Simulation of the Total Urban Water Cycle in a Neighbourhood of a Spanish City and Establishment of Urban Water Sustainable Indicators

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Abstract

Today, cities face problems related to global change, such as population growth, urbanization increase, climate change, etc that directly affect the environment and the urban water system. For this reason, the need to manage urban water systems in a more sustainable manner has emerged over the last few decades. A paradigm shift in current urban water management is required if the move towards sustainability is to be achieved. The new approach is based on the view that wastewater and stormwater, which have been considered for decades as system outputs, can be new water sources for low water quality demand uses, such as garden irrigation or toilet flush. Several integrated urban water management modelling programmes exist or are under development in order to build up scenarios that incorporate alternative recycle and reuse options.

The total urban water balance of a Spanish neighbourhood in the city of Zaragoza was modelled during the process of this MSc thesis using an urban water balance model called Aquacycle. The study period is five years and three months and is determined by the availability of climatic data. Results show that the most feasible option for the study area is the on-site wastewater treatment and storage tanks at the unit block scale (block of apartments). However, it is a simplistic model that does not take into account aspects such as energy demand, life-cycle cost, and water quality. For these reasons, more complex models that cover some of these aspects are briefly discussed and recommended as they provide a more holistic scenario giving more realistic data of the total urban water balance of the study area. As a result of the literature review process and taking into account the output of the different softwares, a list of sustainable urban water indicators is proposed.

Acknowledgements

This MSc thesis, framed within the SWITCH Project (Sustainable Water management Improves Tomorrows Cities Health), summarises the work carried out during six months in relation to Sustainable Urban Water Systems Management. I would like to thank all the people that helped me during the thesis realization process:

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Abbreviations

CSIRO: Commonwealth Scientific and Industrial Research Organisation

GC: Global Change

IUW: Integrated Urban Water

IUWM: Integrated Urban Water Management

INM: Spanish National Institute of Meteorology

L.A: Learning Alliance

LCA: Life-Cycle Assessment

MFA: Material Flow Analysis

MMA: Spanish Ministry of Environment (Ministerio de Medio Ambiente)

NGO: Nongovernmental Organization

ORWARE: ORganic WAste REsearch

SD: Sustainable Development

SUDS: Sustainable Urban Drainage System

URWARE: Urban Water REsearch

UVQ: Urban Volume and Quality

UWC: Urban Water Cycle

UWM: Urban Water Management

UWS(s): Urban Water System(s)

WFD: Water Framework Directive

W.P: Work Package

WWTP: Wastewater Treatment Plant

Chapter 1

Introduction

1.1 DESCRITPION OF THE PROBLEM

Management of conventional Urban Water Systems (UWS) is becoming more difficult because of increasing pressures on society such as population growth, increasing urbanization, climate change etc. However, water is not the unlimited resource that was thought of in the past, but it is a scarce resource and essential for life and must be managed in a more sustainable way.

Current Urban Water Management (UWM) practices imported fresh water from natural water bodies that are further and further away from urban areas. The main objectives of the current Urban Water Cycle (UWC) are to supply high water quality for all uses, and to remove stormwater and wastewater efficiently.

An alternative approach is to consider stormwater and wastewater as a potential resource for a portion of the water imported via the reticulated supply system (Mitchell *et al*., 2001), as different uses often require different quality standards. A holistic approach to the urban water cycle that integrates all its components (imported water, stormwater and wastewater), would be to consider this new alternative approach. In addition, a paradigm shift is crucial to achieve the desired UWM practice. Water is a scarce resource. Therefore, it is no longer valid to think along the one-way path of supply to single use, to treatment and discharge.

In order to study the possibilities of stormwater use and wastewater reuse, different integrated urban water modelling programmes have been developed to support decision making processes and urban planning. In addition, sustainability indicators are also criteria which asses the current state of an urban water system to determine whether it is sustainable or not, and evaluate its trend.

This MSc thesis, is framed within the European SWITCH Project (Sustainable Water Management Improves Tomorrow’s Cities’ Health) (see Appendix IV) looks at the

pressures that urban water systems will have to cope in the near future, and how to manage them in a more sustainable way taking into account these pressures.

The city of Zaragoza (Spain), which is located in an arid area, is a good model city for highlight the type of cities that struggle with freshwater scarcity problems. Although currently the city does not suffer scarcity problems it has to struggle with water quality problems. The solution to this problem is similar to that experienced by cities with scarce water resources which import freshwater from water bodies located a significant distance from the urban area. In addition, the city of Zaragoza is experiencing a significant demographic expansion, with is one of the most important pressures on the cities urban water cycle. These reasons justify the need to study the UWC of the city and the search for a more sustainable urban water management.

1.2 SCOPE OF THE THESIS

Today, there are several problems that affect urban water systems (UWSs), such as flooding, water scarcity, health problems, water quality, ageing infrastructure, etc. In a project such as this MSc thesis, it is not possible to deal with all of them and for this reason, a boundary to the project scope has been established: the focus of this MSc thesis is the study of urban water systems in cities that struggle with the problem of freshwater scarcity

This MSc thesis is focussed on urban water systems that struggle with the problem of freshwater scarcity. The study of new alternatives for management of the UWS that suffer problems such as water scarcity is useful for arid regions which experience water scarcity. In addition, looking at alternative techniques for managing UWS will also provide useful methods such as saving water and decreasing the environmental impact on UWS that do not face water scarcity problems, but import large volumes of water from natural watercourses.

1.3 RESEARCH AIM AND OBJECTIVES

The main aim of this thesis is to develop a total urban water cycle model for the Actur-Rey Fernando neighbourhood of Zaragoza and establish a list of urban water indicators with the results of the used sortwares. The objectives followed to achieve this aim were:

- Document Aquacycle, UVQ and SWITCH Aquacycle software and Sustainability Indicators.
- Gather data on the Actur-Rey Fernando neighbourhood to develop the total urban water cycle model.
- Evaluate the issues required for development of SWITCH Aquacycle.
- Develop three models of the total urban water cycle of the study area using three different softwares: Aquacycle, UVQ and SWITCH Aquacycle.
- Analyse and evaluate results from the different models.
- Study the possibility of extending the research to two or three other areas of the city or even the whole city.
- Use the outputs of the softwares to develop a list of Urban Water Indicators

The hypothesis that is required to be confirmed or denied is: The Total Urban Water Cycle of a neighbourhood of the city of Zaragoza can be modelled by using suitable software. The models are useful to identify the quantity of stormwater and wastewater that may be available for reuse throughout the water cycle and the purposes for which it may be reused.

1.4 STRUCTURE OF THE THESIS

Chapter 1 introduces the MSc thesis to the reader defining the problem, establishing the project boundaries, the research aim and objectives and describes the structure of the thesis to give an overview to the reader to facilitate the reading.

Chapters 2 and 3 are based on literature review. Chapter 2 provides an overview of the current situation of the city of Zaragoza and its urban water system. It also describes the urban water system, and the pressures they will have to face in the near future. Finally, sustainable urban water systems are described and the local urban water sustainability indicators of the city of Zaragoza are explained. On the other hand, Chapter 3 is focussed in the process of modelling the urban water system, focussed in softwares, toolboxes and methodologies. The three different ways of modelling are described with examples and compared in table.

Chapter 4 describes the Methodology and research design followed during this project. The first section explains briefly the stages of the thesis. The next sections explain why

the study area and the softwares to be used in the thesis where chose. In addition there is a discussion about comparison of different Integrated Urban Water Management computer models, toolboxes and methodologies. The process of data collection and data gathering are also explained in this chapter, as well as the constraints and limitations encountered during the realization of this MSc thesis, which resulted in failure to achieve some of the initial objectives.

Chapter 5 deals with data analysis and creation of the input files for Zaragoza-Aquacycle. The data was analysed, calculated or estimated in relation to the software requirements of the different input files. For this reason the data analysis, estimations or calculations are explained within the pertinent description of each input file. This chapter also contains an explanation of the development of the different scenarios for the study area.

Chapter 6 focuses on the results of the simulation of the urban water cycle of the study area using Aquacycle, and the different scenarios of new technologies of water recycling and reuse. It is divided into the main focus of the project, (I) the urban water cycle in the study area and (II) the software Aquacycle. This division is aims to facilitate the reading and allow the reader to focus in the results of his/her interest.

Chapter 7 presents discussion of results and Chapter 8 presents recommendations and future work building on the work that has been undertaken during this thesis process. As in Chapter 6, they are divided into the two main focus subjects of the project.

Appendix I clarifies the terminology used in Chapter 4 related to the modelling of the urban water cycle.

Appendix II explains the procedure and equations used to estimate the solar radiation and potential evaporation of the study area.

Appendix III briefly describes Aquacycle and explains where to find useful information to run the program and increase knowledge of the software.

Appendix IV presents the experience of an Author working in the international research project (SWITCH). Advantages and disadvantages encountered during the working period are described in this chapter.

Chapter 2

The Urban Water System

2.1 INTRODUCTION

Nowadays, one of the main concerns of politicians, urban planners and scientists is Global Change (GC) and its effect on both urban and natural environment. A lot of research has been undertaken in order to study the global trends for the city of the future and the impact of the GC in it different services and sectors. According to the published literature, major drivers of GC for urban water systems are: climate change, population growth and urbanisation, globalisation and economic development, increased privatisation, infrastructure systems deterioration, changes in public behaviours and new technologies and increase in the costs of energy (Krishma *et al*., 2006). The UWS is not only a technical system but it includes people (users and organizations), water resources and the environment, which interact with each other. Due to the fact that UWS depends not only on technological issues but on geographic location, social, economic and environmental factors, it is expected that the UWS of the city of the future will suffer significant pressures due to GC.

Although UWM is currently high on the agenda of politicians, engineers, urban planers and environmentalist, water balance techniques were initially developed in the 1940s and 1950s to evaluate the importance of different hydrological parameters Thornthwaite and Mather (1995) applied water balance techniques to gain information relating to periods of moisture surplus and deficit, promoting a basic tool for the evaluation of water resources in rural areas (Mitchell *et al*., 2003).

As previously mentioned, one approach to reduce these pressures is to reuse stormwater and wastewater within the urban area for low quality water demands. The advantage of this approach is to reduce the quantity of high quality water imported into the urban area and reduce stormwater and wastewater discharged to streams and receiving waters (Mitchell *et al*., 2001) and to reduce the cost of wastewater treatment.

Urban Water Models are very useful providing an overview of the current situation of the UWS in a specific area - by studying the urban water cycle and the different possibilities and effectiveness of applying diverse new water recycle and reuse technologies.

2.2 THE URBAN WATER CYCLE

It is important to examine the water cycle. There are a lot of definitions in literature but generally it is defined as a conceptual model describing the storage and circulation of water between the biosphere, atmosphere, lithosphere, and the hydrosphere. Water can be stored in the atmosphere, oceans, lakes, rivers, streams, soils, glaciers, snowfields, and groundwater aquifers. Circulation of water among these storage compartments is caused by such processes as evapotranspiration, condensation, precipitation, infiltration, percolation, snowmelt and runoff, which are also referred to as the water cycle components.(Marsalek *et al*., 2006).

The water cycle found in cities is called the urban water cycle and is more complex than in natural areas due to human activities and influences that modify the natural hydrological cycle. Water is retained within the urban system for a longer time than in natural storage areas, it is manipulated to make it potable and treating the wastewater artificially to remove the nutrients and pollutants to minimise the impact on the receiving water bodies. Fresh water is manipulated to make it potable and wastewater is treating to remove nutrients and pollutants in order to minimise the impact on the receiving water bodies.

Fig. 2.1 represents the urban water cycle with the main inputs (precipitation and imported water), sources of pollution (air pollution, fuel storage, wastewater infiltration, landfills and solid waste management) and main outputs (evaporation, and discharge of treated water). In contrast, Fig. 2.2 is a schematic version of the UWC and its main components and pathways.

The main input is imported water, which is usually taken from natural water bodies placed outside the urban area, with the distance between city and source varying with each situation depending on water demand and availability. Once water enters the system, it is stored and treated, distributed into the area, collected after the use, treated

and discharged into the environment. Not all water that enters into the system is discharged, because there are some steps of the process where water is used by the population or infiltrated into the soil and consequently into the groundwater. The second water input is precipitation. There is two main ways that rain water can enter the urban water cycle (i) soil infiltration in pervious areas or (ii) runoff in impervious areas. Rainwater runoff is discharged directly into water bodies directly or collected and treated before discharging it. The last option seems to be more environmentally friendly because it avoids or minimise the amount of pollutants loaded into the environment but on the other hand it is more expensive and it is often cause of localised flooding, so it is not sustainable. It is better to treat rainwater at source before discharge to watercourse using Sustainable Urban Drainage System (SUDS) (personal communication of Alison Duffy, specialist in the area of SUDS for Urban Water Technology Centre, Abertay University). Although it is an interesting topic, it is outwith the scope of this MSc thesis because of time constraints.

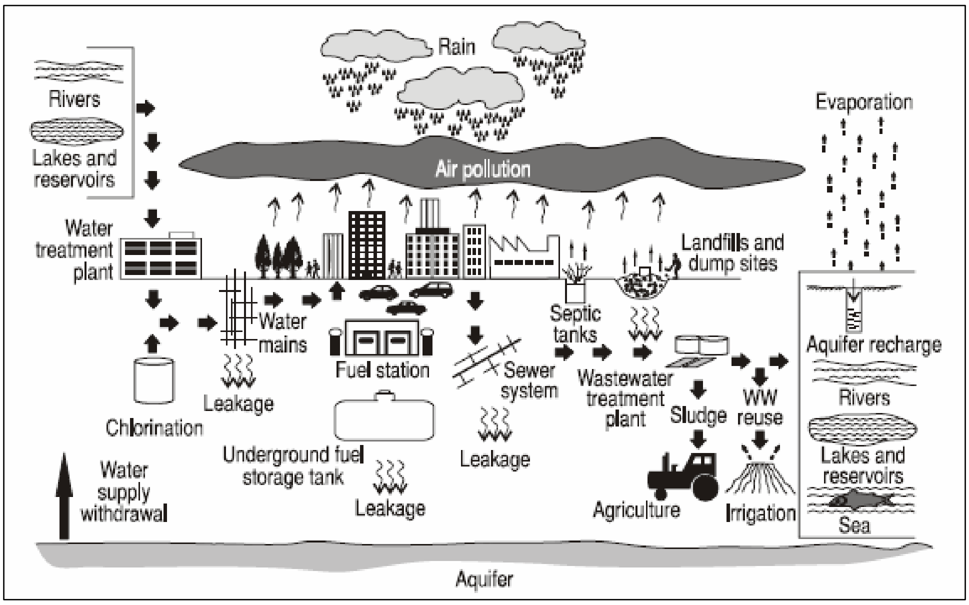

Figure 2.1: The Urban Water Cycle (Source: Marsalek *et al*., 2006).

Water is not the only element involved in the urban water cycle, the air and the atmosphere are important elements of the water cycle due to pollutant fluxes between air and water, which directly enters water bodies or are deposited into soil surfaces. There are less studies and knowledge about this topic. This is also an interesting topic out of the scope of this MSc thesis.

The concept of the urban water cycle that used in this thesis is based on the one provided by the Aquacycle model, as Aquacycle was the only software that was available for the development of this thesis.

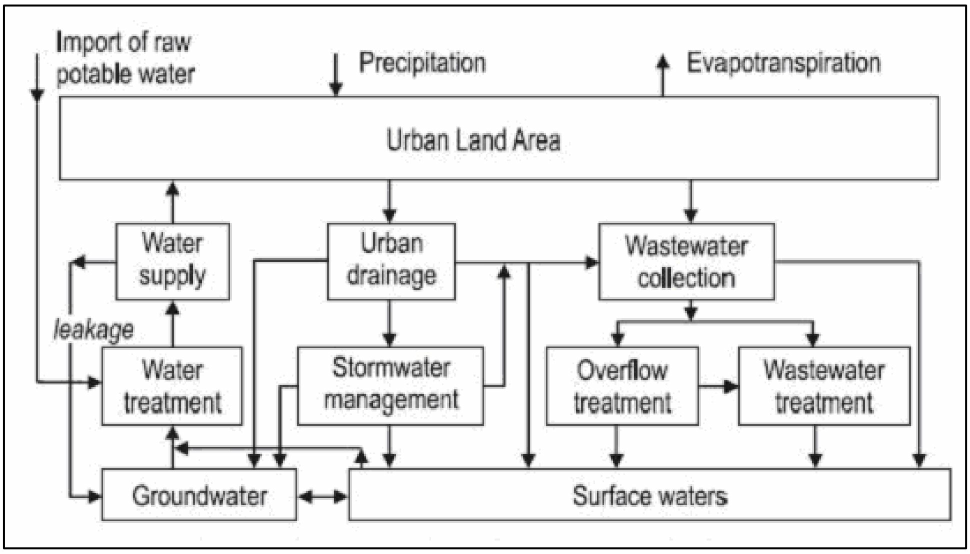

Figure 2.2: Urban water cycle: main components and pathways (Source: Marsalek e*t al*., 2006).

More detailed information about the UWC modelled by Aquacycle and UVQ is provided in Chapter 3.

2.3 URBAN WATER SYSTEM PRESSURES

2.3.1 Climate change

Climate change is the term used to define the change in either the mean state of the climate or in its variability, persisting for several decades or longer. This means changes in the Earth's weather conditions, such as(temperature, precipitation, frequency of heat waves, floods, droughts, storms, hurricanes and other extreme climatic phenomena.

UWS are vulnerable to climate change because of the changes produced in water resources, human settlements, energy, industry, civil services, human health, etc In addition, it is important to remember that the vulnerability of human societies and natural systems to climate extremes is demonstrated by the damage, hardship and death caused by events such as droughts, floods, heat waves, avalanches and windstorms (IPCC, 2001b).

Based on different emission scenarios and global computing models used by the Spanish Ministry of Environment (MMA, Spanish abbreviation), in the report "Study of *Generation of Climate Change Scenarios in Spain*" (MMA, 2007), to estimate the effect of Global Change in Spain, the change of the annual average temperature is 1-2 °C (as shown in Fig. 2.3), 3-5 °C and 5-8 °C for the periods 2011-2040, 2041-2070 and 2071-2100 respectively.(Spanish Ministry of Environment, 2007) However, it is important to highlight that the bigger variations appear in the inland regions of the peninsula where Zaragoza, the study city, is located. In addition, the changes in temperature are uneven through the year, with the biggest changes being observed during the summer months and the smaller changes observed during the winter months.

In the case of precipitation, the trend is not as clear and robust as that observed with temperature. Estimations for the periods 2011-2040 and 2041-2070 show a small decrease in precipitation in the western-half of the Iberian Peninsula and a light increase in the eastern-half (Fig. 2.4). On the other hand, in the last period (2071-2100) the nine models used for the report, show a decreasing trend of average annual precipitation for all of the Iberian Peninsula, with a predominant reduction found in the southern regions (Fig. 2.5).

Due to the predicted changes in precipitation and temperature, UWS are supposed to be affected by these changes. As a result of climate change, there will be greater impacts in water quality and quantity (Krishma *et al*., 2006). If the average annual temperature increases, the permanent ice of the Spanish mountains will melt, resulting in a reduction of one of the most important water storages of the province of Aragon. In addition, in accordance with the expected changes in precipitation, the hydrological cycle will suffer changes that affect the direction and magnitude of groundwater recharge. For these reasons, water availability will be an important issue in arid regions, such as where Zaragoza is located.

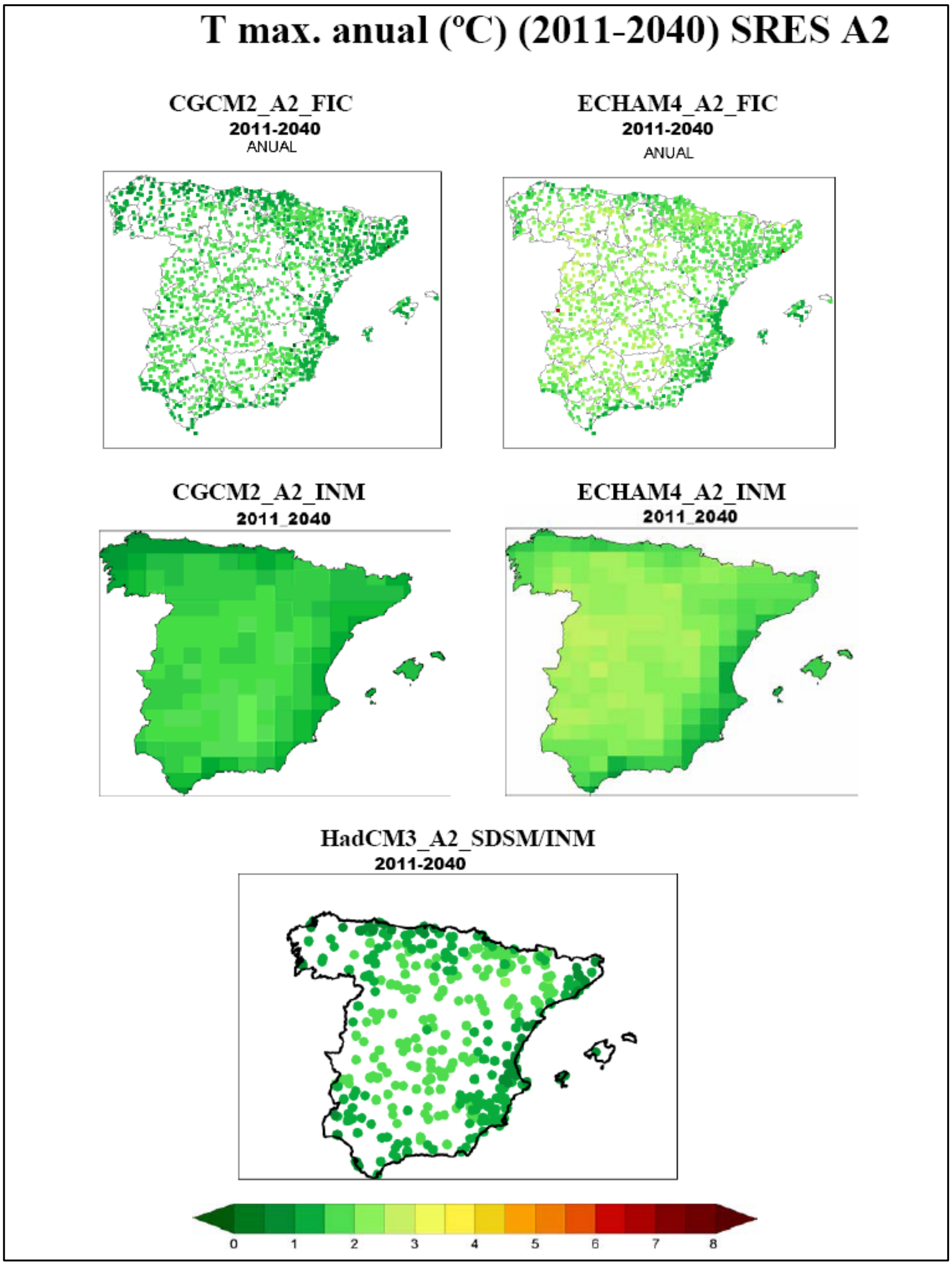

Figure 2.3: Comparison of the annual maximum temperature average change in the period 2011-2040 given by the different models used in the study of the MMA. (Source: MMA, 2007)

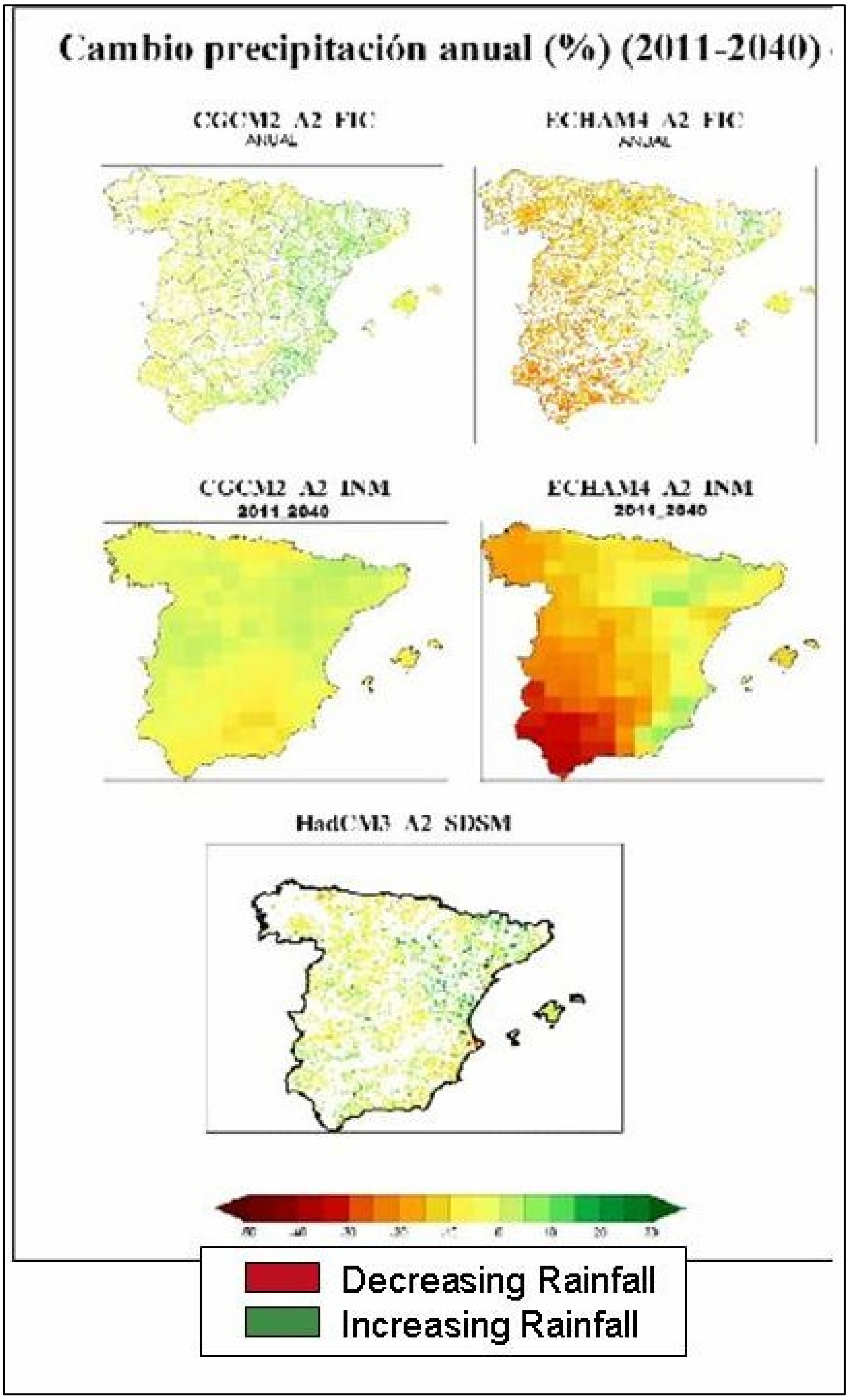

Figure 2.4: Comparison of the annual precipitation average change in the period 2011-2040 given by the different models used in the study of the MMA. (Source: MMA, 2007, cambio de precipitación anual: changes in annual precipitation)

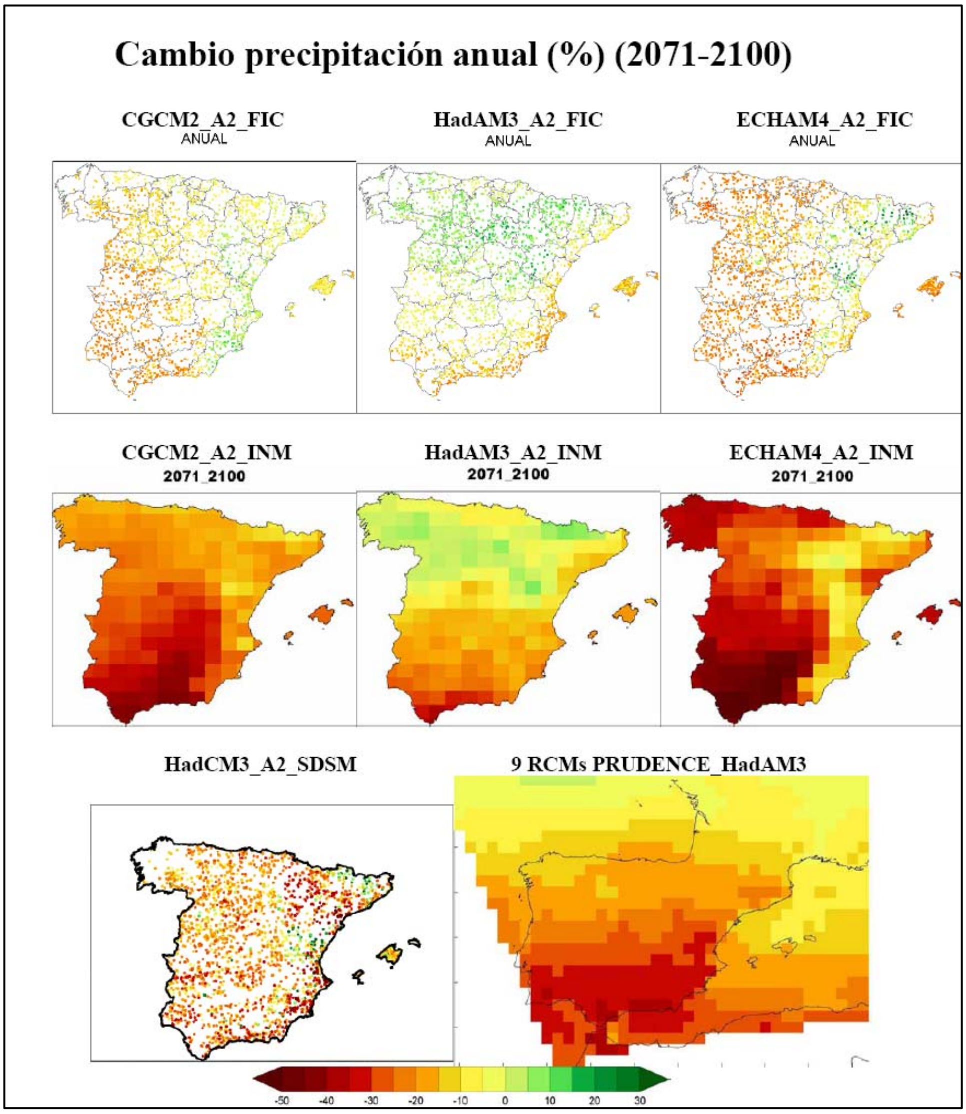

Figure 2.5: Comparison of the annual precipitation average change in the period 2071-2100 given by the different models used in the study of the MMA. (Source: MMA, 2007)

Water quality will also be affected by climate change. The increase in water temperature will alter the rate of operation of bio-geo-chemical processes (degrading and cleaning) and to lower the dissolved oxygen concentration of water. Similarly, increased occurrence of higher runoff will increases pollutant loading (suspended matters and heavy metals) and sewer surcharging. Additionally, increased frequency of flooding of treated or untreated wastewater sewers systems will have a serious knock on effect on biotic life cycles, and there is the increased risk of out-breaks of water borne diseases, such as cryptosporidium. The issue of water quality may also be an issue in lakes as they will be sensitive to these changes resulting in higher incidences of eutrophication process (Hellmuth & Kabat, 2002).

