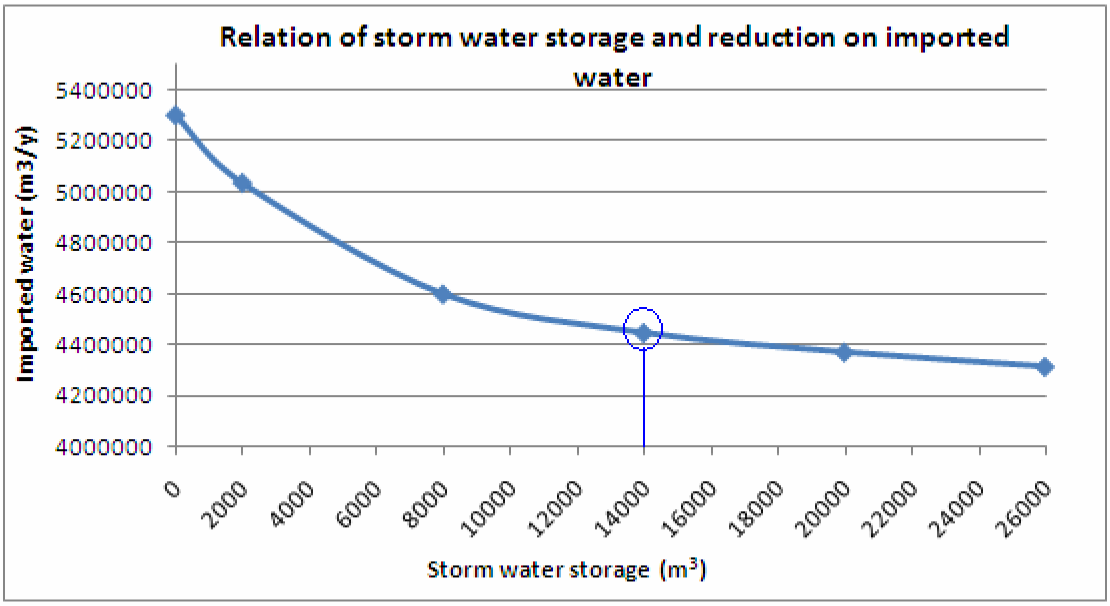

Figure 8.1 Relation between the storm water storage and the reduction in the water imported to the catchment and the optimal storm water storage (14,000m^3).

The same was done for the wastewater storage. This time it was simulated the different volumes of 5,000m^3 to 17,000m^3 for wastewater storage and the effects on reduction on imported water. The same expected pattern for bigger capacities of storage the greater was the reduction on water imported. The optimal, point for the waste water storage is of a volume of 15,000 m^3 (Fig. 8.2).

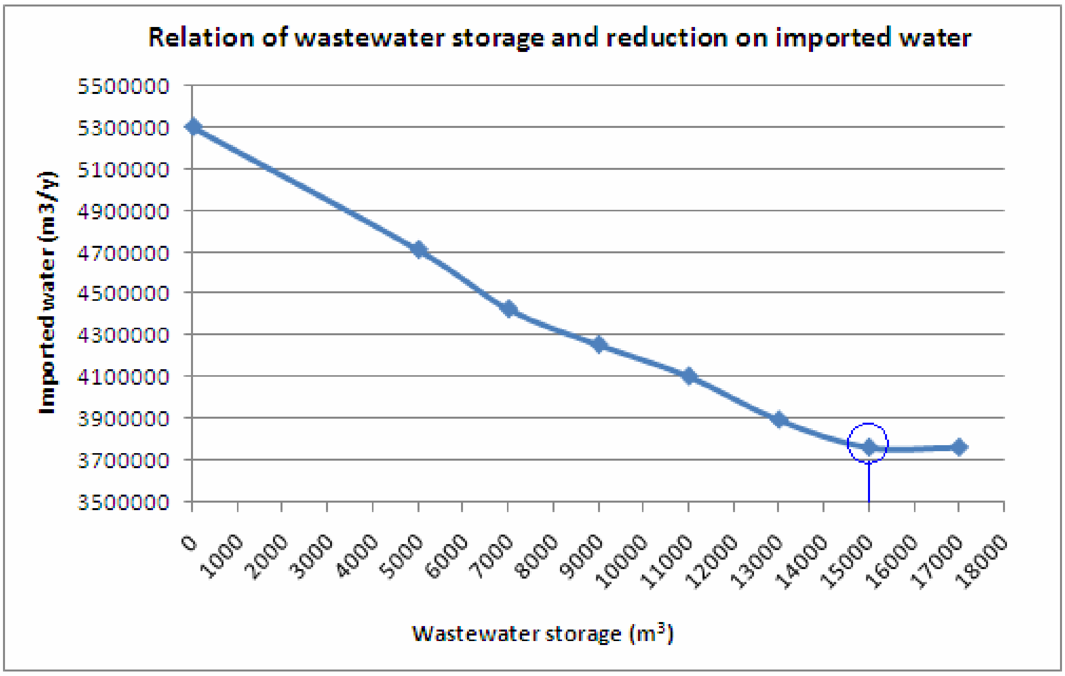

Figure 8.2 Relation between the waste water storage and the reduction in the water imported to the catchment and the optimal waste water storage (15,000m^3).

8.1.3 Scenarios and the different strategies

A series of scenarios were tested to assess their impact on urban water system. This includes quantities of water and their impact on the different components of urban water system, like imported water, storm water runoff and wastewater discharge. (*Change in storage = (precipitation + imported water)-(evaporation + storm water runoff + wastewater discharge).*

The scenarios consider exogenous factors such as climate change and population growth, also alternative scenarios or strategies are tested for their potential water savings. Tables 8.2 and 8.3 show the different scenarios chosen for Wilhelmsburg and the strategies for the year of 2050 and the impacts on the water balance.

Table 8.2 Scenarios and strategies adopted for the urban water balance for a population growth of 1%.

	Population growth 1%					
	Baseline precipitation	Precipitation forecasting		Strategies		
Water Balance in m^3/y	**Baseline**	**2020**	**2050**	**2050 Eco Strategy**	**2050 Moderate strategy**	**2050 Conventional strategy**
Precipitation	15,105,000	15,048,000	16,207,000	16,207,000	16,207,000	16,207,000
Imported Water	1,558,000	1,805,000	2,413,000	608,000	741,000	1,064,000
Evaporation	6,593,000	6,707,000	6,099,000	6,099,000	6,099,000	6,099,000
Storm water runoff	8,037,000	7,961,000	9,766,000	8,398,000	8,132,000	8,455,000
Wastewater discharge	1,805,000	1,995,000	2,565,000	2,128,000	2,527,000	2,527,000
Change in storage	209,000	190,000	171,000	152,000	152,000	152,000

For the water balance a baseline scenario was simulated and scenarios for population growth of 1% for the years of 2020 and 2050. The strategies were simulated for 2050 and all four (4) strategies are considered. For all these scenarios and strategies it was evaluated the whole water balance in m^3/year.

Table 8.3 Scenarios and strategies adopted for the urban water balance for a population growth of 3%.

