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# Systems Analysis of Zaragoza Urban Water System (Spain): A Preliminary Assessment of Environmental Sustainability

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# Systems Analysis of Zaragoza Urban Water System (Spain): A Preliminary Assessment of Environmental Sustainability

Master of Science Thesis
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## Abstract

The environmental performance of Zaragoza urban water system of (Spain) is analyzed by means of LCA with focus on water withdrawal and use; energy and chemical products consumption; $CO_2$ emissions; and emissions of nutrients and heavy metals to the receiving water body and to sewage sludge. All these variables are recommended to be used as indicators for sustainability of this urban water system. The time horizon covers six years between 2000 and 2006; a period where the water supply system is being optimized and industrial and water consumption is being reduced. Results show that despite a significant reduction of water withdrawal and unaccounted, resource consumption and final releases to the environment have remained steady. Groundwater is an important component of the urban water cycle, but due to its origin as agriculture irrigation excess if facing issues of quality. This resource will be possibly threatened in the future if irrigation systems upstream from Zaragoza are optimized. A problem tree analysis revealed that mayor drivers of environmental sustainability for Zaragoza water cycle are population increase; Spanish national policies on water and environment and climate change. A scenario analysis showed that industrial recycling would be a good strategy to continue reducing water withdrawal and it will also contribute to reduce energy consumption as well as $CO_2$ emissions, whereas all other analyzed indicators are expected to worsen as long as current societal production and consumption patterns; and wastewater treatment technologies remain the same. Comprehensive strategies that involve not just technical solutions are required in order to assure the environmental sustainability of this system.

**Keywords:** Environmental performance, Life cycle assessment, sustainability indicators, urban water systems, pollution loads, resource consumption, scenario analysis.

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## Table of Contents

## List of figures

## List of tables

## List of annexes

## Abbreviations

| | |
|---|---|
| BOD | Biological Oxygen Demand |
| COD | Chemical Oxygen Demand |
| CHE | Ebro River Hydrographic Confederation |
| $CO_2$ | Carbon dioxide |
| DBPs | Disinfection By-products |
| DOM | Dissolved Organic Matter |
| DWT | Drinking Water Treatment |
| DWTP | Drinking Water Treatment Plant |
| Gwh | Giga watt per hour |
| EU | European Union |
| GIS | Geographic information system |
| Ha | Hectare |
| LCA | Life Cycle Analysis |
| LCI | Life Cycle Inventory |
| $mg\ l^{-1}$ | milligrams per liter |
| $\mu g\ l^{-1}$ | micrograms per liter |
| mm | millimeters |
| $m^3$ | cubic meters |
| $m^3\ year^{-1}$ | cubic meters per year |
| Mwh | Mega watt per hour |
| $l\ person^{-1}\ day^{-1}$ | liters per person per day |
| OM | Organic Matter |
| PAC | Powdered Activated Carbon |
| SD | Sustainable Development |
| SDI | Sustainable Development Indicator |
| SFA | Substance Flow Analysis |
| SS | Suspended Solids |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| UW | Urban Water |
| UW | Urban Water System |
| WWT | Wastewater Treatment |
| WWTP | Wastewater Treatment Plant |

# 1 Introduction

Approximately half of the world’s population is nowadays living in cities. This percentage is increasing and so is doing their demand for natural resources as well as their pollution loads to the environment. It is reasonable to assume that if cities can become sustainable then society as a whole will follow the tendency. A key aspect on sustainability of the cities is the urban water system (UNESCO, 1999; Hellstrom et al, 2004).

A sustainable urban water system should provide its services while protecting human health and the environment, with an optimum use of scarce resources over a long term perspective (ASCE, 1998). There is a strong need of developing and implementing indicators that make the concept measurable by quantifying trends towards optimization, not just of existing water and wastewater technologies but of urban societies as a whole (Larsen and Guier, 1997).

Along the whole urban water cycle, important impacts on the environment take place: water is consumed, as well as energy and chemical products. On the other hand organic matter, nutrients and persistent pollutants are entering the ecosystems. A quantification of all these negative effects upon the environment is considered to be a good indicator of environmental sustainability (Larsen and Guier, 1997; Varis and Somlyody, 1997; Lundin; 1999).

This study aims to analyze the environmental performance of Zaragoza Urban Water System in Spain with regard to the use of natural resources and pollutant loads to the environment. The use of natural resources is assessed with regard to water withdrawal as well as energy and chemical products consumption. Considered pollution loads are atmospheric emissions, oxygen demands to the river, nitrogen, phosphorus and heavy metals. Such analysis will serve as baseline information for further assessment of sustainable development. This research work only deals with the operational aspects of the UWS and does not include construction, upgrading and demolition of infrastructure.

The present research is included within the SWITCH project framework, program 1 which aims to assess the adjustability of Urban Water Systems to global change pressures from a strategic approach based on sustainability and risk assessment.

# 2 Background

Sustainability of Water resources is a concept that concerns all levels of planning and management, from local to global agendas. Since cities are major water consumers, sustainability of urban water systems is increasingly becoming a major issue, receiving considerable effort from researchers and managers in both developed and developing countries (Larsen and Guier, 1997; Varis and Somlyody, 1997; Lundin; 1999).

Several research projects have taken place during the last decade, mostly in European Countries. But there are also international partnerships which have included studies upon model cities in Africa and Asia. The Swedish Urban Water Project Mistra deserves special recognition since it produced numerous publications, PhD thesis and reports concerning several aspects of Urban Water Systems not just for European, but also to Asian and African cities such as Calcutta and Cairo (Hellstrom et al, 2004). Approaches similar to Mistra are taking place at different scales in Australia, Germany, and Belgium (Lundie et al, 2004).

Assessing sustainability of Urban Water Systems is a major task considering the high complexity of such a system. Decision-making needs to consider several aspects of health, environment, economy, socio-culture and technical function within a framework that includes interactions between users, organizations and technology. Important issues compromising sustainability in all these aspects are the efficient use of water and energy, the assessment for microbial risk, nutrient recycling and the emission toxic substances to the environment (Malmqvist and Palmquist, 2005, Jeppson and Hellstrom, 2002).

The efficient use of water and energy is related to all processes taking place in the Urban Water System, the microbial risk is of primary concern for drinking water supply, nutrient recycling and toxic substances are related to wastewater treatment and sludge disposal. Nevertheless, several studies have proven that untreated storm water is a major responsible for hazardous emissions coming form cities. This fact along with the well known risks related to floods has increasingly turned the attention towards planning and management of storm water as a key element for Urban Sustainability (Jeppson and Hellstrom, 2002)

There is a need of information tools that serve to evaluate this complexity and search for alternatives that make the concept of sustainability fully operational for the Urban Water System. Initial interest of researchers and decision makers in this regard was to produce ad hoc Indicators for Sustainable Development (Lundin and Morrison, 2002)

A large number of indicators are used by water and waste water organizations to assess their technical performance. Such indicators may differ between different organizations and different countries. The results are large amounts of data, difficult to understand and to interpret. Besides only few of those indicators have been developed to quantify sustainability. There is still a need for a limited number of sustainability indicators for urban water systems (Lundin, 1999).

One of the main problems of quantifying sustainability is the lack of a structured methodology to develop indicators, with the consequent risk that such indicators would be ineffective and, possibly detrimental in promoting sustainability objectives (Lundin and Morrison, 2002). Therefore, recent studies have based on Systems Analysis Approach and have used techniques related to the concept of industrial ecology, such as Material Flow Analysis and Life Cycle Assessment. When properly followed, those techniques have proven to be quite effective to evaluate environmental performance of Urban Water Systems. Some authors have concluded that such techniques are needed as a basis for all other studies concerning Urban Water Systems because the flows, the major sources and the fate of water and its major constituents such as nutrients, pathogens and harmful chemicals, must be clear for all alternative management strategies (Ahlman, 2006; Benedetti et al., 2005; Lindqvist and Malmborg, 2004).

LCA analysis is suggested to be a comprehensive technique to assess environmental sustainability of UWS. The term “Life cycle” referes to the major activities in the course of a product lifespan from its manufacture, use and maintenance, to its final disposal, including the raw material acquisition required to manufacture the product. Impacts related to outputs will be emissions to different environmental compartments (Lundin and Morrison, 2002).

The main advantage of LCA is that it can contribute to evaluate the impacts upon different environmental compartments, preventing the implementation of management options that, in the search for mitigation, end up by shifting pollution from one place to another. This is the trade-off of for instance, the alternative of nutrient recycling from wastewater treatment sludge, which will protect the receiving water body, but can constitute a further risk for arable land protection, since such sludge may content not just nutrients, but also heavy metals, being also a further risk for food security (Malmqvist & Palmquist, 2005).

During the last decade there have been many research works using LCA to assess urban water systems. One of the major problems faced by this technique is the definition of system boundaries. Many choices can be made in terms of time horizon, geographic borders as well as functional boundaries. Results will be very much affected by such choices, being often not comparable. For instance most studies have focused on either water supply or on WWT systems.

Crettaz et al. (1997) evaluated different alternatives for alternatives drinking water distribution and treatment as well as wastewater treatment. They also assessed on-site alternatives such as rainwater storage, sewage separation and water-saving toilets. Authors found that rainwater use was not favorable in terms of energy consumption and also it would lead to a higher contamination of heavy metals to water and soils.

Roeleveld et al. (1997) performed an LCA of different conventional wastewater treatment methods in at a national level in the Netherlands. The authors concluded that to improve the sustainability, the discharge of emissions should be reduced from the effluent. Energy use, construction and the use of chemicals were considered less important as compared to the operation of the system.

Matsuhashi et al. (1997) compared different sludge treatment processes: landfilling, incineration, ozonation and composting. One conclusion the authors draw was that when sludge is used to improve soil fertility, the benefit should be compared with an LCA for production and use of chemical fertilizer.

Neumayr et al. (1997) compared six different alternatives for sludge recycling strategies. Authors found that energy consumption, foil fuels used for transportation and direct emissions from composting and dewatering were the most significant impacts. Anaerobic treatment showed lower energy consumption than aerobic digestion.

Swage management alternatives in contraposition form end-of-pipe technologies were evaluated by Bengtsson et al., (1997) compared conventional wastewater systems with liquid composting and urine separation. The study showed that the separation system has lower pollution loads to water and is more efficient for nutrient recycling than conventional systems.

Only few studies have addressed the whole urban water cycle (Lassaux et al, 2005) and even with similar choices of system boundaries, the outcomes might be contrasting. Some publications give more importance to energy and chemical consumption, other stress groundwater withdrawal, other suggest that more attention should be given to pollution burdens (nutrients, BOD, heavy metals, etc). Results will differ from each other depending on the scale of the system, the economic development of the city subjected to study, the external activities that are considered and even the base unit for impact calculation: per year, per person and per year, per cubic meter of water.

System Boundaries should be chosen according to the purpose of the study (Lundin and Morrison, 2002), but LCA is aimed to avoid planning and operation alternatives that improve environmental performance of one sub process but worsen other part of the cycle. In principle an LCA should include as many upstream and downstream externalities associated with the system as possible.

Upstream activities considered in LCA studies of UWS largely focus on chemical use for both drinking and waste water treatment, energy consumption and atmospheric emissions related to transporting chemicals from producers to water facilities should be included within system boundaries. A more comprehensive approach would also include energy consumption and hazardous emissions related to the production of such chemicals (Lassaux et al., 2005; Lundie et al., 2004)

Most evident downstream activity of a UWS is WW discharge. Most LCA studies also focus on sludge production and final disposal. Water recovering, nutrient recycling and minimizing hazardous emissions are the main subject here. Once again energy consumption and atmospheric emissions derived from sludge disposal are suggested to be included within system boundaries.

Another important question concerning system boundaries is water infrastructure. The usual time perspective to plan and construct a UWS is of several decades. But sustainability is a long term concept, therefore a time horizon projection of about 100 years is suggested. The construction of the water supply also may have significant environmental impacts which can be quantified such impact on the basis of the mass of material needed to construct the pipes, considering lengths, diameters and comparing different materials. Environmental Impact of putting pipes into the ground may also be considered (Lundin & Morrison, 2002)

Lassaux et al. (2005) found infrastructure construction as having a significant contribution to the overall environmental impacts of the UWS. This is very important since improving WWT systems will increase environmental impacts in one way, because materials are used for construction, and then chemicals and energy are consumed. The authors also found that construction phase is responsible for important environmental impacts before tap (withdrawal pipeline, drinking water treatment, and distribution network) have less impact than stages after tap (sewer system and WWTP). In fact sewer network construction was the factor that contributed the most to the global environmental load of the anthropogenic water cycle from the Wallon region in Belgium. In contrast, Lundie et al. (2004) found infrastructure construction to contribute with less than 4% of all different categories of burdens to the environment, for both present conditions and alternative future scenarios of Sydney's UWS.

Lundie et al. (2004) used an LCA approach for assessing alternative future scenarios for strategic planning of Sydney's UWS with a high degree of segmentation within the system. In order to select the best environmental performance different alternatives were classified after LCA in two categories: (1) options that improve the overall environmental performance and (2) options that improve one area of the system but worsen other areas. Sustainability is about management options that improve the system as a whole.

This is one of few LCA studies covering the whole UWS. Main focus regarding environmental performance was given to water withdrawal and energy consumption.

Evaluated scenarios included different degrees of upgrading existing technology, centralize vs on-site treatment and demand management. The aim of this study was perform a holistic assessment of the system in order to show which aspects of the business are responsible for the largest environmental burdens and to compare alternative future scenarios. This was part of reviewing the Local Water plan 21.

Authors concluded that implementing desalination plants for drinking water treatment would significantly increase greenhouse emissions while achieving a fairly small increase of water supply, upgrading existing WWTPs to perform tertiary treatment would decrease the potential for eutrophication of coastal waters but it will worsen all other indicators of environmental performance. Authors conclude that scenarios that integrate several management options than just upgrading existing technology are the ones that actually improve the overall environmental performance.

# 3 Materials and Methods

## 3.1 Study site

**Figure 1. Satellite map for Zaragoza and its location in Spain** (Source: google maps, http://maps.google.es/maps?oi=eu_map&q=Zaragoza&hl=en)

Zaragoza is the capital city of the autonomous region of Aragon in Spain, and is located on the Ebro River Catchment, and its tributaries the Huerva and Gállego. The city is 199 metres above sea level and is near the centre of the region. The population of the city is around 700.000, ranking fifth in Spain. 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 concentrated in 67 days, ranking as the driest inland region in Europe. The Ebro River drains a triangular basin with an area of 85.820 Km², between the Pyrenees and the Iberian Mountains, with the Cantabrian Mountains as northern border. The Ebro is the largest river in Spain with a course 928 km long and total annual discharge of 19,000 million $m^3$. The main use of water resources along the Ebro River Catchment is agricultural irrigation, followed by hydropower generation, urban supply and Industrial activities. The river is characterized by a wide range of seasonal variation of the river discharge. Therefore, since the 1930's, 138 reservoirs have been constructed in the river basin, with a total storage capacity of 6,837 Hm³ (CHE, 2007)

The Municipality of Zaragoza is responsible for water planning and management in the city. They own and operate facilities for drinking water supply, sewers and wastewater treatment plants. During the last decade Zaragoza has carried out several important projects concerning water management. In 1993 a WWTP providing tertiary treatment was built. At the same time sewerage system began expanding and nowadays almost all industrial discharges -with two special exceptions that will be further discussed in this report- are connected to sewers.

In 1997 the city started a project called “Zaragoza water saving city”, consisting of education programs to encourage rational water use at households and industries by means of water saving devices and improving consumption habits. The municipality committed within this project to a rational use of water for landscaping. In 2005 this project managed to considerably reduce water demand and it was selected by Habitat UN as one of the 100 successful projects concerning urban sustainability worldwide. Currently municipality is using tariffs for water supply and WWT services as an instrument to punish excessive consumption as well as to reward saving. In the year 2000 both national and regional government approved a project aimed to shift the tap water source from the Ebro to the Aragon River regulated in “Yesa” reservoir in the Pyrenees, where water quality is more suitable for human consumption than in the Ebro River.

In 2002 municipality initiated a seven years project aimed to improve water supply for Zaragoza. This project consists on (1) upgrading the DWTP, (2) replacing, upgrading or taking out of work existing tanks and pumping stations and (3) replacing a considerable percentage of the pipeline network. Total investment for this project is around 82 million euro. As result of all these efforts Zaragoza’s water withdrawal has significantly decreased.

### 3.2 General Approach

A systems approach is used here to analyze the Urban Water System of Zaragoza by means of Life Cycle Analysis (LCA). The procedure usually comprises four steeps: (1) goal and system definition, (2) life cycle inventory (3) impact assessment and (4) interpretation (U.S EPA, 2006; Ayers and Ayers, 2002). For the present work the step 3 was not carried out and interpretation is made from the life cycle inventory.

### 3.2.1 Developing flow diagram

First step to define system boundaries is developing a flow diagram showing the processes to be evaluated. In the present work the aim is to analyze all the major processes for the urban water system: water withdrawal, water treatment and distribution, water use, wastewater transportation and wastewater treatment. Along these processes a water balance is made and major flows and stocks of chemical products, nutrients and heavy metals are considered. The direct and indirect consumptions of energy (transportation of chemical products and sludge) are also considered, as well as direct (sewage sludge treatment and disposal) and indirect atmospheric emissions (derived from energy consumption).

### 3.2.2 Time horizon

An assessment of sustainability should ideally extend over a time horizon of several decades (Lundin and Morrison, 2002). However due to time and data constraints, the time period considered here is six years, which considers major investments on improving the technical performance of the water system.

### 3.2.3 Data collection

Data collection for this M Sc research lasted from November the 8th up to December the 29th. As starting point staff from the Local Agenda 21 Office provided some reports concerning water management in Zaragoza as well as specific features of the Urban Water System and its evolution during the last decade.

Most time was devoted to carefully review those reports in order to fully understand the sustainability issues that have been already identified by the municipality as well as other issues, probably neglected so far and which might be interesting for the SWITCH project.

Recent data necessary to perform mass and energy balances are partially available in different electronic formats such as notepad, pdf, word, excel, etc. Historical data are mostly available only in hard copies. When specific information concerning Zaragoza system was not available, the extrapolation of general information has been considered.

### 3.2.4 Data analysis

A water balance was performed from the information available at Zaragoza municipality (figure 2, and annexes). Mass balances were performed for $BOD_5$, COD, TN, TP and Heavy metals at the WWTPs. As shown in Annex 1 there are several processes for which there are no data available at Zaragoza municipality. For such processes, assumptions and extrapolations from literature values were made. A description of these assumptions and calculations is provided next.

#### 3.2.4.1 Storm water

No data concerning storm water quality exits in Zaragoza (which is understandable for a semiarid region) therefore the possible effects of storm water upon WWT performance are completely unknown. The possible effect of storm water upon the Ebro River is here extrapolated from the chemical characteristics of sewage and the possible overflows, which have not been actually measured, but have been estimated as follows (for raw data and calculations for storm water refer to annexe 10):

$$\text{Estimated storm water} = \text{Precipitation} * \text{impervious area}$$

$$\text{Overflows} = \text{Estimated storm water} + \text{Expected WWTPs inflow} - \text{Actual inflow to WWTPs}$$

Daily precipitation data for Zaragoza was provided by the Local Agenda 21 Office at Zaragoza municipality. There were no data concerning evaporation, extrapolation was made from Marti (2000).

#### 3.2.4.2 **Energy consumption and $CO_2$ emissions from transportation**

Environmental impacts derived from transporting both chemical products and sludge were calculated as energy consumption and $CO_2$ emissions to the atmosphere. Factors from Thonstad (2005) were used (for raw data and calculations refer to annex 9)

#### 3.2.4.3 $CO_2$ Emissions from electricity consumption

Raw data concerning energy consumption of the DWTP and the WWTPs were provided by the Local Agenda 21 Office at Zaragoza. The derived $CO_2$ emissions were calculated regarding the electric energy sources in Spain provided by Ministerio de Industria, Turismo y Comercio de España (2007) referred in figure 9. Emission factors from European Commission (1995) were used (for raw data and calculations refer to annex 8).

#### 3.2.4.4 $CO_2$ production from sludge

Wastewater sludge emits $CO_2$ as a function of the OM concentration. Raw data regarding wastewater sludge production at the WWTPs were provided by the Local Agenda 21 Office at Zaragoza municipality. COD content in the sludge was calculated from the mass balance between inflow and outflow load at each facility. Multiplication factors from Levlin (2005) were used to calculate TOC content and $CO_2$:

$$\text{TOC} = 40\% \text{ of COD}$$

$$CO_2 = 3.66*\text{TOC}$$

### 3.2.5 Scenario analysis

Based on the collected data, an exercise for Scenario Analysis is presented following the methodology suggested by Assimacopoulos (2007) in which the main drivers for change and sustainability are identified by means of a problem tree analysis. Drivers are qualitatively discriminated under the criteria of importance and uncertainty. Possible scenarios resulting from the combination of drivers considered as more important and more uncertain are set. Finally strategies to cope with such scenarios are suggested. The aim of the strategies is to adapt the system to reach a sustainability vision.