2.3.2 Population Growth and Urbanization

Approximately half of the world's population nowadays lives in cities. This percentage is increasing and so is doing their demand for natural resources as well as their pollution loads to the environment. (UNESCO, 1999; Hellstrom *et al.*, 2004, quoted in Penagos, 2007). There are many reasons for this. In cities, social services, securities and employment are much more available than in rural areas. On the other hand people living in villages and towns are more exposed to natural calamities, the utilities and services are poorer than in the cities… Cities also have rapid rate of population growth, industrial and economic growth which contributes to a rapid urbanization. This rapid urbanization imply in most of the cases a city unplanned development, that according to some environmentalist, is depleting non-renewable natural resources and contributing to global climate change (Krishma *et al.*, 2006).

A report that the United Nations wrote about population prospects in 2006 illustrates that the rate of population growth in urban area is in a higher pace. And, developing countries have a more rapidly urbanization process compared with the developed ones. According to report, population in urban areas in less developed countries will grow from 1.9 billion in 2000 to 3.9 billion in 2030. On the other hand, in developed countries, the urban population is expected to increase, from 0.9 billion in 2000 to 1 billion in 2030. The growth rate of urban areas is nearly double (1.8%) compared to the overall growth rate (1%) for the world for that period. At that rate, the world's urban population will double in 38-years. Similarly, there will be more rapid growth in the urban areas of less developed regions, averaging 2.3 % per year, with a doubling time of 30-years. The urbanisation process in developed countries has stabilised with about 75% of the population living in urban areas and this is forecasted to reach about 84% by 2030.

This situation will vary between continents and countries, so it is important to focus on the study area. Therefore it is important to take into account the demographic evolution of the city of Zaragoza. It is remarkable the high increase during the past six years (2000-2006), which coincides with the study period of this thesis, in which the population has increased in 44,500 inhabitants. The total per year population of the city of Zaragoza is showed in table 2.1.

Table 2.1: Demographic evolution of the city of Zaragoza between 2000 and 2006

Year	2000	2001	2002	2003	2004	2005	2006
Population	604,631	610,976	620,419	626,081	638,799	647,373	649,181

What is more, the Major of Zaragoza, Juan Alberto Belloch stated on May 2007 that the demographic studies show that the city of Zaragoza will increase in 100,000 inhabitants the current population by the year 2015, furthermore by the year 2020 the population will reach almost one million (Castaño *et al*., 2007). This population increase will be followed by an increase in the demand for resources, for this reason it is important to find more sustainable ways of urban management to avoid the depletion of the natural resources. In this case, water is the resource we are dealing with. Additionally, it is important to remember that a lot of communities downstream from Zaragoza also have the Ebro River as their main water catchment, so its management has to allow these communities to have enough water and with a good quality.

Another possible future problem of the city of Zaragoza, related to population growth and urbanization in the lowing of the ground water table. Nowadays, groundwater is used mainly by industries and some public garden irrigation. If the population and industries increase, the amount of extracted water will also increase, because of the increase in water demand. This fact, together with the increase of impermeable areas due to urbanization, will affect negatively to the aquifer.

Rapid population growth and urbanization will result in water scarcity and a huge impact in the natural environment, because in order to satisfy current and future water demands, the water supplied is and will have to be taken from ground or surface sources. The problem is that the water is extracted in a higher rate than the natural recover rate, exceeding the environment carrying capacity. In most of the cases it is and will be taken from very large distances away from the urban areas, increasing the impact on the environment, and so the urban water system footprint. In addition, nowadays many cities are experiencing pressure to satisfy demands for water by urban communities, and minimise the environmental impact caused by stormwater and wastewater.

Fig. 2.6 shows the main impacts of urbanization, a consequence of population growth, in the urban aquatic environment. On one hand, the population increase will lead to the

increase of water demand together with the discharges to the environment, with the respective increase of pollutants, organic and nutrients loads and increase of oxygen demand that will lead to decrease of the most sensitive species, which is an important problem nowadays: loss of biodiversity. On the other hand, urbanization is responsible of the increase of impervious surfaces, which have two main impacts in the UWC: a) increase of stormwater runoff that includes the flooding frequency, and b) decrease of water infiltration into the soil and the resultant decrease of the groundwater level and rivers flows and pollution increase.

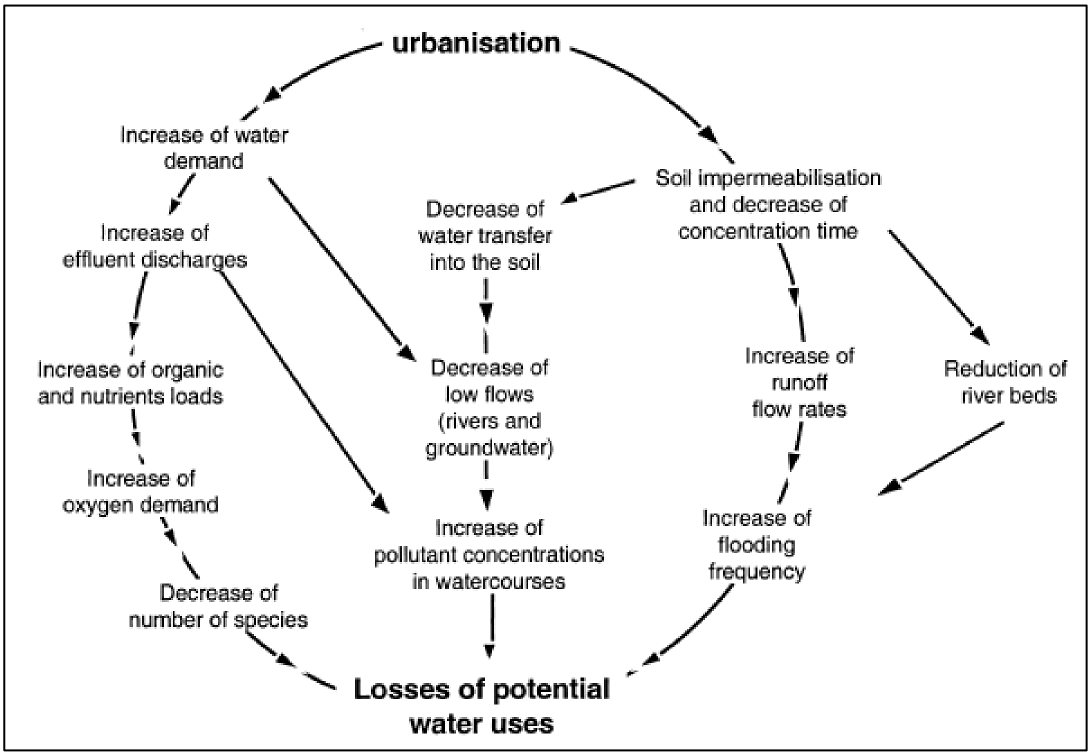

Figure 2.6: Impacts of urbanization on aquatic environments (From Chocat B, editor. Encyclopedie de l'Hydrologie Urbaine et de l'Assainissement., Paris, quoted in Bertrand-Krajewski, *et al*., 2000)

The trends of population growth and urbanisation rate are not similar over the world. It is different from continent to continent, country to country, even city to city. However, there are moves toward the sustainable development and controlled urban planning as well as focuses on governmental polices and actions to balance the population and urban growth. Many national and international organisations are working to keep equilibrium between the population growth and urban carrying capacity (Krishma *et al*., 2006). As a first approach and useful way to work on it, is the study and application of the intergraded urban modelling software.

2.3.3 Globalisation and economic development

The word globalization means the act of integrating the economies around the world, in terms of trade, financial flows, labour and knowledge. Hirst and Thompson (1999) define globalization as the development of a truly supranational economic system. Similarly, according to Brenner (1999), globalization is the accelerated circulation of people, commodities, capital, identities and images through global space, as well as the increasing mobility of ideologies, economic principles, policies and lifestyles.

One of the results of globalization will be the homogeneity of population settlements and their economies. Most of them will be set in urban areas, which are directly related to with the last section of urbanization increase and its impacts. In addition, owing to the economic liberalization caused by globalization, most economic activities will be set in or close to urban areas, which have industrial and manufacturing operations, which are large water consumers and in most of the cases they are significant water polluters and also waste producers.

As a result of globalization, together with other pressures that UWS will have to face in the near future, environmental impacts and pollution, water quality and quantity, service level and pricing issues will be among the primary issues for politicians and the local authorities to address.

On the other hand, since the 1960s there has been a rapid development and progress in information and communication process and mass travel facilities all over the world. This fact has allowed science and innovation to "travel" around the world faster than before and the problems, research activities, new technologies and solutions can now be shared between different water stakeholders from all around the world.

2.3.4 Deterioration of Infrastructure

The main reasons for infrastructure deterioration is ageing systems, poor construction practices, little or no maintenance due to limited financial resources, operation at higher capacities than design specifications and lack of knowledge regarding infrastructure condition.

Infrastructure deterioration leads to different economic and environmental problems. The cost of replacing a pipeline network in a city is very high and can cause problems

between relevant stakeholders. It is the cause of water leakages and reduces water quantity and pressure in the network that in some situations has to be covered by alternative energy systems. Another environmental impact is the infiltration of waste water into the supply system polluting the water and so reducing its quality (risk to human health) or it can overflow over some urban surfaces with the same impact. This also results in increased in maintenance and operation costs.

There is no need to discuss this issue in more detail as Zaragoza Municipality has already renewed all the pipeline network in the study area, (personal communication from a senior civil servant of the Infrastructure Department of the Municipality of Zaragoza). The Municipality is serious about environmental issues, with water issues currently having high priority topic. Proof of this is the fact that they have undertaken a seven year municipality programme called "Improvement Water Plan" (2002 – 2007). The main actions that are dealt with in this plan are: improvement (1.5M€) and control (0.5M€) of water quality, improvement of the water facilities (19.35M€), renovation of the pipeline network (52.98M€), water consumption control (5.34M€), adaptation and upgrading of private facilities (1.38M€). The total cost is around 81.59M€, with the highest investment being renovation of the pipeline network

2.3.5 Governance and Privatisation

The general world trend over the last few years has been to privatise the water sector and reducing the role of government. The most important reason for this is the financial pressures of the ageing urban water infrastructures (in most European countries they are over 100 years old). The investment needed to repair and/or change the infrastructures is extremely high and it seems to be beyond government economic possibilities, so the private sector has taken advantage of this with the process of privatisation. Privatisation has advantages and disadvantages. On one hand, the different multi-national companies are sharing ideas, the best practices and new technologies between different areas of operation and expertise. They can also invest more money in research activities. On the other hand, as private sector is a profit making organisation and not a public service organisation, the risk of excluding lower socio economic areas exists. The government has a duty to supply all the population with potable water and remove wastewater. However, it is possible that private water enterprises will fix very high cost that only a small proportion of the population can afford.

The Town Council of the city of Zaragoza is in charge of the total urban water cycle , which is uncommon in Spain where in most of the cities the water systems are managed by private companies. Today, Zaragoza Municipality is dealing with properly the water system, its infrastructures and financial issues. As already mentioned, there is large investment project aimed at improving water and infrastructure quality in the city. The Treasury Department of Zaragoza Municipality, together with the Applied Economy Department of the University of Zaragoza have developed a fair water tariff where they are able to recover almost all the budget used in the management of the urban water system and this is affordable for most of the citizens. It is defined as fair because the tariff has into account the number of householder occupancy and there is a reward for households that have adopted saving practices. The public management of the UWS is now becoming more efficient and will probably remain in the public sector for the future.

For these reasons, the city of Zaragoza and its efficient urban water management, could be an example and study city for comparing urban water management issues in the public and private sectors (with other Spanish cities) and conclusions could be made regarding the predicted trend of increasing privatisation of urban water services on a global scale.

2.3.6 Changes in the public behaviour

Infrastructure systems are built and operated to meet basic social needs. The needs are very complex in nature alter depending on changes in social behaviour, or the behaviour of the users. Many people act individually and within a group; and at different levels: local, regional, national, and even international. They will have their own expectations on objectives of infrastructure services and their own judgments in meeting their objectives. However, social values change from time to time and place to place. Therefore, selection of infrastructure systems and services will be governed by social priorities (NRC, 1996).

A recent survey report on European consumer's trends of drinking water revealed that the primary social behaviour change is in water supply consumers. Main findings of the study on behaviour change are: growth in bottled water use, greater participation of consumers' in water issues, raising awareness of the consumers' in water issues, no

increase in willingness to pay (WTP), and switching to water metering (Kelay *et al*., 2006).

According to different studies, global bottled water consumption is likely to keep increasing in the future. However, the fact is that according to a study carried out by Canadean -a global market research and data management company focusing on the international beverage industry and its suppliers- bottled water consumption has increased in a spectacular way in the Autonomous Community of Aragon in the last few years, specifically in the city of Zaragoza and its surroundings. In 2006, the total amount of bottled water consumption in Aragon was 203.4 millions litres, which is eight million more than in 2005. The province of Zaragoza is the main consumer, followed by Teruel and Huesca. Water salinity and bottled water consumption are closely related, and the water of Zaragoza has very high salinity as previously been discussed. Moreover, buying bottled water is becoming a habit within consumers, because it is thought that bottled water is healthier and more natural than tap water.

Another important issue related to changes in people behaviour is public awareness. Zaragoza Municipality has undertaken and is undertaking different environmental projects to increase the citizen’s water culture and awareness, such as “Zaragoza, water saving city” or “100,000 commitments with water”.

It is therefore logical to assume that changes in public behaviour will affect urban water systems, primarily in water consumption patterns and water quality standards. These changes will affect water demand management because the increase in social awareness and participation will affect decision making processes of the service provider and the pricing policy.

Public behaviour governed the water and waste water services, so it affects the urban water system.

2.3.7 New technologies and increasing energy cost

An important issue related to public behaviour is the acceptance of new technologies such as separation and decentralized systems in waste water, rain water harvesting in water supply, reuse of grey water etc. These technologies can be very helpful in reducing fresh water extraction, and subsequently the environmental impact and foot

print of the current technologies. However, the cost of replacing the old system or installing these new technologies is high and it would be reflected in the cost of water. Furthermore, they can not be implemented if society does not accept them.

There are two main reasons for increasing energy costs. The first being the higher rate of urbanization and industrialization, and the second being the fact that the price of non-renewable energy sources are always increasing in the global market. There is significant energy consumption in urban water systems because high capacity pumps are needed for the process. These new technologies are expected to be effective and efficient in energy consumption, as well as in water quality and operation. This fact will also affect the cost of water supply and waste water services. For this reason, it is important to evaluate the cost of the service and bear in mind the possibility of using renewable energy sources such as solar, wind and hydro power plants.

As a response to all of the pressures that UWSs have to face in the present to avoid problems in future situations, a rapid response of politicians, urban planners and the scientific community is underway. There are several research studies, projects, directives and legislation etc towards truly sustainable urban water management. The next section explains the objectives and requirements of sustainable UWSs.

2.4 SUSTAINABLE URBAN WATER SYSTEMS

The most common description of Sustainable Development (SD) that is known worldwide is that given by the World Commission on Environment and Development in the Brundtland Report: "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". In relation to services, this means that a sustainable service has to imply the provision of more efficient services that maintain public health and welfare are cost-effective and reduce negative environmental impacts, today and into the future (Shaley *et al*., 2005).

In order to develop more sustainable UWSs, most authors agree that it is important to include past studies of urbanization and water management which focussed mainly on science and engineering. However new concepts such as society (life style, universal access, water demand, public behaviour etc), economy (efficiency, cost recovering etc) and environment (energy efficiency, resource use, environmental impacts, water quality

and quantity etc) should also be included. A sustainable UWS must include the traditional objectives of water supply with good health and quality standards, and wastewater-stormwater collection, treatment and discharge; plus the following objectives: (Morrison *et al*., 2001):

- preserve the quality of raw water resource
- allow for sustainable use of the raw water sources
- supply the general population with safe drinking water in sufficient quantity
- supply the general population with adequate sanitation and
- reduce the use of limited resources and energy to within the levels of sustainability.

According with Lundin M. (1999), there is a set of criteria that a UWS has to compile in order to be sustainable: technical, environmental, social and economic. This set of criteria is explained briefly in the following paragraphs.

Technically, an UWS has to be efficient and effective. It has to be effective to reach the objectives mentioned above and efficient enough to reach them in the most optimal way of resources management. UWS has to be reliable, which means to be able to provide their service even when unexpected events occur, like power cut. As mentioned previously, the urban ecosystem is not static but dynamic, so a sustainable UWS needs to have the potential to change (flexibility) and to be able to adapt to changes that occur within the urban system (adaptability). It is also important that the materials needed to build up the urban water system have a high durability to avoid important investments in infrastructure renewal.

An environmentally friendly UWS is one that fulfils the objectives of prevention of contamination and sustainable use of resources and retains almost the same level and standards of water quality and quantity removing nutrients, excesses of oxygen and pollutants from the water that is returned into the natural system. Is important to reuse and recycle all the outputs of the UWC that can be transformed to new resources or inputs (wastewater and stormwater, nutrients, sludge, etc).

In relation to economy, having drinking water is a human right although unfortunately it is not fulfilled everywhere on a global scale. Theoretically this means that the price of

water has to be affordable for all the population. On the other hand, the water tariff has to be cost-effective for the company in charge of its management.

The last criteria, but not any less essential, is related to society. It is important that the UWS are managed by qualified personnel to ensure a flexible and adaptable organisation. Furthermore, the life cycle of the water has to be safe for the personnel who work in the urban water system and the final users. It is also important to ensure a flexible system regarding public participation where the system works under both circumstances, whether people with a higher environmental awareness are willing to contribute to reduce the environmental impacts or not. Public behaviour is also a key point in sustainable UWS because user behaviour as well as life style affects the function of the UWS.

In order to regulate UWM, several European directives have been created since 1976. In the year 2000 all European directives that related to water issues were integrated in a new piece of legislation: the Water Framework Directive (WFD) which includes water quality for different uses, hazardous substances, Environmental Impact Assessment, Sewage and Sludge management, urban wastewater treatment, prevention of pollution within other related water topics. However, the WFD does not include the most recent innovative ideas and the closing cycles of nutrients and water and energy implications receive very limited attention. (Van der Steen, P 2006). This is why different approaches to sustainable UWS have appeared such as the Swedish MISTRA or the Belliago principles. According to these principles a sustainable UWS should have:

- Human dignity, quality of life and environmental security should be at the centre of the new approach, which should be responsive and accountable to needs and demands in the local setting.
- In line with good governance principles, decision-making should involve participation of all stakeholders, especially the consumers and providers of services.
- Waste should be considered a resource, and its management should be holistic and form part of integrated water resources, nutrient flows and waste management processes.

- The domain in which environmental sanitation problems are resolved should be kept to the minimum practicable size (household, community, town, district, catchment, city) and wastes diluted as little as possible.

To conclude, the challenge of sustainable UWS and the directives is to satisfy different demands in different regions of the world. In many areas the main requirement is access to healthy water and some kind of sanitation. In the industrial world, environmental concerns have grown, focusing on the quality of groundwater, the recycling of nutrients and the reduction of environmental effects (Lundin, 1999).

2.5 SUSTAINABILITY INDICATORS

In order to assess the sustainability of the Urban Water Sector, different indicators have been developed. Hundreds of pages have been and could be written in relation to this topic because it is a hot topic and it is very complicated to establish a list of urban water indicators that can be used worldwide. A brief overview of sustainability indicators in the water sector is provided below.

The framework in which the sustainability indicators are establish, as described in section 2.4, are economic, social, environmental and technology aspects.

Alternatively, there are different definitions for sustainable indicators. As this thesis is framed in the city of Zaragoza the definition given by the Local Agenda 21 of Zaragoza Municipality is going to be used. According to the Local Agenda 21, the main objectives of sustainable indicators are evaluation, quantification and the adaptation of the predicted actions for the achievements established in the process of Local Agenda 21:

- Public awareness and education in environmental and sustainable development related topics.
- Public access to environmental information.
- Public participation.
- Collaboration with NGOs, companies, twin towns…
- Measurement, monitoring and elaboration of reports about the sustainability progress.

The main characteristic of a good indicator is the ability to summarise large amounts of data into a data set that is easily understood. The indicators should also quantify evolution of the economic, social and environmental situation of the municipality. They must also determine trends and allow immediate action to be taken in a specific area if necessary. The indicators proposed by the Local Agenda 21 are sustainability indicators (see Chapter 5), which mean that not only environmental factors are included but also those factors that support them, such as economic factors and also those factors that are directly related with the management of social factors. So Local Agenda 21 considers sustainability indicators those that reflect the interaction between environmental, social and economic aspects that will define the development model of each municipality.

Chapter 3

Modelling the Urban Water System

3.1 INTRODUCTION

There are many pressures that affect and will affect the UWS in the present situation and this will occur with increasing intensity in the future. These pressures are responsible for the problems that cities suffer today in relation to the current approach of urban water system management.

This paradigm considers the three main elements of the UWS (water supply, wastewater and stormwater) as different entities. However, for a good understanding of the UWS, these three components must be treated in an integrated and holistic way. They have been and are treated separately but they must be integrated in order that planning and operation of the elements is treated as a whole system for a more sustainable urban water management. However, the urban water system and its dynamics are treated as an isolated system from the rest of the city (socio-economic and environmental aspects, population growth, public behaviour, etc), but it is a component of the whole urban environment that is influenced and influences other components.

Additionally, the new paradigm proposes the development of more sustainable UWS by using wastewater and stormwater as urban water sources for low water quality demands such as garden irrigation or toilet flush. Fig. 3.1 represents the conventional UWS (blue) and a more sustainable one (orange) taking into account only the technical criterion of the set of criteria established by Lundin M. (1999). As the other three criteria (environmental, social and economic) are not taken into account by Aquacycle (the computer model applied to the study area), they are not represented in Fig 3.1. The conventional one represents one-way path from catchment and supply to a single use, treatment and discharge. On the other hand, a more sustainable UWS is showed in orange in the mentioned figure. The alternative options are mainly recycle and reuse of wastewater and use of stormwater for low quality standard uses, because in a sustainable way, water demand is looked as a multi-faceted way, what means different quality requirements for different uses.

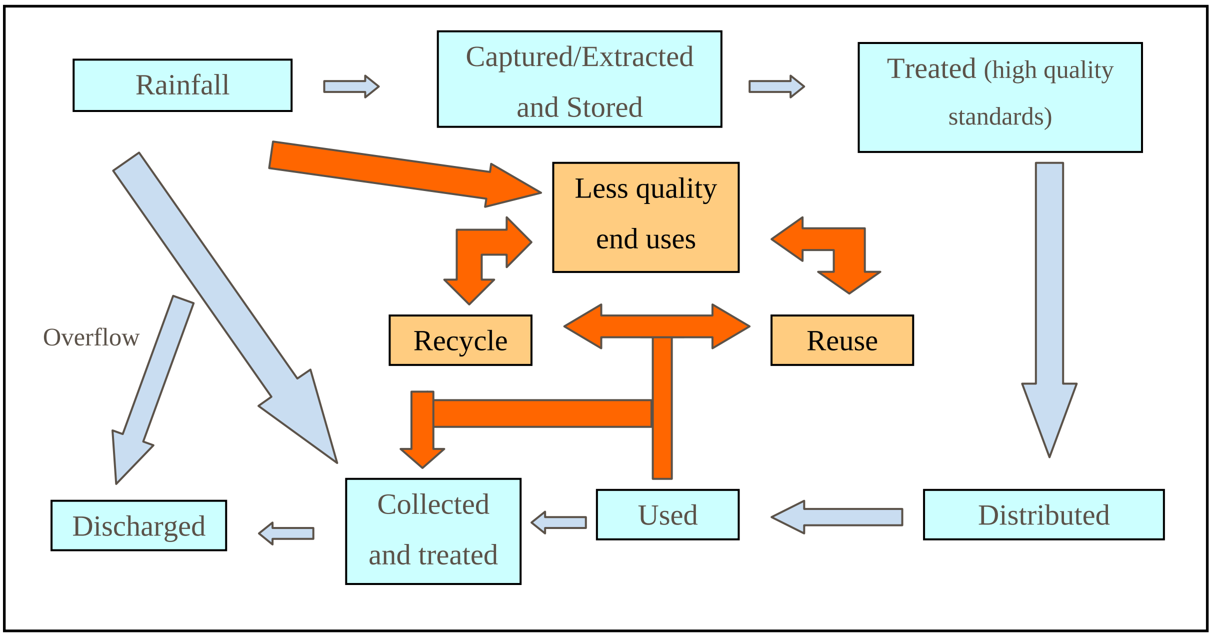

Figure 3.1: Comparative diagram of the conventional UWS and a sustainable one.