	Population growth 3%						
	Baseline precipitation	Precipitation forecasting		Strategies			
Water Balance in m^3/y	**2013 (6000 houses cluster 2)**	**2020**	**2050**	**2050 Eco Strategy**	**2050 Moderate strategy**	**2050 Conventional strategy**	**2013 (6000 houses cluster 2)**
Precipitation	15,105,000	15,048,000	16,207,000	16,207,000	16,207,000	16,207,000	15,105,000
Imported Water	1,976,000	2,394,000	5,301,000	1,520,000	2,147,000	2,508,000	1,729,000
Evaporation	6,631,000	6,441,000	4,921,000	4,921,000	4,921,000	4,921,000	6,631,000
Storm water runoff	8,018,000	8,246,000	11,172,000	8,303,000	8,113,000	8,474,000	7,771,000
Wastewater discharge	2,204,000	2,546,000	5,244,000	4,351,000	5,168,000	5,168,000	2,185,000
Change in storage	209,000	171,000	152,000	133,000	133,000	133,000	209,000

The same is for the population growth of 3% for the years of 2020 and 2050, and now including the year of 2013, and for the strategies it was simulated the year of 2050; where the four (4) strategies are considered, as well as the year of 2013 strategy. All these scenarios and strategies were evaluated for the whole water balance in m^3/year.

8.2 APPLICATION OF AN ENERGY BALANCE SPREADSHEET BASED MODEL

In order to calculate the total energy at the urban water system, a spreadsheet based model was complied for the baseline case, the future scenarios as well as the strategies.

A number of assumptions had to be made due to the lack of data, and those are discussed on Appendix 1. It describes the general features for water quantities and energy consumption at the water supply, wastewater and storm water components for Hamburg and Wilhelmsburg area and the Suederelbmarsch water supply which supplies water for Wilhelmsburg and its adjacent area. Part of those assumptions, were later used as input data for the energy balance model which is shown on Tables 8.4 and 8.5.

Table 8.4 Energy balance inventory of for the urban water cycle for a population growth of 1%.

		Base Scenario	2020 Business-as-usual Scenario	2050 Business-as-usual Strategy	2050 Eco Strategy	2050 Moderate Strategy	2050 Conventional Strategy
			1% Population Growth				
OUTPUTS FROM AQUACYCLE							
water supply							
1. volume of imported water (m3/year)		1,558,000	1,805,000	2,413,000	608,000	741,000	1,064,000
2. volume of imported water (m3/day)		4,268	4,945	6,611	1,666	2,030	2,915
storm water							
3. Volume of storm water (m3/year)		8,037,000	7,961,000	9,766,000	8,398,000	8,132,000	8,455,500
4. Volume of storm water (m3/day)		22,019	21,811	26,756	23,008	22,279	23,166
wastewater							
5. Volume of wastewater (m3/year)		1,805,000	1,995,000	2,565,000	2,128,000	2,527,000	2,547,000
6. Volume of wastewater (m3/day)		4,945	5,466	7,027	5,830	6,923	6,978
INPUT DATA - LITERATURE							
1. volume of imported water (m3/day)		5,635					
2. height of ground water table (m)		133	133	133	133	133	133
Inventory for Energy Balance (kWh/d)							
WATER SUPPLY							
1. Pumping ground water		2,225	2,578	3,447	868	1,058	1,520
2. Pumping water for distribution		190	220	294	74	90	129
Sum energy consumption water supply		2,415	2,798	3,740	942	1,149	1,649
3. Heating water at household level (volume after reuse)		170,740	197,808	264,438	66,630	81,205	116,603
STORMWATER							
4. Pumping storm water		562	557	683	587	569	591
WASTEWATER							
5. Collection of wastewater		5,095	5,632	7,241	6,007	7,134	7,190
6. Treatment of wastewater		4,105	4,537	5,833	4,839	5,746	5,792
Sum energy consumption wastewater		9,200	10,168	13,074	10,846	12,880	12,982
7. Biogas/Sludge incineration energy production		-6,164	-6,813	-8,759	-7,267	-8,630	-8,698
Total net energy consumption		176,753	204,518	273,176	71,739	87,173	123,127
REUSE STRATEGY CONSUMPTION							
8.Rain tanks energy					2,707	2,707	2,707
9. Stormwater reuse distribution					30	511	
10.Wastewater reuse	Treatment				1,361		
	Distribution				689		
Final net energy consumption		176,753	204,518	273,176	76,525	90,391	125,834

Table 8.5 Energy balance inventory of for the urban water cycle for a population growth of 3%.

	3% Population Growth						
	2013 Scenario	2020 Business-as-usual Scenario	2050 Business-as-usual Strategy	2050 Eco Strategy	2050 Moderate Strategy	2050 Conventional Strategy	2013 Strategy
OUTPUTS FROM AQUACYCLE							
water supply							
1. volume of imported water (m3/year)	1,976,000	2,394,000	5,301,000	1,520,000	2,147,000	2,508,000	1,729,000
2. volume of imported water (m3/day)	5,414	6,559	14,523	4,164	5,882	6,871	4,737
storm water							
3. Volume of storm water (m3/year)	8,018,000	8,246,000	11,172,000	8,303,000	8,113,000	8,474,000	7,771,000
4. Volume of storm water (m3/day)	21,967	22,592	30,608	22,748	22,227	23,216	21,290
wastewater							
5. Volume of wastewater (m3/year)	2,204,000	2,546,000	5,244,000	4,351,000	5,168,000	5,168,000	2,185,000
6. Volume of wastewater (m3/day)	6,038	6,975	14,367	11,921	14,159	14,159	5,986
INPUT DATA - LITERATURE							
1. volume of imported water (m3/day)							
2. height of ground water table (m)	133	133	133	133	133	133	133
Inventory for Energy Balance (kWh/d)							
WATER SUPPLY							
1. Pumping ground water	2,822	3,420	7,572	2,171	3,067	3,582	2,470
2. Pumping water for distribution	240	291	645	185	261	305	210
Sum energy consumption water supply	3,063	3,711	8,217	2,356	3,328	3,888	2,680
3. Heating water at household level	216,548	262,356	580,932	166,575	235,288	274,849	189,479
STORMWATER							
4. Pumping storm water	561	577	781	581	567	593	543
WASTEWATER							
5. Collection of wastewater	6,222	7,187	14,804	12,283	14,589	14,589	6,168
6. Treatment of wastewater	5,012	5,790	11,925	9,894	11,752	11,752	4,969
Sum energy consumption wastewater	11,234	12,977	26,728	22,177	26,341	26,341	11,137
7. Biogas/Sludge incineration energy production	-7,527	-8,694	-17,908	-14,858	-17,649	-17,649	-7,462
Total net energy consumption	223,879	270,926	598,750	176,830	247,876	288,022	196,378
REUSE STRATEGY CONSUMPTION							
8.Rain tanks energy				5,567	5,567	5,567	492
9. Stormwater reuse distribution				150	584		
10.Wastewater reuse – Treatment				2,779			
10.Wastewater reuse – Distribution				1,406			
Final net energy consumption	223,879	270,926	598,750	186,733	254,026	293,589	196,871

There are some observations on the Inventory on Energy Balance for the three (3) components of the urban water cycle (water supply, storm water and wastewater) and on the reuse strategies which are explained next:

WATER SUPPLY

1. Pumping ground water:

The energy required for groundwater pumping equals:

E = ø × W × h (1), where E is the total energy in MWh used in pumping out W million cubic meters of ground water from an aquifer; h represents average groundwater depth from land surface during the period of pumping (in this case it ranges from 17-250m depth, so an average was used; 133m) , and f is a coefficient defined by:

$ø = y \times \rho \times g/1000$ (2) in which y is pumping efficiency (usually 0.4 and 0.7, dimensionless, in this case it was used, 0.4), ρ is density of water (1000 kg/m^3) and g is the acceleration of gravity (9.8 m/s^2) (Zhu, 2008).