# 4 Results

## 4.1 Data availability and information gaps

In order to improve processes it is necessary to get a set of data that describes such processes as best as possible. Therefore, one of the goals of this research was to identify current information gaps that need to be filled in order for Zaragoza municipality and other stakeholders to get a better picture of the weaknesses and strengths of the urban water system, which will significantly contribute to set up priorities. The following are the information gaps identified to be important in this research:

1. Groundwater recharge
2. Parasitic water to the sewers
3. Storm water quantity and quality
4. Industrial vs Domestic contribution to pollution loads to the sewage
5. Actual leakage in the distribution network
6. Distribution and Sewer network modeling

Both distribution and sewer network are fully mapped and implemented in a GIS, which is of high potential for covering information gaps and improve water management.

Annex 1 lists the information necessary for LCA and its availability at Zaragoza municipality. The frequency of measurements or samplings, the type of data and the aggregation level are also described. Most data are available from 2000, previous data exists as hardcopies deposited in archives which were not assessed due to time limitation for this M Sc project. Most data gathered were measured with some exceptions were estimations were made from printed reports. Since no modeling has been implemented by the Municipality to any of the UWS process there are no modeled data.

## 4.2 General features of Zaragoza UWS

Figure 2 shows the flow diagram for Zaragoza UWS, including a water balance and material inputs (chemical products) and outputs (sludge). The general features of this water system are summarized in this figure where 8 levels are recognized: (1) water inputs which includes storm water, tap water source, agriculture irrigation and groundwater; (2) drinking water treatment process; (3) distribution system; (4) Water consumption and use, which includes households, public facilities, landscaping, industry connected to the sewer system and industry using exclusively groundwater and not connected to the sewer system; (5) combined sewer system (6) WWTP which includes two public facilities and two private ones (7) receiving environment and (8) chemical products used for both DWT and WWT. Every level will be explained in more detail next and figure 2 will remain as recurrent reference along the text.

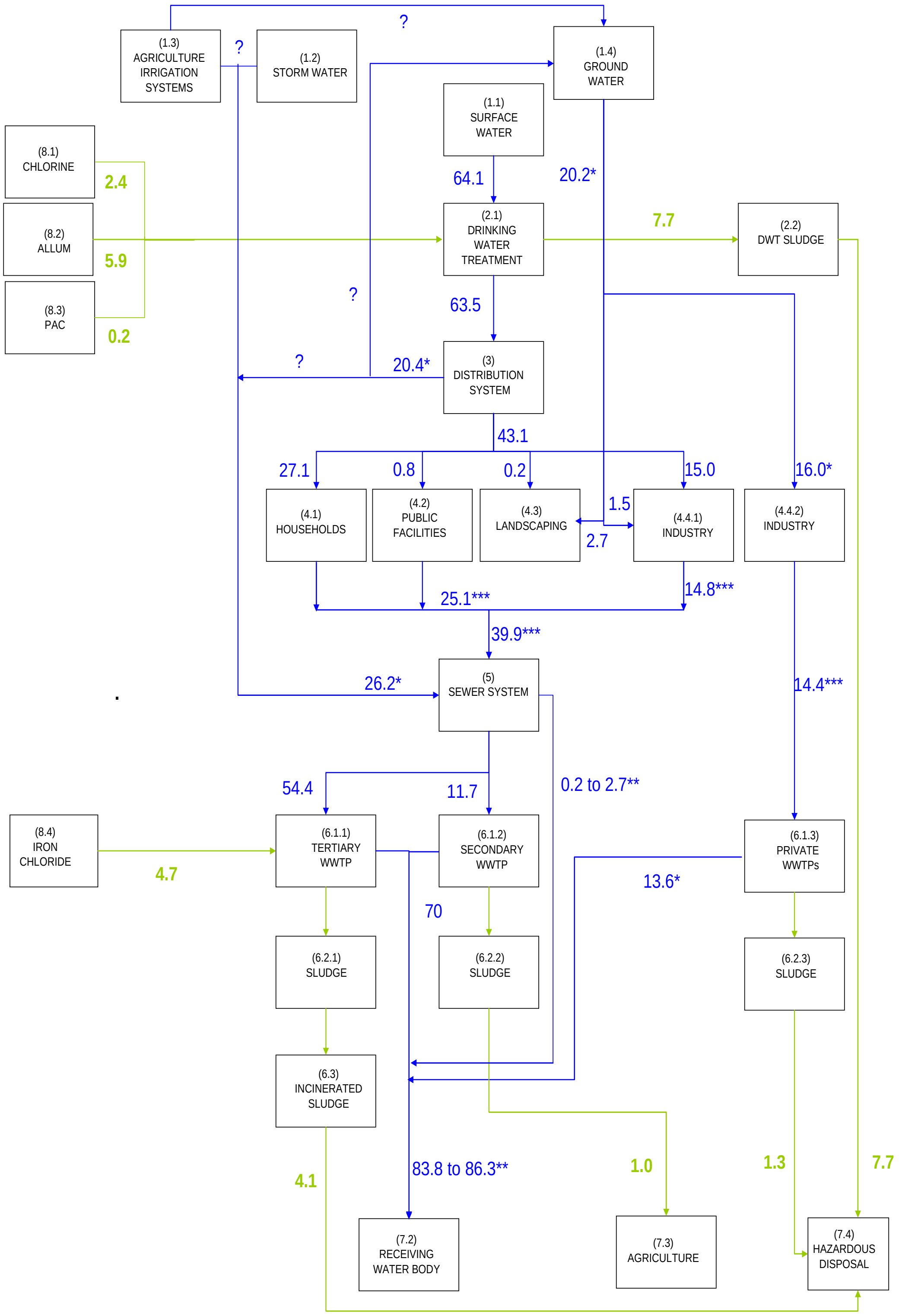

**Figure 2. Flow Diagram for Zaragoza UWS.** Lines and numbers in blue stand for water flows (units are million $m^3$ per year). Chemical products as well as sludge flows are represented by lines and numbers in green (units are thousand tons per year). Data used for this diagram are from the year 2006.

* Values that have not been measured but estimated
** Storm water overflows were estimated for the period 2001 – 2006 and are completely different between years. Therefore an average value is not given, but rather a range.
*** 90% of water use is assumed to go to the wastewater system
? Indicates balances that could not be completed due to information gaps
Values that have been actually measured are not given any mark in this figure

### 4.2.1 Water inputs

#### 4.2.1.1 Tap water source

Tap water source which is the Ebro river diverted 110 km upstream from Zaragoza by “Canal Imperial de Aragon”. Ebro river discharge 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. Quantity is sufficient to supply the city all over the year because the river is largely regulated by dams up stream, otherwise the city would suffer from shortages during summer time. For the year 2006 total water withdrawal for Zaragoza was 64.1 million $m^3$ without including ground water (see figure 3).

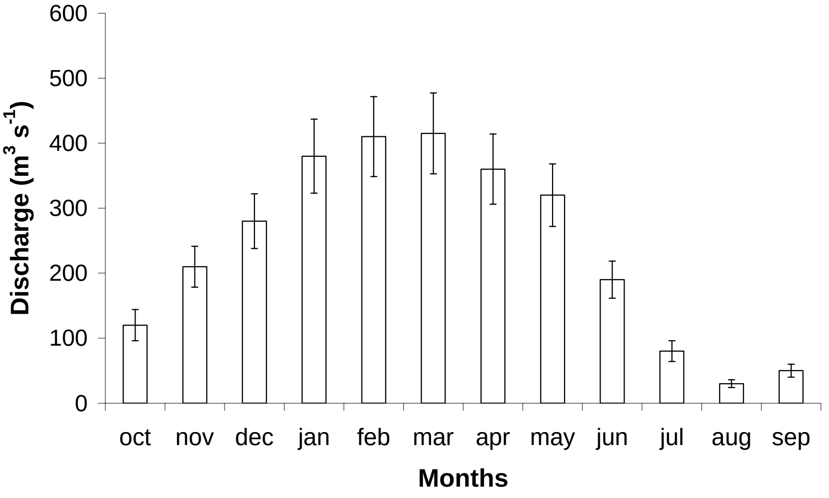

**Figure 3. Ebro river discharge at “Canal Imperial” diversion (Source: CHE, 2007)**

Raw water quality in Zaragoza is very much affected by the seasonal fluctuations of the Ebro River. Conductivity and hardness increase in summer time due to the strong reduction in water discharge, making water eventually unsuitable for drinking purposes. During spring and fall high discharges reduce conductivity but suspended solids and organic matter –mostly humic substances exerting high chlorine demands– significantly increase. More suitable water quality is achieved only during winter time. High chlorine demands eventually lead to hyper-chlorination and to high concentrations of oxidation and disinfection by-products. Several parameters of tap water quality often exceed standard regulations (Local Agenda 21 Office of Zaragoza, 2002). Due to these characteristics of raw water quality, drinking water treatment in Zaragoza requires large amounts of chemical reagents implying not jus a high cost of water treatment, but also a risk to public health due to DBPs.

Shifting to a different raw water source and thereby reducing treatment cost and improving water quality is a strong need for the city. From 2008 the city will receive water from the Pyrenees, specifically from the Yesa reservoir which regulates the Aragon River and is also used for irrigation and hydropower production. A significant improvement of tap water quality for Zaragoza is expected from this new source. This will be discussed further on in the Scenario Analysis section.

#### 4.2.1.2 Storm water

Zaragoza is located in a semiarid region with an average precipitation of 270 mm per year, which is concentrated within 70 to 80 days (see figure 4a, showing 2006 daily based hydrograph as example). Precipitation per day in Zaragoza would rarely exceed 20 mm and dry and wet periods are not quite distinct. However, highest maximums and highest averages are reached in May and in September, but rarely exceeding 50 mm per month. Lowest averages and lowest minimums are usually reached in August and in December (see figure 4b).

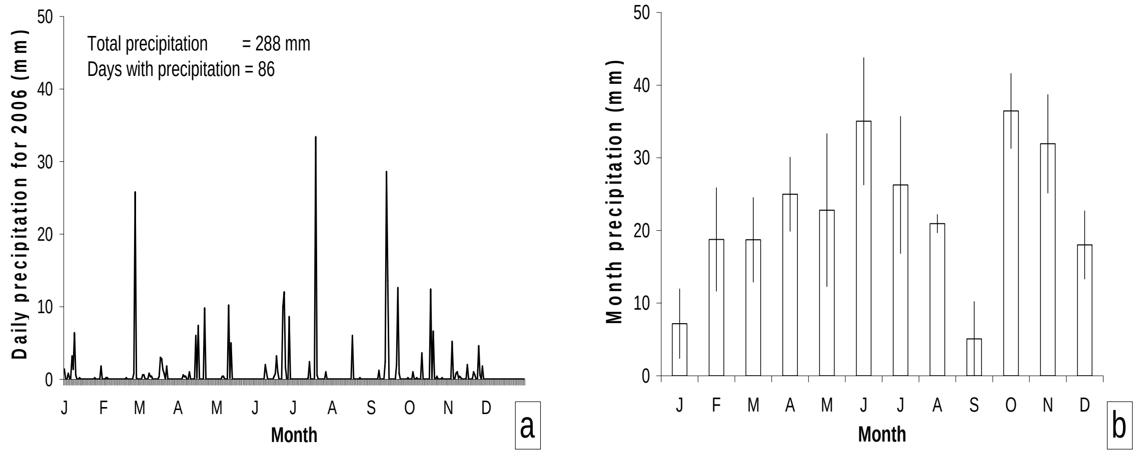

**Figure 4. Annual precipitation hydrographs for Zaragoza.**
**4a. Daily based hydrograph for 2006**
**4b. Month averages**. Error bars represent standard deviation
**Source Local Agenda 21 Office of Zaragoza**

Due to these hydrologic conditions storm water is not considered an issue by the Municipality. Nevertheless eventual overflows of storm water are discharged directly in the Ebro River without any treatment. Therefore Municipality is building two storm water tanks to prevent the consequent pollution of the river. They are also considering about using storm water for cleaning public facilities or for landscaping.

According to the municipality staff the sewer system has got serous dimensional limitations. Therefore, even under the consideration that Zaragoza is a semiarid region, storm water might saturate the system and overflow to the Ebro River under strong rain events

#### 4.2.1.3 Agriculture irrigation systems

The Ebro Valley at Aragon is the driest inland region of Europe. In fact most of the area around Zaragoza is naturally either bare or covered with desert-like vegetation. Water deficits are high due to low precipitation (less than 300 mm) and high evapotranspiration (more than 800 mm). Most of the soils of the region are Aridisols, and show similarities to those of North African deserts. However agriculture is an important activity along the Ebro catchment and the most relevant use of water resources in the catchment is agricultural irrigation. In Zaragoza province, including the surroundings of Zaragoza city, the irrigated area is nearly 177,000 ha (see figure 5).

**Figure 5. Irrigation in Zaragoza province.** This satellite picture shows the desert surroundings of Zaragoza city. All the green areas are irrigated agricultural lands (Source: google maps, http://maps.google.es/maps?oi=eu_map&q=Zaragoza&hl=en)
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Irrigation water is considered here as an input for Zaragoza UWS for two reasons: 1) excess water from irrigation is 100% responsible for recharging the city's aquifer and 2) some irrigation systems in the borders of urban area become parasitic water to the sewer system and end up in the WWTP. Both total contributions to the aquifer as well as to the sewer system are currently unknown.

#### 4.2.1.4 Ground water

In Zaragoza groundwater is not given any price and the water table is relatively shallow (5m in average). It is being extracted for industrial activities and for landscaping but it is not included by Zaragoza's municipality in its account for total water withdrawal because it does not enter the distribution network. The institution responsible for authorizing groundwater extraction is not the Municipality but the CHE.

Figure 2 shows groundwater withdrawal and its use in Zaragoza. The major consumer is Industry that is not connected to sewer system, corresponding to two paper mills owning private WWTPs and discharging into the Gallego and the Ebro River. If groundwater extraction is added to the calculation of water withdrawal, the actual consumption of Zaragoza UWS is 84 million $m^3$ $year^{-1}$ of which 23% is groundwater.

As stated previously, ground water in Zaragoza is not recharged by a natural water cycle. There is no recharge from the Ebro River either. All groundwater in Zaragoza come form agricultural irrigation in the surrounding area. Current rates are estimated in 10,000 $m^3$ $ha^{-1}$ but the total irrigation area that is contributing to recharging the aquifer of the city is unknown and therefore so it is the total recharge (Ebroagua working group, personal communication).

### 4.2.2 Drinking water treatment

Water from the Canal Imperial is treated in a plant with an installed capacity of 6 $m^3$ $s^1$. Conventional treatment is applied, comprising: pre-chlorination, flocculation, sedimentation, rapid sand filtration and disinfection with chlorine. The consumption of chemical products for DWT is summarized in figure 2 and also it will be explained in more detail further on.

As part of the policy of reducing water consumption adopted by the municipality the DWTP has been upgraded to dewater the sludge. Up to the year 2002 sludge with nearly 90% water content was directly discharged into the Huerva River. From 2003 approximately 5 million m$^3$ of water per year (7.7% of total water withdrawal) are being recovered from sludge and recycled into the DWT process.

### 4.2.3 Distribution network

By the year 2002 Zaragoza water distribution network was rather old. Most facilities ranged between 30 and 90 years of being built. Pipelines and reservoirs suffered important leakages and required to be either upgraded or replaced. Uncovered reservoirs were common, which is not convenient for stability of water quality.

Table 1 shows the current situation of distribution network reservoirs. From Casablanca reservoir at the DWTP (currently under upgrading) water is distributed to the whole system. It can be seen that most of the system works by gravity and only one reservoir is a pumping station. Therefore energy consumption by distribution network is very low as compared to other processes of the UWS.

**Table 1. Zaragoza's Primary Distribution System. Current situation** (Source Infrastructure Department, Urban Water Cycle Office of Zaragoza, 2006)

| Tank name | Operation mode | Capacity (m$^3$) | Age (years) | Stage before plan enforcement | Current Stage |
|---|---|---|---|---|---|
| Casablanca | Gravity | 180.000 | 90 | Bad | Upgrading |
| Pignatelli | | 82.000 | 125 | Bad | Out of work |
| Valdespartera | | 50.000 | 30 | Excellent | Same |
| Canteras | | 14.400 | 70 | Suitable | Upgraded |
| Los Leones | | 4.000 | 35 | Suitable | Upgraded |
| Academia | | 15.000 | 35 | Suitable | Upgraded |
| Villamayor | | 150 | 25 | Good | Same |
| Peñaflor (alto) | | 200 | 25 | Good | Same |
| Garrapinillos | | 100 | 25 | Good | Same |
| Villarrapa | | 560 | 25 | Good | Same |
| Valdefierro | Pumping | - | - | Bad | Out of work |
| D.B Oliver | | - | - | Bad | Out of work |
| Garrapinillos | | - | - | Good | Same |

Pipelines are being actively replaced in order to reduce leakages, current replacement rate is about 33 km a year, requiring approximately 53 million euro, being therefore the highest investment issue after the construction of the new pipeline bringing water from the Yesa dam.

One important limitation to properly assess the environmental performance of Zaragoza UWS is the lack of information concerning the flows through the distribution network. There are online meters at most facilities, but there is no data base. Therefore it is not possible to differentiate actual leakages at the distribution network from other factors contributing to unaccounted water, which has been reducing during the last decade, but still continues to be considerably high.

In 2002, starting point of the water supply improvement plan, unaccounted water was as high as 34 million $m^3$ a year, nearly 45% of total withdrawal. Municipality estimated by that time approximately 17 million $m^3$ to be actual leakage in the distribution system, but this is just a rough estimation. In 2006 unaccounted water was around 32% of total withdrawal (see table 2). The goal is to reduce it below 15%. The main demonstration activity for Zaragoza within SWITCH project is to carry out a complete water balance for one sector of the city in order to improve the current knowledge about water consumption and leakage in order to reduce the percentage of unaccounted water.

### 4.2.4 Water use

As it can be seen in figure 2, domestic use accounts for approximately the 62% of metered consumption. Industrial activities represent the 36% and public facilities plus landscaping consume only 2%.

Data concerning water withdrawal and water consumption from 1997 –when campaigns for rationalizing water use at households and industries started– to 2006 are shown in table 2. Along this period water withdrawal has been reduced by 20 million $m^3$ $year^{-1}$ due to both consumption reduction and infrastructure upgrading.

Along the last decade domestic consumption has gone down from 140 to 110 l $person^{-1}$ $day^{-1}$, leading to 6 million $m^3$ $year^{-1}$ less withdrawal; even with population increasing with around 50 thousand people during the same period. Thus infrastructure upgrading accounts for 14 million $m^3$ $year^{-1}$ reduction.

**Table 2. Evolution of water withdrawal and consumption in Zaragoza**

| Year | Withdrawal (million $m^3$ per year) | Population (thousand inh) | Average consumption (l $person^{-1}$ $day^{-1}$) | Metered consumption (million $m^3$ /year) | Unaccounted tap water (%) |
|---|---|---|---|---|---|
| 1997 | 84.7 | 601.6 | 139.8 | 39.9 | 45.6 |
| 1998 | 80.2 | 606.0 | 132.2 | 41.5 | 43.0 |
| 1999 | 80.4 | 607.3 | 132.2 | 41.2 | 43.2 |
| 2000 | 79.3 | 608.1 | 129.4 | 41.8 | 41.2 |
| 2001 | 79.7 | 613.4 | 128.8 | 42.5 | 39.0 |
| 2002 | 74.5 | 622.6 | 124.6 | 42.7 | 39.9 |
| 2003 | 71.7 | 628.4 | 122.4 | 44.1 | 38.2 |
| 2004 | 70.8 | 641.6 | 123.3 | 44.3 | 37.4 |
| 2005 | 68.2 | 650.6 | 118.0 | 44.6 | 35.0 |
| 2006 | 64.1 | 657.0 | 110.0 | 43.1 | 32.8 |

In spite of the important contribution of domestic water savings to the overall reduction of Zaragoza water withdrawal, municipality assumes that households are the major contributor to tap water loses since all over the city there are about 7000 to 7500 drinking water storage tanks installed between 30 to 40 years ago at the basement of buildings with the aim to assure continuous availability of water. At that time shortages were relatively common. Nowadays Zaragoza municipality considers such facilities not just unnecessary -since shortages have became very unusual- but also a source of problems since these tanks are poorly or even not maintained at all. There are three sustainability issues concerning these tanks:

- *Energy losses.* By definition these facilities break the pressure existing in the pipeline –which would be enough otherwise to bring water up to the top of the building– making necessary for the building to consume electricity in order to pump water up.
- *Water losses.* Municipality considers these tanks as the main source for water losses since poor maintenance may leave to continuous overflows that are discharged into the sewers (figure 5), mostly during low demand time (night time and holydays). Such losses become part of unaccounted water since meters are located at the outflow of the tanks (figure 5).
- *Public health.* Legionella, Mycobacterium, enteric Amoebas as well as other opportunistic pathogens and nuisance organisms, some of these largely resistant to chlorine, may multiply inside these tanks when residence time increases (WHO, 2004).