Changes in the UWS will have downstream or upstream impacts that will affect cost, sustainability, etc. Therefore, proposed changes to a particular aspect of the UWS must include a comprehensive view of the other systems and consider the influence on them. For this reason, the need of an Integrated Urban Water Management (IUWM) is increasing to support the necessity of building more sustainable UWS. As they are complex and inter-related, the whole urban region needs to be considered.

This fact justifies the necessity to represent or model the current UWS to obtain a better understanding of the system and to simulate different possible scenarios and their impacts. With this purpose in mind several computer models have been developed. Additionally, several projects have emerged at local, national or international level to deal with the new approach of IUWM. These frameworks aim to develop different computer models and toolboxes that allow modelling and assessment of the UWS. The different software and projects are explained and compared in the following sections.

3.2 INTEGRATED URBAN WATER SYSTEM SOFTWARES

Integrated urban water system softwares give a holistic and global view of the urban water cycle, considering all the components of the urban water system as a complete physical system within an organization framework and as a part of the natural and urban environment. They are useful tools to help decision making processes and to guide and

support an integrated urban management process, taking into account scientific, technical, ecological, and socio-economic points of view. Another reason for the utilisation of these computer models is the overview they give regarding the different alternative technologies that exist to improve the urban water cycle, which are related mainly with water recycle and reuse. These softwares have been improved thanks to advances in urban hydroinformatics, which allows modelling the different phases of the urban water cycle and optimising them in both global and local scale. In particular, the advances in urban hydroinformatics have made significant impacts on the development of new strategies for urban water management. The use of computer models pervades all aspects of water management, supporting wealth creation through products and services, contributing for many, improvements in quality of life. As a result, there is a growing increase in demand for better use, productivity, flexibility, robustness and quality of such modelling systems (Vojinovic Z., 2007).

There are simple models, such as Aquacycle that models the daily urban water cycle of a city which allows studying and evaluating the inputs, outputs and movements of water within a city. From this model, UVQ model (Urban Volume and Quality) has been developed by CSIRO of Australia (Commonwealth Scientific and Industrial Research Organisation), which not only analyses the urban water balance but also the urban water contaminant balance. In addition, new software based on these two models, is being developed by a PhD student at Birmingham University for the SWITCH project. It is called SWITCH–Aquacycle and includes energy balance and cost analysis as new outputs.

The following sections look at and explain other computer models, toolboxes and approaches.

3.2.1 Aquacycle

Aquacycle is a daily urban water balance model which has been developed to simulate the total urban water cycle as an integrated whole. It provides a tool for investigating the use of locally generated stormwater and wastewater as a substitute for imported water alongside water use efficiency. The scenarios of methods of stormwater and wastewater reuse available in Aquacycle are showed in Table 3.1

Table 3.1: Methods for stormwater and wastewater reuse available in Aquacycle (Source: Aquacycle User Guide, version 1.2.1)

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

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

The spatial scale is dived into (i) unit lock (households, commercial buildings, and industries), (ii) cluster (neighbourhood or areas with same land use), and (iii) catchment (the whole study area). The land use in a cluster is separated into unit blocks (lots), road, and public open space. Road areas are assumed to be impervious and all public open space is assumed to be pervious. Unit blocks can be separated into roof, paved and pervious surfaces.

Aquacycle produces daily, monthly, and annual estimations of water demand, stormwater yield, wastewater yield, evaporation, imported water use, stormwater use, and wastewater use, as well as performance measures of any water management strategies selected.

Aquacycle is based on a typical Australian city, which has two systems, (i) the rainfall-drainage system and (ii) the water supply-wastewater system, separated by the dotted line in Fig. 3.2. As one can see in the figure the main inputs into the system are precipitation and imported water; while the outputs are evaporation, stormwater runoff and wastewater discharge. The rainfall-drainage system is a combination of the natural process of rainfall and infiltration into the soil through pervious surfaces, water soil storage and rain runoff into the impervious surfaces and the drainage network with its channels, culverts and pipelines. The supply-wastewater system is simpler; it consists of a number of artificial pipelines, channels, connections, etc. with the purpose drinking water supply and the wastewater collection and removal to the WWTP.

The city of Zaragoza has a combined system, which is different to model scenario, but Aquacycle has been applied to different case studies for other urban areas with combined systems and appears to work adequately, such in the case study of Athens (Karka *et al*., 2007)

Aquacycle has been applied in several case studies in different cities in order to consider stormwater and wastewater as a potential water source to diminish the amount of imported freshwater via the reticulated system. Due to software availability and time restrictions, Aquacycle is the only software used in this thesis in the Actur–Rey Fernando neighbourhood of the city of Zaragoza, henceforth Actur.

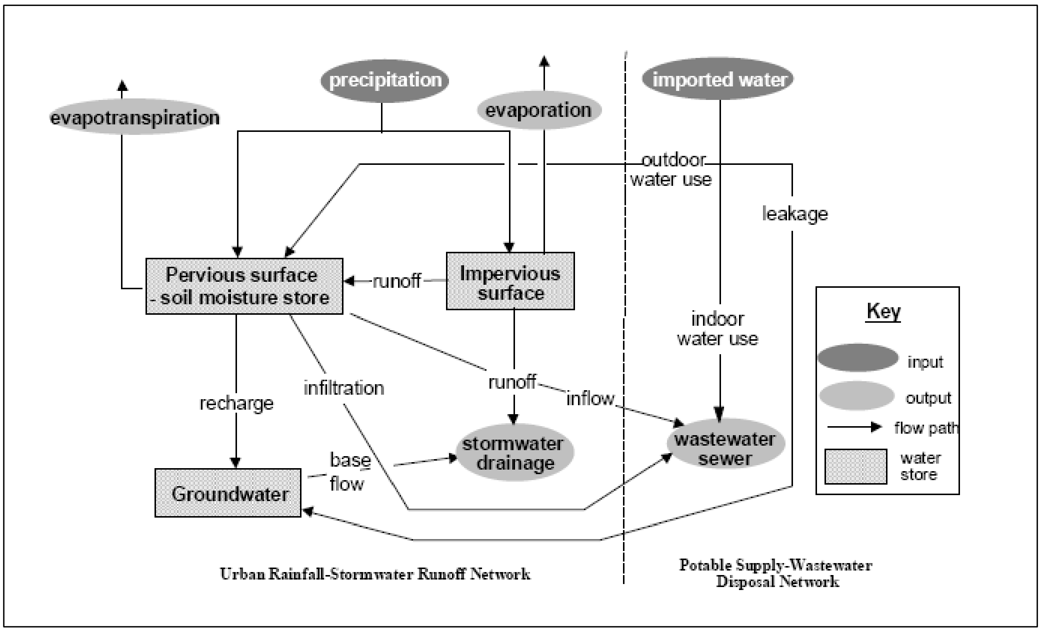

Figure 3.2: Urban water cycle as presented in Aquacycle (Source: Aquacycle User Guide)

3.2.2 Urban Volume and Quality (UVQ)

Aquacycle was enhanced by extending the water balance model to include a number of new water flow paths and incorporating contaminant balance modelling. The result is an urban water balance and contaminant balance analysis tool called UVQ that comprises two components: (i) the water flow balance model, which calculates water flows through an urban water system; and (ii) the contaminant balance model which calculates contaminant loads and concentrations throughout an urban water system (UVQ User Manual, 2005).

The model has been developed to provide a means for rapidly assessing the impacts of conventional and non-conventional urban water supply, stormwater and wastewater development options (scenarios) on the total water cycle, which is very important to understand the impact of the interaction of water with an urban area. As fresh water, waste water and storm water are considered as one system, it is also important to understand the interactions between the flow and the contaminant paths. UVQ provides a valuable insight into the viability of prospective alternative water servicing options in terms of environmental and performance requirements. (Mitchell *et al.*, 2006). Other functions of UVQ are: quantify the amount of water available for reuse and the possible end use demands, provide insight into the primary sources of contaminants and water movements within the urban area, investigate the relationship between the spatial pattern of demand, supply and storage capacity of the reliability of a range of alternative

water sources and provide performance requirements of treatment techniques and technologies to achieve user specified discharge water quality.

It is important to mention that the contaminants mapping (which include load, concentration and flow information for each specific pollutant) coincides with the water flow mapping. Thus, alterations in the water delivery and disposal routes will directly affect the movement and distribution of contaminants in the urban environment (Mitchell *et al*, 2006).

UVQ is a model developed with the goal of providing a modelling tool for the assessment of alternative water management option in urban areas. In addition, UVQ provides a valuable insight into the potential for alternative water servicing, the potential impacts of implementation, and the performance requirements of treatment processes to achieve reuse and environmental quality goals (Mitchell V.G. at all, 2006).

UVQ has the same spatial scale as Aquacycle (land block, neighbourhood and study area). The input data requirements are the following: land uses types, information about storage capacity, treatment performance, water sources and uses, uptake rates, daily rainfall and potential evaporation time series, data describing contaminant concentration for drinking, bore and rain water, evaporation and roof, road and paved area runoff. Contaminant loads for kitchen, bathroom, laundry and toilet, together with fertiliser application rate are also required.

The definition of the urban water cycle is more complex that in Aquacycle. It allows water transfers to be modelled as depths, with individual surface components accumulating or dispersing water. It is given by Mitchell *et al*. (2005): a comprehensive evaluation of the inputs, outputs and movements of water within an urban control volume. This urban volume is a “box”, with unit surface horizontal area, that extends from above roof level to a depth below the groundwater table. This definition of the UWC is used by the UVQ model, and allows the software to have an overview of the contaminants movement among the cycle and so, develop a contaminant balance (See Fig. 3.3).

Some case studies have been carried out in order to study the urban water balance and contaminant balance in different cities. Once all the data requirements are obtained and

introduced into UVQ, the model allows the user to define a series of different scenarios to assess their impact on the urban water system. They include water quality and quantity, demand change, climate change. In addition, alternative water supply scenarios (using the new alternative technologies) can be tested for their potential to save water and/or money. All these scenarios are compared with the base scenario that is the situation at the time that the model is carried out. The flexibility of UVQ to create different scenarios from the base scenario is very useful for decision making because it shows several alternative water management options.

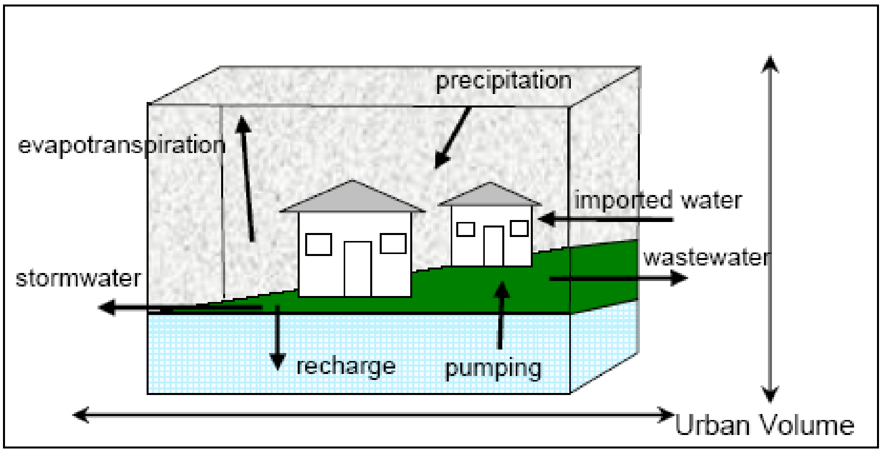

Figure 3.3: Representation of the Urban Water Cycle by UVQ (Source: UVQ User Manual)

3.2.3 Switch – Aquacycle

SWITCH - Aquacycle is currently being developed within the context of Theme 1.2 of the SWITCH Project: "Integrated Modelling and Decision Making for Urban Water Management". This theme proposes a scoping model for urban water sustainability as a decision support tool for Integrated Urban Water Management. One of the main characteristics of the model is simplicity, it is supposed to be a generic model that can be applied in any city around the world with minimal data input requirements (very important issue because data gathering and analysis can be very time and cost consuming, as explained in chapters 3 and 4). The model is intended to provide initial suggestions (indicators) for the development of more sustainable urban water systems. In addition, it will be able to build future scenarios of climate change and population growth.

The water and water quality balance model for the system has been completed. This includes supply, wastewater, stormwater runoff and natural systems (precipitation,

canals, rivers, and aquifers). The modelling is centred on ArcGIS with many different layers providing spatially represented input information and results. It has been based on concepts used in the Australian water balance program Aquacycle and its offspring UVQ. The main features that will be added in relation to other softwares are energy consumption at the total urban water cycle and life cycle cost. The PhD student, Ewan Last from Birmingham University is currently working on energy and life cycle cost data collection.

The overall goal of the model is to be able to determine the most sustainable combination of options for the urban water management at a local level. To provide an appropriate response to this the model has to be capable of addressing the three pillars of sustainability: economic, social and environment by means of different indicators.

The expected product of Theme 1.2 is a scoping model that assesses, using indicators, the sustainability of different water management strategies and displays them in a user-friendly format in ArcGIS.

3.2.4 URWARE

Urban Water REsearch Model (URWARE) is a substance flow model, developed in Sweden. The objective is to provide an analytical tool for analysing environmental sustainability criteria of urban water, wastewater and solid waste systems. As with Aquacycle and UVQ, URWARE was developed from its predecessor ORWARE (ORganic WAste REsearch Model) which evaluates the environmental impacts of different options relating to organic waste management. The main results of URWARE are: find out the typical properties of each system structure and investigate the applicability of different systems structures depending on local conditions (Ocean Arks International Burlington, 2005)

URWARE is based on Material Flow Analysis (MFA) (based on the law mass conservation- and Life-Cycle Assessment (LCA) evaluation of the productive process of an specific service or product along all its life “from the cradle to the grave”). The first one is an important decision making tool. It is improved with the addition of the LCA to calculate the environmental impacts of the urban system. However, URWARE data requirements are more complex than for a usual LCA because it includes substances in the water, wastewater and stormwater (nutrients, organic matter, heavy

metals, etc) as well as data for technical system processes. This data is often difficult to obtain, and can be time consuming. Therefore, this method is likely to give more accurate life-cycle analysis than other LCA models.

3.3 INTEGRATED URBAN WATER TOOLBOXES

The computer models described above have some limitations because they usually focus only on one or two aspects of the UWC. For this reason different projects have been developed in order to try to cope with or minimize the software limitations with the aim of providing a useful toolbox for application by urban planners and managers. Some of them are described in this section.

3.3.1 CSIRO Urban Water

In 1998, the Australian CSIRO began an ambitious program with the aim of improving the sustainability of Australian's urban water systems. The program called CSIRO Urban Water emerged with the vision of "in the face of economic, social and climatic change, enable Australian's urban water systems to improve services to the community and improve economic performance while achieving ecological sustainability" (Zoppou *et al*., 2000).

As a result of the program, the CSIRO Urban Water is a new service that provides urban water consulting, research and technology services to industry; this is classified as a toolbox. It offers (source: www.cmmt.csiro.au/research/urbanwater/):

- Analysis of system lifecycle costs to extend asset life
- Innovative system designs for reduced costs
- Modelling for optimised system design
- Water and contaminant balance analysis
- Social issues analysis for service delivery
- Integration of sewage treatment technologies
- Water use measurement and analysis
- Techniques for aquifer storage and recovery

The CSIRO Urban Water offers this consulting and research service as a result of the research study carried out in the program. Most of the important aspects needed for a

sustainable UWM are covered by their services. However, CSIRO Urban Water will research in the future other important features of the urban water system such as: peak flow and pressure management, externalities, low-cost sewage systems and their impacts, and customer preferences for levels of service (source: http://www.cmmt.csiro.au/research/urbanwater/history.cfm).

3.3.2 The SWITCH Toolbox

The main objective of the SWITCH Project Work Package 1: "Urban Water Paradigm Shift" is providing support to the cities Learning Alliances in their process of self-appropriation of integrated urban water management by means of an integrated information tool or software. The scope of the toolbox would be: to raise awareness of the trends for the future and the possible options in terms of planning and management, to be able to define, test, compare and evaluate scenarios or at least support the activity within the LA and to provide assistance in judgment and decision making at a strategic level (Soutter, 2007). The main toolbox characteristics are simplicity and to be usable in all cities around the globe.

The toolbox may cover a huge variety of elements, such as data, indicators, scenarios, evaluations, models, tools, etc. SWITCH–Aquacycle will be one of these elements a model that for example can address future scenarios of climate change and population growth, according to the developer.

3.3.3 The Urban Water Toolbox

This toolbox is framed within the Swedish MISTRA programme Sustainable Urban Water Management, abbreviated as Urban Water. It was a six year project (1999–2005) designed to develop tools and knowledge to guide the planning and management of the future water and wastewater systems in Swedish cities. The programme has adopted the following general vision for sustainable urban water management: *Every human being has a right to clean water. For urban areas, our vision is water management where water and its constituents can be safely used, reused and returned to nature* (Urban Water Progress Report 2001). It has emerged as a response to the constant question of the level of sustainability of the UWS.

The urban water toolbox is a group of models and assessment methods that assess different kinds of water and wastewater systems. It is based on five groups of criteria

focusing on health and hygiene, the environment, economy, socio-culture, and technical function. The tools cover the need for assessing all the identified criteria, as well as the decision making process. The toolbox is a component of the urban water approach that aims to develop criteria for sustainable water and wastewater systems, reflecting the multi-disciplinary needed for comprehensive understanding and analysis (Sustainable Urban Water Management, 2002). The toolbox is formed by different decision-support tools that evaluate different aspects of the UWC:

- Substance flow analysis - URWARE and SEWSYS
- Microbial Risk Assessment - MRA
- Chemical Risk Assessment - CRA
- Cost estimation tool
- Organisational capacity (practical guidelines for decision makers)
- User aspects (This tool provides support for local organisations in planning and operating new systems)
- Methodologies for integration of knowledge areas – MIKA (a method that is meant to support decision-makers, helping them synthesise and integrate results from the many subject areas they work within Urban Water programme)

The programme, ended in June 2006, and was developed by a number of Swedish Universities and research institutes and the results are now available for practical use. It can be said that it was successful because a consultancy company called CIT Urban Water Management AB has originated from the Urban Water programme. This company provides services within strategic planning of sustainable water and wastewater systems. The mission is to supply support for strategic decisions concerning sustainable water and wastewater systems, especially with regards to the environment, hygiene, economy, organisation, users and technical function. The models developed during the research process are used, as well as other application if needed (source: http://www.chalmers.se/cit/urban-en).

3.4 INTEGRATED URBAN WATER METHODOLOGIES

3.4.1 The Systems Methodology

According with Coombes P.J. and Kuczera G. (2002) Australian cities cannot continue with their current UWS management, harvesting huge amounts of water from the natural reservoirs and ignoring the resource potential of the rain fall that falls on those cities by discharging it to the environment as stormwater. In addition they stated that UWS are complex systems not only because of its physical complexity but also because the involvement of socio-economic and environmental objectives. For all these reasons, they propose a multi-objective planning methodology as a useful decision making philosophy for working with complex systems. This methodology is described by the following steps:

1) Identify system and its important linkages with subsystems.
2) Define objectives and how to measure performance.
3) Identify the feasible solution space.
4) Search for the Pareto optimal solutions.
5) Evaluate Pareto-optimal solutions to identify the preferred solution.
6) Can we do better? Review.

It is important to treat all the subsystems of the UWS as a whole to have an holistic view that allows a better comprehension. When defining the objectives, one has to have in mind what the community requirements are and the principle of minimise lifecycle costs and maximize sustainability in the UWS. In order to find feasible solutions the Pareto frontier (the most sustainable and with less cost within the technical feasible options) describes the solutions that the community should carefully examine in order to arrive to a preferred solution (Coombes *et al*., 2002). However, due to institutional and/or economic constraints, the Pareto frontier is constrained and consequently, the possible alternative solutions are reduced. (See Fig. 3.4)

This is a more complex decision making tool than an integrated urban water modelling programme; in fact these kind of models are a part of the systems methodology that present different technical alternatives. The systems methodology goes further and includes the evaluation of the cost, benefits and design of an integrated urban water

cycle management with diverse alternatives that can substitute or complement the current features of the supplied water, wastewater and stormwater.

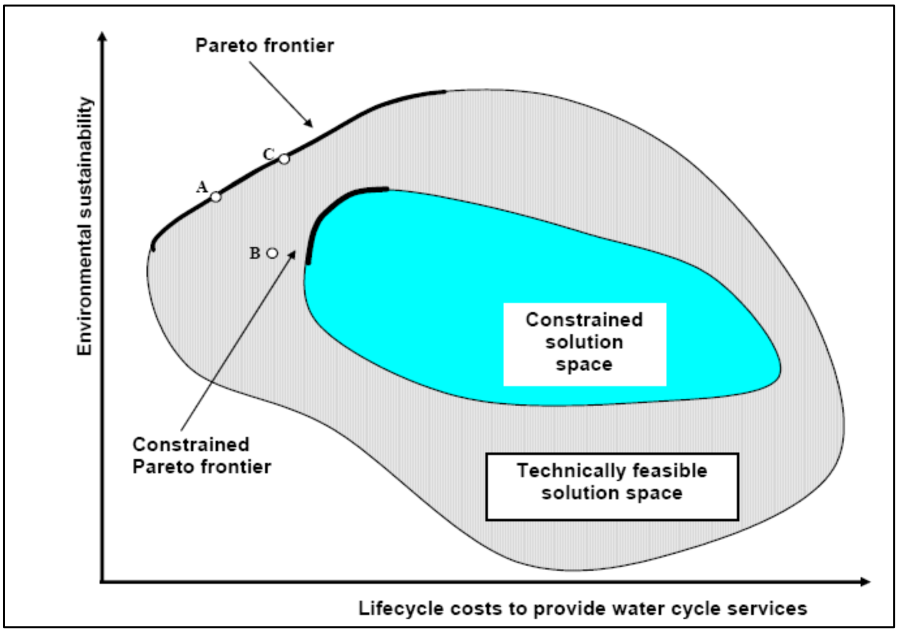

Figure 3.4: Pareto frontiers (source: Coombes *et al.*, 2002)

3.4.2 The land cover type methodology

The aim of this methodology is to help urban planning and decision making process to go in the direction of a more sustainable urban development.

This methodology was used to undertake a case study of the hydrology of the city of Munich, with the aim of studying the “metabolism” (exchange and transformation of energy and matter) of the urban ecosystem. The study area was divided into different land cover units, which have different functions: living, economy, recreation and education. There are physical features that difference the land cover types: surface sealing, vegetation coverage and population density. The reason for different land covers is because they have different behaviours and implications (environmental, social and economic) that might be understood in order to plan the city in a more sustainable way by integrating sustainability principles. In addition, according with Pauleit S. and Dhume F. (2000), the type of human settlement has a big influence on the efforts of reducing environmental impacts by applying more efficient technologies and infrastructures.

In this case study only the water cycle was analysed but the methodology is able to study urban climates, energy demand and carbon dioxide emissions within the urban system, hence the scope of this methodology is very broad. However, to have a better comprehension of the situation, all these aspects should be integrated in one case study. Additionally, according with the authors, environment quality targets and standards for different land cover types would provide a clear framework and guidance for innovative planning and design on a more detailed level than the current one. The input data was taken from literature review, databases and aerial photographs. This methodology is not based on modelling programmes, but on data analysis and the output is an extensive data base.

The methodology asses the annual hydrological balance of the urban cover types and to estimate storm-water runoff rates, establish the relationship between water fluxes and land use and urban physical features of the urban cover types, quantifies the area required for infiltration trenches for on site infiltration of storm-water runoff and explores the options for rainwater use as a substitute for drinking water. In addition, the land cover also served as a base unit to explore the different options for an ecological modernization of the city (Pauleit *et al.*, 2000). It is very useful to define environmental targets to help decision making process, but in order to evaluate the new feasible technical alternatives for each land cover unit it is necessary to carry out its life cycle analysis.

Table 3.2 summarizes the different ways of assessment the Integrated Urban Water System explained in this chapter classified in computer models, toolboxes and methodologyes. In addition, their main features are also compared.

As one can see, the IUW modelling programs can develop scenarios for different management alternatives which support the decision-making process. Nevertheless, most of them are one part of more complex toolboxes together with other elements or tools, which aim to cover many aspects as possible of the UWC to show realistic future scenarios. The user has the final decision about which software, toolbox or methodology should be used according to aspects such as the problem to be addressed, time constraints, software and data availability, funds, etc.

Table 3.2: Different Integrated Urban Water Modelling programmes and its applications

		Simulation urban water cycle	Wastewater recycle and reuse	Stormwater recycle and reuse	Alternative Supply Sources (water management scenarios)	Estimation Contaminant Loads and concentrations	Cost Balance	Social Issues Analysis	Microbiological Assessment	Energy Balance	Decision-Making tool	Data access [2]
	COMPUTER MODELS											
1	Aquacycle	√	√	√	√							3
2	UVQ	√	√	√	√	√						3
3	Switch-Aquacycle	√	√	√	√	√				√		3
4	URWARE											3
	TOOLBOXES											
5	CSIRO Urban Water	√	√	√	√	√	√	√			√	?
6	Switch-Toolbox	√	√	√	√	√	√			√	√	?
7	The Urban Water Toolbox	√	√	√	√	√	√		√		√	?
	METHODOLOGIES											
8	The Systems Methodology[3]						√	√			√	?
9	The land cover type methodology	√		√	√	√[1]				√	√	?

[1]In combination with other methodologies (Paueit *et al.*, 2000)
[2]From 1 easy; 2 difficult; 3 very difficult and time consuming
[3] The detail of study of the UWS of this methodology depend on the computer models that the user decides to apply.

Chapter 4

Methodology

4.1 INTRODUCTION

Once the aim, objectives and scope of this MSc thesis have been clarified in Chapter 1, a brief overview of the different stages followed in this project is described in the flowing paragraphs, and more in detail along the chapter.

Initial work involved general data collection during the MSc internship with the Local Agenda 21 Department of the Town Council of the city of Zaragoza, Spain. The second stage was to compile a literature review that looked at the current water situation of Zaragoza, the three integrated urban water modelling softwares and urban environmental indicators. As only one software was available at the time (Aquacycle), the other two integrated urban water models were compared by reference of the literature review. This section tries to emphasize the increasing importance and necessity of integrated urban water models in order to go to a more sustainable urban water management.

Once the aims and objectives were clearly defined, a third step of data collection was undertaken, this time in more detail and with more specific data to be gathered. This step was undertaken by travelling to the study area, communication via e-mail with the data providers and by literature review. The format of the data that was gathered during the first and second stage of the collection data process is electronic as well as hard copy documents. The electronic data was provided as excel files, GIS layers, pdf documents, power point presentations, word documents and text documents, and the hard copy documents were given as informative leaflets, printed documents of the study area, etc.

Once the available data were collected, a fourth phase of data analysis and estimation was carried out in order to have the required data to run Aquacycle. A further literature review was undertaken during this stage in order to improve understanding about how

to estimate the missing data using available data where possible, to get some of the missing data from literature.

The fifth step was to run the Aquacycle software with the available and estimated data of the study area and the analysis of its outputs. Three feasible scenarios for the study area were developed in order to determine the most realistic alternative option for sustainable UWM.