2. Pumping water for distribution: As no data was available, it was calculated based on the total energy consumption on water supply deducted from the energy for pumping. The total energy is based on the only available data which is the total energy consumption at the water supply for Hamburg, in this way for Wilhelmsburg it was calculated proportional energy consumption based on the population's sizes of Hamburg and Wilhelmsburg.

3. Heating water at household level: The energy required to heat the water can be determined from the specific heat relationship; Q = cmΔT. The energy necessary to heat water is determined by the specific heat of water; c_{water} = 4186 J/kg°C. The energy required to heat one tank of water of 151 liters over the range from 15.6 °C to 60 °C is then about 7.5 kWh of electricity (Nave, 2008). It was assumed that the volume of water heated is corresponds to 80% of the volume of imported water after the reuse options as not all the household water is heated, like for toilet use.

STORMWATER

4. For the 3 stations at Wilhelmsburg to pump storm water there was a total energy consumption of 205,300 kWh in the year of 2007, so per day: 562 kWh.

WASTEWATER

5. Collection of wastewater: Total energy consumption for wastewater subtracted from the treatment of wastewater.
As no data was available, the energy for collection of wastewater was calculated based on the total energy consumption the energy for treatment subtracted from the energy on the treatment of wastewater. The total energy is based on the only available data which is the total energy consumption at the wastewater for Hamburg, in this way for Wilhelmsburg it was calculated proportional energy consumption based on the population's sizes of Hamburg and Wilhelmsburg.

6. Treatment of wastewater (kWh): According to the data found for Hamburg, there is a consumption of 121,150,000 kWh to treat the total wastewater of 145milion m^3/year, therefore based on this for Wilhelmsburg it was assumed consumption 0.83kwh per m^3 of wastewater to be treated.

7. Biogas and sludge incineration energy production: Based on the available data**,** 67% of the total energy produced by the wastewater treatment plant is generated by the biogas and sludge energy production. In this way the biogas and sludge energy production was calculated based on this percentage (67%) of the calculated sum of energy consumption at the wastewater treatment plant. Note that this is the only part of the energy balance where there is a positive input of energy.

REUSE STRATEGIES ENERGY CONSUMPTION:

8. Rain tank energy consumption: The use of rain tanks at the unit block (household) was implemented in all the strategies with the same storage capacities and in all clusters as mentioned previously. The only exception is the 2013 strategy where the rain tanks were implemented only at cluster 2. The energy consumption calculation of

this reuse alternative was simply based on the total water used at the rain tanks in one day multiplied by the energy consumption for pumping water from the rain tanks to the households, which is equivalent to 0.8kWh per m^3 of water pumped (Blue Scope Steel, 2008).

9. Storm water reuse energy consumption: There is no energy consumption for treatment of storm water reuse. The calculation for storm water reuse is based on the assumption that the total amount of water for storm water reuse will not be treated given that the impurities on this water for toilet supply is almost negligible. It was assumed as well, that the distribution network for the storm water will be same as the one for the treated wastewater reuse as both will deliver reused water for all the households for toilet supply. In this way the only energy consumption for the storm water reuse is for distribution, which is 0.63kWh/m^3.

10. Wastewater reuse energy consumption:

The total energy consumption calculation for wastewater reuse was based on two factors; treatment and distribution:

1) Treatment calculation: was based on the total reuse water quantity multiplied by the wastewater treatment energy consumption for Wilhelmsburg. It was assumed a total accretion of 50% on the normal energy consumption due to two factors; (1) an increase of 20% due to the necessity of an improved quality of the treated wastewater as it will be reused at the households, and (2) an increase of 30% due to the operational performance of smaller sizes treatment plants, the bigger the dimension of the plant the less energy it is spent for the treatment.

2) The calculation for the distribution was calculated based on the energy consumption for the distribution of the water supply network which is 0.63kWh/m^3; it was assumed that the energy spent for both water supply and treated wastewater distribution is very similar.

The assumption for this reuse strategy is that there is a decentralized wastewater treatment plant at each cluster and that there will be a new network to distribute the treated wastewater (together with the storm water) back to the households for toilet supply.

Note that for the baseline scenario it is assumed that the treated water is flowing to the River Elbe by gravity; therefore there is no energy consumption in this process.

9 DISCUSSION

9.1 APPLICATION OF AQUACYCLE MODEL FOR WATER BALANCE OF THE ISLAND

An evaluation of the effects of different scenarios and management measures (strategies) on the cities' water balance is discussed in this section.

9.1.1 Scenarios

When comparing the baseline case to the future scenarios of 2020 and 2050 it is observed that the year 2020 has very similar precipitation to the baseline (there was only an insignificant decrease in precipitation). On the other hand, for the year 2050, there was a quite significant increase in precipitation. The storm water quantities followed the same pattern as the precipitation. For the evaporation, the pattern, when compared to the baseline case, was opposite to the precipitation. As expected, due to the population growth scenarios, there was a significant increase in imported water for the years of 2020 and 2050 as well as the wastewater discharge (Fig. 9.1).

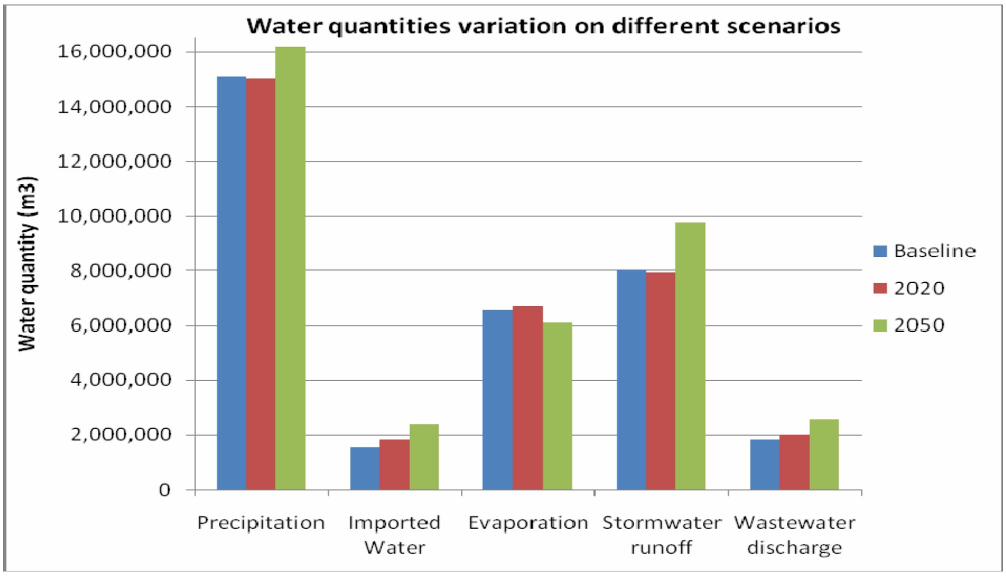

Figure 9.1 Comparison of water quantities in m^3 per year for the different scenarios.