Due to these problems Zaragoza Municipality wants the tanks to be taken out of work, which they cannot do directly since those are private facilities. Municipality is considering to carry out campaigns to inform people about the disadvantages of such facilities, but nothing has been done yet. The Local Agenda 21 Office also suggested an assessment of water losses and energy consumption for these tanks as part of demonstration activities for Zaragoza within the SWITCH framework. Figure 6 shows a scheme of the typical breaking pressure tank as described by municipality staff.

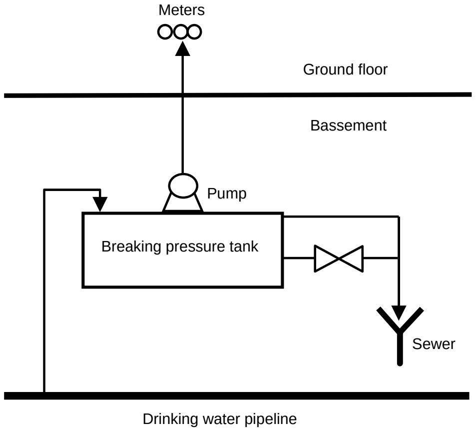

**Figure 6. Scheme of a breaking pressure tank**

### 4.2.5 Sewer system

Zaragoza has got a combined sewer system to which nearly all Industries and neighborhoods are nowadays connected. As previously described, some excess of irrigation water may also reach the sewer system. Nearly all industrial activities are currently taking place in areas surrounding the city, so called “Industrial Polygons”. Industrial discharges are regulated by a local law since 1986. There are 23 physic-chemical parameters that industrial waste waters must meet to be discharged into municipal sewers. Local Agenda 21 Office asks each industry for a discharge statement where all substances and processes involved in the industrial activity must be described. Industries should also implement management options intended to reduce WW pollution. Substances classified as harmful or toxic are not to be discharged into municipal sewers. Agenda 21 Office carries out inspection visits in order to confirm the information provided by the industry. Industrial discharge statements are classified as shown in table 3.

**Table 3. Classification of industrial discharges in Zaragoza in 2005**

| Class | Definition | % of Industrial activities falling in each category in 2005 |
|---|---|---|
| **0** | Similar to domestic WW. No statement required | 25 |
| **1** | Discharge < 15 $m^3$ $day^{-1}$. No toxic substances | 65 |
| **2** | Discharge > 15 $m^3$ $day^{-1}$ and < 50 $m^3$ $day^{-1}$. No toxic<br>Discharge < 15 $m^3$ $day^{-1}$ possible content of toxic substances | 5 |
| **3** | > 50 $m^3$ $day^{-1}$ | 5 |

Iinformation concerning each industrial discharge statement is introduced into a data base. Included aspects are:

- Discharge location
- Industrial activity
- Both potential and actual pollutants emitted to the environment
- Toxic substances used along the industrial process
- Water consumption
- WW quality
- WWT or processes aimed to reduce WW pollution
- Legal information (licences, etc)

Zaragoza sewer infrastructure is fully mapped in a GIS, but it has not been yet modelled, therefore there are no data concerning flows or substances transport and transformation.

### 4.2.6 Wastewater treatment

Zaragoza has got two public WWTP. General features for the two plants are provided in table 4. The average inflow for “La Almozara” is 12 million $m^3$ $year^{-1}$ for “La Cartuja” is 59 million $m^3$ $year^{-1}$. In addition to those public treatment plants there are also two private ones treating industrial sewage from two paper mills which do not use tap water but extract groundwater. Since these two companies own WWTPs they are not connected to Zaragoza sewer system, but discharge into the Gallego and the Ebro River (see figure 2). The authority in charge of controlling such discharges is not the Local Agenda 21 Office but the CHE. These two WWTPs provide the same sewage and sludge treatment than “Almozara” and together they treat even more water, around 13.6 million $m^3$ $year^{-1}$ (see figure 2). Therefore they are also considered for all analyses in this report and they will be referred to as “Paper mills”.

**Table 4. Zaragoza public WWTPs**

| **WWTP** / **Parameter** | **Cartuja** | **Almozara** |
|---|---|---|
| Sewage Origin | Industrial and domestic | Industrial and domestic |
| Average flow at design ($m^3$ $s^{-1}$) | 3.00 | 0.40 |
| Average actual flow in 2006 ($m^3$ $s^{-1}$) | 1.72 | 0.37 |
| Water treatment | Primary sedimentation, Biological treatment by activated sludge and secondary decantation | Primary decantation, Biological treatment by activated sludge and secondary decantation, Phosphorus removal with Iron Chloride |
| Sludge treatment | Primary and secondary digestion plus dehydration by filter press | Centrifuge dehydration flowed by incineration |

As it can be seen in table 4 “Almozara” is working near its actual capacity whereas “Cartuja” seems to be over dimensioned and is working at half of its actual capacity.

## 4.3 Environmental performance of Zaragoza UWS

### 4.3.1 Use of chemical products

Figure 7 shows the annual consumption of chemical products by Zaragoza UWS from 2000 for DWT and from 2001 for WWT. There is a steady trend over these years, but Chlorine and Allum shows a clear reduction for 2005 and 2006, from around 3000 to 2500 ton and from 8000 to 6000 ton respectively. PAC use for DWT started in 2003 and it has not been steady since then.

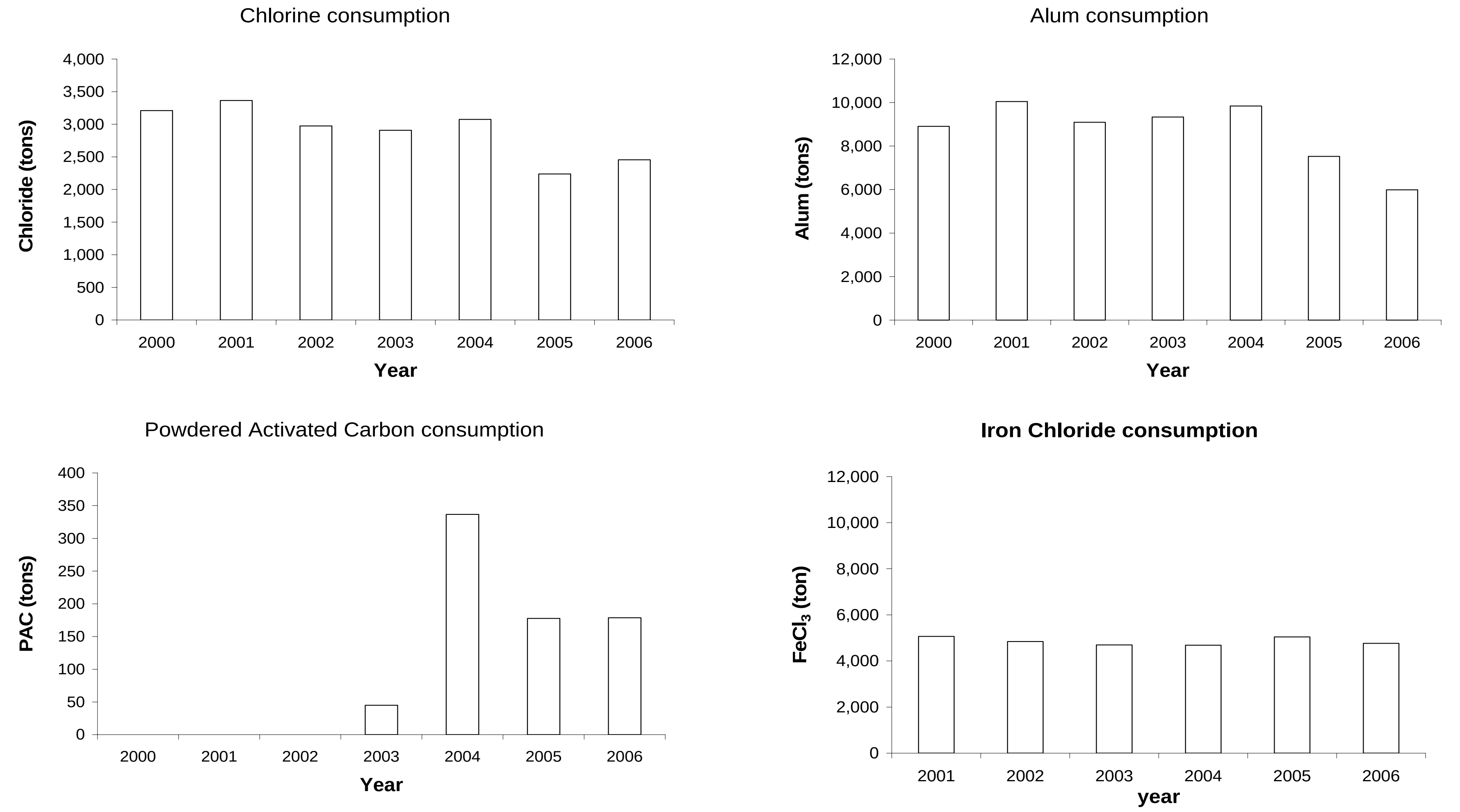

**Figure 7. Chemical products consumption by Zaragoza UWS. Chlorine, Allum and PAC are used for DWT whereas Iron Chloride is used for WWT in “Carjuja”plant**

### 4.3.2 Energy consumption and Atmospheric emissions

Figure 8 shows the total energy consumption of Zaragoza UWS discriminated by process. Both direct as well as indirect energy consumption are included. Direct consumption is electric power required for operation. Indirect consumption is the one required for transportation of both sludge and chemical products. It can be seen that around 60% of total consumption is due to WWT process. The contribution of groundwater extraction to total energy consumption is negligible. Energy consumption per water cubic meter is around 0.35 Kwh for WWT, 0.12 Kwh for DWT and 0.02 Kwh for groundwater extraction. Sludge digestion at “Almozara” and “Paper mills” as well as heat recovery at “Cartuja” allow energy production by the UWS for about 4 Gwh every year, which represents 10% of total energy consumption by the UWS system. (see figure 8).

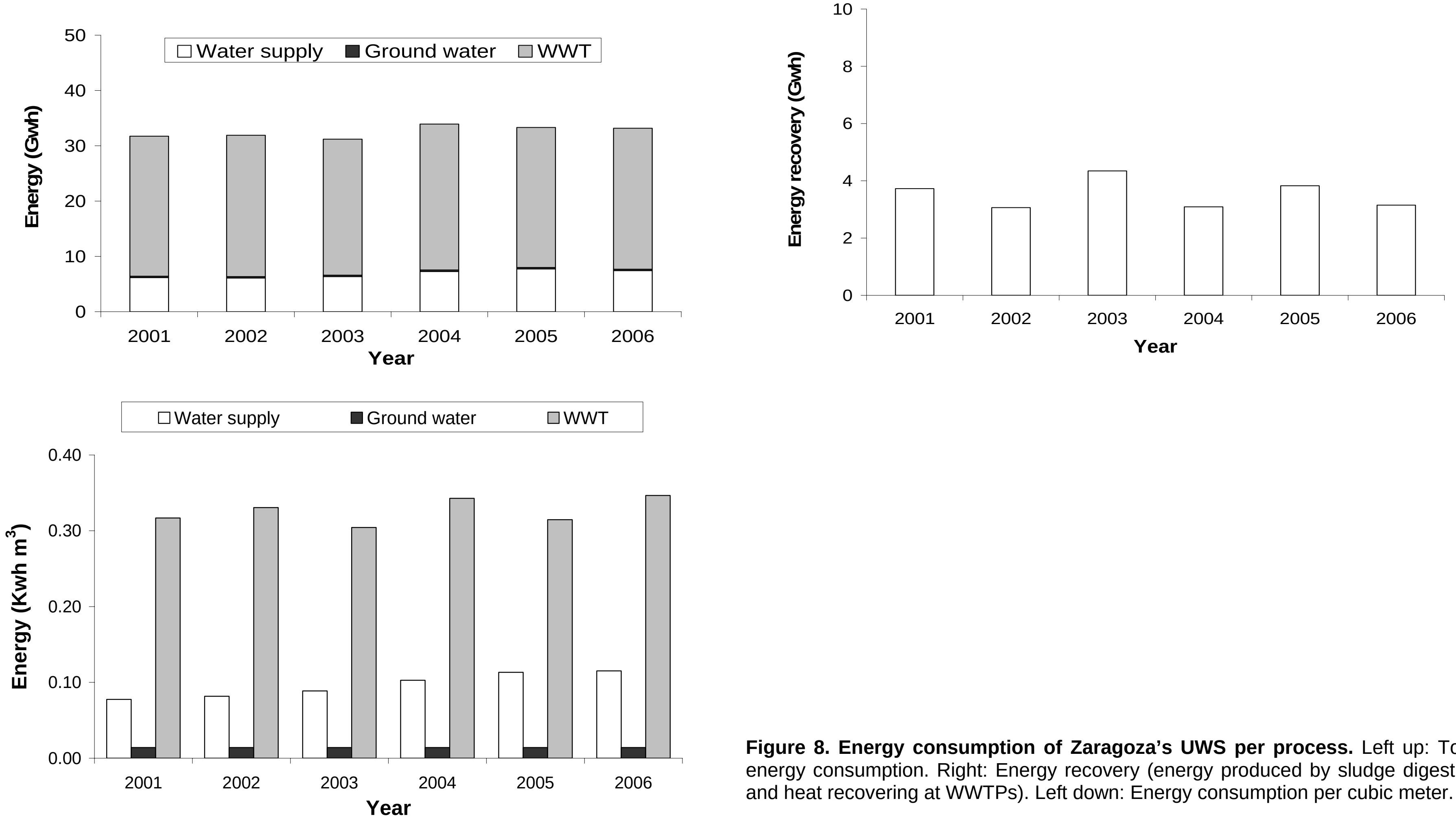

**Figure 8. Energy consumption of Zaragoza's UWS per process.** Left up: Total energy consumption. Right: Energy recovery (energy produced by sludge digestion and heat recovering at WWTPs). Left down: Energy consumption per cubic meter.

Figure 9 shows the current composition of electric sources in the market stock for Spain. It can be seen that nearly half of electric production is using fossil fuels (coal and combined cycles). From these percentages CO2 emissions produced by electric energy consumption are 436 ton per Gwh.

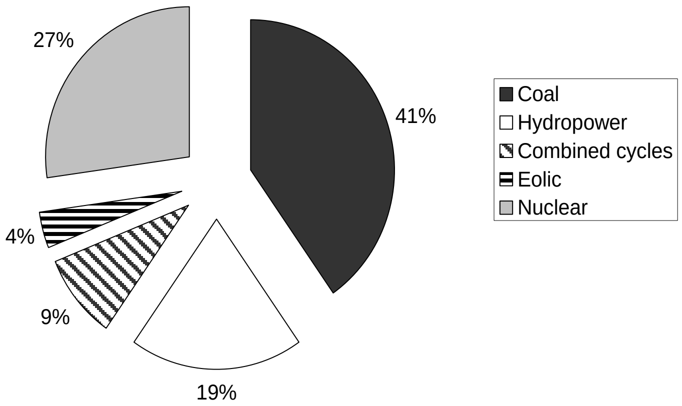

**Figure 9. Current Sources of Electric Energy in Spain.**

Figure 10 shows the main causes for atmospheric emissions derived from the operation of Zaragoza UWS. It is important to point out that water supply does not directly produce atmospheric emissions, but only indirectly from transportation of chemical products as well as from electricity use. Groundwater produces only indirect emissions from electricity use. All direct emissions from Zaragoza UWS are derived from WWT and correspond to: 1) sludge digestion; 2) further emissions from digested sludge degradation at landfill site (for paper mills); as well as 3) at agriculture fields (Almozara), and finally from sludge incineration (Cartuja). It is remarkable that only 36% are direct emissions whereas 63% are indirect emissions derived from electricity use, which results from the market composition described in figure 9.

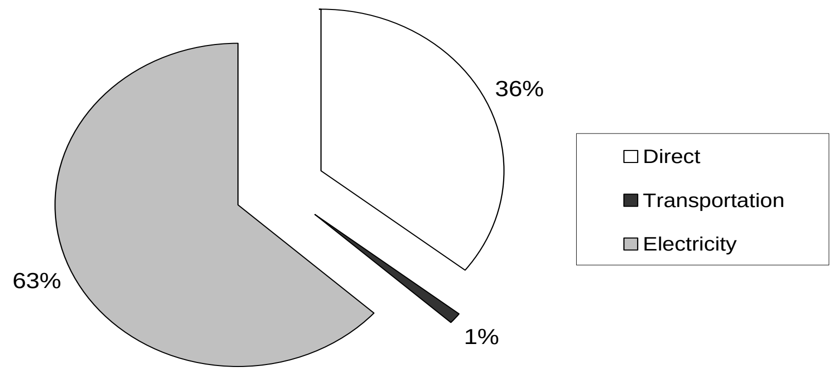

**Figure 10. Direct and Indirect $CO_2$ emissions of Zaragoza's UWS** (Source: Ministerio de Industria, Turismo y Comercio de España, 2007),

As result of facts described by figures 8 to 10 WWT process is responsible for most atmospheric emissions (see figure 11).

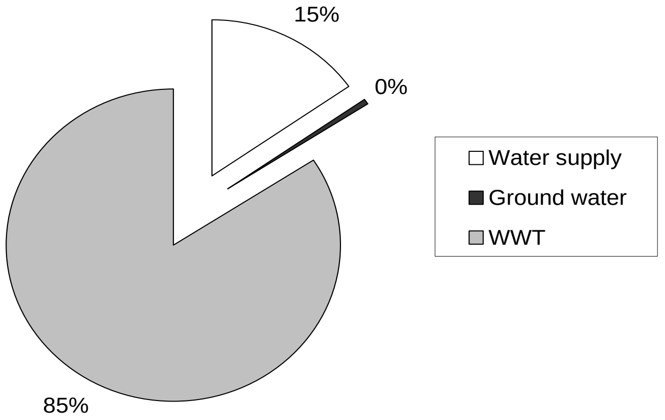

**Figure 11. $CO_2$ emissions of Zaragoza's UWS per process.** Total $CO_2$ emissions = 23 ton

### 4.3.3 Heavy metals

Figure 12 shows the heavy metal loads in Zaragoza sewage. Zinc (48%) and nickel (25%) are the most abundant.

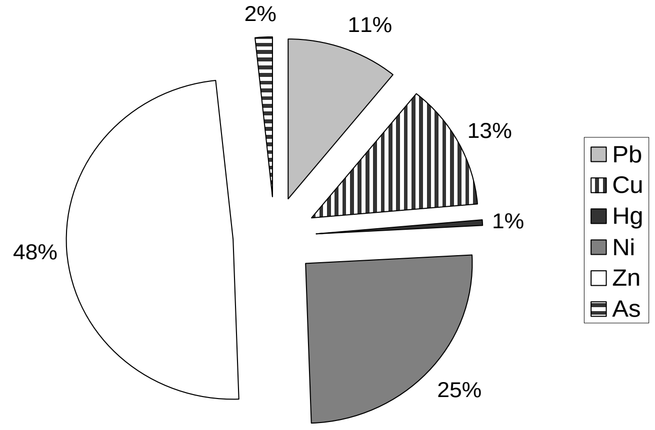

**Figure 12. Heavy metals in Zaragoza waste water**

Figure 13 shows the heavy metal annual loads from Zaragoza UWS to the environment. WWT technologies in Zaragoza are not designed to remove those, therefore it is not surprising that nearly 60% of total load every year is going to the Ebro river. Around 80% of the loads to the river are produced by “Cartuja” plant. “Almozara” produces loads that are quite similar to those from “Paper mills”. The impact of storm water is considerably low. Around 39% of heavy metals from sewage is disposed at landfill site and only a negligible fraction (around 1%) ends up in agriculture fields. Total annual loads to the river are around 23 ton year$^{-1}$ whereas total loads to landfills are around 13 ton year$^{-1}$. Loads to agriculture are 300 kg year$^{-1}$. Comparison between years shows only small differences with no clear tendency of heavy metal loads to either increase or decrease over time.

### 4.3.4 Organic matter

Biodegradable and non-biodegradable organic matter loads to the Ebro River expressed as BOD and COD respectively are shown in figure 14. BOD loads are around 1,000 ton year$^{-1}$ and COD loads are around 4,500 ton year$^{-1}$. Again around 80% loads come from “Cartuja” plant and loads from “Almozara” plant and from “Paper mills” are similar. Again the impacts from storm water are relatively low except for the year 2001 when it produced half of BOD load, increasing the city total two folds. COD load from storm water in the same year was not as high as BOD load, but it was comparable to those of “Almozara” and “Paper mills”.

### 4.3.5 Nutrients

Just as other pollution loads previously described annual loads of nitrogen and phosphorus do not show any tendency to either increase or decline over the years. Nitrogen loads to the Ebro River are around 3,000 ton year$^{-1}$. “Cartuja” plant accounts for 75% of the total load to the river. Once again “Almozara” and “Paper mills” loads are quite comparable. Nearly 60% of nitrogen is being removed from the sewage by the WWT system and ends up in the sludge (no data concerning denitrification were available).