The final steps were the process of discussion, and drawing of conclusions and recommendations for future work.

It is important to mention that, due to the nature of this work, there are two main focuses (1) the optimisation of the urban water system management of the study area and (2) the assessment of the use of Aquacycle in a Spanish city. For the sake of making the reading easier the chapters of result analysis, conclusions and recommendations are divided into Part I: Zaragoza and Part II: Aquacycle. It is important to mention that some information is present in both parts."

4.2 ZARAGOZA AS THE STUDY CITY

4.2.1 Election of the study city

The city of Zaragoza, Spain, was chosen as the research area for several reasons that can be divided into three main areas, which are interconnected: development of the MSc internship in Zaragoza; characteristics of Zaragoza; and the fact that Zaragoza is a demonstration city for the SWITCH Project.

The MSc internship was carried out in the Local Agenda 21 prior to development of this MSc thesis During this period, some general information and data about the city, the urban water cycle, awareness campaigns undertaken in the city, information about local indicators, etc was gathered. Once the internship was completed, the author had good background knowledge surrounding the current water issues of Zaragoza and also useful contacts for further data collection, which is important for this kind of research project.

Although Zaragoza is located in a very arid region of Spain, currently the city does not suffer water scarcity problems due to its location on the largest river of the Iberian Peninsula, the Ebro River (see Chapter 5). However, there are water quality problems as

the Ebro River has a high salinity index. For this reason water that is more suitable for human consumption will be imported from the “Yesa” dam in the Pyrenees , 146 km far away from the city of Zaragoza (source: Google maps) by the beginning of 2008 (expected date) (personal communication by Alfonso Narvaiza. head of the Total Urban Water Cycle Service Department of Zaragoza Municipality). To minimize the environmental and economic impact a possibility could be the use of stormwater and wastewater for low quality water demands, so the amount of water imported will be lower than expected. This study is the same that this ones oriented to cities with scarce water resources, in which the main issue apart water saving is water recycle and stormwater use. Even more, it is important to remark that Zaragoza is considered as a representative city of Spain, where other studies are undertaken.

One of the main reasons for doing the internship in Zaragoza was the involvement of the author in an international project (SWITCH) and the issue of language because the project needed Spanish and English speakers in Zaragoza. Additionally, Zaragoza is a SWITCH demonstration city and results obtained could be compared with other demonstration cities with similar conditions in the future, and contribute to the development of the project.

The weak points of the election of the city of Zaragoza as the study area are mainly related to data availability. A very important issue is the lack of data for calibration of the software.

As demonstrated, there are more advantages than disadvantages for choosing Zaragoza as the study city. General background knowledge gained, staff contacts made within Local Agenda 21, the climatic conditions of the city, involvement in an international project etc far outweighed the disadvantages.

4.2.2 Election of the study area

As this Master thesis is framed within the SWITCH Project, the chosen study area is the same as for the W.P. 3.1: “Water Demand Management”. The selection was made in order to be able to compare or include the results of this thesis with other research activities undertaken by SWITCH.

The study area is the Actur-Rey Fernando neighbourhood of the city of Zaragoza, which had a population of 51.199 inhabitants in 2006 of the 650,000 who live in Zaragoza. It is a relatively new neighborhood that was built twenty years ago. It is mainly a residential area with the respective services (public health, school, sport centers, civic centers etc). There is also a large commercial area in the center of the study area. There are no industrial activities in the neighborhood. The average population of this area consists of young families. Additionally, it is characterized as being a participative sector of the city (explained by Maria Luisa Campillos, Civil Servant of the Local Agenda 21 in a SWITCH-Zaragoza meeting)

Another notable event in which the city is involved is the International Exposition of 2008, known as EXPO 2008, with the slogan: “Water and sustainable Development”. The SWITCH Project is willing to participate in EXPO with the aim of showing visitors that an urban water paradigm shift is possible. SWITCH study area is located near to the area in which where EXPO 2008 will take place, and is the same area investigated in this thesis: the Actur-Rey Fernando neighbourhood.

4.3 LITERATURE REVIEW

4.3.2 The urban water system

A research activity through internet (the SWITCH project website, scientific data bases, Google, etc) was made to find articles, studies, etc. about the urban water system including the urban water cycle, the main pressures of the UWS, information about sustainable UWS and urban water sustainability indicators. The proposed literature by the supervisors was also taken into account and read in this process of literature review. In addition, hard copies provided by the Local Agenda 21 were read and used in the development of Chapter 2.

All the articles of interest in relation to the topic were read in detail for a good understanding and used to write the mentioned chapter. This procedure was followed in the same way for the development of Chapter 3, explained more in detail in the next section.

4.3.2 Modeling the urban water system

4.3.2.1 Software used in this MSc thesis

The initial idea of the application of the three softwares: Aquacycle, UVQ and Switch-Aquacycle in the study area was a fixed requirement at the beginning of the project where the author had no choice in the decision. It was chosen because it is framed within the SWITCH Project.

This project is developing a computer model called Switch-Aquacycle which is based on Aquacycle and UVQ. It was in the interest of the project that different users run the softwares in diverse cities in order to compare the results and draw some conclusions about the softwares. The idea is that the users, based on their experience of working with the softwares, could draw conclusions and make recommendations for further development of the new Switch-Aquacycle software under development.

Another important reason for the choice was the availability of the computer models at no cost to the MSc thesis. Unfortunately, only Aquacycle was available and is the one used in this project.

4.3.2.2 Integrated Urban Water Management Tools

Today, there is a large number of tools to assess the UWS of a city or human settlement. They study the urban water balance in relation to different possible problems that could be experienced in an urban area, such as water quality, water quantity, floods etc.

Although it is not the objective of this thesis, it is important to mention that there are several tools related with IUWM. They can be classified into two main sub-categories, (i) one focuses on water conservation, efficiency and quality; and (ii) focuses on water sensitive planning and design. The first sub-category, studies the utilisation of non-conventional water sources including roof runoff, stormwater, greywater and wastewater; the application of fit-for-purpose principles; stormwater and wastewater source control, these ones that study the combination of soft (ecological) and hard (infrastructure) technologies and pollution prevention and stormwater flow and quality management can also be included. Examples of the second sub-category, which is more complex than the first one because it includes aspects that are not just technical, such as technologies that have taken into account non-structural aspects such as education, pricing incentives, regulation and restriction regimes.

The sub-populationapplied in this MSc thesis to assess and optimize the UWC of the study area is the first, which focuses on water conservation, efficiency and quality. Reasons for applying this sub-population are explained in section 2.3.1. It is important to mention here that the second sub-populationincludes more non-technical aspects that were not possible to study in the limited time period of six months required for this MSc thesis.

Within the first sub-population different aspects of the UWC are studied and it varies regarding to the complexity of the softwares. For example, Aquacycle only models urban water quantities while UVQ also simulates urban water quality. In order to facilitate the reading of the MSc thesis, this sub-population was divided into computer models, toolboxes and methodologies (see Appendix I for the terminology). Comparison and evaluation of the different elements of the second classification is described in Chapter 3 which is based on literature review.

The research strategy for collecting the different samples that are compared in Chapter 3 can be observed in Table 3.2. This was based on an internet intensive search in order to find different tools for IUWM support. Google, Google scholar and different scientific on-line data bases, such as science direct were searched. In addition, MSc thesis supervisors provided some literature which could be used.

Once the literature was collected initial overview reading was undertaken to select the correct literature for comparison of the different ways of applying IUWM. During this first stage, more literature was searched for on-line by reference of the previous literature. Once the selection was made detailed reading was carried out in order to gain a better understanding of each software, toolbox or approach. Finally, Table 3.2. was developed according to the characteristics of each software, toolbox or approach.

4.4 DATA COLLECTION

General data and information about the city of Zaragoza, the total urban water cycle, the activities undertaken by the Local Agenda 21, the local indicators that have been developed for the city, etc. were collected during the MSc internship. In addition, many literature and reports were given to the student by the Civil Servants of the different Departments involved in the urban water system management of the city of Zaragoza.

Despite living in the same city and working in the Local Agenda 21 (where most of the data is available), it took a long time to collect the data and information. Furthermore, the MSc thesis was not defined by the time of the end of the internship, so the specific data for this thesis was unknown and could not be collected.

The most conflictive data to be collected was the meteorological aspects of the city because in Zaragoza Municipality they have climatic data in different stations within the city, but the data they produce is not the official source. This is the data that is gathered at the airport by the National Institute of Meteorology (INM, Spanish abbreviation) the institution in charge of collecting, managing and giving the official data to people who apply for it. For this reason, an application form was filled in and sent to the office of the INM of Aragon, in Zaragoza, asking for hourly and daily rainfall and temperature, potential evaporation and evapotranspiration, wind speed, solar radiation and studies about the effect of climate change both in the city of Zaragoza and surroundings, and in the whole of Spain. The last question was solved very quickly with an e-mail sent by the INM with a link to a report about the effects of global change in Spain called "*Generation of Climate Change Scenarios in Spain*", published in February 2007 by the Environmental Ministry of Spain in collaboration with the National Institute of Meteorology and the General Secretary for Pollution and Climate Change Prevention. This report is written in Spanish and the INM was pleased to provide the data used to make this report. On the other hand, the rest of the information was not so easy to obtain. The application form was sent from the regional office in Zaragoza, to the central office in Madrid but the data required is considerably large. This means that it was going to take a long time to receive the data required, probably months. By the date of the data analysis for this report, the data were still unavailable; despite the author stressing that it was to be used in an international project. Subsequently calculations and estimations were undertaken in order to estimate potential evaporation.

Staff of the Department of Air Pollution of the Local Agenda 21 advised that it would take a long time to receive the required climatic data. Staff then searched within their department for some data and found an excel file with official data -from 1858 to 2000- which had been used to make the thermal map of the city of Zaragoza. However there were not enough data for the purpose of this thesis. For this reason, they gave the non official data recorded in a meteorological station within the city, which is the data used

in this report. These data are not as accurate as the official data and is prone to errors. It is important to mention that the data was given as a personal favour to allow the MSc to continue with the research activity and is for **exclusive use by the student Maria de la Paz de San Miguel Brinquis in her thesis**.

The author visited Zaragoza again in June 2007, once the objectives and the required data required were clear. However, it was not possible to collect all the required data during this visit, so as soon as the data was collected it was forwarded by e-mail. If the worst case scenario occurred where the data was not made available, some assumptions and estimations were made to continue with the work. This has been undertaken for potential evaporation and roof areas. This is explained in more detail in Chapter 5.

4.5 DATA ANALYSIS

4.5.1 Introduction

Once the data was collected, an initial analysis was undertaken in order to organize it and clarify what data was available and what was missing. After that, a second stage of data analysis was carried out in line with the following: (i) the analysis of the available data to organize it in the input files as required by Aquacycle, and (ii) the literature review and creative thinking to estimate the missing data. These actions are explained more in detail in the next section, together with the challenges faced by the author to cope with the required data that was unavailable.

It is important to clarify that Aquacycle was made especially for a typical Australian city which spatial structure differs form the city of Zaragoza and most European cities with high population density. For this reason some data was manipulated in order to fix the study area into the model. In Australia most houses are individual ones, while in the study area people live in buildings of apartment flats with around 8 floors.

The climatic data given by Zaragoza Municipality is measured every half an hour, and it was not processed when given. It was a very time consuming work to calculate the daily main air temperature, maximum and minimum temperature, precipitation, wind speed, relative humidity, for every day during the last six years. As evaporation data was not available, the challenge to solve it was its estimation. The Penman formula (see Appendix II) was used to estimate the potential evaporation. This formula requires

radiation data, which had to be estimated as well because it was not clear whether the values were about net radiation or total radiation and moreover, the units were missing, so it also had to be estimated. All the procedure, conversion from every 30 minutes data to daily data, the establishment of the method to estimate net radiation and potential evaporation, the creation of the Excel sheets to work with and the creation of the formulas, was very time consuming. For this reason, it is important to develop simple models with easy access to the input data, because if not it is very time and economically costly.

Some of the information was in GIS format, to extract it the Author had to increase her GIS knowledge by self studying by reading a manual of ArcGIS and with the support of experts within UWTC of Abertay University of Dundee and form Zaragoza Municipality.

Some of the data related to the neighbourhood population was available in the website of the Spanish Statistics Institute. The Local Agenda 21, by means of the Municipal Statistics Department, guided the Author to work in this website and they provided the codes of each district of the study area. In addition, a more specific file was sent by e-mail to the student, with the total population and number of households per SWITCH sector within the study area. They were not data available about building characteristics, such as garden or roof area, so some assumptions were maid to be able to run the software.

4.5.2 Definition of the spatial scale

Before going through data analysis it is important to explain the spatial scale of the software, because the creation of the input files depend on this organisation,

- Unit Block: The buildings of the Actur have between 4 and 8 floors under the ground (see Fig 4.1). Due to this fact, the unit block cannot be a single household but is an apartment block of 6 floors (as an average building), which involve more than one household. Usually, each floor has 4 households (personal communication by Pilar Egea, a local neighbour involved in SWITCH Project by Zaragoza University), assuming that the unit block has 24 households.

Fig. 4.1: Unit Block in Cluster 1 (Source: Google Earth)

- Cluster: The clusters are each sector defined for the W.P. 3.1 of the SWITCH Project, but with the addition of one more sector. The new cluster is named cluster number 7 and although it has some households, it is mainly a commercial area. The reason for this division is because the Actur, with exemption of the commercial area, has the almost the same structure and the criteria used to make the clusters to have to possibility of make a comparison within the results obtained with Aquacycle and the ones obtained in W.P. 3.1, or maybe to use Aquacycle Outputs in the mentioned work package.
- Catchment: with the same criteria than for the cluster, the catchment area is going to be the Actur-Rey Fernando neighbourhood.

Fig 4.2: Cluster (red) and catchment (blue) of the study area. (Source: Google Earth)

4.5.3 Creation of the input files

This section described the input files of Aquacycle and its required data. Within the files, there were just few data that could be recorded directly from the available data without any type of processing, but in most of the cases the data ha to be estimated or calculated. The calculations and/or estimations done in each input file are explained in the following sections.

.4.5.3.1 Indoor water usage profile file

This file contains the identifier of the file (Zaragoza) and data on domestic water use for the study area and in a period of time. In this case the year used to calculate the indoor water usage profile was 2004, because in this year the projects undertaken by the Spanish Statistical Institute and the University of Zaragoza, in relation to water consumption, were finished.

One of the outputs that the SWITCH Project wants to achieve in the city of Zaragoza is to know the indoor water usage profile, so nowadays there is not real available data on this issue. For this reason estimation needs to be made according to statistics.

In 2004 the (INE) made a research in Spain called “Enquiry about water supply and treatment”. In the report they conclude that the average consumption per day and

inhabitant was 171 litres (INE, 2004). The distribution of the water consumption within a house is given by Table 4.1:

With this information, the percentage of water use in each part of the house can be calculated:

- Bathroom: 36%
- W.C: 27%
- Kitchen: 10%
- Laundry: 20%
- House cleaning: 7%

Table 4.1: Spanish water consumption (l/p/day).
(Source: http://www.agua-dulce.org/htm/consejosdeahorro/hogar1y2.asp)

Use	**Current Consumption** Estimation in litters per person per day	**Efficient Consumption** Estimation in litres per person per day
Toilet / Shower	61.4	45.5
W.C.	46.1	16.4
Laundry	33.8	18.2
Kitchen and water for drink	19.5	12.7
House Cleaning	10.2	7.2
TOTAL	**171**	**110**

On the other hand, the Treasury Department of the Town Council of Zaragoza, in collaboration with the University of Zaragoza, undertook a study in the period 2002-2004 in order to determine the water consumption habits of the population of the city of Zaragoza, they conclude the following: there is a fix water consumption in every household, independent of the occupancy, that is 3.5 m^3/ month. The water consumed above this amount is directly proportional to the members of the households in a factor of 2.5 m^3/ month, therefore the basic consumption per household (one person) is 6 m^3/ month, or what is the same, 200 L/p/day.

With all the calculation of the water use percentage in each room of the house, and the results of the study explained before, the indoor water usage profile for the city of Zaragoza (litres/p/day) is summarized in Table 4.2:

Table 4.2: Indoor water usage profile in Zaragoza

Nº of occupants	Kitchen	Bathroom	Toilet	Laundry
1	34	72	54	40
2	48	102	76	57
3	62	132	99	73
4	76	162	121	90
5	90	192	144	106
6	105	221	166	123
7	119	251	188	140

A literature research was done about the proportion of hot water use to total water use in each room of the house, both in the city of Zaragoza and in Spain and but not data, no research were found. For that reason, the data used is the one given in Aquacycle User Guide by Koomey *et al*., (1994), that provides details of the split of hot and cold water for the various residential end uses in the USA, although there are differences in style of life, climate, etc. there is not other information more accurate for the city of Zaragoza, so these percentages are going to be assumed for the city of Zaragoza to undertake this study. From this information it is assumed that 60% of kitchen, 50% of bathroom and 25% of laundry water is hot.

4.5.3.2 Climate data file

This file contains historic daily rainfall potential evaporation data series, in units of millimetres per day. The rainfall data was provided by the Local Agenda 21, while the potential evaporation data was estimated with the available data (see Appendix I).

As it was not possible to obtain the official climatic data by the National Institute of Meteorology the one used in this thesis is the one provided by the Local Agenda 21, that can be divided into official and unofficial:

Official data:

- 1889- 2000:
  - Daily Temperature: min, max and average
  - Monthly Temperature: min, max and average
  - Daily Precipitation (mm).
  - Monthly precipitation(mm).

- 2000-2006:
  - Monthly Temperature (min, max, med)
  - Monthly Precipitation (total and average)
  - M. Hours of soil
  - M. Relative humidity
  - M. Steam tension
  - M. Wind (frequency and velocity)
- 1940-1990
  - ETP monthly values

Unofficial data (not validated, errors can be assumed) from October 2000 until December 2006, the data is provided in periods of every 30 minutes and without units:

- Temperature (air, maximum and minimum)
- Evapotranspiration (not available in the year 2000)
- Solar energy and solar radiation (without units)
- Atmospheric Pressure
- Wind speed
- Precipitation

The data used to estimate the potential evaporation was the unofficial one because it had all the required climatic data to estimate it. All the data is measured every half an hour with the exception of evapotranspiration (ET), which is measured every hour. The measures start at 00:00 am and finished at 23:30 pm. The meteorological station where the data was collected is called Eduardo Ibarra o Romareda and it is placed in the city of Zaragoza, which is 199m above sea level. The meteorological station in placed in the Planning Town Management building, very close to the football stadium of the city of Zaragoza and near to the city centre. It is placed in a residential area near to one of the biggest parks of Zaragoza. In the area one can find the University of Zaragoza, the Clinic Hospital, the Auditorium and the Municipal Sport Palace. The meteorological station is not placed within the study area, there is one placed within the Actur neighbourhood but it is newer than the one from which the data was collected, and there were less data available. In order to have more years of data, having in mind that Zaragoza is not a very large city, and according to a personal communication of Mariano Aladrén (Civil Servant of the Air Pollution Department of the Local Agenda 21), one can assume that the climate data do not change significantly from one place to the other.

The climatic data for the period October 2000 – December 2006 was provided in a text file for every half an hour for every day. In order to process and analyse the date, the files were imported and treated in excel sheets, where the daily average of temperature, ET, pressure, wind speed and relative humidity, as well as the daily precipitation were calculated. Once the daily averages were made and organised, one has to check the non-measured data and make estimations to fill it. Two methods were used to estimate the missing data depending on the amount of days without measurements: (i) if the non-measured period was up to 10 days, the moving average where applied to estimate them; (ii) if the period overpasses 10 days, the estimation was the average made from the same dates of the other years.

The units of the climatic data were not given in the files. For some climatic parameters it was easy to understand the units –wind speed, pressure, ET and precipitation-, but for the solar energy and radiation it was very complicated. The column of solar radiation had values from 10 to 250 while the column of solar energy has values from 0.50 to 10. According to a research made on internet, neither of both values were logical values for solar radiation in the International System units of MJ m^{-2} day^{-1}, they were very high or very low. Not successfully contact was made by e-mail or phone call with the Local Agenda 21, to clarify the units. It was very important to know the Net Radiation in order to calculate the potential, evaporation so a literature review and internet searching was made to find out the units, as well as discussions with experts. Some theories were found but they could not be explained scientifically, furthermore it was not said if the data given by Zaragoza Municipality referred to global radiation, net radiation… As net radiation is needed to estimate the potential evaporation, an estimation explained in the next section was made.

4.5.3.3 Unit block file

This file contains details on the options selected for the unit blocks within each cluster being simulated. As explained before, there are 7 clusters in the study area. From every cluster there is a list of 33 characteristics that are mainly related to the irrigation, the recycling and reuse technologies for wastewater and stormwater. As in Zaragoza these kind of technologies are not used in the present (there are not storm tanks neither wastewater recovery and reuse along the study area). With exception of the first question (garden irrigation with fresh water) which is 1 that means that the garden

irrigation is made with fresh water, the other 32 characteristics have 0 as their numeric values.

4.5.3.4 Cluster file

This file contains details in the water options selected for each cluster within catchment being simulated.

Seven clusters are simulated in this file. Here 19 characteristics are described. As in the unit block file, with exception of the characteristic number 14 (which is the public garden irrigation with fresh water) The others are related to stormwater, wastewater and aquifer storage. As in the Actur this kind of tanks and technologies are not applied, all the numeric values are 0, except for the characteristic number 14.

4.5.3.5. Catchment file

The catchment scale file contains details on the water options selected for the catchment within each cluster being simulated.

In this file, as in the others, there is only one numeric value that differs from 0 because the other 7 characteristics are related to stormwater and wastewater storage properties that the catchment does not have. The one that differs is the catchment size in hectares.

An interactive service given by the Town Planning Department of Zaragoza Municipality website was used to determine the catchment size. It is called “Siggurz” and it is the New Town-Planning Data Consultancy Service. It has a very useful tool that measures the area of the polygon the user selects, actually is the one used to determine the catchment area. (see figure 4.3)

4.5.3.6. Parameter and initial value file

This file contains details on the measured parameters, calibrated parameters, and initial storage level for each cluster in the catchment being simulated.

The file is structured in three blocks separated by a line containing a single zero. Each line in a block relates to a single cluster.

I. The first block contains mainly physical and population information like number of blocks in the cluster, average household occupancy, different areas (unit

block, roof, paved, public open spaces, etc), total area of cluster, etc- All this information has been extracted or estimated from the different formats of information provided by Zaragoza Municipality as explained in the following paragraphs (excel files, GIS maps, personal communications, etc). The water supply leakage rate was given by the Infrastructure Department of Zaragoza Municipality.

a. Areas

The total cluster area was determined with the tool “Siggurz”. For the roof, pavement, road and green areas the information given in a GIS format was used. However, the information associated to the layers was not enough to calculate all the areas. Some assumptions were made out from the areas given by the GIS layers.

It was impossible to determine the roof area of the unit block. So, the next assumption was made: the average unit block in every cluster has 4 households per floor; an average household has 90 m^2 and one can assume that the common spaces (lifts, stairs, etc) have the same area of one household. So we have a roof area of $90m^2$ multiplied per 5, which is $450m^2$ of roof area. A second assumption was made about the unit block: an average value of $520m^2$ for clusters 1 and 5, of 7772 m^2 for cluster 7 the commercial one, and $500m^2$ for the rest block of apartments is cluster 7.

Only clusters 1, 5 and 6 have gardens in the unit blocks, for the first two clusters the garden area is assumed to be 20 m^2 and for cluster number 6 is $150m^2$. Knowing the unit block area, the roof area and the garden area, the paved area was estimated as the subtraction of the unit block and the roof and garden areas. (For all this estimations a the GIS information provided by the Local Agenda 21 and the application of Google earth were taken into account)

The same problem was found for the road areas, the GIS layers has the length of the roads and making an assumption of the wideness of the roads, the area could be estimated. However, it is not a very effective method and it is very time consuming because each road is divided into different sectors, so the sum of the length of every sector would have to be done, and later estimate the area. As this thesis is time limited, a faster method was used to estimate the road area. The

cluster area was known, and also the area of public open spaces or other green areas and the number of unit blocks and its area were estimated. The road area was estimated as the cluster area that was not green area, unit block, etc.

b. Number of Unit Blocks

In the information provided by Local Agenda 21, it was not clear the number of unit blocks in each cluster. This information contains the population per cluster and the number of households in the whole cluster. As assumed before, the average unit block that is used within this research has 24 households. With this numbers a simple estimation was done to obtain the number of units block in each cluster.

c. Population and household occupancy

The Municipal Department of Statistics of Zaragoza provided an Excel file, via the Local Agenda 21, about the number of households and the amount of people living in each sector of the Actur neighbourhood. Working with this data and the estimated number of unit blocks household the average occupancy was estimated.

II. The second block contains the calibrated parameters, such as area of pervious store, capacity of pervious store 1 and 2, roof area maximum initial loss, base flow index, base flow recession constant, etc. This information was not available for the study area, so the values used in this block has been taken from literature review. The values used in this block have been taken from a number of projects that have utilised Aquacycle; these values are from the Woden Valley, a region in the south west of the city of Canberra, Australia (Source: Mitchell *et al.*, 2001). This set of calibration parameters is provided in Aquacycle user guide, to enable the user to have an approximate idea of the range of values.

III. Finally, the third block contains the initial storage level values for each cluster, as there is not storage tanks in the study area, all values are zero.

4.5.3.7 Reordered file

This file can be created in order to simulate the performance of Aquacycle. It contains the subsequent observed water supply, stormwater and wastewater specific data of the catchment: surface runoff, base flow, stormwater discharge, inflow and infiltration into

wastewater system, total imported water use and outdoor water use. As the study area is not the whole city of Zaragoza but a neighbourhood, nowadays the required data to create the recorded file is not available, so it cannot be created.

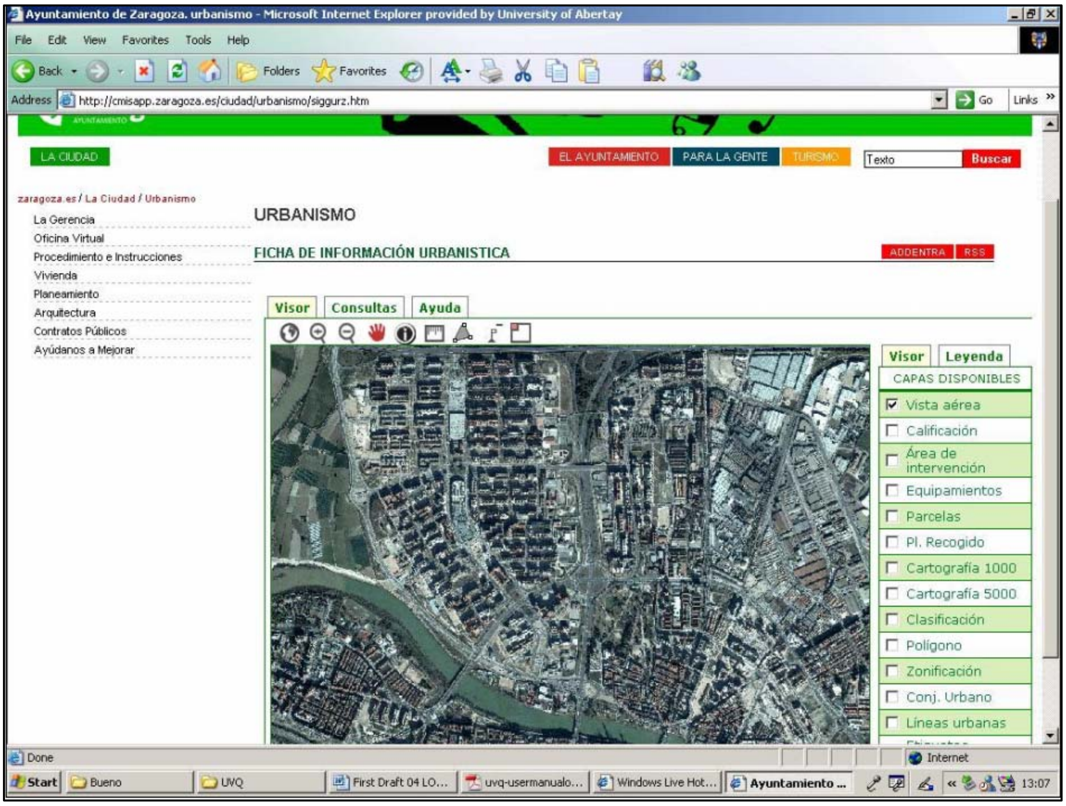

Figure 4.3: "Siggurz" New Town-Planning Data Consultancy Service. (Zaragoza Municipality website)

4.5.4 Scenarios

Aquacycle has been used for modelling and assessing the performance or urban water reuse options in the study area. For this reason it is important to determine the feasible options of stormwater use and wastewater reuse within the possibilities that Aquacycle offers, shown in Table 3.1.