9.1.2 Strategies

Just like for the scenarios comparison, for the strategies (the year of 2050) it was compared between the business-as-usual strategy where there were no reuse interventions and the ones with reuse strategies. The future scenarios of population growth reveal the same pattern on reductions, though as expected involving different orders of volume since the population size is much bigger.

Very significant reductions are observed on imported water for the strategies when comparing the business-as-usual strategy. There is a pronounced reduction of 75% and 71% for 1% and 3% population growth respectively, on imported water for the eco strategy, which is the strategy that incorporates the rain tanks at households, and storm water and wastewater reuse at cluster scale. For the storm water, there were

also reductions observed from the business-as-usual strategy to the reuse strategies, it can be noticed that the storm water runoff is slightly higher for the conventional strategy as this was the only strategy which did not incorporate the storm water reuse. The reductions on the wastewater discharge were almost negligible (around 1%) for the moderate and conventional strategies (those did not incorporate the wastewater reuse), the eco strategy though had a reduction of wastewater discharge of 17% (Fig. 9.2 and 9.3).

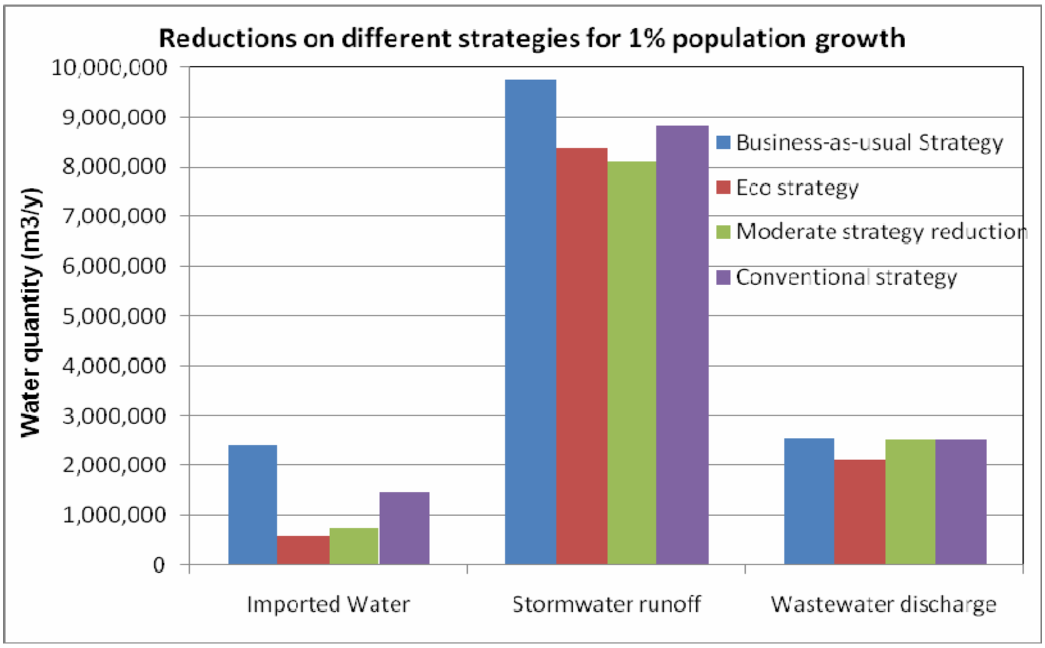

Figure 9.2 Comparison of reduction of water quantities in m^3 per year from the business as usual strategy (no intervention) to the other three strategies for a population growth of 1%.

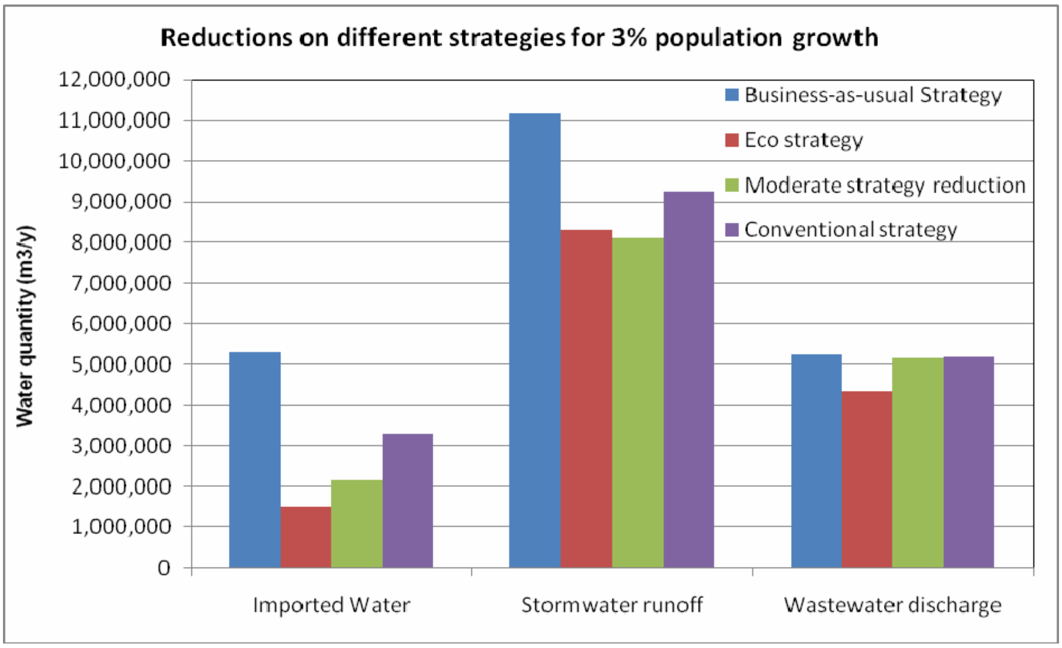

Figure 9.3 Comparison of reductions on water quantities in m^3 per year from the business as usual strategy (no intervention) to the other three strategies for a population growth of 3%.

The 2013 strategy takes into account only the implementation of rain tanks of 0.25m^3 at cluster 2. It can be seen that there were reductions for the base case compared to the strategy case mainly on the imported water and storm water runoff, for waste water discharge the reduction was almost negligible (Fig. 9.4).