Since “Cartuja” plant is designed to remove phosphorus, the relative contribution of this facility to the TP loads to the Ebro River is relatively low as compared with all other pollution loads that have been already mentioned and it is even comparable to those loads from the other two facilities. As consequence of TP removal at “Cartuja” plant 65% of this nutrient is disposed in a landfill for hazardous materials (see figure 2) and only 3.5% is recycled to agriculture.

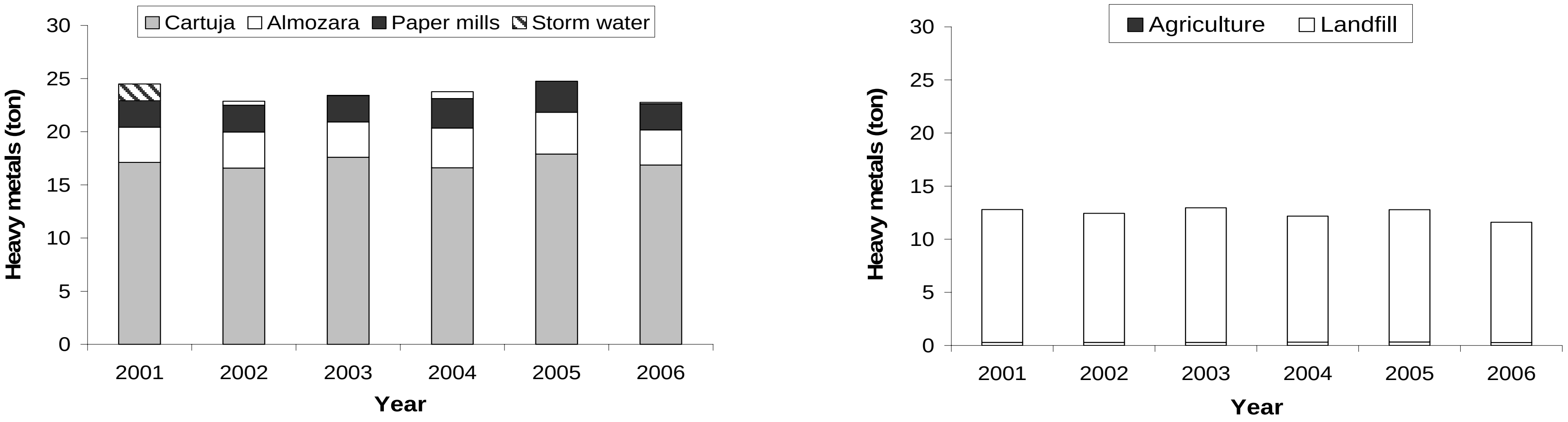

**Figure 13. Heavy metals loads to the environment from Zaragoza UWS.** Left: Loads to receiving water body. Right: Loads to landfill and agriculture

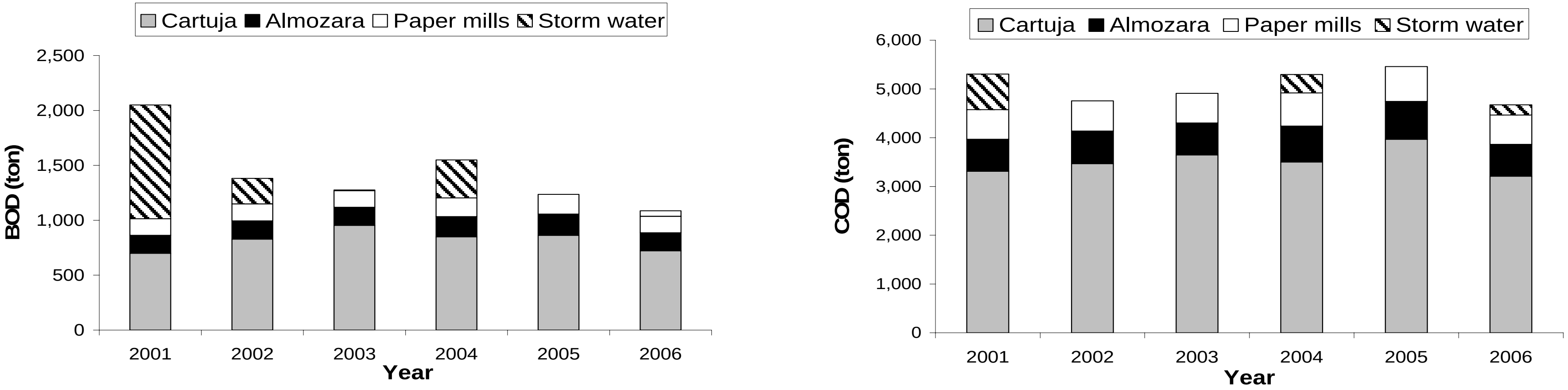

**Figure 14. BOD and COD loads from Zaragoza's UWS to the Ebro River**

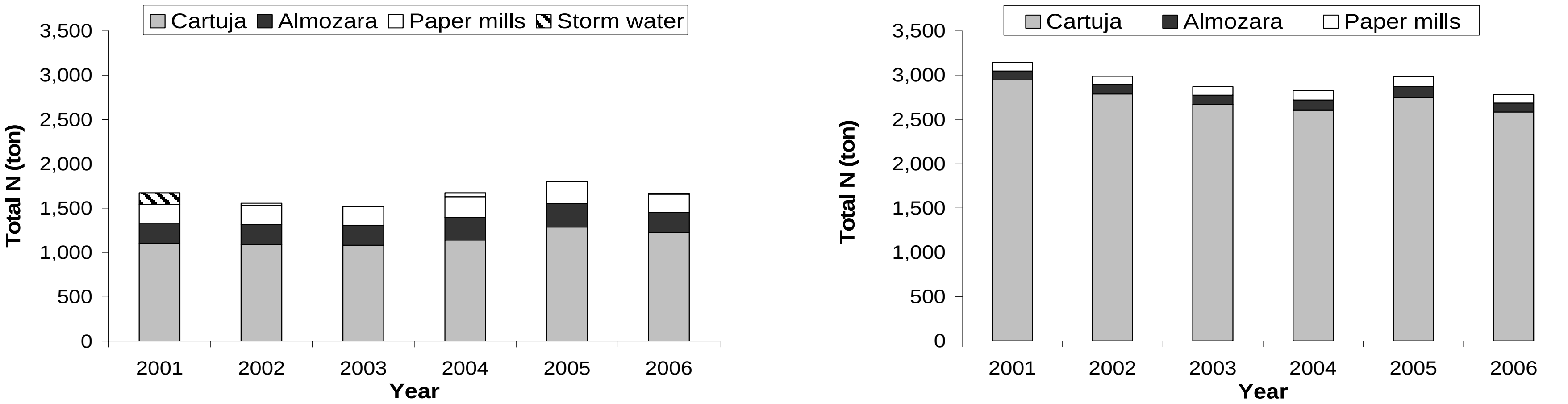

**Figure 15. Nitrogen loads to the environment from Zaragoza UWS.** Left: Loads to receiving water body. Right: Loads to landfill and agriculture

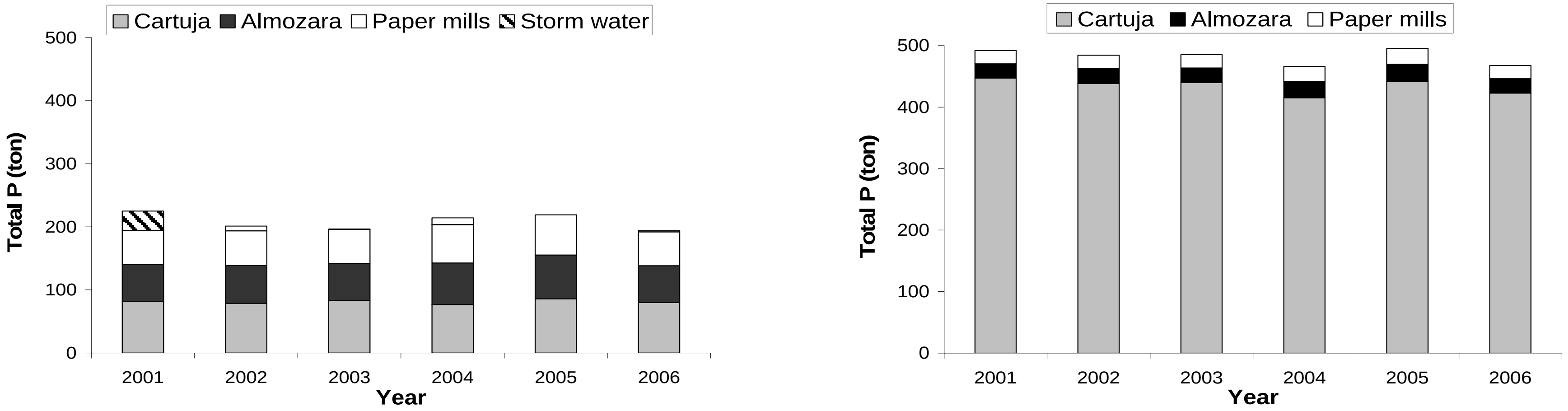

**Figure 16. Phosphorus to the environment from Zaragoza UWS.** Left: Loads to receiving water body. Right: Loads to landfill and agriculture

### 4.3.6 Sludge production

Figure 17 shows the annual production of sludge (dry matter) produced by Zaragoza UWS. Here both DWT and WWT sludge are presented together. Clearly those two are completely different kind of waste and impact the environment in different way. However, solid waste production as such is generally used as environmental performance indicator for urban systems. Hence it is also considered here as well.

It is evident that solid waste production from this UWS has significantly increased from 2001. The reason is that DWTP began dewatering sludge from 2002. From 2003 DWT sludge becomes the major component of solid waste for the water system. Total solid waste from the water system is around 14,000 ton year$^{-1}$. According to the Local Agenda 21 Office this amount represents around the 4% of total solid waste produced by the city every year.

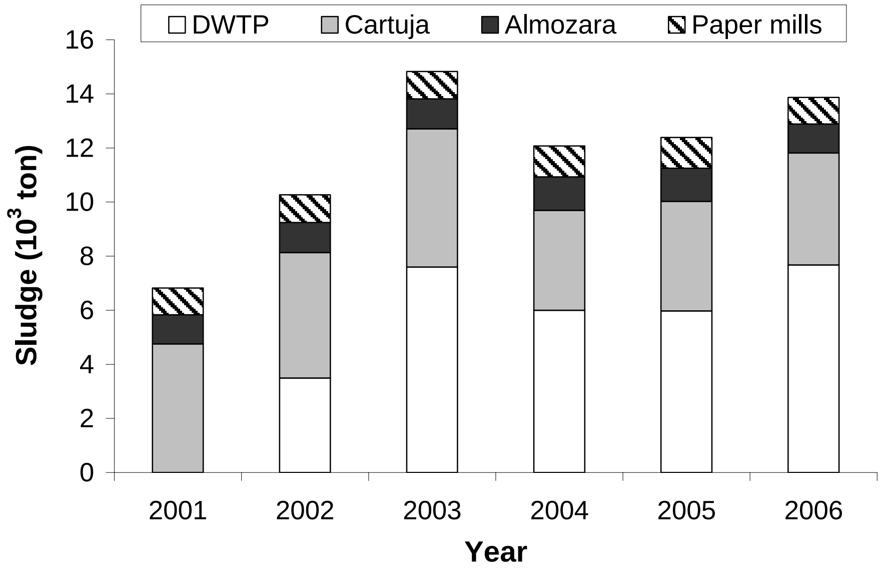

**Fig 17. Sludge (as dry matter) production by Zaragoza UWS**

### 4.4 Zaragoza UWS in the future

The vision of Zaragoza for its UWS has been focused on water supply. The main goal was to reduce water withdrawal to 65 million$^3$ year$^{-1}$ by 2010 and has already been achieved. Other goal is to reduce unaccounted tap water below 15%, but there is no time horizon for this goal. However this indicator has been reducing 2% per year on average since 2002 when the plan for improving water supply started (see table 2). If the city manages to keep decreasing unaccounted water at such rate, it will reach 15% by 2015.

Other aspects of environmental urban water sustainability are not expressed as goals for the water system. However Zaragoza city signed the Aalborg summit for sustainable European cities. The goals of Zaragoza sustainability vision that apply to the UWS and a list of suggested actions to achieve each goal are shown in table 5.

**Table 5. Goals of the Aalborg summit that apply to the UWS of Zaragoza**

| Goal | Necessary actions to achieve the goal |
|---|---|
| **1** To reduce water withdrawal | Water recycling, infrastructureupgrading (on going action), demand management (demo activity within the SWITCH project) |
| **2** To reduce unaccounted water | Infrastructure upgrading, demand management |
| **3** To improve water supply quality | Shifting to a different raw water source (on going action), shifting to a different DWT technology |
| **4** To contribute to improve the ecological Status of the Ebro River | To reduce pollution loads to the River |
| **5** To reduce dependence on fossil fuels | Shifting to renewable energy sources (depends on National Government Policies) |
| **6** To reduce the ecological footprint | To reduce resource consumption |
| **7** To reduce the production of solid waste | To reduce sludge production |

### 4.4.2 Focus problem and drivers affecting Zaragoza sustainability vision

The tree problem methodology is used here to define the goal of environmental sustainability as the focus problem of Zaragoza UWS. Several drivers that might affect the environmental performance of such system are shown in figure 18.

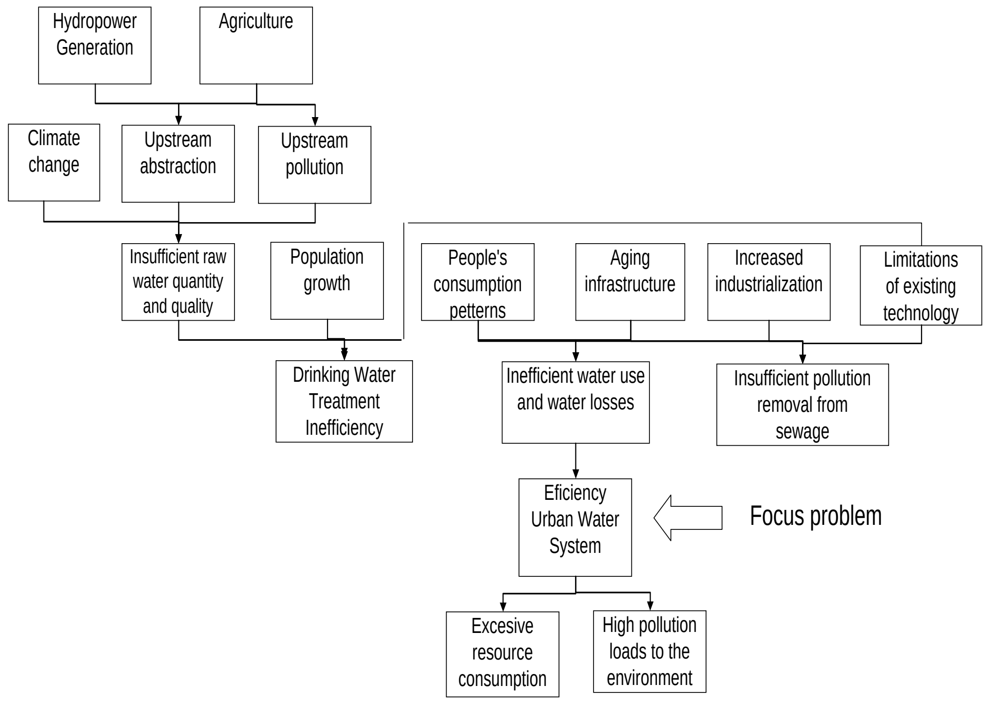

**Figure 18. An exercise of problem tree analysis for Zaragoza.** The core problem would be to improve the effectiveness and the efficiency of the UWS.

The drivers identified in figure 18 are classified in figure 19 by a matrix of uncertainty vs importance. The criteria for such classification are described next.

Increasing importance ↑

| | |
|---|---|
| **More important – less uncertain**<br>• Urbanization<br>• Availability of funds<br>• Dependence on fossil fuels<br>• Existing infrastructure | **More important – more uncertain**<br>• Climate change<br>• Water abstraction use<br>• Population increase |
| **Less important – less uncertain**<br>• DWT and WWT technologies | **Less important – more uncertain**<br>• Storm water |

Increasing uncertainty →

**Figure 19. Matrix of uncertainty vs importance to classify drivers of Zaragoza UWS sustainability**

### 4.4.1 Criteria for classification of drivers

#### 4.4.1.1 Less important – less uncertain

- Introduction of new DWT and/or WWT technologies is not planned for Zaragoza during the next decade since current infrastructure is being upgraded and costs will still be paid in the coming years.

#### 4.4.1.2 Less important – more uncertain

- According to data analyzed in this report, storm water does not seem to be a determining issue for the environmental performance of Zaragoza UWS, which is also logic considering precipitation and evapotranspiration in this region. Given the erratic precipitation patterns that characterize Zaragoza, the uncertainty level is also high.

#### 4.4.1.3 More important – less uncertain

- Urbanization in Zaragoza is increasing, but it is planned, therefore its uncertainty level is low, its importance for the environmental performance of Zaragoza UWS is high.

- Availability of funds for improving the system is an important issue, but it is assured for the upgrading plans and the education campaigns that are already in place.

- From the data presented here it is evident that the dependency on fossil fuels for electricity production in Spain is still high and it is an important component of the UWS environmental impacts. However Spain has signed the Kyoto protocol and there are already plans to expand the electricity production from renewable sources. Figure 20 shows the expected composition of electric power production market projected by the National Plan on Energy proposed by 2015 in Spain (Ministerio de Industria, Turismo y Comercio, 2007). This composition will reduce the dependence on fossil fuels and also reduces atmospheric emissions from 436 to 320 ton Gwh$^{-1}$.

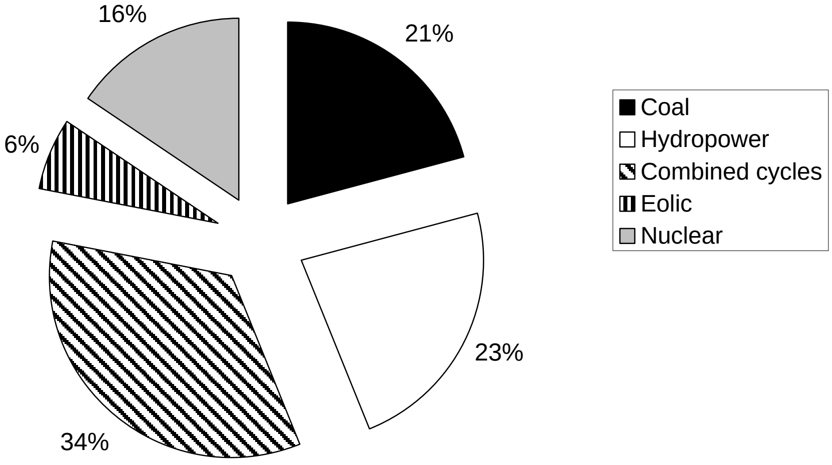

**Figure 20. Composition of electric power production market in Spain projected by 2015 by National Plan on Energy** (Source: Ministerio de Industria, Turismo y Comercio de España, 2007)

- Infrastructure ageing is one of the most important limitations for Zaragoza UWS, moreover when water efficiency use is considered. However this upgrading has been taking place during the last decade and it is planned to continue during the years to come.

#### 4.4.1.4 More important – more uncertain

- Spain is a country with problems of water stress. In addition to this, the Aragon valley is the driest region in Europe, as it was already mentioned. Therefore the effect of climate change upon the water resources is a major issue and this may threaten the quantity and the quality of the water required by Zaragoza in the future. In addition to this, the environmental impacts of the city upon the Ebro River downstream will be also dependent on the river discharges, which will also be affected by climate change.

- Upstream water use is a major issue for Zaragoza since it can exacerbate the effects of climate change upon water quantity and quality. Additionally, as it was described previously, excess water for irrigation upstream from Zaragoza is responsible for recharging city’s groundwater, which accounts for the 23% of current water requirements.

- Population in Zaragoza has increased in a 1% average during the last decade. There is a study about population increase projections, but it ends up in 2008. Therefore it is not clear the rate of population increase in the future years. Therefore this is an uncertain factor that strongly affects both resource consumption (water, chemical products, energy, etc) and pollution loads.

### 4.4.3 Scenario analysis

#### 4.4.3.1 Setting Scenario

Several combinations of the 4 factors considered as more uncertain and more important are possible. Table 6 shows three examples for possible scenarios. Climate change effects are considered as percentage of projected reduction of water availability in the Ebro catchment by 2020 (Ayala-Carcedo, 2000).

**Table 6. Possible drivers scenarios for Zarzgoza UWS**

| Scenario | Climate change | Water use upstream | Population | Classification | |
|---|---|---|---|---|---|
| **Sc1** | 0% | < | < | best | unlikely |
| **Sc2** | -6% | = | = | bad | unlikely |
| **Sc3** | -13% | > 10% | 1% | worst | likely |

Scenario Sc3 can be considered likely in every aspect since:

- Climate change is expected to reduce water availability in the Ebro basin in 40% to 2060 which means 13% by 2020 if a constant reduction rate is considered (Ayala-Carcedo, 2000).
- The National Irrigation Plan that is about to be implemented in the years to come aims to increase 10% of current irrigated area in Spain by 2015 (MAPA, 2007), which directly means 10% more water abstraction upstream from Zaragoza because irrigation is already the major water consumer in the Ebro Catchment.
- Zaragoza urbanization plan assumes that city will continue expanding and therefore it is very likely that population will continue increasing.