In order to compare different scenarios the first stage is the simulation of a baseline scenario, showing the current situation of the study area, in relation to imported water, stormwater runoff and wastewater discharge. It is important remark that there are no rain tanks or wastewater tanks in the Actur neighbourhood, so all water is supplied with fresh water coming from the drinking water treatment plant.

Regarding to the situation of the city of Zaragoza, the most feasible scenarios are within the unit block scale: the rain tank and the on-site wastewater treatment unit. The sub-surface irrigation of greywater is not very useful because in Spain the houses usually do not have big garden areas and with the water used for irrigation in the on-site wastewater treatment unit would satisfy the garden irrigation demand. However, a preliminary simulation for sub-surface irrigation was made to confirm this hypothesis and the reduction of imported water was not significant at all; only 0.2% reduction of imported water was the result of this scenario. The cluster and catchment scale have been ruled out because according with a personal communication of a senior technician of Zaragoza Municipality, the energy cost needed to pump up the water to the final use will be higher than the savings of implementing any new technology. This is a good example to show the needed of new softwares, such as Switch-Aquacycle, that will study the energy costs and demand

In base of the last paragraph three scenarios within the unit block have been developed in the study area with the help of Aquacycle:

- Scenario 1: On-site rain water use: by introducing a rain tank of 1m3 capacity at the unit block scale in cluster 1 to 6, and a 2m3 capacity rain tank in cluster 7. The water source is the roof runoff and the uses are indoor uses (bathroom, laundry and toilet) and outdoor uses (garden irrigation). As a fixed option of the software, if there is overflow it goes directly to the sewer and the supply deficits are covered with fresh water.
- Scenario 2: On-site wastewater reuse: the water source is household grey water from the kitchen, bathroom and laundry. It is treated in an on-site wastewater treatment unit. The capacity of the wastewater tanks per cluster are shown in Table 6.4. The water was used for toilet flushing and garden irrigation, the overflow was discharged into the sewer system.
- Scenario 3: this scenario is a combination of scenario 1 and 2.

In order to develop the different scenarios, an intensive search on internet, literature review and personal communication by senior technicians was made in order to estimate the appropriate characteristics (size, expose surface, first flush…) of the rainwater and wastewater tanks. According with different case studies (Karka *et al.*, 2007, Mitchell *et al.*, 1999), reports (Lower Hunter & Central Coast Regional Environmental

Management Strategy, 2001, Sydney Water) and personal communications, the common size of the stormwater tanks and wastewater tanks varies between 5 and10 m^3. An initial value of 5 m^3 was given in the each unit block scale for both tanks, except for cluster 7 which has a higher roof surface and a volume of 10 m^3 was given. The rain tank exposed surface is also a value obtained by literature review (3.9 m^2 in a rain tank of 5 m^3). And the first flush was calculated according to the most spread criteria for calculating the minimum volume of the tank that is the ability of storage the first contamination load produced by a rainfall of 10 litres per second and hectare during 20min of rainfall. This criterion is given by the British Standard and the design criteria of the "Confederación Hidrográfica del Norte" (Hydrostank Catalogue). In addition, the application of Aquacycle for optimising the size of a store was used; the results are shown in table 4.3.

Table 4.3: Tank sizes given by the optimisation function of Aquacycle

Tank size (m^3)	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
Stormwater	1	1	1	1	1	1	2
Wastewater	2.4	2.2	2.2	2.2	1.9	2.2	2

4.6 CONSTRAINTS

As in every research study, the author had to deal with different constraints during the realization the project. There is a variety in the constraints, going from limited time to not available data.

The constraints that had the biggest impact on the scope of this MSc thesis are (i) limited period of time (ii) missing data (because it has slow down the process due to estimations and assumptions) and (iii) software availability (because only one software out of the three initial ones could be applied in the study area). Another important constraint is the lack of funds that for example, would speed up the process of obtaining official climatic data.

Because of these time constraints (software availability and limitations, missing data, etc) it was not possible to fulfil some of the initial objectives of this MSc thesis. The literature review has been completed, although it is little information about the software SWITCH- Aquacycle, because it was still in developing process at the end of this

project. In addition, this is the reason why it has not been applied in the study. A similar situation happened with the UVQ software, because although it was already developed and some case studies were undertaken with the model, it was not available for users by the time of the process of this thesis. Some e-mails to the software developer team (contact person: Clare Diaper) were sent to ask for the UVQ software, but the reply always was that the software would be accessible for users later than initially expected. However a literature review about UVQ and some case studies using it were done to have more knowledge of it scope.

As Aquacycle was the only software available it is the only one that was applied into the study area to develop its total urban water balance and analyse different scenarios of alternative technologies in water reuse and recycle. The unavailability of UVQ and SWITCH–Aquacycle have limited in a significant extension the objective of development a list of urban water indicators out from the outputs of the softwares. Aquacycle is a simple model, which main outputs are estimations of imported water, wastewater discharge and stormwater discharge. As explained in Chapter 5, the city of Zaragoza already has these measurements established as local urban water indicators. This topic will be discussed more in detail in Chapter 7.

Chapter 5

Background information

5.1 THE CITY OF ZARAGOZA

The city of Zaragoza is the capital city of the autonomous region of Aragon in Spain. It is placed in the North East of the Iberian Peninsula (See Fig 5.1).According to 2006 data from Zaragoza Municipality; it has a population of more than 659,000, ranking fifth in Spain. A high percentage of residents (90% approximately) live in apartment blocks which means that the city is compact. Because of its size and population characteristics Zaragoza is a model city for Spain, where many demonstration projects are undertaken.

Figure 5.1: Map of the situation of Zaragoza in Spain. (source: http://maps.google.es/maps?hl=es&q=mapa%20espa%C3%B1a&oe=UTF-8&um=1&ie=UTF-8&sa=N&tab=wl)

It is located on the Ebro River Catchment, and its tributaries the Huerva and the Gállego rivers. The Ebro is the largest river in Spain (928 km) and has a total annual discharge of 19,000 million m^3. Climatic conditions of Zaragoza are a transition between

Mediterranean and Continental climate with an average temperature of 15ºC. The Ebro River Valley at Zaragoza is a semiarid region with an average annual precipitation of 367 mm per year concentrated in 67 days, ranking the area as the driest inland region in Europe.

The main water supply for the city of Zaragoza is the “Canal Imperial de Aragon”. This is an artificial channel which takes water from the Ebro River 80 km upstream of the city of Zaragoza. Ebro River flow strongly fluctuates on a seasonal basis, being as high as 500 $m^3 s^{-1}$ in March and as low as 30 $m^3 s^{-1}$ in August. Water quantity is sufficient to supply the city all year round because the river is largely regulated by dams upstream, otherwise the city would suffer from shortages during the summer months. There is an alternative catchment that is fed directly from the Ebro River, which is only used when the Canal is being cleaned or during emergency situations. Groundwater is used mainly for industrial purposes and swimming pools. During 2006 the total water withdrawal for the city of Zaragoza was 64.1 million m^3 (excluding ground water abstraction) (see Fig 5.2).

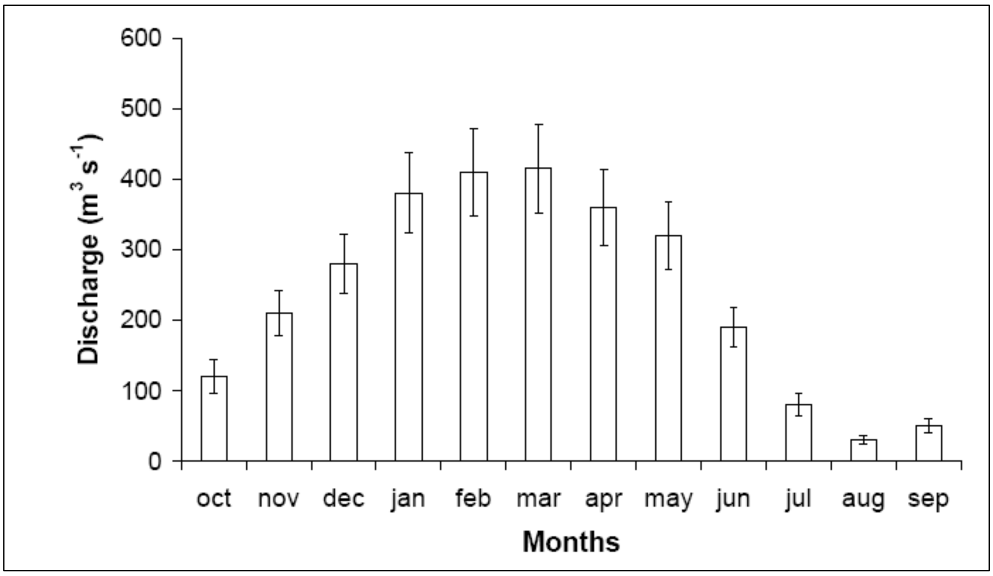

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Figure 5.2: Ebro River discharge at “Canal Imperial” diversion (Source: Ebro River Hydrographic Confederation)

Fresh water is treated at the public drinking water treatment plant at Casablanca which supplies potable water to the whole city of Zaragoza. At the moment, maintenance and renewal programs are being implemented in order to improve the facilities and save

water where possible. For example, storage tanks are being remodelled and covered to avoid pollution and water losses form evaporation. T

he city has a combined sewer system. There are two public wastewater treatment plants. The average inflow for “La Almozara” is 12 million m^3 $year^{-1}$ and for “La Cartuja”, which is the main WWTP is 59 million m^3 $year^{-1}$. It is important to mention that urban water management in Zaragoza is an exception when compared to most Spanish cities, as everything is managed by the Public Authority and not by a private enterprise as is the normal situation in other cities in Spain.

There is not a specific department within Zaragoza Municipality in charge of all the issues relating to water. Responsibilities for water management are divided within a wide range of departments. For example, the Infrastructure Department is in charge of the maintenance and exploitation of the water network, the Treasury Department is in charge of water fees, etc.

Zaragoza is one of the Spanish cities with higher environmental awareness from both parts, politicians and citizens. Many projects relating to the water environment and sustainability have been undertaken. The city has a large number of environmental projects that are currently under way. The main pioneers of these projects are the City Council, some NGOs and some private enterprises, such as banks whose main role is to sponsor the projects and of course the citizens. Within the City Council, Local Agenda 21 is in charge of environmental issues. In addition, the Education Department is in charge of promoting and encouraging environmental projects, such as “Zaragoza, water saving city”, “100,000 commitments with water”, which are mainly related to public behaviour, with the objective of increasing knowledge and encourage participation and awareness of the citizens in water related topics to in order to achieve more sustainable behaviours.

With the aim of achieving a more sustainable urban water system, the activities must be focussed on all aspects of the water system: environment, society and economy. For this reason, more technical projects are undertaken, such as the SWITCH Project (which also includes citizen participation and awareness managed by the Education Department), or the “Improvement Water Plan” which is explained in more detail in the next section. The objective of this project is the improvement of the current water

facilities, the application of new technologies (water saving devices, recycle and reuse alternatives etc.) aimed at reducing water consumption and environmental impacts, such as fresh water withdrawals or contaminant loads to water bodies. These kinds of project are based mainly on research activities.

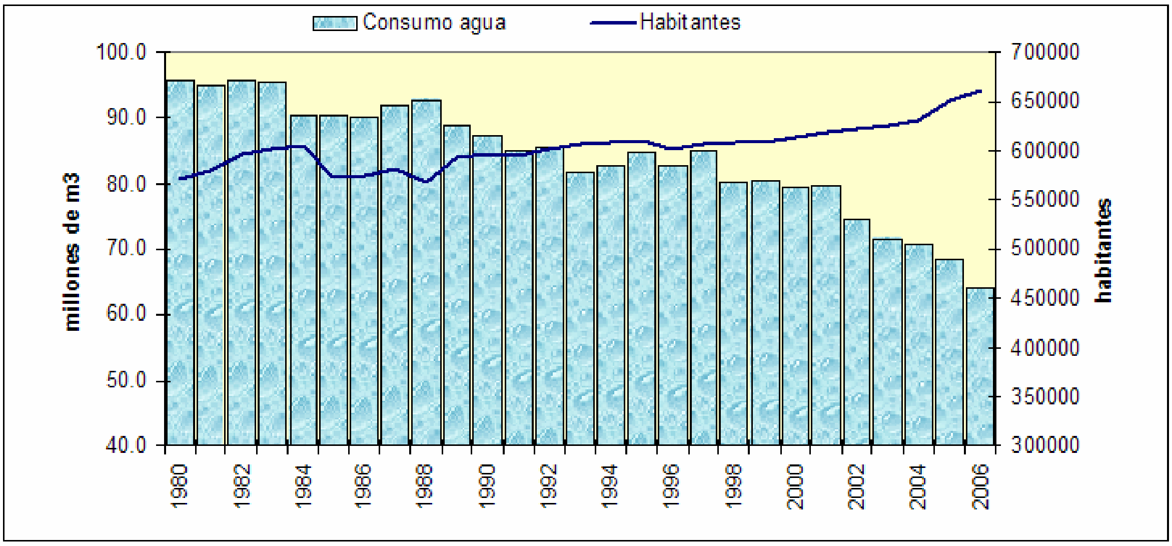


Fig 5.3: Trend of water consumption in relation to population growth (Source: Local Agenda 21 of Zaragoza Municipality; millones de m3: millions of m^3, habitantes: inhabitants; consumo agua: water consumption)

Although the economic aspect is not a topic covered in this thesis due to time constraints, it is important to mention that currently the city of Zaragoza has a good, sustainable and fair water fee, which rewards households that have a sustainable water consumption (decrease in water use from one year to another).

A good example of the commitment of the city of Zaragoza toward water issues is the fact that they had an aim of reducing water consumption of 65 millions of m3 per year by 2010 and they have already reached this target by the begging of 2007. The new objective proposed by the politicians of Zaragoza Municipality for the year 2010 is to reduce water consumption to 90 litres/person/day; the daily average water consumption per inhabitant in the city of Zaragoza was 104 l/p/d in the year 2006 (Source: Local Agenda 21).

From Fig. 5.3, although the population of the city of Zaragoza is increasing at a high rate, urban water consumption is decreasing. This graph highlights the results of the

efforts that the city of Zaragoza has undertaken with the objective of reducing water consumption toward a more sustainable urban water system.

5.2 LOCAL URBAN WATER SUSTAINABLE INDICATORS

The city of Zaragoza has taken on board ten of the Indicators of Sustainability as proposed by the European Agency of Environment, under the initiative "Towards a profile of local Sustainability: European Common Indicators". The EEA have developed 25 specific local indicators, where five water indicators (those with the most relevance for this thesis) are detailed below.

The city of Zaragoza has the following 5 water sustainability indicators. The last update of these indicators available for public information was the 31st of December 2005:

- Ag1 Potable Water Quality Index.

The objective of this indicator is to have water suitable for human consumption in the urban water supply network. The aim that follows is the improvement of water quality of drinking water, reduce it inappropriate use and encourage its study.

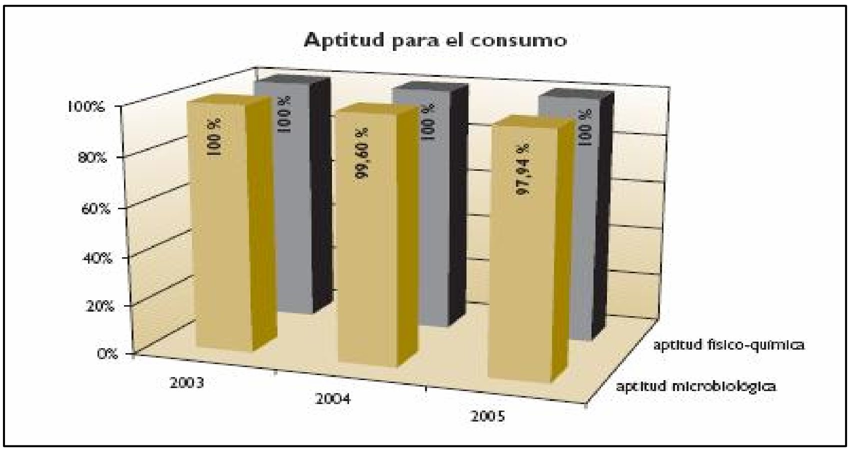


Figure 5.4: Indicator Ag1: Potable Water Quality Index of public water supply. (Source: Zaragoza Local Agenda 21; aptitud fisico-quimica: physic-chemical quality -grey - and aptitud microbilogica: microbiological quality –in khaki colour-)

The quality for water consumption is evaluated at the outlet of the drinking water treatment plant of Casablanca. The time scale is annual and the assessment is made within the last three years. This indicator has been developed, in accordance with the IWA (International Water Association) water quality indicators, although in this case

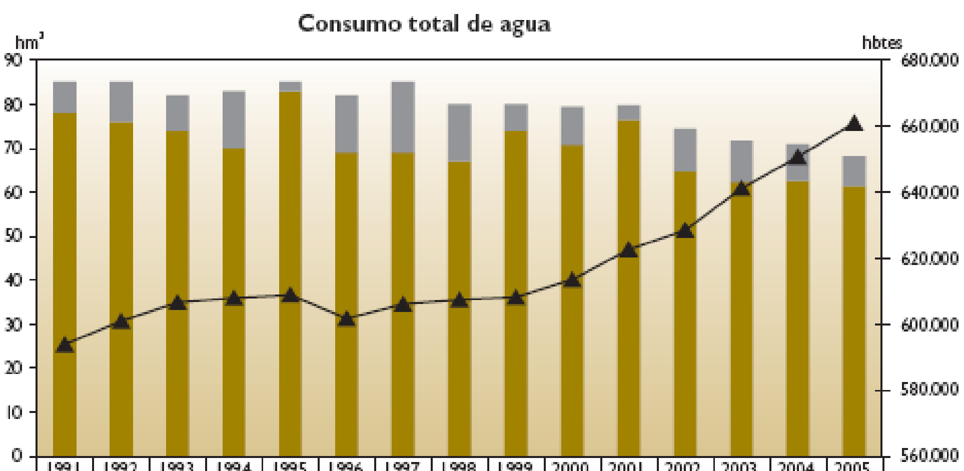
drinkable parameters are not taken into account. Fig. 5.4 is the graphic representation of the Ag1 indicator.

➢ <u>Ag2 Total water consumption</u>

The objective is to improve the efficiency of water consumption. As with Ag1, the aim that follows is the improvement of water quality of drinking water, reduce its inappropriate use and encourage its study. The calculation model is the measurement of the fresh water catchment to be treated in the drinking treatment plant, it also has an annual timescale. As one can see in Fig. 5.5, the two main catchments are measured individually (Canal Imperial de Aragon (grey) and Ebro River). The population is represented by the black line. The desired trend of the indicator is to reduce with the time due to improvements in the water supply network and the drinking water treatment plant, and also with increasing public awareness.

This indicator has three sub-indicators:

- Water supply distribution by activity sectors
- Efficiency of the water supply network system
- Satisfaction of the population



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Ebro	7	9	8	13	2	13	16	13	6	9	3	10	9	8	7
Canal	78	76	74	70	83	69	69	67	74	71	76	65	62	63	61
habitantes	593.832	600.892	606.620	607.899	608.844	601.674	606.069	607.362	608.180	613.433	622.602	628.401	641.081	650.592	660.895

Figure 5.5: Indicator Ag2 Total water consumption (Source: Zaragoza Local Agenda 21; consumo total de agua: total water consumption, hbtes=habitantes: inhabitants)

As one can see in Fig. 5.5, the general trend is to reduce the fresh water catchment, for example in 2005 there were a reduction of 2.64 millions of m^3 in the catchment. In addition, the water consumption per inhabitant (including commercial and industrial uses) reduced from 109 m^3 in 2004 to 103 m^3 in 2005.

➢ <u>Ag3 Incorporated flows to EDAR through the net of municipal collectors.</u>

The objective is to limit water to be treated in the EDAR (Spanish abbreviation of WWTP). The aim that follows is the encouragement of the reduction of supplied water and wastewater. This is also an annual measurement that compares the amount of water that enters into the WWTP with pollutants concentration expressed as BOD (see Fig. 5.6). There is a sub-indicator Ag3.1: connexion of the municipal sewers to the WWTP.

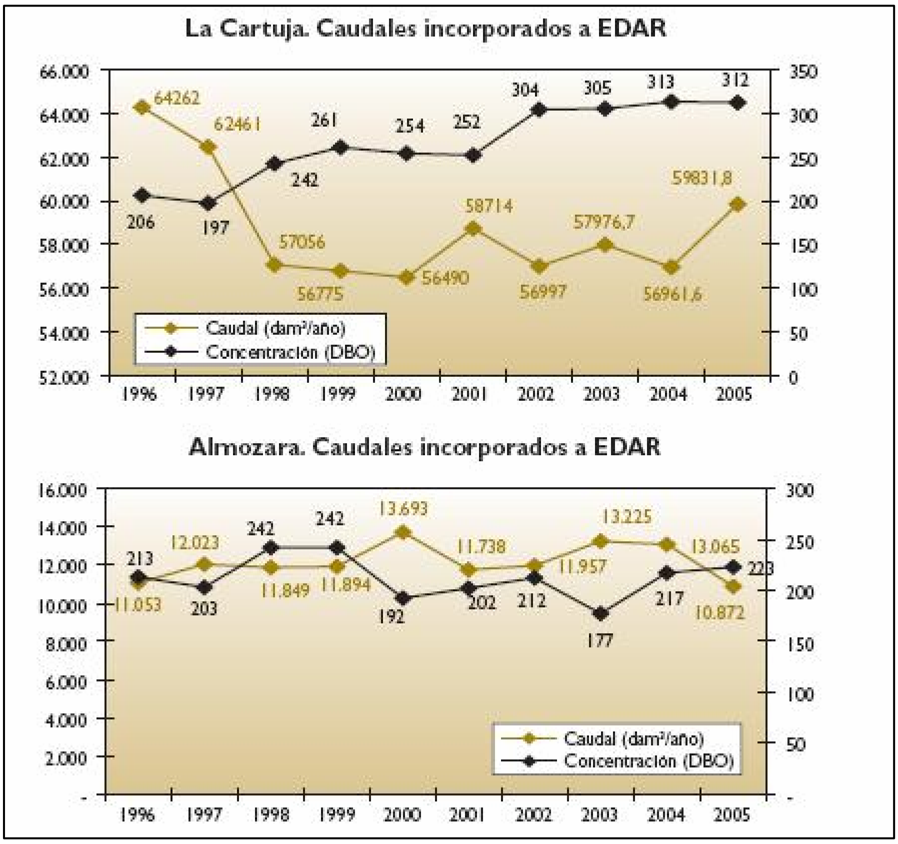
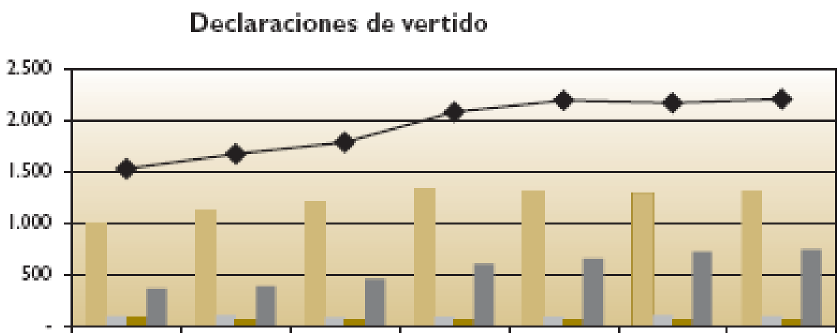


Figure 5.6: Indicator Ag3 Incorporated flows to EDAR (WWTP) through the net of municipal collectors (Source: Zaragoza Local Agenda 21; caudales incorporados a EDAR: input water flow into the WWTP, caudal : flow, concentración (DBO): concentration(BDO))

In “La Cartuja” WWTP the inflow has reduced since 1997 because of the decrease in water consumption as a result of a renewal of the water supply network which began in 1996. In 2001 the inflow increased as a consequence of the incorporation to the WWTP of the sewer from the River Ebro tributary River Huerva in the same year, but BOD levels remained constant. Nowadays the sewer of the other tributary Gállego River and the industrial polygon of Malpica are connected to the “La Cartuja” WWTP.

➢ <u>Ag4 Concessions of authorizations of wastes for industrial activities.</u>

The objective is to control the load of industrial wastewater. Each activity that produces industrial wastewater has to own a load authorization. These authorizations are divided into four categories according with the Environmental Municipal Ordinances, the division is related to the discharged flow (see Fig. 5.7).



	1999	2000	2001	2002	2003	2004	2005
primera	1.004	1.123	1.199	1.337	1.305	1.289	1.318
segunda	95	98	80	86	91	99	95
tercera	67	66	51	59	56	54	54
no exigible	363	385	458	605	656	724	741
total acumulado	1.529	1.672	1.788	2.087	2.197	2.171	2.208

Figure 5.7: Indicator Ag4 Concessions of authorizations of wastes for industrial activities (Source: Zaragoza Local Agenda 21; declaraciones de vertido: authorizations of wastes discharges)

As one can see, the indicator follows the desired trend of increase, which allows a more intensive control of industrial loads and associated pollutant concentrations.

➢ <u>Ag5 Ecological state of rivers</u>

This indicator has the objective of preserving the rivers aquatic ecosystem. The calculation model is based on the measurement of the basic parameters that determine the ecological state of the rivers. As one can see in Fig. 5.8, the fist graph shows the

ecological state of the Ebro River (water quality, habitats of aquatic fauna, river bank fauna, morphology/hydrography, river bank vegetation quality). The second graph show the macro-invertebrates net of the Ebro River and its two attributes in the city of Zaragoza. The last one shows the diatoms net in the three rivers.