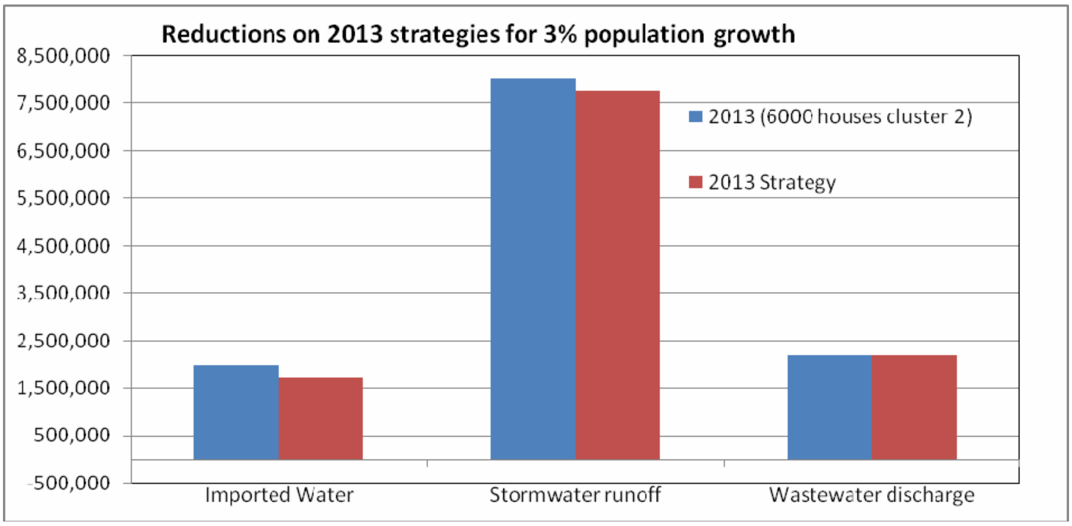

Figure 9.4 Comparison of reductions on of water quantities in m3 per year from the base scenario of 2013 and the scenario of 2013 strategy for a population growth of 3%.

9.2 APPLICATION OF A SPREADSHEET BASED MODEL FOR ENERGY BALANCE FOR THE ISLAND

A compassion analysis of energy consumption is discussed in this session from the base scenario and the reuse strategies for the different population growths of 1% and 3%.
For both scenarios of population growth, a quite significant reduction of the energy consumed when comparing the baseline case to the reuse strategies is observed. The eco strategy has the highest reduction (65% and 70% for population growths of 1% and 3%) since it is the strategy which includes the rain water harvesting, the reuse of storm water and wastewater (Fig.9.5 and 9.6). When compared to the 2013 baseline scenario and strategy, there were also observed reductions of about 12% (Fig. 9.6).

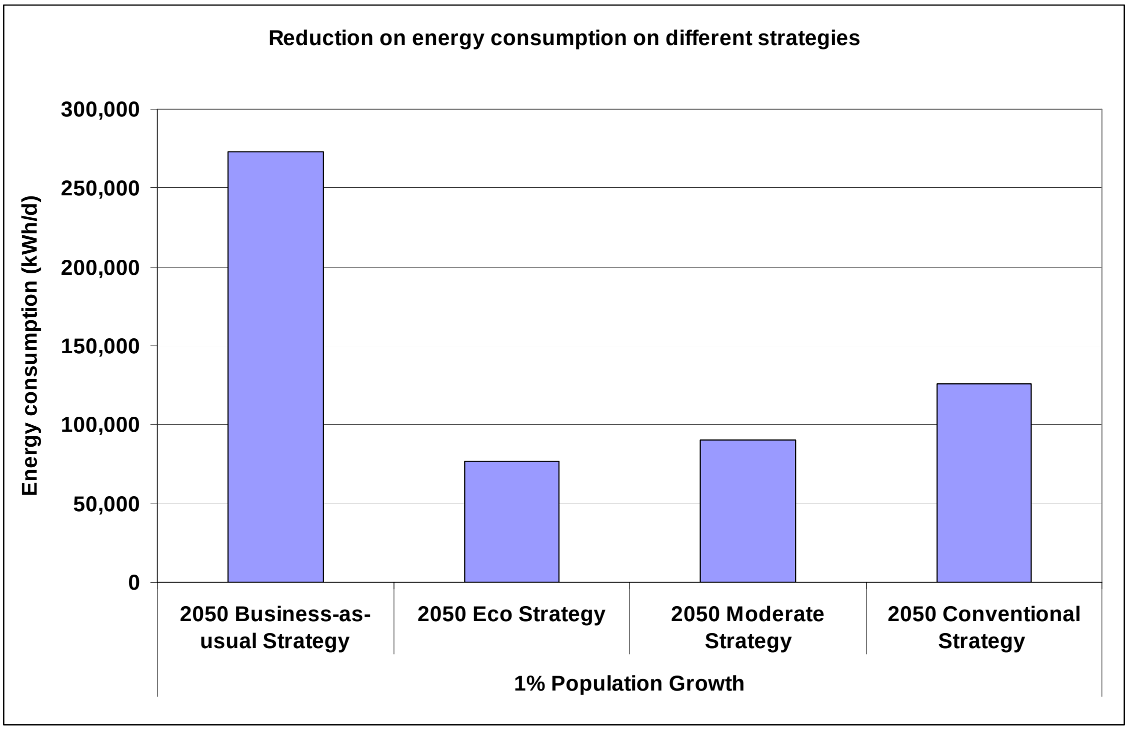

Figure 9.5 Reduction comparison of energy consumption in kWh per day from the base scenario and the reuse strategies for a population growth of 1%.