#### 4.4.3.2 Assumptions for Scenario analysis

Zaragoza sustainability vision will be analyzed for the time horizon 2020 under Sc3 scenario considering climate change and Spanish national policies on water as major drivers. Due to time constraints, other likely scenarios are not analyzed. Under Sc3 scenario, several assumptions that can be considered realistic are made:

- From 2002 when water infrastructure started being upgraded, unaccounted water has been decreasing in 7% every year. Funds to continue upgrading are available. In addition to this, demand management is going to be implemented as demonstration activity for Zaragoza within the SWITCH project. Therefore unaccounted water is expected to continue reducing. If current reduction rate is sustained, then unaccounted water will be around 10% of total withdrawal by 2020.
- Since most components of water infrastructure either are being upgraded or have been recently upgraded, there is no possibility that existing DWT and WWT technology in Zaragoza will change before 2020.
- Consumption and production patterns in Spanish society are assumed to stay the same, or will even increase by 2020. Therefore pollution loads to the sewage system will increase at the same rate as population is increasing.

### 4.4.3.3 Suggested strategy: Industrial water recycling

#### 4.4.3.3.1 Effect of water recycling on water withdrawal

Under Sc3 scenario Zaragoza population is expected to be 14% larger than now by 2020. As shown in figure 21, water withdrawal is expected to reduce from 64 million $m^3$ in 2006 to 56 million $m^3$ in 2020 just as a consequence of infrastructure upgrading, meaning 14% reduction of current water withdrawal. If the city aims to reduce water withdrawal below 56 million $m^3$ by 2020, then also domestic and industrial water consumption must be reduced. Current strategies going on in Zaragoza also aim to optimize water use for landscaping, however this use only represents 5% of total water requirements (including groundwater). Therefore such strategy is not going to have a significant effect.

Presently domestic consumption in Zaragoza is already 110 l $person^{-1}$ $day^{-1}$, which is already a low consumption, to reduce it below this level is not very likely. On the other hand, current industrial water needs in Zaragoza are approximately 40% of total water requirements (including groundwater). A suitable alternative for continuing reducing water requirements of Zaragoza city would be recycling industrial water. For this scenario analysis two strategies consisting on 10% and 30% recycling are considered. This will represent additional 2% and 7% less water withdrawal respectively (see figure 21). This strategy considers both tap and groundwater.

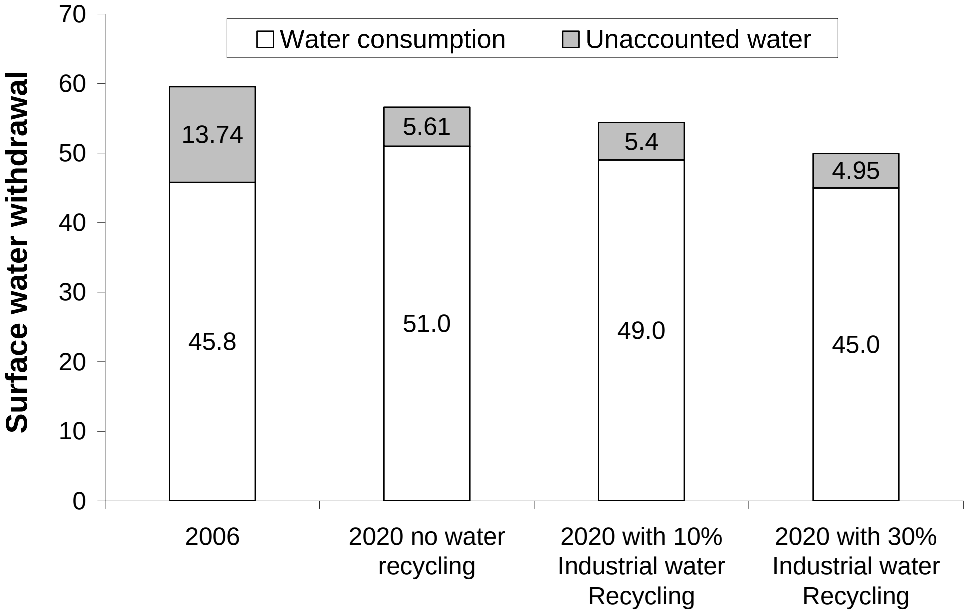

**Figure 21. Water withdrawal discriminated by actual consumption and unaccounted water under Sc3 scenario and different strategies for water reuse**

#### 4.4.3.3.2 Effect of water recycling on chemical products consumption

Two factors have an effect on the use of chemical products for DWT: 1) water withdrawal and 2) raw water quality. The effect of projected water withdrawal may simply be calculated from figure 21. The effect of raw water quality is more complex since it is the consequence of several variables such as pH, SS, DOM, etc.

The effect of water quality on the future use of chemical products is very relevant for Zaragoza since a new raw water source will be used from 2008. The Yesa reservoir is expected to provide a higher water quality than the Ebro River. In order to get a hint about how much less chemical products will be necessary to treat water from Yesa reservoir as compared to the Ebro River a regression analysis between chemical products dose per $m^3$ and raw water quality was performed. The considered variables of raw water were DOM (as UV absorbance) and SS. Unfortunately no significant correlation was found (data not shown). In addition to this, a comparison between the same two variables between Canal Imperial and Yesa reservoir was made. It was found that the two sources have very different values for suspended solids, but the values for DOM are quite similar (data not shown). Therefore the only assumption that can be made concerning chemical products consumption for water supply in Zaragoza is that it will decrease according to water withdrawal.

#### 4.4.3.3.3 Effect of water recycling on Energy consumption

If water withdrawal is expected to decrease by 2020 then electric energy consumption is also expected to decrease. However, energy consumption of water facilities has got two components, a fixed value and a variable value that is proportional to the inflow. In order to identify such components a regression analysis between water inflow and energy consumption was performed for the water supply system in Zaragoza. The correlation is expressed by $r^2 = 0.2$ (data not shown). Meaning that 80% of energy consumption of the water supply process can be considered as a fixed value and 20% can be considered as flow dependent.

The variable energy consumption for the water supply process is 0.1 Gwh per million $m^3$. The energy consumption of pumping groundwater in Zaragoza is around 0.02 Gwh per million $m^3$. Recycling industrial water means increasing energy consumption because pumping will be necessary. An assumption here is made that recycling water will consume more energy than groundwater pumping, but of course much less than the variable energy consumption by water supply. This assumed value is 0.03 Gwh per million $m^3$. Figure 22 shows an analysis of energy consumption by Zaragoza UWS for 2006 and for scenario 2020 considering these values as well as different levels for the industrial water recycling strategy.

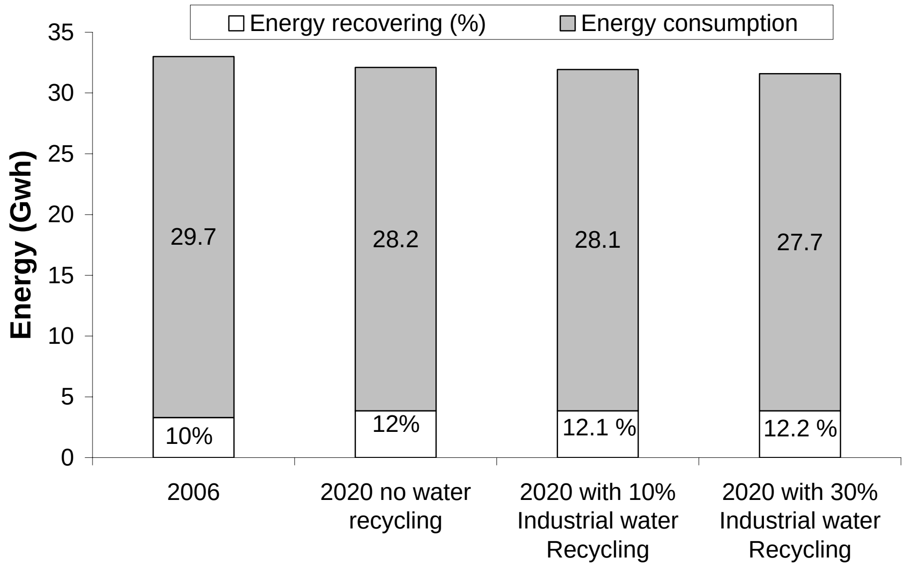

**Figure 22. Energy consumption of Zaragoza UWS in 2006 and 2020 scenario with different levels of Industrial water recycling strategy**

Water recycling will result in less energy consumption for Industries using tap water since recycling is less costly than tap water supplying. For industries that do not use tap water, recycling is more expensive than extracting groundwater. Their additional consumption would be 0.16 and 0.51 Gwh per year for 10% and 30% recycling respectively. However the energy savings supposed by tap water recycling are so significant, that Zaragoza taken as a whole system will be actually consuming slightly less energy if Industrial water recycling is implemented (see figure 22).

#### 4.4.3.3.4 Effect of water recycling on $CO^2$ emissions to the atmosphere

Figure 23 shows an analysis of $CO^2$ emissions, considering the described figures for energy consumption, the National Plan on Energy and the expected increase on organic matter loads to the sewage by 2020.

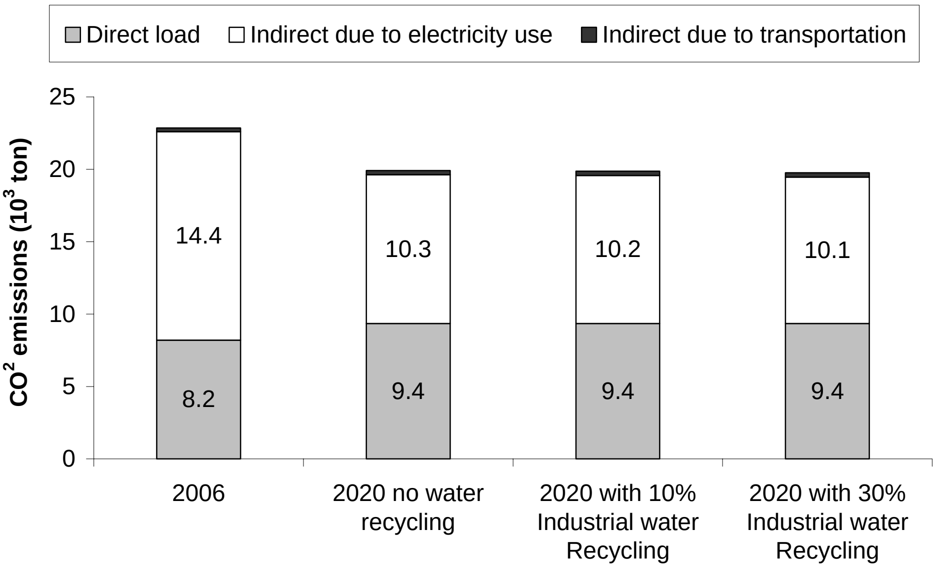

**Figure 23. $CO^2$ emissions from Zaragoza UWS in 2006 and 2020 scenario with different levels of Industrial water recycling strategy**

As previously described, the major contribution to atmospheric emissions by Zaragoza UWS is indirectly by electricity use. As expected from figure 23, the joint effect of the National Energy Plan and the reduction on energy consumption supposed by decreasing water withdrawal, imply a significant reduction of atmospheric emissions from 22,600 ton in 2006 to 19,700 in 2020.

As organic matter loads to the sewage are expected to increase 14% (see section 4.4.3.3.4) direct emissions will increase likewise, going from 8,200 to 9,400 ton per year. Indirect emissions by transportation of chemical products and sludge seem negligible in the figure, but those will increase from 250 in 2006 to 291 ton in 2020. The savings on energy supposed by industrial water recycling would represent an additional reduction of 50 and 100 ton per year for the 10% and the 30% strategies respectively.

#### 4.4.3.3.5 Effect of water recycling on pollution loads to the Ebro River

Under the assumptions previously described it is expected that 14% larger pollution loads will be dumped into 14% less sewage volume by 2020. Hence BOD, nutrients and heavy metals will be 28% more concentrated in the sewage. If industrial water recycling is considered then pollutant concentrations in sewage will increase 30% for 10% recycling and 37% for 30% strategy. As consequence of this increased concentration in the inflow, higher removal efficiency at WWTPs would be expected. In order to calculate how much this increasing efficiency would be a regression analysis between pollutant concentrations and removal efficiency was performed for all WWT facilities in Zaragoza. However, no significant correlation was found ($r^2$ = 0.028, data not shown). Therefore, the assumption is made here that with the current WWT technology and current societal production and consumption patterns, pollution loads to the Ebro River will increase 14% by 2020, even if unaccounted water is reduced and even if industrial water is recycled.

### 4.4.3.4 **Assessment of water quantity and quality for Zaragoza in the future**

Considering the figures previously described for Sc3 concerning upstream water use and the effect of climate change upon water availability in the Ebro catchment. An assessment of the risk for water availability in Zaragoza was performed. Here an additional scenario for the year 2060 was projected. From figure 24 it is evident that Zaragoza can relay on Yesa reservoir as raw water source for the years to come since Zaragoza requirements projected by the year 2060 with increasing population and no water recycling are well below the projected capacity of the reservoir, even under the worst climate change and water extraction scenario.

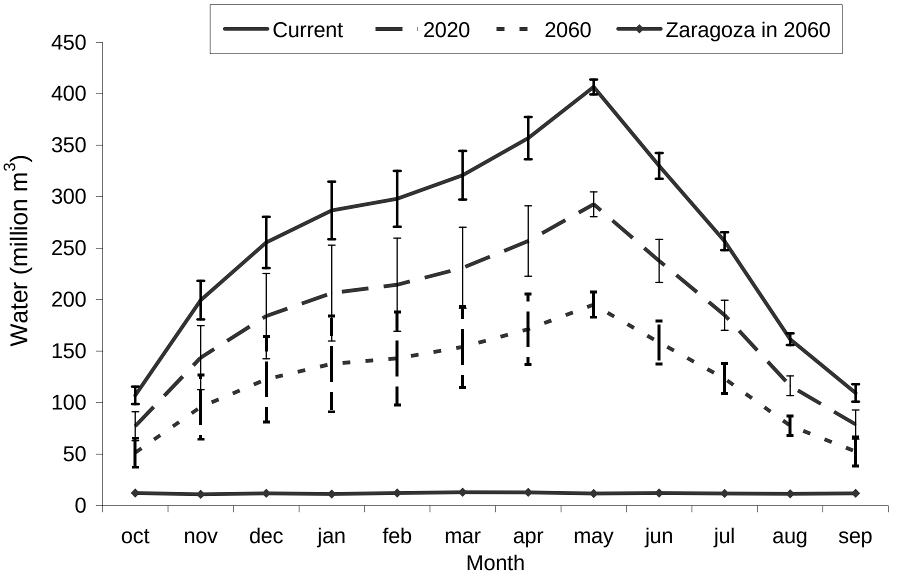

**Figure 24. Current and projected water storage regimes for Yesa reservoir on a hydrologic year basis under Sc3 scenario.** Regimes also include the expected increase in water demand for agriculture as planned by the National Irrigation Plan (Sc3).

In this analysis total Zaragoza requirements are included, even those that are currently fulfilled from groundwater. The reason is that National Irrigation Plan also considers the need of upgrading current irrigation technologies to minimize loses. This will reduce the groundwater recharge in Zaragoza and the water table might eventually drop so that it is not that feasible anymore. In such scenario, either the whole city becomes dependent on tap water or the activities that currently use groundwater will turn to the Ebro River, whose discharge will be already considerably reduced by that time.

Water quality of Yesa reservoir is more difficult to project. However it is possible to consider TP concentrations as reference point. Current Yesa average TP concentrations on year basis are 21 ug/l. If current inputs are expected to remain constant, then by 2020 average TP concentrations might rise to around 40 ug/l and 60 ug/l by 2060. This situation encompassed with increasing temperature and radiation (due to climate change) would increase the risk for the reservoir to experience algal blooms, which might negatively affect water supply quality for Zaragoza.

#### 4.4.3.5 Setting priorities for pollution loads

This report provides insights about the environmental impacts of Zaragoza UWS operation on a year basis. However such impacts are not constant all over the year and might vary seasonally. In fact, even if pollution loads remained constant all over the year, there will be a seasonal variation of the receiving environment. This is more evident for the water bodies and is remarkable for the Ebro River which exhibits an important variation of its discharge along the year. The current hydrograph for the Ebro river on a month average basis is provided in figure 25. This figure also shows the worst climate change scenario expected for water availability in this basin for the year 2020 and the year 2060.

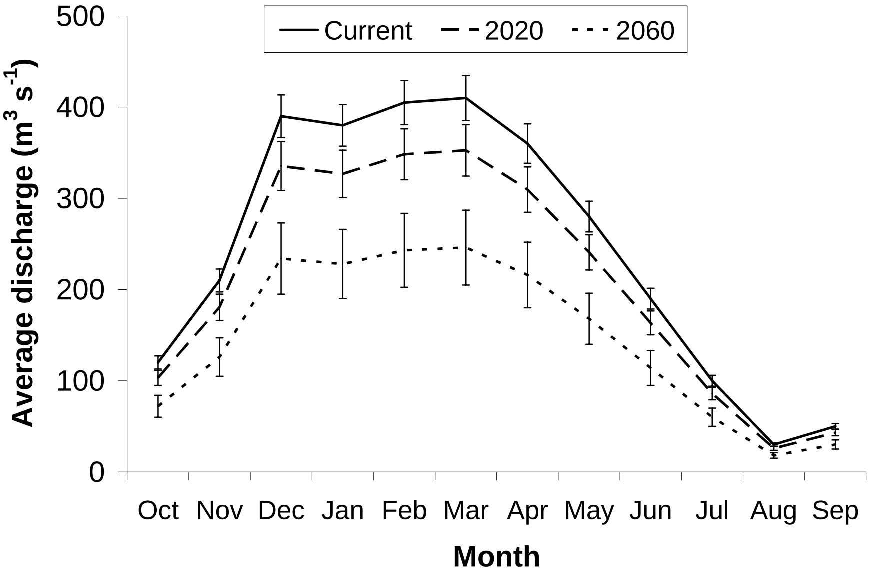

**Figure 25. Regimes for Ebro River at Zaragoza under current conditions and projected conditions under Sc3 Scenario.** Error bars represent standard deviations on a month basis (Source for current regime: CHE, 2007)

In current conditions maximum discharges of nearly 400 $m^3$ $s^{-1}$ are expected between December and April. Minimum discharges are expected during summer time, especially in August, where they can be as low as 30 $m^3$ $s^{-1}$. This also means that the impact of Zaragoza UWS upon the Ebro River is not constant all over the year and it reaches a maximum in August. Figure 26 provides an example of the seasonality of this impact taking total phosphorus as an example.

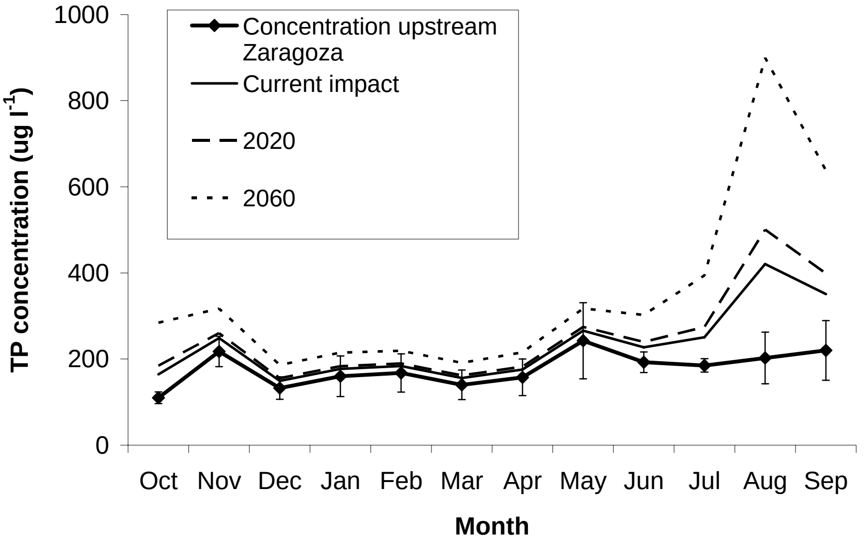

**Figure 26. Impact of Zaragoza UWS upon TP concentrations at the Ebro River.** Only upstream concentrations have been actually measured (CHE, 2007). Error bars represents standard deviation on a month basis. The other three concentrations are the ones that can be predicted from Zaragoza TP loads to the river at current conditions and at worst climate change scenario (Sc3?...worst climate change conditions, population growing at same rate as in the last ten years, no changes on WWT technology, no changes on people consumption patterns)

TP concentrations in the Ebro River, upstream from Zaragoza, range between 100 to 200 µg $l^{-1}$. Under current conditions the city does not have a significant impact on the river from October to May, but from June onwards the impact becomes more important and it may raise the TP concentrations up to 400 µg $l^{-1}$. In August when –as previously described– river discharge may drop down to 30 $m^3$ $s^{-1}$. For the 2020 scenario the pattern is quite similar, but for the 2060 scenario August TP concentration goes up to 900 µg $l^{-1}$, which is more than three times the present upstream concentration.