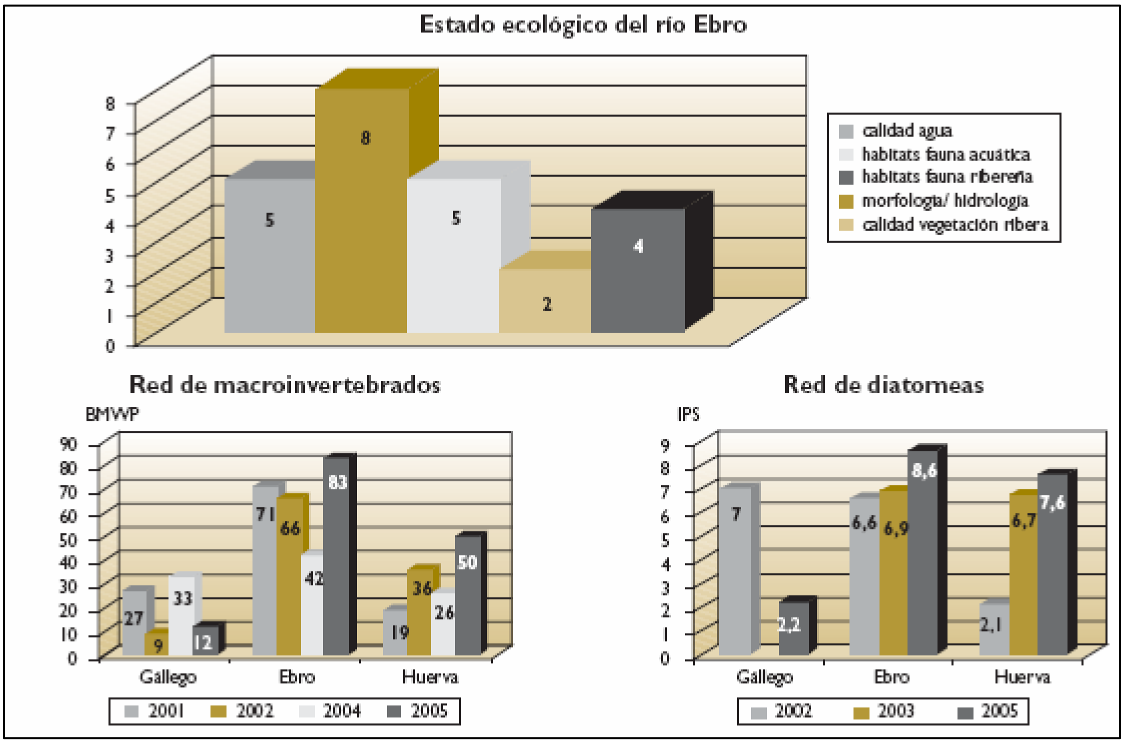


Figure 5.8: Indicator Ag5 Ecological state of rivers (Source: Zaragoza Local Agenda 21)

The range of the parameters of water quality, habitats of aquatic and river bank fauna, morphology/hydrography, river bank vegetation quality are the following: optimum (10-9), sub-optimum (8-6), regular (5-3) and bad (2-0).

In relation to the macro-invertebrates net is: very good (> 65), good (56-65), moderate (41-56), deficient (20-40) and bad (<20). For the aquatic flora (diatoms) very good (20-17), good (17-13), moderate (13-9), bad (9-5) and very bad (5-0). These two characteristics are sub-indicators.

The results, for each case is: subject to significant pressures, impact checked, and high risk of non achievement of the good ecological state established in the Water Macro Directive.

These are the sustainable urban water indicators that the city of Zaragoza has currently adopted. They are all important indicators of the performance of the urban water cycle and its impact on the environment. However, those ones more related to this thesis are Ag2 Total water consumption and Ag3 Incorporated flows to EDAR (WWTP) through the net of municipal collectors. These are two indicators that are directly related to the UWS management.

Chapter 6

Results

6.1 PART I: ZARAGOZA

6.1.1 Baseline scenario

Initially the baseline scenario was simulated in Aquacycle. Input files with the available and estimated data of the study area were plugged into the software and the software run.

This first simulation illustrated the urban water balance of the study area for the six years and three months that data was available for. In order to be able to compare and analyze results, the three months (for 2000) were discarded. The period analyzed was from 2001 to 2006.

It was not possible to calibrate the simulation due to lack of data. The total imported water in the catchment scale simulated by the Aquacycle software was therefore plotted against time. The expected graph was different from that obtained from the simulation. In Chapter 5, Fig. 5.3 shows a significant decreasing trend in water consumption over time of the study period. However, Fig 6.1 shows a constant trend over the years. The data available for comparison with the simulation results is the reduction of water consumption in the whole city of Zaragoza, provided in an Excel file by the Local Agenda 21. In the period 2001-2006 the water consumption decreased by 20% for the whole city, while Aquacycle shows only a small decrease in imported water with a ratio below 1.5% for the period 2001- 2006.

Possible reasons for this difference in the expected reduction in imported water and the simulated imported water volumes given by Aquacycle are discussed in section 7.2.

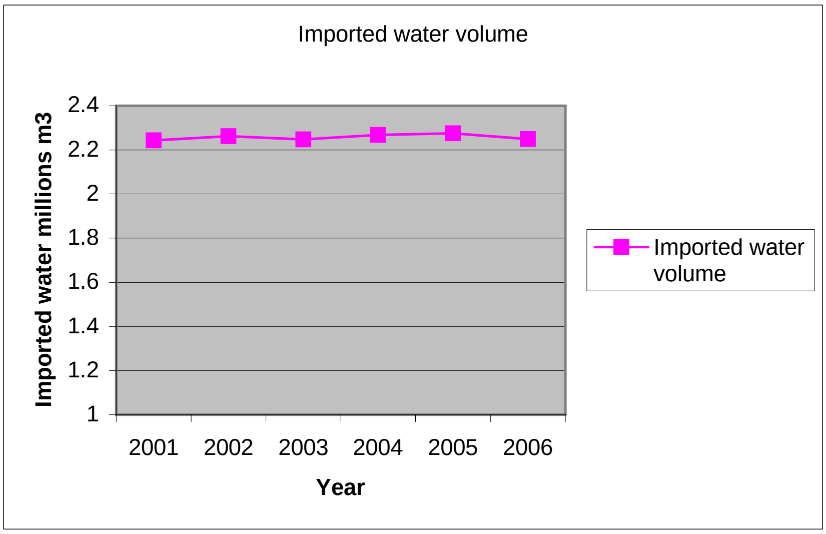


Figure 6.1: Simulated imported water along the study period.

6.1.2 Comparison of the different scenarios

Three sustainability indicators obtained from literature review were used to analyse the performance of the three scenarios and the baseline model. The indicators are related to the outputs of the model:

- reduction in imported water, which is related to the minimization of freshwater withdrawals and the corresponding cost and environmental impacts,
- reduction in wastewater production, related to the minimization of wastewater treatment costs and environmental impacts from untreated wastewater discharge,
- reduction in stormwater runoff, which is related to the minimization of pollution at the receiving water bodies, the minimization of wastewater treatment costs in the case of combined sewerage systems (as is the case in the city of Zaragoza) , and possibly contributes to reduced flood risks (Karka *et al*., 2007).

The performance of each scenario is assessed using these three indicators with the average data output files being used to evaluate the results. These are summarized in Table 6.1.

The results shown in Table 6.1 can be illustrated in a bar chart, which gives a faster overview of each situation and the benefits of implementing one scenario over another (Fig. 6. 2)

Table 6.1: Performance of the different scenarios applied in the study area

	Imported water (m^3/y)	Stormwater runoff (m^3/y)	Wastewater discharge(m^3/y)
Current state	2250561	2048231	646621
Rainwater tank	2191201 (-3%)	2046451 (-9%)	589027 (-0.1%)
Wastewater tank	1696346 (-25%)	1494339 (-0.04%)	646346 (-27%)
Combination	1647575 (-27%)	1492876 (-7%)	599007 (-27%)

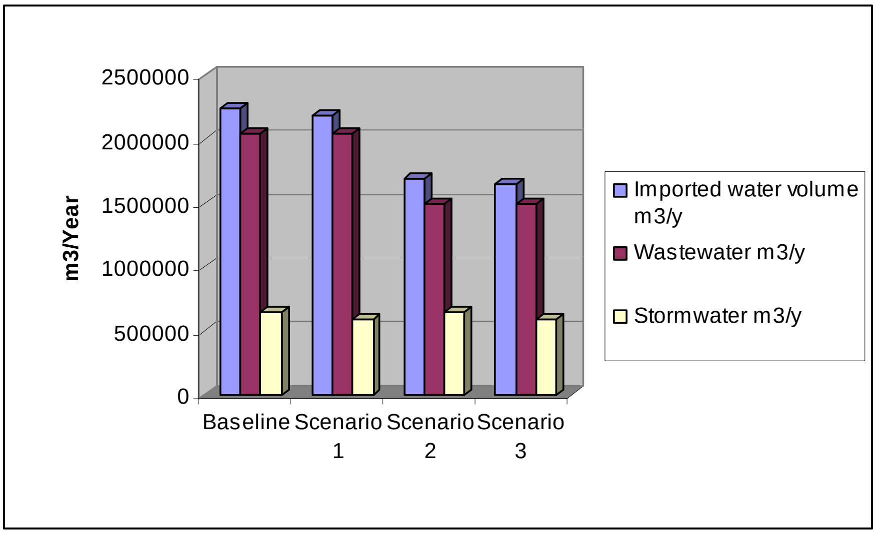


Figure 6.2: Performance of the different scenarios applied in the study area

It is shown that the option that decreases the volume of imported water the most is scenario 3 (the combination of scenario 1 and 2). This is reasonably logical as it includes the application of technologies to use and reuse stormwater and wastewater. However, the economic cost of the installation of both technologies should be analysed in detail in order to ascertain whether it is cost effective to install both or only one technology. However, Aquacycle does not have the option for economic evaluation so other aspects must be evaluated in order to find out the best alternative option. One important aspect that can help in the decision making process is the number of event failures (when the alternative option is unable to supply the total demand of water in a given time step) which is also measured as the deficit of the wastewater/stormwater tanks to deliver a given water volume demand. According to the results obtained in Aquacycle the rain tank scenario has more events failures than the wastewater treatment option. The first one has an average of 346 days of failure per year which means that the rain tank is unable to cover the water demand almost the whole year; while the

wastewater alternative has an average of 1 event of failure in clusters 1 to 4, which are quite similar in size and have similar characteristics. Cluster 5 has an average of 6 failure events while cluster 6 has an average of 12 failure events per year. Cluster 7 has a higher average of 174. The main reason for this is that cluster 7 is mainly commercial and water uses in commercial areas are quite different than for residential ones. In addition, the amount of water used for outdoor purposes (public and household garden irrigation) decreases from cluster 7 to clusters 5-6 and finally clusters 1-4. It could be assumed that one of the most important reasons for the increasing number of failure events is due to the fact that the increase of water demand for green area irrigation implies an increase in the deficit of treated wastewater. Table 6.2 contains the data of the three indicators per cluster within the study area regarding to the simulation of scenario 2. Fig. 6.3 illustrates this impact of the introduction of wastewater treatment and storage tanks in the unit block scale. As one can see, the effectiveness of the application of technologies is highest in the most inhabited areas (Clusters 1-4).

Table 6.2: Values of the indicators of Baseline Scenario and Scenario 2 per cluster

Cluster number		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Imported water volume m3/year	Baseline	328282	1294	528980	566667	87433	115971	16352
	Scenario 2	242993	453324	393965	427470	68684	95020	14890
Wastewater output m3/year	Baseline	310937	568321	499684	515197	74908	73206	5978
	Scenario 2	225698	414856	364749	376082	56171	52268	4517
Stormwater Discharge m3/year	Baseline	151119	121015	143696	112550	30365	27798	60077
	Scenario 2	151077	120939	143629	112481	30356	27788	60075

Scenarios 2 and 3 are the more sustainable options in relation to water issues and it is suggested that the more feasible option for the Actur–Rey Fernando neighbourhood and probably the whole city of Zaragoza, is scenario 2; wastewater treatment and reuse. However, scenario 3 shows the highest decrease in importation of fresh water but regarding wastewater discharge and stormwater runoff, the city of Zaragoza is in an arid region with low annual rainfall and Aquacycle shows that most days of the year rain tanks would be unable to supply the demanded water. However quality analysis has to be undertaken because the water authorities of the city of Zaragoza are concerned about health issues, especially legionnaire’s disease which affects a significant amount of the

population every year (personal communication of Victor Bueno, Civil Servant of Local Agenda 21)

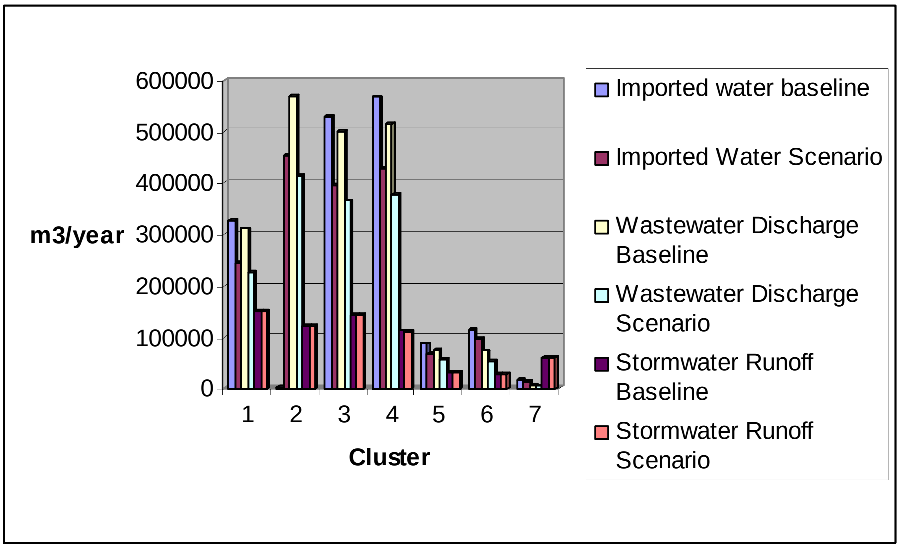


Figure 6.3: Impact of the wastewater treatment option per cluster

6.1.3 Urban Water Sustainable Indicators

The three main aspects of the urban water cycle that Aquacycle estimates (outputs) within a specific area and a given period of time that could be used as urban water sustainability indicators are the three indicators used to evaluate the different scenarios developed for the study area. These indicators are: reduction of imported water, reduction of wastewater discharge and reduction of stormwater runoff.

In this case study, the city of Zaragoza already has these indicators on the Local Agenda 21list. The reduction of total imported water is the same as that indicator found in “Ag2 Total water consumption” of the Local Agenda 21. As described in section 2.4, this indicator measures the volume of imported fresh water in each catchment. The other two outputs can be combined into one indicator, the “Ag3 Incorporated flows to EDAR (WWTP) through the net of municipal collectors”. The sewer system of Zaragoza is a combined system and, with the exception of expected rainfall events which are intense, short duration events that cause overflowing of the WWTP, all wastewater discharged and stormwater runoff go through the sewage system to the WWTP. The sum of both parameters should be quite similar to the incorporated flows to the WWTP.

6.2 PART II: AQUACYCLE

The results of the application of Aquacycle in a Spanish city are given and analysed in section 6.1. Nevertheless, an assessment of the software as a user of Aquacycle can be made. This section has been made with the intention of highlighting the problems experienced in relation to the computer model during the period of this thesis. These results, which are discussed in more detail in the following chapters, can be useful for personnel involved in the development of this kind of IUMW software.

There are some problems related to the way that the software processes the inputs and outputs. Firstly, there is an error in the option that allows to record and load unique input files called “group file” that contains other input files. This is discussed in more detail in Chapter 4. This option seems to be very useful for the users. Secondly, only one indoor water use profile can be loaded into the model which is the household profile. This does not take into account commercial or industrial water usage, which obviously differs significantly from the household profile. Thirdly, the units of the outputs are given as units of aerial depth (mm) instead of volume units (m^3). This is not very useful because analyses of water use profiles are usually made in volume units. Finally, the graphs and tables that show the results can not be saved directly from the software as excel books, images or other kind of files. If the user wants to analyse the results or compare different scenarios, the graphs and tables results given by Aquacycle have to be saved manually on an individual basis, which is time consuming.

Another important aspect is the afore-mentioned differences between the urban design of Australian cites and the common urban design found in Spanish cities and most of western continental European cities. This fact forces the user to make assumptions in order to model block of apartments as single households. The impact of such assumption on the results could not be analysed because of the missing data of the study area for the calibration and verification process.

Finally, it is important to mention that the software does not address short-term changes in water uses or important meteorological events, which influence urban water balance in terms of amount of imported water and irrigation demand. Additionally, it cannot simulate future scenarios of population growth or climate change that are two main pressures of the UWS.

Chapter 7

Discussion

7.1 INTRODUCTION

As stated in this thesis, due to increasing global change, population growth and urbanization pressures, current urban water systems have to be planned and managed in a more sustainable way, based on the three pillars of sustainability: economy, society and environment.

Within this framework the SWITCH Project was developed with the aim of catalysing the change of the current UWM towards more sustainable management. With this objective, the SWITCH Project aims to promote an holistic and integrated approach of the UWS and stakeholder involvement with the inclusion of non-technical and socio-economics concerns in the decision making process. The SWITCH Project has different Work Packages, all of them related to UWM. This MSc thesis is framed within the W.P. 1.2 “Integrated Modelling and Decision Making for Urban Water Management”, whose aim is to develop a simple model for urban water sustainability as a decision support tool for Integrated Urban Water Management. As previously mentioned in Chapter 3, SWITCH has ten demonstration cities and Zaragoza, Spain, is one of them. The SWITCH demonstration neighbourhood is the Actur–Rey Fernando, and for the same reason it is the chosen study area of this project.

Finally, one of the IUW modelling softwares was used to develop the urban water cycle of the city of Zaragoza and draw down conclusions and recommendations.

7.2 PART I: ZARAGOZA

7.2.1 Zaragoza - Aquacycle limitations

The following is a discussion surrounding the application of the Aquacycle model to the study area. For reasons that will be explained, it is expected that the urban water balance calculated in this thesis is not precise, but it helps to have a rough idea of the urban water balance of the study area. There are two main limitations that dictate the level of

reliability of the results of the software. These are primarily related to the problems experienced with data collection as well as limitations of the Aquacycle software itself. In the next chapter, some recommendations are proposed in order to solve or minimize these limitations.

7.2.1.1 Calibration and verification

It was not possible to undertake the process of calibration and verification of the model in the study area due to lack of data. This option requires the development of a recorded file with specific catchment data, explained in section 4.5.2.3.7. Currently, the city of Zaragoza does not have the needed data in the cluster; this data is probably only available for the whole city. Some of these data will be made available in the near future because the City Council of Zaragoza in collaboration with SWITCH has isolated SWITCH sector 1 of the study area (the same cluster 1 used in this thesis) and has installed one water meter to control the imported water that comes into the area and catalogue water consumption patterns.

7.2.1.2 Required Data

One of the main characteristics of an IUW model that aims to support decision making process should be simplicity.

Some of the input data required by Aquacycle is not easy to obtain if you are not working within the Municipality or the company/organisation that has the needed data or in a company with a significant influence and/or available economic and human resources to pay for the data and/or collect it. During the process of the thesis some problems related to unavailable data were solved to the best of the author knowledge and ability. As previously mentioned in Chapter 4, the most difficult data to obtain was climatic data. It is important to point out that the climatic data required for this thesis was given to the author as a personal favour by the civil servants of the Department of Air Pollution of the Local Agenda 21 of the city of Zaragoza. **It is not official data and cannot be used in other research activities but this thesis**. However, the department did not have data for potential evaporation, which was also a required data input of the Aquacycle software. There were two main reasons why it was very time consuming to estimate this data, (i) finding the formulas required to calculate the estimation with no available data and (ii) the amount of calculations and steps of the estimation itself. Due to estimation of the potential evaporation and the fact that climatic data is not validated

and can contain errors, the climatic information can be assumed to contain errors. However, it is useful to have an approximate idea of the climatic situation of the city and allowed running of the software to take place.

Other limitation relating to data collection is the season in which the thesis was undertaken. It was during summer time, which is the most common holiday period of the civil servants of the City Council of Zaragoza; for that reasons and because the contact persons or the ones who had the data were on holidays, it was not possible to acquire the required information within time constraints of the project. This is why some assumptions regarding number of unit blocks and their characteristics, estimation of cluster and catchment area etc had to be undertaken using the available data to be able to continue with the project. However, the contact persons of the Local Agenda 21 do not have this information and has to be applied to other departments as the urban planning one who, as in the same situation than the staff of the Local Agenda 21, they are very few workers in relation to the amount of work they have, and unfortunately the data processing is not one of their priorities.

As the study area does not have rain tanks nor wastewater treatment and storage tanks, a literature review was undertaken to provide a basic knowledge about characteristics such as these that the software requires as input data. In addition, it assumes that the tanks are for single households and not for blocks of apartments, one more reason the model needed to be adapted for European cities.

7.2.1.3 Break Pressure Tanks

There is a local problem in the city of Zaragoza related to water losses produced by break pressure tanks. These tanks were installed below most of the apartment blocks 40 years ago in order to maintain a continuous water supply to the population because, at that time, the pipeline network was in poor conditions and supply cuts occurred very often. Nowadays, there is around 7,000 and 7,500 private break pressure tanks in the city and the City Council does not have access to them without community permission. These tanks cannot be removed without their permission nor can the Municipality access these tanks to undertake research studies without permission of the local residents. Today, there is no reason to have these tanks because the network has been improved and usually cuts in the supply of water are fixed within minutes or hours. In

addition, there are some disadvantages about the existence of the break pressure tanks (Bury *et al*., 2006):

- The access to these tanks usually is very difficult, so most of them have a scant or void maintenance regime, this leads to a high leakage of drinking water directly to the sewer system. It is estimated that water losses by this tanks are between 3 and 5 millions of m^3 throughout Zaragoza. (Agenda Local 21).
- Use of additional energy is needed to pump water up to the households because as it is storage, the water loss the pressure of the network.
- If the storage time is high, there is a significant health risks in relation with legionnaire’s disease and other opportunistic pathogens and nuisance organism.

In order to study the impact of the UWC of these tanks, the Infrastructure Department of Zaragoza Municipality, within the SWITCH Project, has planned to install water meters in some pilot break pressure tanks to calculate water loss more accurately (Ayuntamiento de Zaragoza, 2006).

Water leakages directly to the sewer system are not possible to simulate in the model and this is another reason for the decrease in accuracy of results from the simulation of the study area. As it is a local problem, it was not worthwhile to include break pressure tanks in an IUW computer model although it has been developed for the city of Zaragoza. Some recommendations are given in the next chapter about this problem.

7.2.2 Actur–Rey Fernando results

Once the limitations of this thesis have been explained and having in mind that a lot of assumptions and estimations had to be done in order to develop the total urban water balance of the city of Zaragoza, the results can be discussed in the next sections.

Section 6.1 states that in the study period (2001-2006) the water consumption decreased in a 20% in the whole city of Zaragoza, while Aquacycle show a small variability of the imported water with a ratio below 1.5%. The fact of finding practically a constant water imported water volume instead the decreasing trend of the city can be caused for the model itself, its assumptions and calculations, or because of the specific situation of the study area. As it has not been possible to undertake calibration and verification, all these factors, which discussed in the next sections, must be taken into account. The factor or

factors that drive to different results than the expected one cannot be determined in this thesis because it goes beyond its scope, but they can be described.

7.2.2.1 Specific situation of the study area

This unexpected trend can be simply caused because of the fact that the neighbourhood behaves in a different way than the rest of the city. The average trend of the city is to decrease the volume of imported water. It does not have to be necessarily constant in every neighbourhood, but can change from one to other. A research study about the neighbourhood (about the evolution of the population, the citizens behaviour, the people should be undertaken to find out whether it follows the city trend or not.

7.2.2.2 Data availability

The data of water consumption that is being compared has different spatial scale, the city of Zaragoza against a small area of the city, because there is not data on the study area. A lot of social factors can cause the fact that the imported water decrease in the city, but stays constant or even increase in some neighbourhoods. Aquacycle does not have into account changes in population density, population behaviour, etc that affect directly to the amount of demanded water.

7.2.2.3 Household average occupancy

The model is designed for single households (unit blocks) of a typical Australian city, which differs significantly with the study area where the unit blocks are blocks of apartments. The indoor water use (one of the factors of the estimated imported water) is calculated with the indoor water usage input file and the average occupancy both given by the user. The model only gives the option to introduce up to 7 inhabitants per household. In the study area the average occupancy is approximately ten times more (because each unit block included several households). In this case, the model uses the 3 person household water use to calculate the amount of water used by room of the household (kitchen, toilet, bathroom and laundry) and the total amount.

This fact can lead to errors in the amount of imported water, because the households of the study area have an average occupancy much lower than the one given as an input. In addition, in every cluster the given household average occupancy is higher than 7 (to study every block of apartments as a unit block), so the indoor water use is calculated

with the profile of 3 person per household. The effect of this huge difference between the input data and the reality is not known, but it could affect the results.

7.2.2.4 Effect of the precipitation

It is important to mention that the output results of the study area given by Aquacycle show a small variability of the imported water with a ratio below 1,5% in the period 2001- 2006 (see Fig. 7.3). The reasons of this small fluctuation are describing in this chapter as limitations of the software or especial situations of the study area, such the big awareness campaign about water saving that was carried out in the city of Zaragoza during the study period. The higher peaks occurs in the years with less annual precipitation while the lower amount of imported water has place in the years of higher precipitation. Figure 7.4 is the same than fig 7.3 but in more detail in order to show the positive correlation between imported water and precipitation

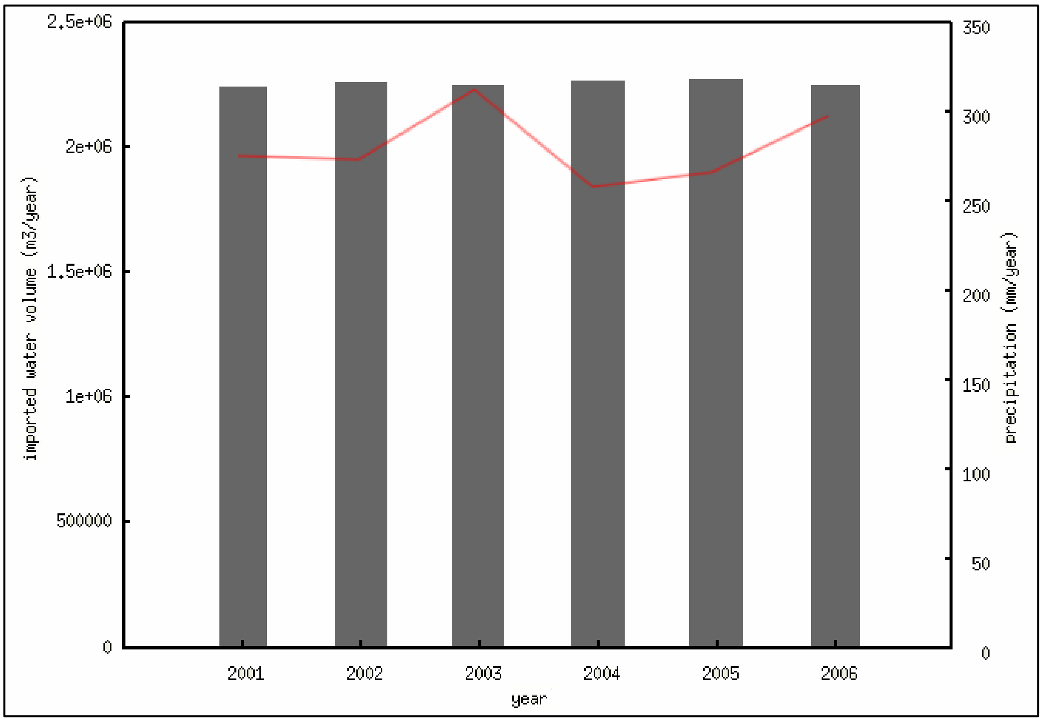


Figure 7.3: Simulated imported water volume versus recorded precipitation

This fact is due to the reason that Aquacycle calculates the imported water as a function of indoor water use, irrigation and leakage. The first one is a constant given by the user, the second one depends on the precipitation and the third one on precipitation and indoor water use. For that reason, if the precipitation increases, the imported water decreases because the program assumes that the higher precipitation the less water is

needed for irrigation. This fact does not fit in the situation of Zaragoza, where whether it rains or not, the same amount of water is used for irrigation. This fact explains the fluctuations between years of a increasing and decreasing events on the imported water, and does not show the expected decrease trend.