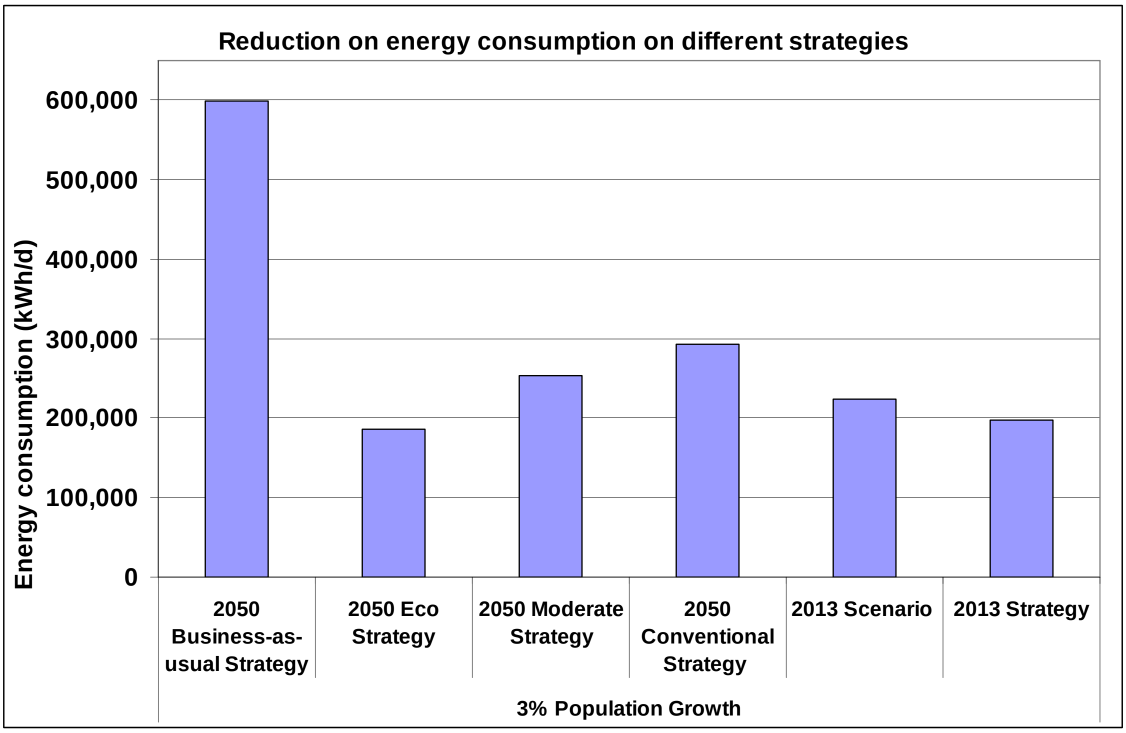

Figure 9.6 Reduction comparison of energy consumption in kWh per day from the base scenario of 2013 and the scenario of 2013 strategy for a population growth of 3%.

It is important to notice that in the energy balance for the urban system for Wilhelmsburg, there is a consumption of energy in all components of the urban water cycle. It starts in the supply water, the distribution and treatment of wastewater to the storm water pumping. There is also production of energy at the wastewater level,

where biogas and sludge derived from the wastewater generate energy. Another important component of this energy inventory is the reuse strategies which also have extra consumption of energy to the strategies scenarios. According to White et al, 2003, source substitution and reuse options increase energy consumption by 500 to 1000kWh/ML.

There is a lot of interest in new sources of water, since traditional water development is both expensive and controversial nowadays. For example, treated wastewater may be made available for other uses. Depending on the intended re-use, this water usually requires more extensive and energy intensive treatment than the process of discharging wastewater into the environment. Reclaimed water is increasingly being considered for reuse for domestic water consumption. At this time, water quality standards and caution require complete re-treatment of the wastewater. This is being done by feeding the treated wastewater back through a water treatment plant. This extra pumping and "double-treatment" results in significantly higher energy requirements than for traditional water sources (California Energy Commission, 2004).

For the case of storm water and wastewater decentralized systems, the energy per capita will be higher (more wastewater plants for a smaller area instead a bigger wastewater plant for a broader coverage area). Also, as the wastewater now will not be discharged into the river but will be reused at the households, the water needs to achieve a higher quality, meaning again an increase in energy consumption on the treatment process. This has been shown in cities in Australia where dual reticulation systems generally have a higher unit cost due to the high treatment level necessary, the duplication of reticulation infrastructure (White et al, 2003). To achieve the costs and energy reduction on the decentralized system, the wastewater network distribution could be combined to the storm water network; both networks should return to each household and should have the same water quality.

Even though the reuse options can increase the energy consumption, when analysing the future scenario of 2050 and the reuse strategies, the overall energy consumption has decreased with the reuse strategies. The green eco strategy (rain water, storm water and wastewater reuses) had the higher reduction of about 70%, for the population's growth rates of 1% and 3%. The moderate strategy (rain water, and storm water reuses) had reductions of 57% and 59% respectively for the population growth rates of 1% and 3%. The conventional strategy (rain tank reuse) had the lowest reduction of 40 and 52% respectively for the population growth rates of 1% and 3%. In Fig 9.20, it can be seen the reductions of energy consumption for the 1% and 3% population growth rates.

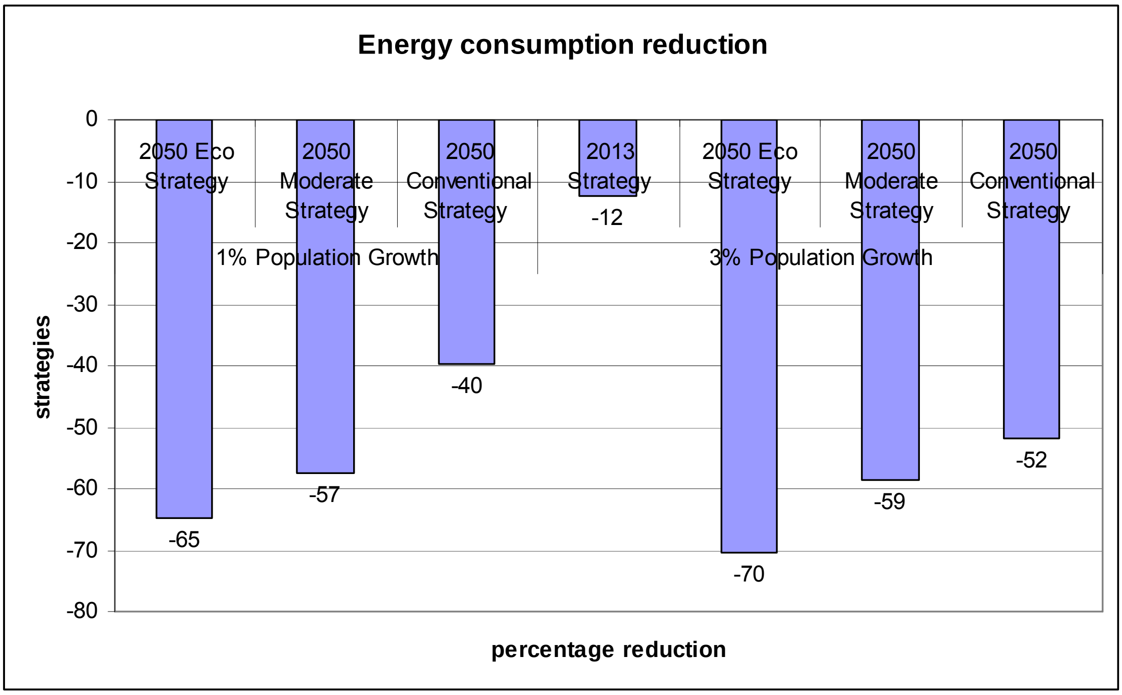

Figure 9.7 Energy consumption reduction in percentage for the different strategies on populations growths of 1% and 3%.

10 CONCLUSION

The utilization of storm water and wastewater as an urban water resource rather than a waste product offers an alternative to present approach to water supply and disposal. Such alternatives like; rainwater use, wastewater reuse and subsurface grey water irrigation hold the key to lessening environmental impacts in living towns. Such benefits to the environment include: (1) reductions of quantity of storm water and wastewater discharge from urban areas, (2) reduction of quantity of imported water, and (3) the volume of storm water and wastewater discharged from an urban catchment though storm water and wastewater reuse. Less water being that is needed to be imported into cities means also less energy to spend on water transportation within the network distribution. In addition, when less wastewater and storm water are discharged, there is a reduction in energy for wastewater treatment and less flow of contaminants from the storm water.