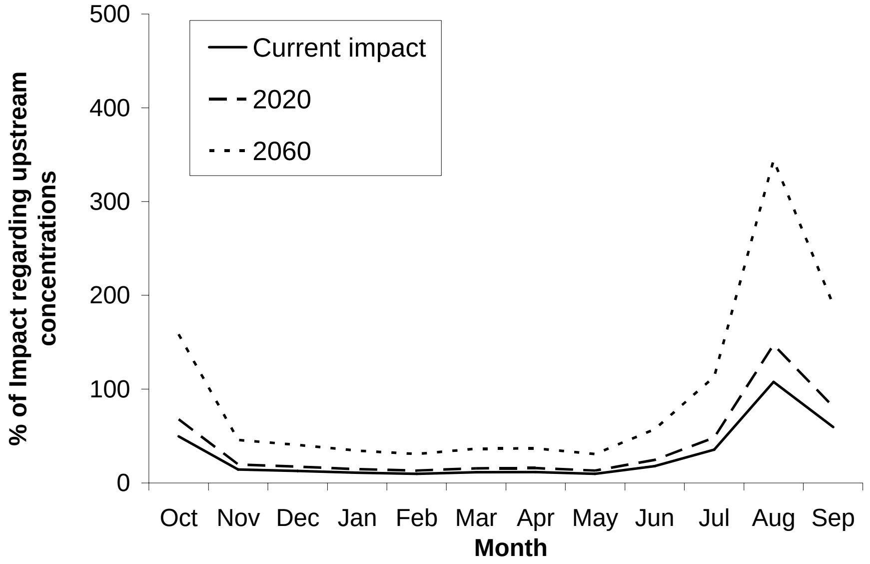

**Figure 27. Seasonal variability of impact percentages of Zaragoza UWS on the Ebro River taking TP as example. Current and future scenarios.**

If the differences between upstream concentrations and the predicted ones are converted into percentages, then these can be called impact percentages on the river and might possibly be used as indicators for sustainability. Figure 27 shows such percentages, again with reference to TP as an example.

Current scenario shows an impact below 20% from November to May. Again in June it begins increasing and it goes up to 110% in August. For the 2020 scenario the peak impact also in August is nearly 150%, and finally the seasonal impact peak for the 2060 scenario goes up to 350%.

Table 7 shows the values of these seasonal impact peaks for BOD, COD, TN, TP and Heavy Metals at: 1) current, 2) 2020 and 3) 2060 scenarios. Interestingly the highest value goes to TP with 110% for present scenario, followed by COD with 50%, TN with 33%, Heavy metals with 17% and finally BOD with 13%.

Considering these results it would be possible to say that priorities for Zaragoza UWS to increase its environmental performance, at least with regard to the receiving water body are as follows:

1. Phosphorus
2. Non biodegradable organic matter
3. Nitrogen
4. Heavy metals
5. BOD

This is a very interesting outcome that reflects several internal aspects of Zaragoza UWS as well as its relation to the surrounding environment.

Secondary WWT via activated sludge is a technology for BOD removal and it works quite well on this regard. Therefore it is possible to say that improving BOD removal is not a priority for this UWS.

Since activated sludge is a biological treatment it does not work that well to remove non biodegradable OM, remaining COD in treated sewage has got a relatively high impact on the receiving water body.

Zaragoza WWT system is not designed to remove nitrogen. However biodegradable OM removal is also removing about 40% nitrogen from sewage. The remaining 60% is still high but it does not seem to have an important impact on the Ebro River, which might be explained by the fact that nitrogen concentrations in the river are already high (see table 7).

Concerning heavy metals, again it is important to say that Zaragoza WWT system is not designed to remove those, nearly 40% are retained by the sludge though. Also untreated Zaragoza sewage does not contain high heavy metal concentrations. Therefore this impact is not that significant.

Concerning phosphorus it is possible to say that 68% of Zaragoza WWT system (Cartuja plant) is actually designed to remove phosphorus. However the effectiveness of this technology is just around 80%, in addition to this, the combined impact of Almozara and paper mills WWTPs, which do not remove nutrients, is so important that TP has got a large impact on the Ebro River. Therefore reducing phosphorous loads may be considered as the priority for improving Zaragoza UWS with regard to the Ebro River.

**Table 7. Seasonal impact peaks of Zaragoza UWS upon the Ebro River under present conditions and worst climate change scenarios for 2020 and 2060.** These impacts are calculated on the basis of current pollutant concentrations in August, when river discharge is at minimum and projected river flows for the same month in 2020 and 2060. (see figure 27). So this can be considered as the maximum impact that Zaragoza might annually have upon the Ebro River

| **Parameter** | **Current concentrations upstream from Zaragoza during summer time** | **Current impact of Zaragoza** | | **2020** | | **2060** | |
|---|---|---|---|---|---|---|---|
| | | **Expected raising of Concentration** | **%*** | **Expected raising of Concentration** | **%*** | **Expected raising of Concentration** | **%*** |
| BOD (mg $l^{-1}$) | 6.4 – 10.4 | 7.5 – 11.5 | 13 | 7.9 – 11.9 | 18 | 6.7 – 13.7 | 20 |
| COD (mg $l^{-1}$) | 5.2 – 14.4 | 10.1 -19.3 | 50 | 11.8 – 21.0 | 67 | 19.6 – 28.8 | 147 |
| TN (mg $l^{-1}$) | 2.8 – 7.9 | 4.6 – 9.7 | 33 | 5.2 – 10.3 | 45 | 7.9 – 13.0 | 95 |
| TP (µg $l^{-1}$) | 120 – 200 | 326 - 406 | 110 | 396 – 476 | 173 | 718 – 798 | 374 |
| Heavy metals (µg $l^{-1}$) | 113 – 324 | 152 - 363 | 17 | 165 – 376 | 24 | 225 – 436 | 51 |

*** The percentage in this table refers to the increasing with respect to the current value.**

# 5 Discussion

The main goal of water management in Zaragoza in the recent years has been to reduce fresh water withdrawal below 65 million $m^3$ $year^{-1}$. The time horizon for this goal was the year 2010 but it has been already achieved in 2006. In addition to this, unaccounted water in Zaragoza has been significantly reduced along these years from 40 to 32%, but it still remains too high and the volume of actual leakages is still unknown. This particular aspect is to be assessed by the SWITCH project in Zaragoza as a demo activity. However it is possible to say that water supply is significantly and consistently improving in the city. The open question now is whether this improving makes the urban system as a whole more sustainable.

## 5.1 Sustainability of UWS

The starting point for assessing sustainability of urban water systems is a definition of the basic services the system is supposed to provide, before start looking for alternatives to improve existing technology (Larsen and Gujer, 1997). The services the urban system should meet are basically three:

- Reliable supply of safe water to all residents for drinking, hygiene and household purposes
- Safe transport and treatment of wastewater
- Adequate drainage of impervious areas

Zaragoza UWS is currently providing these basic services. However in a second level, there are some requirements for such services to be considered sustainable that also need to be assessed. Lundin (1999) propose the following list:

a. Technical performance: defined as the degree of effectiveness (degree of goal achieving) and efficiency (resource optimization).
b. Reliability, flexibility and adaptability: defined as the capacity of continuing on providing the service when unexpected events occur, encompassed with the potential for the system to change.
c. Durability: referring to infrastructure
d. Environmental protection: pollutant emissions as low as required to maintain the quality of the environment (atmosphere, aquatic ecosystems and soil)
e. Cost-effectiveness: cost recovering of the service and affordability of investments

f. Skilled and sufficient staff: to operate and maintain the system. But also personal with knowledge on microbiology, chemistry and ecology. Gender diversity is also required.
g. Social dimension: the service should be socially and culturally acceptable
h. Public awareness: on sustainable behavior

This work has quantitatively analyzed the aspects a. and d. of Zaragoza UWS. One important aspect that has been neglected in this research is the water infrastructure, which is determinant for sustainable urban planning in terms of scale, use of space and longevity (Lundin & Morrison, 2002). Nevertheless for the SWITCH project it might be interesting to evaluate, for instance, the environmental impacts and the long time perspective of the ongoing projects on infrastructure upgrading in Zaragoza.

## 5.2 LCA as a tool for Sustainability assessment

The methodology used for this research is based on the LCA methodology, that is being extensively used to assess environmental sustainability of Urban Water Systems and it has proven to be very useful. However it has got some important drawbacks as well. For instance some authors criticize the fact that it overlooks important geographic variations such as the resilience of receiving water, also some qualitative aspects, such as sludge quality or ecosystem health are difficult to assess with LCA. Finally, water consumption is not incorporated in the analysis, therefore, it can be considered as a useful tool, but complementary information should also be included for a more complete approach to evaluate urban sustainability (Lundin, 1999)

The present work evaluated the sustainability aspects of water extraction, but also resource consumption and pollution impacts. Such values are presented as indicators for environmental sustainability with the main purpose of providing comprehensive and quantitative information to decision makers in Zaragoza.

## 5.3 Sustainability Indicators

There are many indicators that are currently being used by water organizations around the world to assess their performance and they are suggested to be sustainability indicators but only few actually are (Lundin and Morrison, 2002). For instance percentages of pollution removal at WWT facilities are often suggested as sustainability indicators but those provide information only about the performance of existing end-of-pipe technologies. Percentages of removal can for instance remain the same over time while both pollution concentrations and pollution loads to the environment are actually increasing. Additionally, higher effectiveness may decrease the efficiency, since more resources are required per amount of pollutant that is removed. In this sense, total loads are more useful indicators, since they can actually reflect, not just the technical performance of WWT, but also whether pollution sources within the city are controlled. An example of this is the management of heavy metals and other toxic substances by Local Agenda 21 Office in Zaragoza. Being aware that the existing WWTPs in the city are unable to treat such substances, they are controlling industrial activities to prevent those to enter the sewer system. Such control on industrial activities will be reflected in the total heavy metal loads, but it won’t be quantified by the percentage removal at all.

In this report the definition of sustainability indicator from Lundin (1999) is used as reference point: “A sustainability indicator should link (or at least balance) different areas of society e.g. life styles, economy, resource use and environmental problems or relate to a sustainability target. Consequently, an indicator of environmental sustainability can be defined as an environmental performance indicator (EPI) where the target reflects a sustainable situation. It should ideally provide an early warning for potential problems, being understandable and usable, within the urban water sector and/or for the public and information for calculated should be available”.

Basically most data presented here more or less fulfill this definition and is therefore are suggested to continue being used as part a pool of sustainability indicators Zaragoza Urban Water System. Evidently these indicators relate only with the environmental dimension of sustainability. The social and economic dimensions will require different ones. Also additional indicators would be necessary to fully evaluate the environmental performance of the system. A list of indicators derived from this work is provided next:

1. Water withdrawal
2. Water consumption
3. Energy consumption
4. Chemical product consumption
5. $CO_2$ direct and indirect emissions
6. Pollution loads to the Ebro River (TP, TN, BOD, COD and Heavy Metals)
7. Percentage of Impact upon the river by target pollutants (TP, TN, BOD, COD and Heavy Metals)

8. Sludge production
9. Nutrient recycling to agriculture
10. Heavy metals loads to agriculture

So far water withdrawal and water consumption have already been discussed, but there is major component of water withdrawal which is not being considered by Zaragoza municipality within its goals is groundwater, which is under the authority of the Ebro River Confederation (CHE). Ground water is currently fulfilling 23% of water requirements for Zaragoza city. Major consumers are industries not connected to sewer system, corresponding to two paper mills owning private WWTPs.

Groundwater preservation is one of the criteria used to evaluate environmental sustainability. Being relatively cheaper and usually of higher quality than surface water, groundwater reserves are being over-exploited in several European countries, leading to the drying up of spring waters, destruction of wetlands and saline intrusion of aquifers in coastal zones (Hellstrom et al, 2004). All those problems have been indeed taking place in Spain, and especially in the Ebro Delta, which is a Ramsar site and it’s considered as the second most important natural reserve of the country (CHE, 2007).

The role of groundwater extraction on the environmental impacts of Zaragoza city on the Ebro Catchment is difficult to assess because this groundwater is not part of the natural water cycle, but the result of inefficient use of water for irrigation upstream. According to the Ebro River Working Group this artificial recharge is also feeding the Ebro River flow (personal communication). Considering that 177,000 ha in Zaragoza province are currently irrigated and percolation is around 10,000 $m^3$ $ha^{-1}$ the influence of Zaragoza upon this artificial aquifer is probably negligible, but this would require further research.

In addition to quantity there is also a matter of quality that requires to be assessed concerning groundwater. First, due to its origin, this groundwater is contaminated with nitrates (Mema et al, 2006) and probably also with pesticides. Additionally there is a contamination by persistent chlorinated substances in one of the largest industrial polygon of Zaragoza city. This is consequence of the inadequate practices of a large company that used to work there between 1976 and 1985; and it was discovered in 2006 (CHE, 2006). The implications of speeding up the cycle of this polluted groundwater in Zaragoza are still unclear. Zaragoza municipality and CHE must work together to make clear not just this aspect, but in general all matters related to groundwater planning and management.

Concerning the indicators not related to water withdrawal but to water pollution. Zaragoza city introduced WWT between late 1980s and early 1990s in order to minimize pollution loads to the Ebro River. This time period was not analyzed here. If the time horizon were expanded over two or three decades it would become evident that the city reduced has reduced its oxygen demanding loads to the Ebro River. However there are yet several environmental burdens that require attention regardless the compliance with local and national regulations.

During the time period of the present study the consumption of energy and chemical products, as well as the pollution loads to the Ebro River and the atmospheric emissions have remained more or less constant. Optimizing the water system to reduce such environmental impacts should be expressively included within the goals for water management. To become sustainable WWT systems have to evolve from a reactive approach aimed to remove environmental pollutants to process optimization where the focus is cycling materials as well as saving energy (Lundin & Morrison, 2002).

### 5.4 Sustainability vision

Zaragoza has committed to a list of environmental goals derived from the Aalborg summit for sustainable European cities. This work suggests seven of such goals to be specifically included as environmental goals for the urban water system. In order to do so, the whole Zaragoza sustainability vision has to be adjusted to the SMART principle: Specific, Measurable, Acceptable, Realistic and Time bound (Assinmacopoulos, 2007). This principle was implicit in the goal for reducing water withdrawal and it showed to be very successful.

Setting sustainability goals would also require setting action priorities. From the results presented here it is possible to conclude that energy consumption and its indirect impacts on atmospheric emissions would be a priority, specifically for WWT system. Technical options for optimization should be explored by the municipality. But due to time constraints, such options where not explored by this research work. However a follow-up to the National Plan on Energy would provide some hints about how to reduce the atmospheric emissions derived from electricity production. Since this resource is subjected to an open market dynamics, the municipality could indirectly influence its $CO_2$ emissions by selecting the company that is using more sustainable sources.

Concerning pollution loads, a methodology to set priorities, based on comparing upstream concentrations vs expected concentrations downstream was used in this work and the seasonality of such impacts was included as an important component. From this methodology BOD, heavy metal and nitrogen loads from Zaragoza apparently don't have an important impact upon the water quality of the Ebro River. Therefore such loads should still be considered, but a priority action for sustainability would be reducing Phosphorus loads considering the impact of more than two fold increase on downstream concentrations. This impact is also expected to exacerbate as a consequence of climate change. A reasonable goal would be, for instance: "to reduce by half the emissions of phosphorus to the Ebro River by the year 2020".

The methodology based on impact percentages seems to be straight forward and it could be used to also evaluate the impacts of heavy metals on agriculture soil. But it has got several drawbacks because it could lead to the wrong assumption that, if the environment is already polluted it wont be that important to produce more pollution. This is of particular importance when the effect of, for instance, atmospheric emissions on global change is considered. Additionally, this methodology does not consider the fact that environmental impacts are not necessarily linear to the scale of loads. This is particularly valid for heavy metals and for persistent pollutants in general. In such cases, other factors such the dispersion of pollutants, the exposure, the potential for bioaccumulation and biotransformation, as well as dose-response functions should be of major concern.

In addition to waste water, storm water is also considered as a major component of the urban environmental burden (Ahlman, 2006). The present study included a rough estimation of the possible pollution loads from storm water. Due to the lack of data for storm water quality, such estimation is probably far from reality since pollution loads were assumed to be the same as for untreated sewage, but heavy rain events are rare in Zaragoza, therefore it is reasonable to expect that large loads of pollutants accumulate in the streets and buildings and they are washed away by rain water when heavy rain events take place. The resulting runoff must have a very different composition as compared to the dry period sewage. Additionally, the methodology used here to calculate potential overflows is inaccurate since daily precipitation was used as input data. It is evident that two different days with same cumulative value for precipitation might have completely different hydrographs that, may or may not, lead to sewer overflows. Finally the expected inflow to WWTPs used for storm water calculation is not a reliable value due to the lack of data concerning parasite flows to the sewer system from irrigation channels and overflows from breaking pressure tanks. Therefore the pollution loads from storm water presented here are not to be interpreted as actual impacts but rather as potential scenarios. Further studies for Zaragoza concerning this matter are required.

### 5.5 Drivers for sustainable urban water planning and management

With this overview of current situation of water management in Zaragoza it is now valid to discuss the drivers that will contribute to define the future of water management in the city. There are some internal drivers that are under the control of Zaragoza planning, such as urbanization, population increase and availability of funds. But cities are far from being isolated systems and they are in fact very much affected by local, national and global processes at environmental, social, political and economical level. Therefore a more comprehensive analysis it is important to widen the perspective both in geography and time. Major external drivers for water management in Zaragoza that have been considered here are National Policies (National Plan on Energy and National Irrigation Plan) and Climate change.

The concern of Zaragoza about water withdrawal makes sense since between 30-60% of Spain is at immediate risk from desertification and the Ebro Valley at Aragon is already the driest inland region of Europe (UNCD, 2007). Under current trends is very possible that Zaragoza will still continue to reduce its fresh water withdrawal via infrastructure upgrading. However, if a further reduction is pursued then additional strategies will be required. Ongoing strategies in Zaragoza also aim to optimize water use for landscaping, but this use only represents 5% of total water requirements (including groundwater). Therefore such strategy is probably not going to have a significant effect. Presently domestic consumption is already 110 l person$^{-1}$ day$^{-1}$, which is already a low consumption. On the other hand, industrial consumption in Zaragoza is approximately the 40% of total water requirements (including groundwater). In this report industrial water recycling is proposed as a suitable alternative to continue reducing water withdrawal. This alternative has not been considered by the city yet because extracting ground water is technically more feasible and economically cheaper. However this seems to be the only possibility to continue reducing water consumption, considering the constraints of reducing domestic consumption already have.

A likely scenario for the year 2020, considering different levels of water recycling was analyzed here, and the probable performance of the UWS under the most negative predictions for climate change and upstream water extraction was assessed by means of the sustainability indicators previously presented and discussed.

According to the scenario assessed here, water from Yesa reservoir will remain available for the city and it will be able to fulfill all requirements during the next 50 years, even under worst possible scenario for climate change and irrigation. However, as consequence of very low volumes during summer time, coupled with expected increased radiation and temperature there is some possibility for algal blooms that might threaten drinking water quality in the years to come. Under this scenario, water from Ebro River will be even more unsuitable for drinking purposes. Therefore Zaragoza will have to completely relay on the Yesa reservoir to fulfill its water demand.

In current conditions it seems also that ground water supply for Zaragoza is granted. However the National Irrigation Plan that is about to be implemented has the purpose of upgrading the existing irrigation technology to optimize water use. If increasing evapotranspiration is also expected due to climate change (Ayala-Carcedo, 2000). As consequence it is probable that groundwater recharge for Zaragoza will not remain at the current rate, and the water table will probably drop down and ground water extraction will not be as feasible as now, but this is not possible to know now since there are no studies about groundwater recharge in this aquifer. Such studies are urgently required and this is partially the subject of the Ebro River Working Group (2007).

The recycling water strategy proposed here would obviously have a direct benefit upon water withdrawal. Also a slightly positive effect is expected on energy consumption and thereby also on $CO_2$ emissions to the atmosphere. No effect of this strategy is expected on pollution loads to the Ebro River neither to agriculture soil. In fact if population and industrial activities continue to increase, even under a reduction of water withdrawal scenario, pollution loads to the environment are expected to increase likewise. Therefore, with current WWT technology and societal behaviors it will be possible to improve just some aspects of the environmental performance of the system.