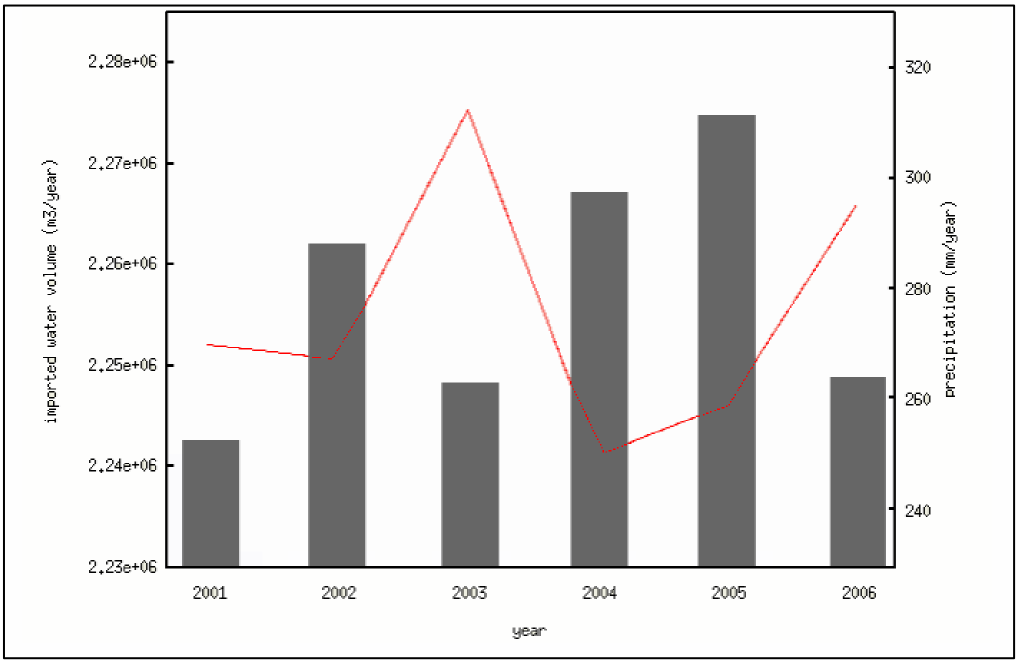


Figure 7.4: Detailed Simulated imported water volume versus recorded precipitation

7.2.2.5 Network renewal

The city of Zaragoza has an aged pipelines network and the materials were worst than the actual ones, so the pipelines leakages and breaks were very high. In 2002 the "Improvement Water Plan", explained in section 2.2.3.5 started. The 65% of the investment was placed to the renewal and restoration of the pipelines. However, the renewal and restoration works in the study area were finished in the year 2006; In addition it is though that a significant amount of the imported water was lost within the (personal communication of a senior technician of the Infrastructure Department of Zaragoza Municipality). The leakage rate of the water supply system has a constant value in the whole simulation period because the software does not give the choice of specify this rate for each year. In the simulation period, it is important to have this option because the renewal process was made along the study period and it varies the calculated amount of imported water.

The study area is a relatively new neighbourhood, so it can be assumed that the network was not in a bad state and the impact of the works were not as big as in the older areas of the city. It could explain the fact that the water consumption does decreases in the whole city by the influence of the old areas and not by the influence of the study area, and so the leakage decrease is not very significant in the study area. Another reason could be the fact that the software does not model the impact of the decrease of the leakage in a realistic way and underestimates it.

This is an interesting area of research for the improvement of Aquacycle of the development of new softwares; unfortunately it goes beyond the scope of this MSc thesis.

7.2.2.6 Public behaviour

Another important variable that remains stable within the model but varies during the study period is public behaviour and awareness on water use patterns. The city of Zaragoza is very aware of water issues, especially water saving techniques within the population. The project “Zaragoza, water saving city” has been running since 1997 (source: http://www.zaragozaconelagua.org). The project illustrates how it is possible to deal with water scarcity problems in a cost effective and sustainable without social conflicts by increasing efficiency in water use. This approach is directed at all citizens, companies, professional sectors etc and has been carried out at different levels addressed to different stakeholders. This program seems to have a good impact on the population of the city of Zaragoza, at both personal and professional levels, because according to the official website it has contributed to a decrease in water consumption to 105 l/inhabitant/day in 2005, which is a low water consumption rate.

During the study period two phases of the project “Zaragoza, water saving city” took place, the second and the third of four phases.(source: personal communication by Laurent Sainctavit, representative of the NGO “Fundación Ecología y Desarrollo” during a SWITCH meeting in Zaragoza and the NGO website: www.ecodes.org). The second phase called “50 good practices” (2000-2003) was very important because it focussed mainly on water saving technologies aimed at large water consumers (public buildings, industries, parks and gardens, etc). The aim was to achieve permanent water saving because when the awareness campaign ends, the population mainly lose the incentive and return to their previous behaviour, but technology persists after the

campaign. The objective was to find 50 good practices of water saving for the different sectors. The aim of the next phase (2004-2006), called “Water Efficiency Use School”, is an extension and diffusion of the knowledge based on the rational and efficient water use obtained during the previous phase

As a result of the third phase campaign, 1,800 households of the study area installed water saving devices (Fundación Ecología y Desarrollo, 2006). In this campaign water saving devices were provided. This resulted in 40% water and energy saving from taps. In addition, the citizens showed a keen interest in the campaign and more than 800 people applied for information about how to save water in their households.

These kinds of campaigns have a great impact on population behaviour and the effect on the water demand, and ultimately on the volume of imported water. In this case, the campaign was undertaken during the study period in an area where the population is very active and participate in this kind of project (personal communication by Marisa Campillos, Department of the Local Agenda 21 of Zaragoza). The software Aquacycle cannot simulate the impact of such campaigns, because of two main reasons. First of all because the indoor water profile is constant during the whole simulation period and variations in water demand are not taken into account. Secondly, because it was mainly aimed at large consumers, who have a different water consumption pattern than a household, but this is not distinguished in Aquacycle.

7.2.3 Similar research studies

To the author knowledge, there are no previous research studies relating to the urban water balance of the study area and the development of SWM (using rainwater and wastewater as water sources), that is available for in the form of public information. This MSc thesis therefore gives an initial overview and provides suggestions about the possibilities of the most feasible ways of UWM. As stated in Chapter 5, Aquacycle results show that the best option for the study area in terms of water saving by the implementation of alternative technologies that allows the use of the system outputs (stormwater and wastewater) as input or new sources is the use of one-site wastewater treatment and storage tanks in the unit block scale. This preliminary idea can be useful for the SWITCH Project in order to study in more detail and for a longer project time the possibility of the implementation of the on-site wastewater treatment and storage technologies to the whole city of Zaragoza, and not only the study area. In addition, due

to experiences of the author using Aquacycle, some suggestions and recommendations about the development of the software SWITCH–Aquacycle are proposed.

The results can be compared with a case study that took place in the city of Athens. Climatic characteristics are similar, with maximum daily temperatures ranging from 13ºC in January to 33ºC in July in the city of Athens and an average annual rainfall range between 200 and 300 mm/yr (Karka *et al*.,. 2007). In the city of Zaragoza the annual average rainfall ranges between 200 and 370 mm/yr and maximum daily temperatures range from 16ºC in January to 35ºC in July. The study area in the city of Athens is bigger than the neighbourhood chosen in Zaragoza, and includes an industrial area and different types of households (detached and semi-detached). The estimated indoor water profile, is larger than in the city of Zaragoza in the bathroom, toilet and laundry but smaller in the kitchen. After the application of Aquacycle with the differing scenarios of rainwater use, on-site wastewater treatment and subsurface irrigation with grey water, the same results as those demonstrated in the Actur–Rey Fernando neighbourhood were observed: the most effective method for achieving reduction in fresh water (41% reduction) is the on-site wastewater treatment method. In addition, it has a significant impact on wastewater discharge, reduction of 54%. The same method seems to be the most effective for both Mediterranean cities.

7.3 PART II: AQUACYCLE

7.3.1 Software limitations

With respect to software limitations, there is a bug in either the load group or save option. Once all the input files are loaded into the main screen there is an option called “save group” that saves all the input files as an unique file to facilitate the following demonstrations of the software. When the user tries to load the recorded “group file” it does not work because it does not recognise the indoor water usage file. It is not clear if the problem happens when recording or when loading the group file, but the fact remains that it would be faster for the user to load just one file (the group file) than the other six files one by one which is the case at the moment due to this bug in the software.

It is also important to mention that some difficulties have arisen due to the fact that the model was developed for typical Australian cities, where urban planning is quite

different form Spanish cities, especially the study area. Usually, Australian cities have detached houses and individual households while the city of Zaragoza has blocks of apartments in which more than one family lives. The average unit block chosen for this thesis is one block of apartments that contains 24 households. The household average and parameters were reordered and analysed in order to fit the Australian city structure, but the impact of this action on results is unknown.

An incoherence found in the input data is that the clusters are selected and divided by soil use (residential, commercial and industrial mainly) but there is only one input file for indoor water usage which is residential use. It is logical that water usage is not the same in a household than in a commercial area and even more different in an industrial area depending on the type of industry. In this case, every building is considered as a household, a fact that makes the water balance differ from reality. Additionally, at least in Spain, there are a lot of non inhabited households. For example, in the study area almost 10% of the total households are uninhabited. This is also an important aspect to take into account when looking to improve data sets for inputting into Aquacycle or the development of new IUW modelling programmes. If the household average is calculated without taking empty houses into account then, the output of the program will not be accurate as it will be assumed that all the houses are occupied and the population density will be bigger than the actual one. On the other hand, if the average occupancy is calculated taking into account the empty households, then water consumption will also vary from the real one, because when there are more people living in the same house, water use is more efficient. Also this is one more reason why the model should be adapted for cities with blocks of apartments instead of individual households.

According to the research team who developed the Athens Aquacycle case study and in agreement with the author’s opinion, the software does not address short-term alterations to water use. This affects water supply requirements and wastewater production and is related to changes in seasonal population or different profiles such as the indoor water usage due to meteorological changes. Variability in precipitation is important for estimating water availability for collection and use in the rain tanks

Another important limitation is the fact that Aquacycle does not include the possibility to develop scenarios for urban expansion/population growth. In addition, it does not

include energy, life-cycle costs and water quality, which are very significant aspects within the urban water system management.

7.3.2 Constraints of Aquacycle software

All these limitations make it difficult to produce very realistic and accurate figures for the urban water balance in the study area. For reasons such as this and with the aim of solving them, other softwares have been or are being developed. For example, the lack of water quality analysis can be solved by using UVQ software that assesses the contaminant balance through the urban water cycle. Energy and life-cost analysis will be assessed by the SWITCH–Aquacycle software. However, there are still some aspects that appear to be important, at least in this case study, that are not covered by these two softwares.

Recently, there have been significant social and political discussions drivenby a research study that was carried out by a Spanish magazine (Salinas *et al*., 2007), confirming that water of the city in the city of Zaragoza is of bad quality. The debate that water supplied to the Zaragozan citizens is dangerous because it contains levels of trihalomethanes that are over and above the maximum level established by the European Union (these levels have not come into force yet, they will do the beginning of the year 2009) (Salinas *et al*., 2007). Trihalomethanes are by-products of the drinking water process. If they are continuously consumed by humans in high levels they can cause cancer and encourage cancer growth. The City Council of Zaragoza stated that there is not any danger from potable water and that the maximum levels is not reached. However, this debate is outwith the scope of this thesis, but the situation aims to show that in order to have a good overview of the total urban water cycle, a suggestion could be the introduction of the analysis not only of the pollution produced by water use (analysed by UVQ) but also chemical products that are added during the water supply process.

The wastewater treatment process is not analysed by any of the three studied softwares, but it is also a part of the urban water cycle: the final stage before water is discharge into water bodies. As observed in Fig. 7.5 - the total urban water cycle. Wastewater treatment also has environmental impacts and should be taken into account in the improvement or creation of IUW modelling programs to support decision making.

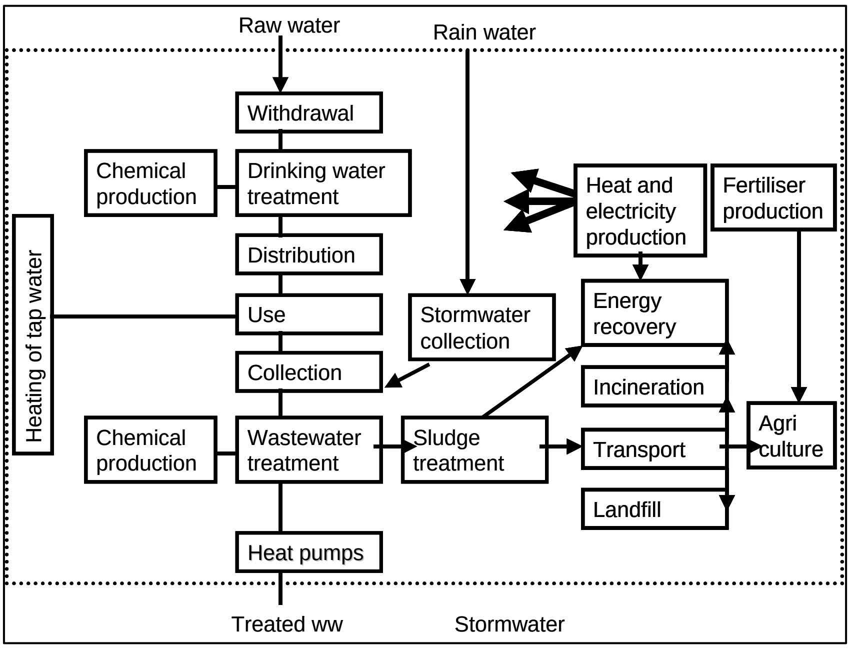


Figure 7.5: Urban Water System From Lundin and Morrison (2002) (Source: Peter van der Steen, 2006)

7.4 SUSTAINABILITY INDICATORS

Limitations in establishing a list of urban water sustainability indicators is related to both Part I: Zaragoza and Part II: Aquacycle. For this reason it is discussed in a different section.

As previously discussed, the outputs of Aquacycle that could be considered as sustainability indicators are imported fresh water, wastewater discharge and stormwater runoff. These indicators already exist in the city of Zaragoza. The only new indicator that Aquacycle can add is the volume of reused water in the water cycle. Because of the unavailability of the two other softwares, the objective of "develop a list of urban water indicators with the outputs of the IUW models" cannot be fulfilled.

It can be said that Aquacycle is not an innovative model to develop urban water indicators, at least in the city of Zaragoza. Other softwares, for example SWITCH – Aquacycle, can contribute with the development of new indicators such as energy recovery and consumption, economic cost, etc

However, taking into account local water indicators that already exist in the city of Zaragoza, the known and expected outputs of UVQ and SWITCH–Aquacycle, and

literature review process (Lundin 1999, Morrison *et al*., 2001, Shaley *et al*., 2005, Nixon *et al*., 2003), several indicators are suggested in Table 7.1.

Table 7.1: Suggested urban water sustainability indicators for the city of Zaragoza.

Indicator	Measure
Water consumption	Water use per capita and per day
Energy consumption	Energy use in the whole UWC
Energy recovery	Energy recovered, heating and power
Economic costs	Budget of the whole UWC
Reuse of water	Reused water
Distribution	Water leakages
Treatment performance	Removal of BOD5, P and N
Loads to receiving water	Loads of BOD5, P and N
Resource use	Chemical and energy used for wastewater treatment
Recycling nutrients	N and P recycled
Sludge quality	Concentration of selected heavy metals (Cd, Pb, Hg and Cu)

Chapter 8

Conclusions and Recommendations

8.1 GENERAL

The main purposes of this thesis were to develop: (i) a total urban water cycle model using data from Actur-Rey Fernando neighbourhood of Zaragoza and (ii) develop sustainable urban water indicators. The first one was achieved through the application of the urban water balance model Aquacycle to data from the study area. Results showed that the best alternative for sustainable management of the urban water cycle in the study area is at the on-site wastewater treatment tank at the unit block scale. According to result shown, it can be concluded that the thesis hypothesis is partly true, because the model can be applied in the study area -with the difficulties mentioned along this thesis-. However, the feasibility of the results cannot be compared with similar research studies because there are none available for local conditions found in this area of Spain. Checking model feasibility through comparison of Aquacycle simulated imported water results with actual imported water data for the study area would be required (verification and calibration process); unfortunately, the calibration and verification is not possible at the moment of writing because these processes require data that is not available for the study area. A recommendation, in order to assess the performance of the programme, will be the application of the model in the whole city. Due to time constraints it has been not possible to develop it in this project.

8.2 PART I: ZARAGOZA

According to the results of the simulation of the urban water cycle of the Actur-Rey Fernando and the different scenarios, the best option for the study area is the implementation of on-site wastewater tanks in the unit block scale for irrigation and toilet flushing. However, Aquacycle results show a constant trend of the imported water along the study period, a trend that does not follow the expected one of decreasing imported water. Due to the impossibility of the calibration and verification of the software, it cannot be determined whether this unexpected trend is caused by the

application of Aquacycle to an urban area which is significantly different from those that the model has been designed for or not.

In order to be able to undertake the model calibration and verification of the simulation of the study area of the Actur–Rey Fernando neighbourhood, it could be interesting to install at the input and output of the catchment two water meters to measure the total imported water and the sewage output. Studies about the surface runoff, outdoor water use and inflow and infiltration into the wastewater system should be carried out. Furthermore, it would be interesting to undertake a research to have real data about the calibrated parameters of the study area (section 4.5).

In relation to the break pressure tanks, two recommendations can be made. The first one is related to the accuracy of the figures produced by Aquacycle. The Infrastructure Department of the city of Zaragoza has estimated the amount of water lost in these break pressure tanks; but the estimation is made for the whole city, not only for the study area. A preliminary research study could be done in order to determine the amount of break pressure tanks in the study area and estimate its water losses. The estimation of the water losses of the break pressure tanks could be introduced in the parameter and initial value input file, as one of the components of “water supply leakage rate”, together with the network leakage. These tanks are responsible of part of the leakages that occurs within the UWS. Thus, if the losses were taken into account in the leakage rate, more realistic figures could be obtained in the simulation of Aquacycle. The second recommendation or suggestion for future work is a research study of the possibility of place the on-site wastewater treatment (the most feasible solution of the simulation on Aquacycle) in the rooms were the break pressure tanks are placed nowadays. It could be a good starting point as a pilot project to check the efficiency of this new alternative in the study area and also the popular acceptance of grey water reuse. The break pressure tanks were designed to be able to provide water to the community in case of a big water supply shortage, so their storage capacities may be enough to reuse the household grey water for toilet flushing and garden irrigation. In addition, the energy needed to pump up the water to the residents could probably be estimated from the energy used by the break pressure tanks.

8.3 PART II: AQUACYCLE

Aquacycle is a simple model; some recommendations can be drawn from the experience of the author as a user.

First, the accuracy of using Aquacycle model in block of apartments instead of single households is unknown. With regard to the development of new IUW models (especially SWITCH – Aquacycle that aims to be a simple model and applicable in a world level), it is important to study the impact of the application of a model designed for a different urban planning on the results. If there is a significant difference, a recommendation could be the establishment of two options in the software, one for single households and other for block of apartments.

With regard to input data, it seems to be difficult to have recorded data about time series data of potential evaporation. If it is available, it is usually necessary to pay to obtain this information; and when it is not available, its estimation is time consuming. A good improvement of the existing software or for the new ones should be the introduction of a function that estimated the potential evaporation using the most common data available (precipitation, maximum and minimum temperature, wind speed, radiation and relative humidity). This function might save a significant amount of time and money, which is important in research projects.

More than one indoor water usage profile is needed to develop a more accurate urban water balance: not only the household input file, but also commercial and industrial. Another aspect that should be studied, and improved if necessary, is the existence of empty houses that can affect the amount of population or the water usage profile. Furthermore, the fact that Aquacycle does not take into account seasonal and temporal population variations should be arranged somehow because it affects the urban water demand and also the water usage profile.

As one of the main objectives is simplicity, general information about rain tanks and wastewater treatment and storage tanks should be provided in the user guide as an appendix to give the user a basic knowledge of the sizes and other basic characteristics, such as litres of the first flush or exposed area.

The bug caused in Aquacycle by the action of loading or recording the group file should be fixed. Additionally, it would be very helpful for the user if the simulations of the different scenarios could be recorded in a file and open directly in the software without needing to run the simulation again every time the user wants to see the results in the "results screen". Furthermore, an option to save the graphics as images would be very useful in the process of result analysis and comparison of different scenarios and also for presentation of data and results.

As one of the main pressures to the environment is population growth, it is important to develop scenarios in which the user -especially for decision making processes- can study the impact of the population increase in the urban water cycle and the best feasibly option for its sustainable management. This option should be included in the new softwares, as SWITCH – Aquacycle. Another recommendation for the new IUW models is the introduction of a new feature in the programme to estimate the by-products produced in the drinking water treatment process. This is a significant issue related to health and regulated by European and National legislation that should be taken into account in the urban water cycle management.

In relation to this, a significant concern in the city of Zaragoza is the legionnaire's disease. Furthermore, it is important in every city that the drinking water is free of pathogens. For these reason it could be interesting to include in the new softwares a microbial risk assessment model that place the hot points of human exposure to micro-organisms produced by the waste water and evaluate the level of risk.

Integrated urban water modelling programmes, such as Aquacycle, are good tools for supporting decision making process in the urban planning management. They provide a holistic and integrated overview of the urban water cycle and recommend the most feasible alternative option for a more sustainable management. However, the current models do not take into account social (changes in citizen's behaviour, temporal mobility patterns, etc) and economic (life-cycle costs, investments for the installation of new technologies, etc) issues. For that reason, a lot of projects and research studies have been carried out successfully at a local and national level (e.g. CSIRO Urban Water); that is, as matter of fact, one of the reasons of the development of the SWITCH Project. It is important to continue developing more complete IUW models to have a more

realistic approach of the current and especially future situations in order to manage the resources in the most sustainable way.

Finally, the author would like to point an important suggestion to improve the Aquacycle output screen. In the results screen, the water balance is shown in aerial depth (mm) and not in volume units (m^3), which are usually the units in which the user analyses the results. In addition, in the output excel files, only the imported water appears in volume units. In order to avoid extra calculations and to save time, it would be very useful if the results were given in volume units (m^3).

Although Aquacycle does not provide any new indicator for the study area, it could be a useful tool for estimating the *future trend* of the indicators that it produces (reduction of imported fresh water, reduction of wastewater discharge, and reduction of storm water runoff). However, for the software to model future situation scenarios, the input data (such as climate data –having into account climate change-, population growth, changes in indoor water usage profile, etc) must be available. An interesting line for future work is the development of software tools that developed medium and long term future scenarios taking into account population growth and climate change (pressures that will affect significantly the UWS). The developing of these computer models will permit the assessment of the trend of the UWS to determine whether an UWS goes towards a more sustainable trend or not.

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APPENDIX I: TERMINOLOGY

For the sake of clarifying the terminology related to the modelling and assessment of the urban water cycle in this MSc thesis, this appendix contains the definition of the most conflictive terminology.

- Computer model/ software/tool: is a computer program that attempts to simulate an abstract model of the urban water cycle.
- Toolbox: group of different computer models or tools that aims to represent or model the urban water cycle.
- Model: pattern, plan, representation, or description designed to show the structure or workings of the urban water cycle. In this project a model is the description of the urban water system given by the analysis of the results of the computer modes or toolbox. (source: www.wikipedia.org)
- Methodology: The analysis of the principles of methods, rules, and postulates employed by a discipline / the development of methods, to be applied within a discipline / a particular procedure or set of procedures. (personal communication by Okke Braadbart)
- Paradigm/ Approach: way of thinking, worldwide (personal communication by Okke Braadbart)

APPENDIX II: POTENTIAL EVAPORATION

Calculation of the evaporation

One of the most productive issues dealt in the Birmingham meeting (see Appendix IV) was the calculation of the daily potential evaporation. The PhD student Ewan Last gave guidance about how to find the formula to estimate it. This is one of the advantages of working in a international and multidisciplinary project like SWITCH.

Meteorological factors determining evaporation

The meteorological factors determining evaporation are weather parameters, which provide energy for vaporization and remove water vapour from the evaporating surface. The principal weather parameters to consider are presented below (FAO - Food and Agriculture Organization of the United Nations, 1998):

Solar radiation

The evaporation process is determined by the amount of energy available to vaporize water. Solar radiation is the largest energy source and is able to change large quantities of liquid water into water vapour. The potential amount of radiation that can reach the evaporating surface is determined by its location and time of the year. Due to differences in the position of the sun, the potential radiation differs at various latitudes and in different seasons. The actual solar radiation reaching the evaporating surface depends on the turbidity of the atmosphere and the presence of clouds which reflect and absorb major parts of the radiation. When assessing the effect of solar radiation on evaporation, one should also bear in mind that not all available energy is used to vaporize water. Part of the solar energy is used to heat up the atmosphere and the soil profile.

Air temperature

The solar radiation absorbed by the atmosphere and the heat emitted by the earth increase the air temperature. The sensible heat of the surrounding air transfers energy to the surface and exerts as such a controlling influence on the rate of evaporation.

Air humidity

While the energy supply from the sun and surrounding air is the main driving force for the vaporization of water, the difference between the water vapour pressure at the evaporating surface and the surrounding air is the determining factor for the vapour removal.

Wind speed

The process of vapour removal depends to a large extent on wind and air turbulence, which transfers large quantities of air over the evaporating surface. When vaporizing water, the air above the evaporating surface becomes gradually saturated with water vapour. If this air is not continuously replaced with drier air, the driving force for water vapour removal and the evapotranspiration rate decreases.

The evaporation is high in hot dry weather due to the dryness of the air and the amount of energy available as direct solar radiation and latent heat. Under these circumstances, much water vapour can be stored in the air while wind may promote the transport of water allowing more water vapour to be taken up. On the other hand, under humid weather conditions, the high humidity of the air and the presence of clouds cause the evapotranspiration rate to be lower. The effect of increasing wind speed is also an significant parameter in evaporation. The drier the atmosphere, the larger the effect on evaporation. For humid conditions, the wind can only replace saturated air with slightly less saturated air and remove heat energy. Consequently, the wind speed affects the evaporation rate to a far lesser extent than under arid conditions where small variations in wind speed may result in larger variations in the evaporation rate.

The Penman formula was used to calculate the potential evaporation, next section.. In order to use the Penman formula, it was necessary to estimate the daily radiation data.

Penman Formula

The basic Penman formula for open water evaporation is going to be used in this thesis. In a classical study of natural evaporation Penman (1948) developed a formula for calculating open water evaporation based on fundamental physical principles, with some empirical concepts incorporated, to enable standard meteorological observations to be used (Shaw E. M., 1988). The formula is the following one:

$$E_o = \frac{\frac{\Delta}{\gamma} \times H + E}{\frac{\Delta}{\gamma} + 1} \qquad \text{(Eq. 1)}$$

where

E_o Potential evaporation [mm day^{-1}]

Δ slope of saturation vapour pressure curve at air temperature T [kPa C^{-1}],

γ Psychrometric constant [kPa C^{-1}]

H solar net radiation [mm day^{-1}]

E evaporation as result of convection and vapour pressure deficit [mm day^{-1}]

All these factors of the equation 1 are explained above.