Simulations results from Aquacycle and energy balance model shows that for the water balance, there were large reductions of imported water, storm water and wastewater when the reuse strategies were applied. For the 2050 eco strategy (rain water, storm water and wastewater reuses) there were quite large reductions of about 70% on imported water when compared to the business-as-usual strategy.
The energy balance model also shows reductions on energy consumption when the reuse strategies are applied.

Lifecycle analysis of urban water cycle infrastructure with retrofitting of reuse measures reveals large environmental (water and energy) savings to the community. Still there are costs involved on implementation and maintenance which should be taken into account.

10.1 FINAL RECOMMENDATIONS

For future research on the water and energy balance for the island of Wilhelmsburg, it is suggested the following recommendations:

- ✓ Cost benefits analysis for the reuse options. The cost for the facility, including engineering, construction, and construction inspection, as well as the energy consumption costs for the reuse options of rain tanks, storm water, and wastewater.
- ✓ Analysis of the flow of nutrients and contaminants on the urban water cycle.
- ✓ To implement a complete chart for decision making with additional future scenarios and costs for reuse strategies.

11 REFERENCES

Anh, N. V., Ha, T. D., Nhue, T. H., Heinss. U., Morel. A., Moura, M., Schertenleib, R. (2002). Decentralized wastewater treatment - new concept and technologies for Vietnamese conditions, 5th Specialized Conference on Small Water and Wastewater Treatment Systems Istanbul-Turkey, 24-26 September 2002.

Arkell, D. (2005). Offisite2005; Modern methods of construction come of age. Retrieved on 24/03/2008 from http://www.offsite2005.com/presentations/ThursAM.pdf.

Australian Government by the Australian Greenhouse Office, within the Department of the Environment and Heritage. (2005) Technical manual, design for lifestyle and the future, 3rd Edition. . Retrieved on 29/03/2008 from http://www.yourhome.gov.au/technical/

Blue Scope Steel, 2008. Retrieved on 29/03/2008 from http://www.bluescopesteel.com.au/.

California Energy Commission, (2004). Water energy use in California. Retrieved on 29/03/2008 from http://www.energy.ca.gov/pier/iaw/industry/water.html.

Cegelec (2005). Hamburger Stadtentwässerung beauftragt Cegelec mit der Erneuerung von Leit- und Automatisierungstechnik der KETA. Retrieved on 24/03/2008 from http://www.cegelec.de/de/news/PI_Keta_Int.pdf.

Clark, E. H. (2007). WATER PRICES RISING WORLDWIDE. Retrieved on 24/03/2008 from http://www.earth-policy.org/Updates/2007/Update64.htm.

Consulaqua, (2006). Hamburg-Koehlbrandhöft WWTP Operation & Maintenance Free and Hanseatic City of Hamburg, Germany. Retrieved on 24/03/2008 from http://www.consulaqua.de/files/PDFs/Projektblatt/Koehlbrandhoeft%20E.pdf.

Coombes, P. J., Kuczera, G. (undated), Integrated Urban Water Cycle Management: Moving Towards Systems Understanding. Retrieved on 30/09/2007 from http://rambler.newcastle.edu.au/~cegak/Coombes/)
Deutscher Wetterdienst, 2008. Retrieved on 15/01/2008 from http://metportal.dwd.de.

Eiswirth, M., Wolf, L., Hotzl, H., (2003), Assessing the sustainability of urban water resources. Mittl. Inst. Groundwasserwirtschaft TU Dresen, Bd. 3: 205-215.

Hamburg Wasser (2008). Retrieved on 24/03/2008 from http://www.hamburgwasser.de/cms/website.php?id=/de/index/leistung/wasserversorgung/wasserwerke.htm.

Hamburger Stadtentwässerung, (2006) The goal is clear: Waste water in numbers, Retrieved on 24/03/2008 from http://www.hamburgwasser.de/cms/website.php.

Hellstrom, D.; Jeppson, E.; Karrman., (2000), Framework for system analysis for sustainable urban water management. Environmental Impact Assesment Review, (20), 311-321.
http://www.bluescopesteel.com.au/index.cfm?objectID=B303F6BA-88F6-475D-AEE714D5A6DE2644

Hulme, M. and Sheard, N. (1999) Climate Change Scenarios for Germany Climatic Research Unit, Norwich, UK, 6pp.

Hunt, J., Anda, M., Mathew, K, Ho, G., (2004), Decentralized wastewater recycling schemes in WA: towards integrated urban water management, WSUD2004, 641-646.

Karka, P.; Manoli, E.; Lekkas, D. F.; Assimacopoulos, D. (2007), A case study on integrated urban water modelling using Aquacycle. CEST.

Lundin, M., Molander, S., Morrison, G. M., (1997) Indicators for the Development of Sustainable Water and Wastewater Systems. Sustainable Research Conference, Manchester.

Mitchell, V. G., (2004), Integrated urban water management: a review of current Australian practice. Report for CSIRO and AWA Australian Water Conservation and Reuse Research Program Stage 1 Review, CMIT-2004-075.

Mitchell, V. G.; Mein, R. G.; McMahon, T. A. (1999), The reuse of urban storm water and wastewater. Industry report, report 99/14.

Mitchell, V. G.; Mein, R. G.; McMahon, T. A. (2001), Modeling the urban water cycle. Environmental Modeling and Software, 16 (7), 615-629.

Nave, R. (2008), Householf energy use. Retrieved on 24/03/2008 from http://hyperphysics.phy-astr.gsu.edu/Hbase/thermo/houseenergy.html

Organisation for Economic Co-operation and Development (2002). Household energy & water consumption and waste generation: trends, environmental impacts and policy responses, Working Party on National Environmental Policy.

Water Supply and Sanitation Technology Platform (2005), Water European vision for water supply and sanitation in 2013 - Water safe, strong and sustainable. Retrieved on 24/03/2008 from http://www.wsstp.org/Shared%20Documents/WSSTP%20report%20for%20public%20consultation/Vision%20documents%20(comments%20to%20Kiwa)/Draft%20merged%20Vision%20document/Vision%202030%2007-10-05.pdf

White, S., Turner, A. (2003) The Role of Effluent Reuse In Sustainable Urban Water Systems: Untapped Opportunities. National Water Recycling in Australia Conference, Brisbane.

Wikipedia (2008). Retrieved on 24/03/2008 from http://en.wikipedia.org/wiki/Hamburg-Wilhelmsburg.

Zhou, Y., Tol, R.S.J.,(2004) .Evaluating the costs of desalination and water transport December 9, 2004 , Working paper FNU-41 revised

Zhu, T., Ringler, C., Cai, X. 2008. Energy Price and Groundwater Extraction for Agriculture: Exploring the Energy-Water-Food Nexus at the Global and Basin Levels. Retrieved on 24/03/2008 from http://www.iwmi.cgiar.org/EWMA/files/papers/Energyprice_GW.pdf

Morrison, G., Fatoki, OS., Zinn, E., Jacobsson, D., (2001), Sustainable development indicators for urban water systems: A case study evaluation of King William's

Town, South Africa, and the applied indicators. Water SA, Vol. 27 No. 2, 219-232.