Along this work it has been stated that sustainability of urban systems is a broad concept involving more than just the technical components and the end of pipe solutions to reduce pollution. But so far, only these technical aspects have been discussed. There are, of course important links between society and environment that are the focus of research on sustainability. For a long period, industries were the target of environmental issues. Today, households are recognized to contribute about 50% of the chemicals and metals ending up in wastewater. Domestic use of water is also a focal point for reducing urban water consumption. Minimizing hot water use is of particular interest, since it represents 15% of the households' overall energy use (Krantz, 2005).

Urban systems nowadays are characterized by an alienation of households from nature. Specialized organizations are responsible of water supply and WWT, and hence they are seen as responsible for the environmental impact, the effect of household routines is usually overlooked (Krantz, 2005). Sustainability is very much about using fewer resources at every level of society. In this sense sustainable water organizations would be the ones that, in addition to optimizing technical performance also promote public awareness on sustainable practices. It is possible to say that municipality and other stake holders in Zaragoza (mainly NGOs) have been particularly successful on promoting sustainable practices regarding water consumption at industries and households. As mentioned before, public awareness campaigns in this city reduced water withdrawal in about 6 million $m^3$, which was acknowledged by Habitat UN as one of the 100 successful projects concerning urban sustainability worldwide.

Public awareness also demonstrated to be in a high level one in 8th October 2000, around 400,000 people (more than 60% of Zaragoza's population) went to the streets in order to protest against the National Water Plan proposed by the former national government to divert around of a billion cubic meters of water each year from the River Ebro to arid regions on the Mediterranean zone of the country. The plan was not implemented by the current government.

It can be concluded then, that Zaragoza citizenships are very much aware about water related issues and this is of a high potential to improve the overall environmental performance of this UWS.

### 5.6 Set vs achieved goals for this research

It is possible to say that the goals set for this research were achieved on a large proportion. A total water balance for the UWS was performed, although some sub-balances could not be closed due to missing data. Energy and chemical products consumption were fully calculated. Pollution loads to the Ebro River in terms of BOD, COD, nutrients and heavy metals were quantified. A quantification of toxic organic substances would be also necessary, but it was not possible due to the lack of information. According to its purpose, this work is going to serve as baseline information for further assessment of sustainable development for this UWS.

It is possible also to say that goals were surpassed regarding the future perspectives for Zaragoza UWS derived from the scenario analysis, which was not part of the initial goals for this research. However, this scenario analysis can be considered incipient because it only focuses on the aspects related to the collected data. The suggested strategy is just a technical solution that could be useful, but it has been included in this work basically as an exercise in order to extract more information form the provided data. However, this scenario analysis has defined some important problems that Zaragoza might face in the future. Comprehensive strategies to cope with such problems are to be set by all important stakeholders in Zaragoza and the SWITCH project would contribute with important initiatives to the process. A follow-up of the parameters presented here as sustainability indicators will contribute to assess the success of the set strategies.

# 6 Conclusions

**6.1** The present work evaluated the sustainability aspects of water extraction, resource consumption and pollution impacts by means of LCA, which showed to be a useful methodology even when the impact assessment phase is not applied. However, complementary information such as surface water withdrawal, water consumption, ground water extraction, water leakages in distribution network, etc should also be included for a more comprehensive approach.

**6.2** Zaragoza has been successfully reducing fresh water withdrawal by means of integral strategies involving infrastructure upgrading and promotion of public awareness. The success of these projects shows a good potential to improve the overall environmental performance of this UWS.

**6.3** Zaragoza will still reduce its fresh water withdrawal via infrastructure upgrading. However, further reduction requires additional measures. The ongoing strategy of optimizing water for landscaping won't be very significant. Presently domestic consumption is already low, therefore Industrial water recycling is proposed as a suitable alternative. From this strategy also a slightly positive effect is expected on energy consumption, $CO_2$ emissions. No effect is expected on pollution loads to the Ebro River neither to agriculture soil.

**6.4** Ground water is a major component of Zaragoza urban water cycle. Due to its origin on agriculture irrigation and also due to industrial pollution of soil in the past, groundwater is subjected to important threats of both quantity and quality. Zaragoza municipality and catchment authority should plan together the adequate use of this resource.

**6.5** During the time period of the present study (last six years) the consumption of energy and chemical products, as well as the pollution loads to the Ebro River and the atmospheric emissions have remained more or less constant. Optimizing the urban water system to reduce such environmental impacts should be expressively included within the goals for water management.

**6.6** Zaragoza has committed to the Aalborg summit for sustainable European cities, and it has set a sustainability vision. However it still requires adjusting such goals to be Specific, Measurable, Acceptable, Realistic and Time bound.

Otherwise it won’t be possible to monitor the trends of the system towards sustainability.

**6.7** Priorities for urban water sustainability would be: 1) continuing on reducing water withdrawal and unaccounted for water, 2) optimizing energy consumption and its indirect impacts on atmospheric emissions 3) reducing phosphorus loads to the Ebro. The impact of heavy metals and other persistent pollutants also deserves attention since such impact is not necessarily linear to the scale of loads. Storm water does not seem to be a major problem for Zaragoza, but the results presented here are not reliable enough. Further studies concerning this matter are required.

**6.8** Major drivers for water management in Zaragoza are population increase, National Policies on water and environment and climate change. Combined effects are expected to worsen problems of water management for Zaragoza in the future.

**6.9** Water from the new source, the Yesa reservoir will be able to fulfill Zaragoza’s water requirements during the next 50 years, even under worst possible scenario for climate change and irrigation. However in the future might experience some negative changes on water quality. Ebro River will be even more unsuitable for drinking purposes. Therefore Zaragoza will have to completely relay on the Yesa reservoir to fulfill its water demand.

**6.10** Comprehensive strategies to cope with such problems are to be set by all important stakeholders in Zaragoza and the SWITCH project would contribute with important initiatives to the process. The parameters presented here as sustainability indicators will contribute to assess the success of the set strategies.

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# Annexes

## Annex 1.
## Inventory for data necessary to perform LCA and its availability in Zaragoza

| Process | Availability | Frequency | Data type | Aggregation level |
|---|---|---|---|---|
| ***1*** **Inputs** | | | | |
| ***1.1*** Surface water withdrawal | | | | |
| ***1.1.1*** Energy | | | | |
| 1.1.1.1 Consumption | 2000 – 2006 | Monthly | Measured | Individual |
| 1.1.1.2 Energy sources | No data | | | |
| ***1.1.2*** Inflow water | | | | |
| ***1.2*** Groundwater extraction | | | | |
| ***1.2.1*** Energy | | | | |
| 1.2.1.1 Energy consumption | 2000 | Sporadic | Measured | From one well and extrapolated to the whole system |
| 1.2.1.2 Energy sources | No data | | | |
| ***1.2.2*** Water | | | | |
| 1.2.2.1 Flow | 2003 – 2006 | Trimester | Measured | Composite |
| ***1.3*** Storm water | | | | |
| ***1.3.1*** Precipitation | 2000 – 2006 | Daily | Measured | Composite |
| ***1.3.2*** N | No data | | | |
| ***1.3.3*** P | No data | | | |
| ***1.3.4*** Heavy metal concentration | No data | | | |
| ***1.3.5*** Persistent Organics | No data | | | |
| **2** **Drinking water treatment** | | | | |
| ***2.1*** Energy | | | | |
| ***2.1.1*** Energy consumption | 2000 – 2006 | Monthly | Measured | Individual |
| ***2.1.2*** Energy sources | No data | | | |
| ***2.2*** Water | | | | |
| ***2.2.1*** Inflow | 2000 – 2006 | Daily | Measured | Individual |
| ***2.2.2*** Outflow | 2000 – 2006 | Daily | Measured | Individual |
| ***2.3*** Chemical products consumption | | | | |
| ***2.3.1*** Alum | 2000 – 2006 | Monthly | Measured | Individual |
| ***2.3.2*** Powdered Activated Carbon | 2000 – 2006 | Monthly | Measured | Individual |
| ***2.3.3*** Chlorine | 2000 – 2006 | Monthly | Measured | Individual |
| ***2.4*** Sludge production | 2000 – 2006 | Monthly | Measured | Individual |
| ***3*** **Distribution system** | | | | |
| ***3.1*** Energy | | | | |
| ***3.1.1*** Energy consumption | 2002 – 2006 | Trimester | Measured | Composite Dist Netwrk |
| ***3.1.2*** Energy sources | No data | | | |

| | | | | |
|---|---|---|---|---|
| ***3.2*** Water | | | | |
| ***3.2.1*** Flows | No data | | | |
| ***3.2.2*** Leakage | No data | | | |
| ***4*** **Water consumption** | | | | |
| ***4.1*** Household | 2000 – 2006 | Trimester | Measured | Composite |
| ***4.2*** Public Facilities | 2003 – 2006 | Trimester | Measured | Composite and incomplete***** |
| ***4.3*** Landscaping | | | | |
| ***4.3.1*** Tap water consumption | 2003 – 2006 | Trimester | Measured | Composite and incomplete***** |
| ***4.3.2*** Groundwater consumption | 2003 – 2006 | Trimester | Measured | Composite and incomplete***** |
| ***4.4*** Industry | | | | |
| ***4.4.1*** Connected to sewers | | | | |
| ***4.4.1.1*** Tap water | 2002 – 2006 | Trimester | Measured | Individual |
| ***4.4.1.2*** Groundwater | 2002 – 2006 | Trimester | Measured | Individual |
| ***4.4.2*** No connected to sewers****** | 2000, 2000, 2003 | Sporadic | Estimated | Individual |
| ***4.4.2.1*** Tap water | No consumption | | | |
| ***4.4.2.2*** Groundwater | 1995, 2000, 2003 | Annual | Estimated | Average |
| ***5*** **Sewer system** | | | | |
| ***5.1*** Industrial | | | | |
| ***5.1.1*** Flow | 2005, 2006 | Annual | Measured | Composite*** |
| ***5.1.2*** N | 2005, 2006 | Annual | Measured | Composite*** |
| ***5.1.3*** P | 2005, 2006 | Annual | Measured | Composite*** |
| ***5.1.4*** Heavy metals | 2005, 2006 | Annual | Measured | Composite*** |
| ***5.2*** Household | | | | |
| ***5.2.1*** Flow | No data | | | |
| ***5.2.2*** N | No data | | | |
| ***5.2.3*** P | No data | | | |
| ***5.2.4*** Heavy metals | No data | | | |
| ***5.3*** Storm water | | | | |
| ***5.3.1*** Flow | No data | | | |
| ***5.3.2*** N | No data | | | |
| ***5.3.3*** P | No data | | | |
| ***5.3.4*** Heavy metals | No data | | | |
| ***6*** **Wastewater treatment** | | | | |
| ***6.1*** “La Cartuja” (tertiary treatment) | | | | |
| ***6.1.1*** Energy | | | | |
| ***6.1.1.1*** Energy consumption | 2000 – 2006 | Monthly | Measured | Individual |
| ***6.1.1.2*** Energy Production | 2000 – 2006 | Monthly | Measured | Individual |
| ***6.1.1.3*** Energy sources | No data | | | |

| | | | | | |
|---|---|---|---|---|---|
| ***6.1.2*** | Water | | | | |
| ***6.1.2.1*** | Inflow | | | | |
| 6.1.2.1.1 | Flow | 2000 – 2006 | Daily | Measured | Individual |
| 6.1.2.1.2 | N | 1997 – 2006 | Daily | Measured | Individual |
| 6.1.2.1.3 | P | 2001 – 2006 | Daily | Measured | Individual |
| 6.1.2.1.4 | $BOD_5$ | 2001 – 2006 | Daily | Measured | Individual |
| 6.1.2.1.5 | COD | 2001 – 2006 | Daily | Measured | Individual |
| 6.1.2.1.6 | Heavy metals | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.1.2.2*** | Outflow | | | | |
| 6.1.2.2.1 | Flow | 2001 – 2006 | Daily | Measured | Individual |
| 6.1.2.2.2 | N | 2001 – 2006 | Daily | Measured | Individual |
| 6.1.2.2.3 | P | 2001 – 2006 | Daily | Measured | Individual |
| 6.1.2.2.4 | $BOD_5$ | 2001 – 2006 | Daily | Measured | Individual |
| 6.1.2.2.5 | COD | 2001 – 2006 | Daily | Measured | Individual |
| 6.1.2.2.6 | Heavy metals | 2000, 2003 | Sporadic | Measured | Average |
| ***6.1.3*** | Iron Chloride consumption | 2001 – 2006 | Daily | Measured | Individual |
| ***6.1.4*** | Sludge**** | | | | |
| ***6.1.4.1*** | Production | 2001 – 2006 | Daily | Measured | Individual |
| ***6.1.4.2*** | N | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.1.4.3*** | P | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.1.4.4*** | Heavy metals | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.1.5*** | Atmospheric emissions | | | | |
| ***6.1.5.1*** | Flow | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.1.5.2*** | $CO_2$ | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.1.5.3*** | $NO_x$ | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.1.5.4*** | Heavy metals | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.2*** | “La Almozara” (Conventional treat) | | | | |
| ***6.2.1*** | Energy | | | | |
| ***6.2.1.1*** | Energy consumption | 2001 – 2006 | Monthly | Measured | Individual |
| ***6.2.1.2*** | Energy Production | 2001 – 2006 | Monthly | Measured | Individual |
| ***6.2.1.3*** | Energy sources | No data | | | |
| ***6.2.2*** | Water | | | | |
| ***6.2.2.1*** | Inflow | | | | |
| 6.2.2.1.1 | Flow | 2001 – 2006 | Daily | Measured | Individual |
| 6.2.2.1.2 | N | 2000, 2003, 2005 | Sporadic | Measured | Average |
| 6.2.2.1.3 | P | 2000, 2003, 2005 | Sporadic | Measured | Average |
| 6.2.2.1.4 | $BOD_5$ | 2001 – 2006 | Daily | Measured | Individual |
| 6.2.2.1.5 | COD | 2001 – 2006 | Daily | Measured | Individual |
| 6.2.2.1.6 | Heavy metals | 2000, 2003, 2005 | Sporadic | Measured | Average |

| | | | | |
|---|---|---|---|---|
| ***6.2.2.2*** Outflow | | | | |
| 6.2.2.2.1 Flow | 2001 – 2006 | Daily | Measured | Individual |
| 6.2.2.2.2 N | 2000, 2003, 2005 | Sporadic | Measured | Average |
| 6.2.2.2.3 P | 2000, 2003, 2005 | Sporadic | Measured | Average |
| 6.2.2.2.4 $BOD_5$ | 2001 – 2006 | Daily | Measured | Individual |
| 6.2.2.2.5 COD | 2001 – 2006 | Daily | Measured | Individual |
| 6.2.2.2.6 Heavy metals | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.2.3*** Sludge | | | | |
| ***6.2.3.1*** Production | 2001 – 2006 | Daily | Measured | Individual |
| ***6.2.3.2*** N | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.2.3.3*** P | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.2.3.4*** Heavy metals | 2000, 2003, 2005 | Sporadic | Measured | Average |
| ***6.3*** Paper mills | | | | |
| ***6.3.1*** Inflow | | | | |
| ***6.3.1.1*** Flow | 2005 | Sporadic | Measured | Average |
| ***6.3.1.2*** N | 2005 | Sporadic | Measured | Average |
| ***6.3.1.3*** P | 2005 | Sporadic | Measured | Average |
| ***6.3.1.4*** Heavy metals | 2005 | Sporadic | Measured | Average |
| ***6.3.2*** Outflow | | | | |
| ***6.3.2.1*** Flow | 2005 | Sporadic | Measured | Average |
| ***6.3.2.2*** N | 2005 | Sporadic | Measured | Average |
| ***6.3.2.3*** P | 2005 | Sporadic | Measured | Average |
| ***6.3.2.4*** Heavy metals | 2005 | Sporadic | Measured | Average |

## Annex 2
## Raw Data for the Drinking Water Treatment Plant of Zaragoza on monthly basis

| Year | Month | Water Inflow (m3) | Water Outflow (m3) | Electricity consumption (kW/h) | Chlorine (ton) | Alum (ton) | PAC (ton) | Sludge as Dry matter (ton) |
|---|---|---|---|---|---|---|---|---|
| 2000 | Jan | 6,770,097 | 6,606,332 | 422,389 | 129 | 493 | | |
| 2000 | Feb | 6,173,221 | 6,053,436 | 424,006 | 231 | 539 | | |
| 2000 | Mar | 6,434,724 | 6,242,472 | 423,525 | 206 | 873 | | |
| 2000 | Apr | 5,914,356 | 5,573,862 | 422,125 | 207 | 748 | | |
| 2000 | May | 6,644,068 | 6,141,830 | 425,700 | 254 | 954 | | |
| 2000 | Jun | 7,108,234 | 227,622 | 424,344 | 305 | 946 | | |
| 2000 | Jul | 7,275,509 | 6,624,409 | 430,381 | 441 | 697 | | |
| 2000 | Aug | 6,826,737 | 6,376,162 | 413,254 | 418 | 815 | | |
| 2000 | Sep | 6,835,202 | 6,570,241 | 412,545 | 418 | 820 | | |
| 2000 | Oct | 6,549,294 | 5,311,733 | 392,909 | 289 | 750 | | |
| 2000 | Nov | 6,216,782 | 5,412,375 | 400,145 | 130 | 760 | | |
| 2000 | Dec | 6,605,970 | 5,012,027 | 428,945 | 182 | 508 | | |
| 2001 | Jan | 6,526,381 | 6,252,197 | 406,363 | 131 | 515 | | |
| 2001 | Feb | 5,858,885 | 5,620,512 | 422,539 | 102 | 546 | | |
| 2001 | Mar | 6,352,281 | 6,015,076 | 445,242 | 234 | 639 | | |
| 2001 | Apr | 6,054,660 | 5,789,890 | 392,909 | 289 | 750 | | |
| 2001 | May | 6,450,521 | 6,082,503 | 453,096 | 102 | 664 | | |
| 2001 | Jun | 7,166,591 | 6,721,492 | 451,972 | 466 | 816 | | |
| 2001 | Jul | 7,066,998 | 6,637,223 | 449,333 | 467 | 853 | | |
| 2001 | Aug | 6,874,706 | 6,465,713 | 412,272 | 365 | 954 | | |
| 2001 | Sep | 6,786,170 | 6,389,769 | 404,713 | 469 | 873 | | |
| 2001 | Oct | 6,735,425 | 6,332,661 | 408,636 | 491 | 1,144 | | |
| 2001 | Nov | 6,562,416 | 6,228,397 | 407,091 | 181 | 1,116 | | |
| 2001 | Dec | 6,902,742 | 6,637,920 | 414,498 | 68 | 1,175 | | |
| 2002 | Jan | 6,671,771 | 6,336,940 | 425,772 | 219 | 961 | | |
| 2002 | Feb | 5,689,575 | 5,545,301 | 416,763 | 126 | 816 | | |
| 2002 | Mar | 6,234,004 | 5,965,224 | 428,447 | 126 | 689 | | |
| 2002 | Apr | 5,761,476 | 5,661,557 | 435,805 | 151 | 83 | | |
| 2002 | May | 6,097,677 | 6,035,169 | 436,828 | 301 | 786 | | |
| 2002 | Jun | 6,508,874 | 6,412,899 | 441,668 | 289 | 750 | | 454 |
| 2002 | Jul | 6,669,855 | 6,564,184 | 429,573 | 529 | 1,156 | | 366 |
| 2002 | Aug | 6,093,249 | 6,000,995 | 418,739 | 375 | 658 | | 612 |
| 2002 | Sep | 6,199,178 | 6,169,763 | 408,178 | 329 | 824 | | 777 |
| 2002 | Oct | 6,231,246 | 6,150,255 | 408,734 | 303 | 875 | | 677 |
| 2002 | Nov | 6,173,832 | 6,121,811 | 413,999 | 126 | 852 | | 373 |