Mean saturation vapour pressure (es)

As saturation vapour pressure is related to air temperature, it can be calculated from the air temperature. The relationship is expressed by:

$$e^0(T) = 0.6108 \exp\left[\frac{17.27T}{T + 273.3}\right] \qquad \text{(Eq.2)}$$

where

e°(T) saturation vapour pressure at the air temperature T [kPa],

T air temperature [°C],

As one can see in the equation 2 the values of saturation vapour pressure are function of air temperature Due to the non-linearity of the above equation, the mean saturation vapour pressure for a day, week, decade or month should be computed as the mean between the saturation vapour pressure at the mean daily maximum and minimum air temperatures for that period:

$$e_s = \frac{e^0(T\max) + e^0(T\min)}{2} \qquad \text{(Eq.3)}$$

Using mean air temperature instead of daily minimum and maximum temperatures results in lower estimates for the mean saturation vapour pressure. The corresponding vapour pressure deficit (a parameter expressing the evaporating power of the atmosphere) will also be smaller and the result will be underestimated. Therefore, the mean saturation vapour pressure is going to be calculated as the mean between the saturation vapour pressure at both the daily maximum and minimum air temperature.

Slope of saturation vapour pressure curve (Δ)

For the calculation of evaporation, the slope of the relationship between saturation vapour pressure and temperature, Δ, is required. The slope of the curve (Fig. 11) at a given temperature is given by equation 2:

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T+237.3}\right)\right]}{(T+237.3)^2} \qquad \text{(Eq. 4)}$$

where

Δ slope of saturation vapour pressure curve at air temperature T [kPa °C^{-1}],

T air temperature [°C],

In the Penman equation, where Δ occurs in the numerator and denominator, the slope of the vapour pressure curve is calculated using mean air temperature (Equation 4).

Relative humidity

The relative humidity (RH) expresses the degree of saturation of the air as a ratio of the actual (e_a) to the saturation (e°(T)) vapour pressure at the same temperature (T):

$$RH = 100\frac{e_a}{e^0(T)} \qquad \text{(Eq.5)}$$

Relative humidity is the ratio between the amount of water the ambient air actually holds and the amount it could hold at the same temperature. It is dimensionless and is commonly given as a percentage. Although the actual vapour pressure might be relatively constant throughout the day, the relative humidity fluctuates between a maximum near sunrise and a minimum around early afternoon. The variation of the

relative humidity is the result of the fact that the saturation vapour pressure is determined by the air temperature. As the temperature changes during the day, the relative humidity also changes substantially.

Actual vapour pressure (e_a)

The actual vapour pressure (ea) is the vapour pressure exerted by the water in the air. When the air is not saturated, the actual vapour pressure will be lower than the saturation vapour pressure. The difference between the saturation and actual vapour pressure is called the vapour pressure deficit or saturation deficit and is an accurate indicator of the actual evaporative capacity of the air.

There are different methods to calculate the actual vapour pressure, for example by derivation from the dewpoint temperature, from psychometric data or from relative humidity data. In this project the last option is going to be used because the relative humidity is one of the data given by Local Agenda 21. It is not clear if it is the RH maximum, minimum or the average, as in the temperature it is distinguish between Tmax and Tmin, it is going to be assumed that is the RH as mean relative humidity because it is not specify if it is maximum or minimum. The vapour pressure (e_a) (kPa) can be calculated form equation, as following:

$$e_a = \frac{RH_{mean}}{100} \times e^0 (T_{mean}) \qquad \text{(Eq.6)}$$

In the equation 6 the daily mean air temperature and the daily mean relative humidity are used to calculate the actual vapour pressure because it has been set that equation 6 produce more accurate results than the equation which is based on the calculation of the actual vapour pressure by means of the maximum and minimum temperatures. This statement is written into the Spanish version of the document *"Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56"* from where most of the formulas to calculate evaporation have been taken.

Evaporation as result of convection and vapour pressure deficit

In Equation 7, E is found using the coefficients derived by experiment for open water (Elizabeth M. Shaw, 1983):

$$E = 0.35 \times (e_s - e_a) \times \left[0.5 + \frac{U}{100} \right] \quad \text{(Eq. 7)}$$

The equation given is one of the equations originally published by Penman and subsequentelly used by Wales-Smith (1971) and McCulloch (1965). The formula was not used with the International Units Systems, for that reason the units are:

E evaporation as result of convection and vapour pressure deficit [mm/day]

(e_s -e_a) vapour pressure deficit [mm of Hg]

U wind speed in miles/days at height of 2 m.

Which means that in order to introduce the data into the formula with the proper units, the vapour pressure deficit calculated in kPa has to be converted to mm of Hg, and the wind speed from m/s to miles/days.

Psychometric constant (γ)

The psychrometric constant, g, is given by:

$$\gamma = \frac{c_p \times P}{\varepsilon \times \lambda} \quad \text{(Eq. 8)}$$

where

γ psychrometric constant [kPa °C^{-1}],

P atmospheric pressure [kPa],

λ latent heat of vaporization, 2.45 [MJ kg^{-1}],

c_p specific air heat, 1.013x10^{-3} [MJ kg^{-1} C^{-1}],

ε ratio molecular weight of water vapour/dry air = 0.622.

> P: atmospheric pressure is the pressure exerted by the weight of the earth's atmosphere. The data of atmospheric pressure is available in mm of Hg, so it has to be converted to kPa (1mm Hg = 101,325 Pa = 101.325 kPa). Although the effect of pressure is small, the daily atmospheric pressure is going to be used to calculate the psychrometric constant.
>
> λ: The latent heat of vaporization expresses the energy required to change a unit mass of water from liquid to water vapour in a constant pressure and constant temperature process. The value of the latent heat varies as a function of

temperature. At a high temperature, less energy will be required than at lower temperatures. λ is given by: $\lambda = 2.501 - (2.361x10^{-3})\ T$ (Eq.9)

where:

λ latent heat of vaporization [MJ kg-1]

T air temperature [°C]

c_p: The specific air heat at constant pressure is the amount of energy required to increase the temperature of a unit mass of air by one degree at constant pressure. Its value depends on the composition of the air, i.e., on its humidity. For average atmospheric conditions a value $c_p = 1.013x10^{-3}$ MJ kg^{-1} C^{-1} can be used.

Solar net radiation

As stated at the beginning of this section the net radiation has been one of the most conflictive data for the calculation of evaporation. After some workdays of thinking about the best way to use the data without units given by Zaragoza Municipality, a final decision was made to estimate the net radiation. Although this estimation is time consuming, the time spent on it is worthy because it is more accurate than using the numbers of solar energy or solar radiation without units.

The following process to determine the net radiation in the absence of radiation data has been taken from the mentioned FAO document.

The net radiation (R_n) is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net longwave radiation (R_{nl}):

$$R_n = R_{ns} - R_{nl} \qquad \text{(Eq. 10)}$$

In the following paragraphs the different steps to achieve this final equation are explained in detail.

In order to calculate the net radiation is necessary to know that the meteorological station is placed in the city of Zaragoza (41º 39´N), which is 199 m above sea level. To estimate the radiation the latitude has to be converted from degrees and minutes to radians by:

$$[radians] = \frac{\pi}{180}[decimal \deg rees] \quad \text{(Eq.11)}$$

So, from degrees and minutes to decimal degrees: 41º 39´ = 41 + 39/60 = 41.65º; and then from decimal degrees to radians: $\varphi = \frac{\pi}{180} * 41.65 = 0.727 rad$

The extraterrestrial radiation, Ra, for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24 \times 60}{\pi} G_{sc} d_r [\varpi_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\varpi)] \quad \text{(Eq.12)}$$

where

R_a extraterrestrial radiation [MJ m^{-2} day^{-1}],

G_{sc} solar constant = 0.0820 MJ m^{-2} min^{-1},

d_r inverse relative distance Earth-Sun (Equation 13),

ω_s sunset hour angle (Equation 15) [rad],

φ latitude [rad] (Equation 11),

δ solar decimation (Equation 14) [rad].

Ra is expressed in the above equation in MJ m-2 day-1.

The inverse relative distance Earth-Sun, d_r, and the solar declination, δ, are given by:

$$d_r = 1 + 0.033 \times \cos\left(\frac{2\pi}{365}\right) J \quad \text{(Eq.13)}$$

$$\delta = 0.409 \times \sin\left(\frac{2\pi}{365} J - 1.39\right) \quad \text{(Eq. 14)}$$

where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

The sunset hour angle, ω_s, is given by:

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)] \quad \text{(Eq.15)}$$

Once the extraterrestrial radiation is known, the next step is the calculation of the solar radiation data derived from air temperature differences. The difference between the maximum and minimum air temperature is related to the degree of cloud cover in a location. Clear-sky conditions result in high temperatures during the day (T_{max}) because the atmosphere is transparent to the incoming solar radiation and in low temperatures during the night (T_{min}) because less outgoing longwave radiation is absorbed by the atmosphere. Therefore, the difference between the maximum and minimum air temperature (T_{max} - T_{min}) can be used as an indicator of the fraction of extraterrestrial radiation that reaches the earth's surface. This principle has been utilized by Hargreaves and Samani to develop estimates of ETo using only air temperature data.

The Hargreaves' radiation formula, adjusted and validated at several weather stations in a variety of climate conditions, becomes:

$$R_s = k_{Rs} \sqrt{(T_{max} - T_{min})} R_a \qquad \text{(Eq. 16)}$$

where
R_a extraterrestrial radiation [MJ m^{-2} d^{-1}],
T_{max} maximum air temperature [°C],
T_{min} minimum air temperature [°C],
k_{Rs} adjustment coefficient for interior locations (0.16) [°$C^{-0.5}$].

The next step is the calculation of the clear-sky solar radiation (R_{so}) by:

$$R_{SO} = \left(0.75 + 2 \times 10^{-5} z\right) R_a \qquad \text{(Eq. 17)}$$

where
z station elevation above sea level [m]

One step forward is the calculation of the net shortwave radiation resulting from the balance between incoming and reflected solar radiation is given by:

$$R_{ns} = (1 - \alpha) \times R_a \qquad \text{(Eq. 18)}$$

Where α is albedo that can be assumed as 0.21.

The previous step to calculate net radiation, is the calculation of net longwave radiation, R_{nl}, which is proportional to the absolute temperature of the surface raised to the fourth power. The formula for R_{nl} is:

$$R_{nl} = \sigma \left[\frac{T^4 \max + T^4 \min}{2} \right] * \left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{SO}} - 0.35\right) \quad \text{Eq. 18}$$

where

R_{nl} net outgoing longwave radiation [MJ m^{-2} day^{-1}],

σ Stefan-Boltzmann constant [4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}],

Tmax, K maximum absolute temperature during the 24-hour period [K = °C + 273.16],

Tmin, K minimum absolute temperature during the 24-hour period [K = °C + 273.16],

e_a actual vapour pressure [kPa],

R_s/R_{so} relative shortwave radiation (limited to ≤ 1.0),

R_s calculated (Equation 16) solar radiation [MJ m-2 day-1],

R_{so} calculated (Equation 17) clear-sky radiation [MJ m-2 day-1].

With all these formulas, one can calculate the solar net radiation with equation 10, the result is given in MJ m^{-2} day^{-1}, in order to use the net radiation in the Penman Formula for evaporation, it has to be converted to equivalent evaporation in mm day^{-1} by using a conversion factor equal to the inverse of the latent heat of vaporization (FAO paper 56, 1998). The conversion from energy values to depths of water or vice versa is given by:

$$Radiation[depthofwater] = \frac{Radiation(energy / surface)}{\lambda \rho_W} \quad \text{(Eq.19)}$$

where

λ latent heat of vaporization [MJ kg^{-1}],

ρ_W density of water, i.e., 1000 kg m-3,

[depth of water] is expressed in m,

[energy/surface] is expressed in MJ m-2

Once the radiation was estimated, the Penman formula (Eq.1) was applied to estimate the daily potential evaporation. To be able to work out such amount of data, it was treated in different excel files.

APPENDIX III: HOW TO USE AQUACYCLE ZARAGOZA

Aquacycle is a free software that can be downloaded form the Catchment Modelling Toolkit website:

http://www.toolkit.net.au/cgibin/WebObjects/toolkit.woa/1/wa/productDetails?productID=1000043&wosid=xnVeYO9extkx6AAstWcRj0

Once Aquacycle has been installed and opened there is an option called “Help” in the main screen that opens the user guide that explains the model and its algorithms. In addition, it has access to two websites where the user can find useful information about the software (Toolkit and Aquacycle websites). Information about the software and contact details for further information is shown in the websites.

In the Aquacycle website, there is a link to a support e-group in which the users and also the writer of the user guide (Grace Mitchell). Some of the questions that appeared during the application of the problem were already discussed in the e-group forum with the solution of the problem, and other question were asked in the forum. Usually, members of the forum replied to the question within a short period of time.

The user guide proposed some articles as further reading to gain more knowledge about the software and how does it works. These articles have been very useful for the development of Zaragoza Aquacycle. One more article about a case study in the city of Athens is recommended as further reading:

- Karka P., Manoli. E., Lekkas D.F., Assimacopoulos, D (2007). A case study on integrated urban water modelling using Aquaclyce. School of Chemical Engineering, National Technical University of Athens.

APPENDIX IV: WORKING IN AN INTERNATIONAL PROJECT

SWITCH PROJECT

This MSc thesis is framed within the context of the SWITCH Project (Sustainable Water management Improves Tomorrow's Cities' Health) led by UNESCO-IHE. Working in a Project of this dimension is not easy because one find a lot of difficulties in the process, but once solved the overall result is very worthy and rich.

In this chapter the advantages and disadvantages of working in an international project are described, but first of all is important to have an overview of the SWITCH Project.

SWITCH is a European Union funded action research program being implemented and co-funded by a cross-disciplinary team of 32 partners (see Table A.1). The "consortium" is from the fields of academic, urban planning, water utility and consulting interests. This network of researchers and practitioners are working directly with stakeholders in ten cities around the globe (see Table A.2 and Fig, A.1). The goal behind this global consortium is that by demonstrating research and sharing knowledge across a range of different geographical, climatic and socio-cultural settings, global adoption of more sustainable solutions can be accelerated (SWITCH Executive Summary, 2007). In other words, SWITCH Project seeks a Paradigm shift in water management to face the pressures of global change (climate change, population growth, increasing urbanization, etc.) to achieve more sustainable cities.

Other important aspect of the SWITCH Project is the development of a group of different stakeholders related to urban water management. This group called Learning Alliance (LA), can be defined as a group of interconnected players that typically includes public sector (ministries, utilities, regulators, educators, research institutes, etc), private sector (industry, financial services, tourism, etc), and civil society players (NGOs, media, professional bodies and unions, advocacy organizations). The main objective of this group is to discuss about the problems of the conventional urban water management (each player has different priorities) find more sustainable solutions by sharing the knowledge and try to achieve the paradigm shift needed to face the pressures that cities are suffering currently due to the global change.

Table A.1: SWITCH partners

Netherlands	**Spain**
UNESCO-IHE	Ayuntamiento de Zaragoza (AYTO)
Stichting International Water & Sanitation Centre (IRC)	**Poland**
ETC Foundation (ETC)	University of Lodz (UL)
Wageningen University (WU)	**Ghana**
United Kingdom	International Water Management Institute (IWMI)
Middlesex University Higher Education Corporation (MU)	Department of Civil Engineering, Kwame Nkrumah University of Science and Technology (DCE-KNUST)
The University of Birmingham (UNI BHAM)	**Brazil**
Ove Arup and partners Limited (ARUP)	Prefeitura Municipal de Belo Horizonte (SUDECAP)
UGMT Limited (UGMT)	Univesidade Federal de Minas Gerais (EFMG)
Loughborough University (WEDC)	**Switzerland**
University of Abertay (UA)	Swiss Federal Institute of technology Lausanne (EPFL)
Germany	**Greece**
Technische Universitat Hamburg-Harburg (TUHH)	National Technical University of Athens (NTUA)
ICLEI – European Secretariat, GmbH (ICLEI)	**Colombia**
Ingenieurgesellschaft Prof. Dr. Sieker mbH (IPS)	Centro Inter-Regional de Abastecimiento y Remocion de Aqua (CINARA)
Technische Universitat Berlin (TU Berlin)	Universidad Nacional (UNAL)
Hamburg Municipality (FHH/BSU/LP)	**Peru**
Israel	IPES – Promocion del Desarrollo Sostenible (IPES
Mekorot Israel National Water Company (MEKOROT)	**Palestine**
The Hebrew University of Jerusalem (HUJI)	House of Water and Environment (HWE)
China	**Egypt**
Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Science (IGSNRR CAS)	Centre for Environment and Development for the Arab Region and Europe
Chongqing University (CHONU)	

Zaragoza, as each demo city, has its own Learning Alliance which was constituted before the start of SWITCH Project. It is called the Water Commission and is a multidisciplinary consultancy team. The meetings are held when there are important topics related to water to be addressed. There are 29 Water Commission members

including university, civil society groups, and neighbourhood representatives. The secretariat is held by the Local Agenda 21 office.

Table A.2: SWITCH demonstration cities

Demonstration City	Country
Germany	Hamburg
U.K.	Birmingham
Poland	Lodz
Spain	Zaragoza
Israel	Tel Aviv
Egypt	Alexandria
Ghana	Accra
China	Beijing
China	Chong Qing
Brazil	Belo Horizonte

EXPERIENCE WITHIN AN INTERNATIONAL PROJECT

Once one knows a bit more about the project, one can imagine its huge scope and the large amount of people involved in it. In the next paragraphs the experience of this MSc research gives an idea of the difficulties and advantages of working in an international project like SWITCH. It is important to mention that only one demonstration city (Zaragoza) and five partners (Wageningen University, University of Birmingham, Municipality of Zaragoza, WEDC Loughborough University and University of Abertay Dundee) are involved in the development of this thesis.

Disadvantages

- Communication

After almost one year of implication within this project, one can state that one of the most important problems is the communication process between partners mainly because of the existence of different mother tongues. The international language used in projects of such extension is English, but the current situation of Zaragoza is that it is difficult to find civil servants within the City Council with the proper required technical skills and a good level of English. Although this situation is changing, there are still a lot of senior employees without English knowledge. This fact makes difficult and slows down the working process due to several communication problems: misunderstandings,

unclear objectives or action plans, unclear implication or tasks of each partner, impossibility of replying the e-mails sent by other partners or even the management team, etc. In addition one can gave the feeling that the other partner is not doing anything in relation to the project but the reality is that they are working in the project but they cannot keep updated the others about their improvement on the project because it is very difficult and time consuming for them to write reports. One solution could be to hire a translator or some one who has all the required skills but it is very costly and furthermore, the City Council does not have the freedom that an university or a private enterprise has to hire staff, the process is more difficult because if the Mayor agrees that this job is needed then there is a public concurrence to get the job and is a slow process.

- Diversity of collaborators

  - Diverse organizations attributes

In relation to the previous paragraph, there is another important aspect that has to be taken into account in an international project: the different organization attributes of the partners that are working in the same project: universities, institutes, private enterprises, municipalities, etc. Depending on it, each organization has more or less resources to dedicate to the project, different priorities, budgets, mobility, etc. Most of theses problems caused by the different type of partners can be explained on the basis of working in Zaragoza Municipality and in collaboration with different universities during the months previous to the realization of this thesis. In Spain, every municipality has a fixed number of staff formed by civil servants that can be hardly increased. In addition, as explained before, a municipality cannot hire people to work full time in the SWITCH Project. This is the current situation of the Local Agenda 21 of Zaragoza Municipality who, besides the daily task that the staff has, it is involved in many environmental projects, both local and international, with very limited human resources. For this reason civil servants have to deal with different projects and tasks at the same time. In addition they have to be available to reply the enquiries that the citizens make. For these reasons, is not possible, as in a university or a private enterprise to have full time workers in the project to make it working faster.

  - Hierarchy of priorities

It is important to have into account that the different partners have a different hierarchy of priorities. Furthermore, due to the staff scarcity if an important report has to be made,

emergency takes place, etc the civil servants in the municipality have to deal with these events of first priority as soon as possible stopping or leaving the other tasks in a second or lower level of priority.

- Mobility

Mobility is an essential characteristic of an international project. Along the process of SWITCH Project many international meetings, in which all partners are welcome to participate, have been held, are held, and will take place in the next years. These meetings seems to be efficient and productive to clarify in each step of the project the responsibilities, commitments, economic aspects, tasks, etc. of each partner. The intention of these meetings varies in function of the necessities, there were kick-off meetings at the beginning, meetings about Learning Alliances, training meetings, to discuss about the project itself and the different Work Packages, to put in common the progress of every demonstration city, etc. Although Zaragoza Municipality knows the value of these meetings, they cannot assist to all of them that are of their interest because of the bureaucracy process. To approve an official application for a business travel takes a lot of time, in the best situation it is approved months after the meeting was held.

- Culture

Another important issue is the culture because is very related to the way of working. More and more the use of internet and e-mail correspondence is becoming a daily and spread working and communication tool all around the word. However, within an important amount of the senior civil servants in Zaragoza Municipality it not a common practice, so it takes time to get used to this way of working. In addition, sometimes is so huge the amount of e-mails that they can receive per day that is practically impossible to read, reply to all of them and do the daily tasks. This fact can cause delays in the replies and slow down the process, at least until the people get used to this new way of working.

Advantages

Fortunately, not everything in an international project are disadvantages. This kind of projects allows having a broad overview of the issue they are working on, the urban water management in the case of the SWITCH project. As a result of discussions between different stakeholders all around the world about different points of view, priorities, worries, necessities, pressures, etc. and the sharing of knowledge, more

sustainable solutions can be found to solve specific problems rather than looking only to local aspects of a global problem.

- Multicultural and multidisciplinary research team

International projects, such as SWITCH, allows people from all around the world working in the same or related topics, with the same tools, etc to create an international, multicultural and multidisciplinary researching and learning group. In these groups the knowledge is shared, discussions via Internet or in meetings. The main academic outputs of these global projects are the enrichment of the researches and the fact that studies/research/tools, etc. can be improved or complemented with the experiences of different places worldwide with diverse social, economic, climate, geographic, etc. characteristics and priorities. The main research and practical objectives the SWITCH project wants to achieve is a paradigm shift in the conventional urban water management.

- Sharing experiences

Nowadays, sharing experiences and knowledge is easier than in the past thank to a great improvement of the different sort of communication. The Internet is a very useful communication and working tool where one can search for information, share files, speak with people from all around the world at little or no cost. Furthermore, transport has also been improved, so mobility is easier, cheaper and faster than in the past, and with it the post mail can reach it destination faster.

- Meetings

There are good opportunities of meeting people who are working on the same or related topics and tools. This gives the opportunity to interchange knowledge, discuss encountered problems, and share the solutions to these problems. It is also an excellent teaching method because experts or more experienced people can assist. They advice about good literature and share knowledge with beginners, who later will continue with the knowledge cycle.

INTERNATIONAL MEETINGS

Two different meetings, with different purposes, were held during the study timeframe of the thesis. The first one was held in Zaragoza the second week of June and the second one was held in Birmingham the first week of July. The objectives of the meeting in Zaragoza were the assistance to a SWITCH meeting and data collection, while the

objective of the meeting in Birmingham mainly the discussion about the Aquacycle software. Both meetings, which are described in the next paragraphs, were very productive and useful for the development of this thesis.

Zaragoza meeting

A workshop was held during the second week of June 2007 within Zaragoza Municipality, Abertay University and Loughborough University, a SWITCH partner working on W.P. 3.1 Water Demand Management, the one in which Zaragoza is committed. It was a good opportunity for the Author to go to this event due to several reasons. After three weeks of literature review and once the objectives of the thesis were clearer, it was easier to specify the required data and ask directly to the proper department or at least to make contacts for future situations. The fact of going to Zaragoza was a good opportunity to collect data due to the difficulties of do it in the distance. Another important reason is the occasion of meeting Sam Kayaga, a senior researcher from Loughborough University who is working in W.P. 3.1 and discuss with him about the study area, the urban water management and have his support and interest to collect the data needed for this thesis. Furthermore, the Author gives support in translation and communication in the meetings that here held when needed.

Several meetings were held with all the departments of the Local Agenda 21 involved in the SWITCH project. The Cabinet of Environmental Education explained the program and activities that are going to be undertaken in the academic year 2007/2008 in the schools and in more detail these ones which are related to water and SWITCH. They explained as well that the SWITCH project is going to be introduced to the neighbours of the study area during the summer of 2007 in the swimming pools. Another important action of this department for SWITCH is the act of making contacts to find volunteers that allow the Municipality to control their water uses within the houses and to make enquiries about their water consumption behaviour. This data -water indoor usage- is one of the large lists of required data for this thesis that is not available currently and will be measured as an objective of SWITCH. The University of Zaragoza, the Applied Economy Department, is going to analyse and make conclusions about water indoor usage in the Actur-Rey Fernando neighbourhood, with the data gathered by the water meters in the houses and enquiries.

Another meeting was held as well with the Infrastructure Department of Zaragoza Municipality, exactly with the section of Conservation and Exploitation that is the one involved directly in SWITCH. They are in charge of the Total Urban Water Cycle of the city of Zaragoza, from the drinking water treatment plant to the wastewater treatment plant. They have all the information about the network system in Zaragoza, the rates of leakages, etc. A map of one sector of the study area was provided to both visitors. Once again, as an objective of SWITCH they will find out the water consumption and pattern in each sector of the Actur area. One water meter is already installed in an isolated sector of the Actur, but unfortunately by the date of the meeting the data was not available because the meter had been active only one week and there were problems with the readings. This meeting was very productive to continue with the development of W.P 3.1.

The department in charge of noise pollution provided a folder with GIS information about the city of Zaragoza, very useful to obtain the required data about roofs, roads, paved and open spaces areas. In the GIS one can also know the use of the soil (residential, green areas…), the area of the buildings and the number of floors that each building has. Together with this information, an excel file with the population per district in each area was provided. There were a problem when trying to open the folders and they gave fast and efficient support by e-mail. In addition, some weeks later, a more detailed excel file with the population per sector was sent.

Although the visit to Zaragoza was very productive, it was not possible to collect all the data as a result of a short stay of only three working days, the attendance to the meetings related to SWITCH, the fact that some staff were on holidays and that the data is not entirely available in the Local Agenda 21 and they have to ask to other departments to collect it and send it. In the worst situation the data is not available and some assumptions have to been made to continue with the research.

Birmingham meeting

The second meeting was held in Birmingham with a PhD student working under the direction of Professor Rae MacKay who is also working with the Aquacylce software. The PhD student had more knowledge because he had been working for a longer period making the meeting very productive for the Author who did not have all the data

available to run the program by the date of the meeting. For this reason, the main topic of the meeting was how to solve problems when data is not available as opposed to sharing the outputs and comparing the models made of different cities. The PhD student was very helpful and explained how to deal with the difficulties and where to look for literature. Initially, he was a bit reluctant to share a document with calculations about potential evaporation – a required input data for the program- in which he spent two working weeks, but quickly he changed his mind and decide to share it. The PhD student also explained and shared the document with the instructions about how to use an ArcGIS tool, needed to calculate areas, which are also input data. A further important topic was the development of SWITCH Aquacycle, in which the PhD student was working on and will be used by her to model the total urban water cycle of the city of Zaragoza including energy consumption.

This meeting showed that, once collaborators know each other, is easier to keep in touch by e-mail o phone to talk about the problems, the models and the outputs.

CHALLENGES

It is a very good way to deal with global problems that affect the whole world population at an international level and not only at local one, as it is the case of Urban Water Management. For this reason, it is important to increase the stakeholders and partners awareness about the pressures that our planet is suffering and work together. This is not an easy task because a significant effort of all the partners and collaborators is needed, to find a more sustainable ways of the current UWM.

In addition, the communication problems, different stakeholder's priorities, different kind of partners with diverse limitations (budget, mobility, etc.) explained in section 4.2. Have to be solved as better as possible because if the final result of the SWITCH project is the expected one, the benefit of the overall project overcomes the disadvantages.