SWITCH, (2006), An overview of existing tools, data needs and demo cities. Integrated project, global change and ecosystems report.

SWITCH, (2007), Sustainable Water Management Improves Tomorrow's Cities' Health. Retrieved on 01/10/2007 from http://www.switchurbanwater.eu/)

Van der Steen, P. (2007), Integrated urban water management (IUWM) and the use of sustainability indicators. Switch project document. UNESCO-IHE, Delft, The Netherlands.

Vanrolleghem, P. A.; Benedetti, L.; Meirlaen, J., (2005) Modelling and real-time control of the integrated urban wastewater system. Environmental Modelling & Software, 20, (4), 427-442.

APPENDIX 1: DATA CALCULATIONS FOR ENERGY BALANCE MODEL

		Hamburg	Wilhelmsburg	Aquacycle	Water Supply
1	Population size	1,766,000	49,000	49,000	73,200
2	Area (km2)	755.30	35.30	19.00	47.20
3	**Daily Total Water Supply (m3/day)**	312,500	25,500		38,000
4	Residential Water Supply (m3/day)		5,635	4,268	
5	Commercial/industrial Water Supply (m3/day)		19,865		
6	Yearly Total Water Supply (m3/y)	120,000,000	9,307,500		
7	Residential Water Supply (m3/y)		2,056,775		
8	Commercial/industrial Water Supply (m3/y)		7,250,725		
9	Energy consumption water supply (kWh/day)	176,792	2,415		
10	Energy consumption (kWh/y)	64,529,000	881,311		
11	**Pumping storm water (m3/year)**		9,603,112		
12	Energy consumption pumping (kWh/day)		205,300		
13	Pumping storm water (m3/day)		26,310		
14	**Wastewater**				
15	Energy consumption (kWh/year)	121,150,000	3,361,467		
16	Energy consumption (kWh/day)	331,918	9,209		
17	Sludge energy production Biogas (kW/year)	81,140,000	2,251,336		
18	Sludge energy production Biogas (kW/day)	222,301	6,168		
19	Digester Gas production (m3/year)	31,660,000	878,448		
20	Digester Gas production (m3/d)	86,740	2,407		
21	Volume of wastewater (m3/year)	145,000,000	4,023,216		
22	Volume of wastewater (m3/day)	397,260	11,023		

Parameter 1: Population size

Hamburg: data from Wikipedia

Wilhelmsburg: Statistische Berichte, 2007

Suederelbmarsch: Estimation based on the districts' population from the water supply area of Suederelbmarsch.

Parameter 2: Area

Hamburg: data from Wikipedia

Wilhelmsburg: data from Wikipedia

Wilhelmsburg (Aquacycle): Google Earth calculation

Parameter 3: Daily Total Water Supply (m3/day)

Wilhelmsburg: Estimation based on districts area population.

Suederelbmarsch: Data from Hamburg Wasser (2008).

Parameter 4: Residential Water Supply (m3/day)

Wilhelmsburg: Calculation based on 115l per person per day X population size.

Parameter 6: Yearly Total Water Supply (m3/y)

Hamburg: data from annual report (Hamburger Stadtentwässerung, 2006)

Wilhelmsburg: Calculated based on daily supply.

Parameter 9: Energy consumption water supply (kWh/day)

Wilhelmsburg: Calculated based on yearly supply.

Parameter 10: Energy consumption (kWh/y)

Hamburg: data from annual report (Hamburger Stadtentwässerung, 2006)

Parameter 11: Pumping storm water (m3/year)

Wilhelmsburg: Data from pumping stations.

Parameter 12: Energy consumption pumping (kWh/day)

Wilhelmsburg: Data from pumping stations.

Parameter 14: Wastewater

Hamburg: data from annual report (Hamburger Stadtentwässerung, 2006)

Wilhelmsburg: Calculated based on proportion of population sizes of Hamburg and Wilhemsburg.

APPENDIX 2: PUMPING STATIONS AND THE VOLUMES OF WATER PUMPED ON THE YEAR OF 2007 AND ITS ENERGY CONSUMPTION (SOURCE: FREIE UND HANSESTADT HAMBURG).

	water pumped (m3/h)	hours per year of work	total water pumped (m3/year)	Energy consumption per year kWh
9. Finkenriek				
pump 1	1,440.00	774.96	1,115,942.40	
pump 2	4,320.00	365.99	1,581,076.80	
pump 3	4,320.00	323.28	1,396,569.60	
total volume pumped	**10,080.00**	**1,464.23**	**4,093,588.80**	**76,700.00**
10. Kuckuckshorn				
pump 1	10,800.00	76.65	827,820.00	
pump 2	10,800.00	110.17	1,189,836.00	
total volume pumped	**21,600.00**	**186.82**	**2,017,656.00**	**85,915.00**
11. Sperlsdeich				
pump 1	3,132.00	383.84	1,202,186.88	
pump 2	3,132.00	554.54	1,736,819.28	
pump 3	3,132.00	176.52	552,860.64	
total volume pumped	**9,396.00**	**1,114.90**	**3,491,866.80**	**42,685.00**
			total volume pumped	**total E consumed**
			9,603,111.60	**205,300.00**

APPENDIX 3: SETUP FOR MEASURED PARAMETERS FOR AQUACYCLE MODEL.

baseline					
UNIT BLOCK SCALE	CLUSTER 1	CLUSTER 2	CLUSTER 3	CLUSTER 4	CLUSTER 5
number of blocks	5635	900	12900	1900	375
average occupancy	3	2	2	2	2
area of unit block (m2)	120	140	200	150	200
area of garden (m2)	10	30	40	40	40
area of roof (m2)	100	100	150	100	150
area of pavement (m2)	10	10	10	10	10
percent of garden irrigated (%)	0	0	0	0	0
CLUSTER AREA IN kM2	3.1	1.7	7.8	5.7	0.7
TOTAL AREA OF BLOCKS IN EACH CLUSTER IN HA	67.62	12.6	258	28.5	7.5
AREA OF CLUSTER WITHOUT ROAD AND OPEN SPACE HA	242.38	157.4	522	541.5	62.5
	243.58	157.4	522	541.5	62.5
CLUSTER SCALE					
total area of cluster (ha)	310	170	780	570	70
road area (ha)	200	57.4	22	41.5	60
area of open public space (ha)	43.58	100	500	500	2.5
public open space irrigated (%)	0	0	0	0	0
leakage rate	9	9	9	9	9
stormwater output flows into cluster x	0	0	0	0	0
wastewater output into cluster x	0	0	0	0	0

	CLUSTER 1	CLUSTER 2	CLUSTER 3	CLUSTER 4	CLUSTER 5
n blocks	5635	900	12900	1900	375
occupancy	3	2	2	2	2
n inhab.	16905	1800	25800	3800	750
total inhab.	**49055**				