| Year | Month | Water Inflow (m3) | Water Outflow (m3) | Electricity consumption (kW/h) | Chlorine (ton) | Alum (ton) | PAC (ton) | Sludge as Dry matter (ton) |
|---|---|---|---|---|---|---|---|---|
| 2002 | Dec | 6,134,871 | 6,012,239 | 416,031 | 100 | 640 | | 230 |
| 2003 | Jan | 6,089,380 | 6,028,486 | 421,370 | 148 | 557 | | 252 |
| 2003 | Feb | 5,371,790 | 5,318,072 | 426,697 | 74 | 679 | | 484 |
| 2003 | Mar | 5,693,297 | 5,636,364 | 429,461 | 150 | 710 | | 555 |
| 2003 | Apr | 5,387,239 | 5,333,367 | 435,687 | 175 | 600 | | 372 |
| 2003 | May | 5,932,808 | 5,873,480 | 435,968 | 327 | 712 | | 708 |
| 2003 | Jun | 6,339,409 | 6,276,015 | 331,702 | 476 | 874 | | 791 |
| 2003 | Jul | 6,549,021 | 6,483,531 | 424,539 | 377 | 986 | | 811 |
| 2003 | Aug | 6,313,334 | 6,250,201 | 416,306 | 401 | 863 | | 510 |
| 2003 | Sep | 6,041,265 | 5,980,852 | 512,727 | 328 | 914 | | 903 |
| 2003 | Oct | 6,144,342 | 6,082,899 | 539,999 | 278 | 733 | 18 | 693 |
| 2003 | Nov | 5,822,186 | 5,763,964 | 501,818 | 100 | 740 | 27 | 920 |
| 2003 | Dec | 5,999,298 | 5,939,305 | 558,181 | 75 | 964 | 0 | 596 |
| 2004 | Jan | 5,634,038 | 5,577,698 | 530,909 | 174 | 495 | 0 | 482 |
| 2004 | Feb | 5,270,245 | 5,217,543 | 476,363 | 149 | 354 | 0 | 151 |
| 2004 | Mar | 5,848,789 | 5,790,301 | 519,999 | 220 | 547 | 0 | 331 |
| 2004 | Apr | 5,451,585 | 5,397,069 | 492,727 | 224 | 465 | 0 | 504 |
| 2004 | May | 5,936,482 | 5,877,117 | 521,818 | 273 | 789 | 0 | 452 |
| 2004 | Jun | 6,520,613 | 6,455,407 | 576,363 | 372 | 1,110 | 0 | 546 |
| 2004 | Jul | 6,416,490 | 6,352,325 | 570,909 | 368 | 1,137 | 22 | 733 |
| 2004 | Aug | 5,912,750 | 5,853,623 | 567,272 | 397 | 899 | 58 | 605 |
| 2004 | Sep | 6,171,743 | 6,110,026 | 570,909 | 325 | 1,118 | 43 | 733 |
| 2004 | Oct | 6,047,407 | 5,986,933 | 607,272 | 223 | 982 | 58 | 645 |
| 2004 | Nov | 5,827,125 | 5,768,854 | 534,545 | 274 | 1,159 | 29 | 478 |
| 2004 | Dec | 5,796,132 | 5,738,171 | 543,636 | 75 | 785 | 128 | 336 |
| 2005 | Jan | 5,921,724 | 5,862,507 | 634,040 | 126 | 596 | 0 | 366 |
| 2005 | Feb | 5,505,974 | 5,450,914 | 578,600 | 126 | 515 | 0 | 277 |
| 2005 | Mar | 5,860,462 | 5,801,857 | 573,528 | 148 | 299 | 0 | 165 |
| 2005 | Apr | 5,601,426 | 5,545,412 | 572,869 | 149 | 299 | 0 | 343 |
| 2005 | May | 5,771,352 | 5,713,638 | 602,325 | 201 | 272 | 0 | 703 |
| 2005 | Jun | 5,960,140 | 5,900,539 | 609,514 | 245 | 517 | 0 | 747 |
| 2005 | Jul | 6,017,296 | 5,957,123 | 607,388 | 247 | 488 | 2 | 482 |
| 2005 | Aug | 5,463,150 | 5,408,519 | 580,835 | 268 | 1,135 | 29 | 752 |
| 2005 | Sep | 5,645,151 | 5,588,699 | 567,770 | 226 | 1,032 | 29 | 671 |
| 2005 | Oct | 5,404,662 | 5,350,615 | 595,041 | 224 | 1,135 | 59 | 579 |
| 2005 | Nov | 5,261,737 | 5,209,120 | 578,447 | 151 | 380 | 30 | 531 |
| 2005 | Dec | 5,772,795 | 5,715,067 | 515,920 | 126 | 859 | 30 | 358 |
| 2006 | Jan | 5,768,970 | 5,711,280 | 669,661 | 156 | 325 | 0 | 411 |
| 2006 | Feb | 4,772,922 | 4,725,193 | 489,938 | 128 | 216 | 0 | 172 |
| 2006 | Mar | 5,227,862 | 5,175,583 | 554,199 | 129 | 298 | 0 | 464 |
| 2006 | Apr | 4,855,018 | 4,806,468 | 448,916 | 153 | 297 | 0 | 474 |
| 2006 | May | 5,620,081 | 5,563,880 | 576,937 | 206 | 432 | 0 | 722 |
| 2006 | Jun | 5,856,470 | 5,797,905 | 579,142 | 305 | 460 | 36 | 714 |
| 2006 | Jul | 5,870,798 | 5,812,090 | 619,655 | 279 | 807 | 0 | 927 |
| 2006 | Aug | 5,266,321 | 5,213,658 | 569,217 | 282 | 644 | 15 | 709 |
| 2006 | Sep | 5,473,739 | 5,419,002 | 586,965 | 256 | 453 | 33 | 1,003 |
| 2006 | Oct | 5,331,003 | 5,277,693 | 549,326 | 207 | 896 | 32 | 1,028 |
| 2006 | Nov | 4,918,971 | 4,869,781 | 517,497 | 154 | 311 | 24 | 458 |
| 2006 | Dec | 5,187,183 | 5,135,312 | 580,419 | 200 | 849 | 39 | 594 |

## Annex 3

## Raw Data for Energy Consumption of the Water Distribution Network in Zaragoza

| Year | Month | Energy consumption (Kwh) | Year | Month | Energy consumption (Kwh) | Year | Month | Energy consumption (Kwh) |
|---|---|---|---|---|---|---|---|---|
| 2001 | jan | 81,273 | 2003 | jan | 63,206 | 2005 | jan | 56,364 |
| 2001 | feb | 84,508 | 2003 | feb | 64,005 | 2005 | feb | 51,455 |
| 2001 | mar | 89,048 | 2003 | mar | 64,419 | 2005 | mar | 51,273 |
| 2001 | apr | 78,582 | 2003 | apr | 65,353 | 2005 | apr | 51,091 |
| 2001 | may | 90,619 | 2003 | may | 65,395 | 2005 | may | 53,311 |
| 2001 | jun | 90,394 | 2003 | jun | 49,755 | 2005 | jun | 54,144 |
| 2001 | jul | 89,867 | 2003 | jul | 63,681 | 2005 | jul | 54,182 |
| 2001 | aug | 82,454 | 2003 | aug | 62,446 | 2005 | aug | 50,909 |
| 2001 | sep | 80,943 | 2003 | sep | 76,909 | 2005 | sep | 50,182 |
| 2001 | oct | 81,727 | 2003 | oct | 81,000 | 2005 | oct | 51,636 |
| 2001 | nov | 81,418 | 2003 | nov | 75,273 | 2005 | nov | 50,364 |
| 2001 | dec | 82,900 | 2003 | dec | 83,727 | 2005 | dec | 45,636 |
| 2002 | jan | 76,639 | 2004 | jan | 53,091 | 2006 | jan | 60,727 |
| 2002 | feb | 75,017 | 2004 | feb | 47,636 | 2006 | feb | 44,364 |
| 2002 | mar | 77,120 | 2004 | mar | 52,000 | 2006 | mar | 48,727 |
| 2002 | apr | 78,445 | 2004 | apr | 49,273 | 2006 | apr | 43,818 |
| 2002 | may | 78,629 | 2004 | may | 52,182 | 2006 | may | 50,727 |
| 2002 | jun | 79,500 | 2004 | Jun | 57,636 | 2006 | jun | 51,091 |
| 2002 | jul | 77,323 | 2004 | Jul | 57,091 | 2006 | jul | 54,000 |
| 2002 | aug | 75,373 | 2004 | Aug | 56,727 | 2006 | aug | 49,455 |
| 2002 | sep | 73,472 | 2004 | Sep | 57,091 | 2006 | sep | 51,636 |
| 2002 | oct | 73,572 | 2004 | Oct | 60,727 | 2006 | oct | 48,398 |
| 2002 | nov | 74,520 | 2004 | Nov | 53,455 | 2006 | nov | 46,909 |
| 2002 | dec | 74,886 | 2004 | Dec | 54,364 | 2006 | dec | 50,727 |

## Annex 4
## Groundwater flows and energy consumed for groundwater extraction

**Energy consumption has been extrapolated from the following assumptions:**

- **Average groundwater table depth in Zaragoza = 5m**
  **(Personal communication, Local agenda 21 Office)**

- **Average energy consumption for groundwater extraction**
  **= 0.02 Kwh/m3 at 5m height**
  **(Personal communication, Local agenda 21 Office)**

| Year | Water extraction ($m^3$) | | | | Energy consumption (Kwh) | | | |
|---|---|---|---|---|---|---|---|---|
| | **Industries connected to the sewer system** | **Landscaping** | **Paper mills** | **Total groundwater extraction** | **Industries connected to the sewer system** | **Landscaping** | **Paper mills** | **Total groundwater extraction** |
| 2001 | 1,369,411 | 1,462,301 | 16,000,000 | 18,831,712 | 27,388 | 29,246 | 320,000 | 376,634 |
| 2002 | 1,566,324 | | | 19,028,625 | 31,326 | | | 380,573 |
| 2003 | 1,457,208 | | | 18,919,509 | 29,144 | | | 378,390 |
| 2004 | 1,568,466 | | | 19,030,767 | 31,369 | | | 380,615 |
| 2005 | 1,309,231 | | | 18,771,532 | 26,185 | | | 375,431 |
| 2006 | 1,481,114 | | | 18,943,415 | 29,622 | | | 378,868 |

## Annex 5
## Raw Data for “Cartuja” WWTP

| year | month | Inflow ($m^3$) | BOD in (ton) | COD in (ton) | TP in (ton) | TN in (ton) | FeCl3 (ton) | BOD out (ton) | COD out (ton) | TP out (ton) | TN out (ton) | TP sludge (ton) | TN to the atmosphere as NOx (ton) | TN sludge (ton) | Sludge as ash (ton) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | jan | 4,403,500 | 1,442 | 3,252 | 42 | 183 | 439 | 60 | 269 | 6 | 89 | 36 | 1.90 | 92 | 455 |
| 2001 | feb | 3,959,200 | 1,184 | 2,793 | 38 | 166 | 398 | 51 | 240 | 6 | 81 | 33 | | 83 | 413 |
| 2001 | mar | 4,183,100 | 1,169 | 2,653 | 38 | 172 | 420 | 34 | 214 | 6 | 85 | 32 | | 86 | 354 |
| 2001 | apr | 4,966,700 | 1,205 | 2,842 | 44 | 198 | 390 | 61 | 299 | 7 | 97 | 36 | | 98 | 386 |
| 2001 | may | 5,452,700 | 1,293 | 3,065 | 50 | 208 | 480 | 57 | 279 | 8 | 103 | 43 | | 103 | 457 |
| 2001 | jun | 5,499,800 | 1,350 | 3,268 | 51 | 201 | 477 | 78 | 327 | 8 | 99 | 44 | | 100 | 398 |
| 2001 | jul | 5,634,700 | 1,286 | 3,117 | 45 | 201 | 427 | 58 | 298 | 7 | 99 | 38 | | 100 | 383 |
| 2001 | aug | 5,319,000 | 1,012 | 2,520 | 43 | 180 | 412 | 56 | 262 | 7 | 90 | 37 | | 89 | 307 |
| 2001 | sep | 4,907,500 | 1,124 | 2,766 | 43 | 170 | 410 | 62 | 261 | 7 | 84 | 36 | | 84 | 422 |
| 2001 | oct | 5,204,400 | 1,260 | 2,962 | 46 | 195 | 425 | 61 | 300 | 7 | 96 | 40 | | 97 | 513 |
| 2001 | nov | 4,641,200 | 1,247 | 3,226 | 43 | 185 | 376 | 66 | 291 | 7 | 91 | 37 | | 93 | 360 |
| 2001 | dec | 4,542,600 | 1,332 | 3,274 | 44 | 187 | 411 | 54 | 274 | 7 | 92 | 37 | | 93 | 307 |
| 2002 | jan | 4,602,000 | 1,419 | 3,317 | 42 | 186 | 419 | 54 | 281 | 7 | 91 | 36 | | 94 | 400 |
| 2002 | feb | 4,301,120 | 1,224 | 2,879 | 41 | 176 | 370 | 53 | 263 | 6 | 85 | 34 | | 89 | 299 |
| 2002 | mar | 4,798,200 | 1,300 | 3,024 | 43 | 186 | 411 | 58 | 275 | 7 | 91 | 36 | | 93 | 391 |
| 2002 | apr | 4,729,700 | 1,287 | 3,010 | 45 | 183 | 420 | 68 | 287 | 7 | 90 | 38 | | 92 | 414 |
| 2002 | may | 5,111,600 | 1,321 | 3,075 | 49 | 195 | 500 | 91 | 333 | 7 | 96 | 43 | | 98 | 438 |
| 2002 | jun | 4,770,400 | 1,341 | 3,260 | 45 | 184 | 425 | 75 | 314 | 7 | 91 | 38 | | 92 | 389 |
| 2002 | jul | 4,834,300 | 1,186 | 2,830 | 43 | 179 | 408 | 46 | 248 | 7 | 88 | 36 | | 89 | 449 |
| 2002 | aug | 4,531,100 | 1,088 | 2,492 | 38 | 156 | 375 | 37 | 203 | 6 | 77 | 32 | | 77 | 346 |
| 2002 | sep | 4,929,900 | 1,272 | 2,992 | 40 | 192 | 275 | 68 | 265 | 6 | 96 | 34 | | 95 | 356 |
| 2002 | oct | 5,032,400 | 1,477 | 3,472 | 45 | 199 | 410 | 94 | 346 | 7 | 98 | 38 | | 99 | 395 |
| 2002 | nov | 5,027,900 | 1,609 | 3,789 | 45 | 204 | 402 | 104 | 370 | 7 | 100 | 38 | | 102 | 361 |
| 2002 | dec | 4,328,100 | 1,368 | 3,288 | 43 | 174 | 426 | 78 | 285 | 6 | 85 | 37 | | 86 | 403 |

| year | month | Inflow ($m^3$) | BOD in (ton) | COD in (ton) | TP in (ton) | TN in (ton) | FeCl3 (ton) | BOD out (ton) | COD out (ton) | TP out (ton) | TN out (ton) | TP sludge (ton) | TN to the atmosphere as NOx (ton) | TN sludge (ton) | Sludge as ash (ton) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | jan | 4,761,500 | 1,576 | 3,754 | 43 | 190 | 426 | 108 | 364 | 7 | 94 | 36 | 2.05 | 94 | 382 |
| 2003 | feb | 2,435,300 | 1,221 | 2,945 | 36 | 146 | 120 | 78 | 285 | 5 | 48 | 30 | | 96 | 132 |
| 2003 | mar | 4,918,700 | 1,292 | 3,050 | 45 | 189 | 408 | 96 | 362 | 7 | 92 | 38 | | 94 | 305 |
| 2003 | apr | 5,655,600 | 1,297 | 3,032 | 44 | 202 | 410 | 95 | 351 | 8 | 101 | 37 | | 99 | 457 |
| 2003 | may | 5,288,600 | 1,303 | 3,121 | 40 | 189 | 385 | 93 | 348 | 7 | 95 | 34 | | 92 | 544 |
| 2003 | jun | 5,372,300 | 1,217 | 2,931 | 47 | 186 | 399 | 104 | 369 | 8 | 93 | 40 | | 91 | 449 |
| 2003 | jul | 5,232,400 | 1,142 | 2,824 | 48 | 180 | 452 | 95 | 330 | 7 | 90 | 40 | | 88 | 410 |
| 2003 | aug | 4,992,800 | 963 | 2,320 | 42 | 163 | 405 | 37 | 235 | 7 | 82 | 35 | | 79 | 392 |
| 2003 | sep | 5,445,400 | 1,186 | 2,896 | 42 | 185 | 409 | 41 | 240 | 7 | 92 | 35 | | 90 | 557 |
| 2003 | oct | 5,560,600 | 1,278 | 3,193 | 46 | 205 | 428 | 97 | 262 | 7 | 102 | 39 | | 100 | 481 |
| 2003 | nov | 4,914,400 | 1,242 | 3,012 | 47 | 192 | 430 | 43 | 219 | 7 | 96 | 40 | | 94 | 547 |
| 2003 | dec | 4,790,800 | 1,243 | 3,028 | 43 | 193 | 419 | 66 | 280 | 7 | 96 | 37 | | 95 | 457 |
| 2004 | jan | 3,782,200 | 1,046 | 2,590 | 38 | 172 | 379 | 51 | 224 | 6 | 84 | 32 | | 86 | 241 |
| 2004 | feb | 4,299,600 | 1,210 | 2,728 | 38 | 183 | 360 | 60 | 265 | 6 | 90 | 33 | | 91 | 292 |
| 2004 | mar | 3,935,100 | 1,308 | 2,959 | 36 | 181 | 357 | 49 | 213 | 5 | 88 | 31 | | 91 | 311 |
| 2004 | apr | 4,753,500 | 1,230 | 2,733 | 43 | 198 | 412 | 74 | 288 | 7 | 97 | 36 | | 99 | 290 |
| 2004 | may | 4,501,400 | 1,269 | 2,813 | 40 | 187 | 372 | 67 | 280 | 6 | 92 | 33 | | 93 | 286 |
| 2004 | jun | 5,730,100 | 1,326 | 2,930 | 47 | 218 | 435 | 101 | 377 | 7 | 108 | 40 | | 107 | 297 |
| 2004 | jul | 5,409,100 | 1,225 | 2,806 | 44 | 200 | 399 | 53 | 274 | 7 | 99 | 37 | | 99 | 317 |
| 2004 | aug | 4,905,300 | 1,031 | 2,456 | 38 | 175 | 360 | 50 | 251 | 6 | 87 | 32 | | 87 | 283 |
| 2004 | sep | 4,786,600 | 1,254 | 2,884 | 38 | 189 | 356 | 64 | 270 | 6 | 93 | 32 | | 94 | 405 |
| 2004 | oct | 5,453,500 | 1,432 | 3,273 | 46 | 215 | 417 | 89 | 366 | 7 | 107 | 38 | | 106 | 333 |
| 2004 | nov | 4,529,400 | 1,347 | 3,148 | 42 | 193 | 423 | 97 | 344 | 7 | 96 | 36 | | 95 | 347 |
| 2004 | dec | 4,753,600 | 1,415 | 3,379 | 42 | 202 | 412 | 95 | 348 | 6 | 101 | 35 | | 99 | 296 |

| year | month | Inflow (m$^3$) | BOD in (ton) | COD in (ton) | TP in (ton) | TN in (ton) | FeCl3 (ton) | BOD out (ton) | COD out (ton) | TP out (ton) | TN out (ton) | TP sludge (ton) | TN to the atmosphere as NOx (ton) | TN sludge (ton) | Sludge as ash (ton) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | jan | 4,570,700 | 1,430 | 3,465 | 41 | 210 | 410 | 92 | 345 | 6 | 105 | 34 | 1.80 | 103 | 271 |
| 2005 | feb | 4,402,000 | 1,574 | 3,266 | 42 | 198 | 414 | 88 | 356 | 7 | 99 | 35 | | 97 | 328 |
| 2005 | mar | 4,969,500 | 1,663 | 3,572 | 44 | 214 | 415 | 101 | 395 | 7 | 108 | 37 | | 104 | 347 |
| 2005 | apr | 5,303,500 | 1,655 | 3,599 | 46 | 223 | 461 | 84 | 378 | 7 | 113 | 39 | | 108 | 362 |
| 2005 | may | 5,707,300 | 1,772 | 4,000 | 52 | 229 | 490 | 121 | 434 | 9 | 117 | 44 | | 111 | 371 |
| 2005 | jun | 5,585,000 | 1,577 | 3,520 | 46 | 228 | 426 | 81 | 387 | 8 | 116 | 39 | | 110 | 405 |
| 2005 | jul | 5,198,800 | 1,484 | 3,198 | 46 | 218 | 435 | 51 | 319 | 8 | 110 | 38 | | 106 | 338 |
| 2005 | aug | 4,884,200 | 1,259 | 2,858 | 42 | 195 | 375 | 38 | 239 | 7 | 100 | 35 | | 94 | 344 |
| 2005 | sep | 5,470,100 | 1,413 | 3,143 | 46 | 224 | 426 | 44 | 297 | 8 | 114 | 38 | | 108 | 388 |
| 2005 | oct | 4,967,000 | 1,551 | 3,276 | 45 | 215 | 435 | 51 | 285 | 7 | 109 | 37 | | 104 | 363 |
| 2005 | nov | 4,479,100 | 1,375 | 2,900 | 40 | 199 | 390 | 56 | 276 | 6 | 100 | 34 | | 97 | 281 |
| 2005 | dec | 4,294,600 | 1,407 | 3,001 | 38 | 193 | 365 | 56 | 258 | 6 | 96 | 32 | | 94 | 249 |
| 2006 | jan | 4,287,060 | 1,536 | 2,955 | 38 | 191 | 373 | 41 | 227 | 6 | 96 | 32 | | 93 | 336 |
| 2006 | feb | 3,370,800 | 1,228 | 2,696 | 34 | 182 | 357 | 57 | 272 | 5 | 92 | 29 | | 88 | 338 |
| 2006 | mar | 3,460,400 | 1,192 | 2,521 | 35 | 189 | 332 | 63 | 243 | 6 | 90 | 29 | | 97 | 175 |
| 2006 | apr | 4,393,600 | 1,421 | 3,320 | 44 | 207 | 412 | 87 | 312 | 7 | 104 | 37 | | 101 | 303 |
| 2006 | may | 5,045,900 | 1,707 | 3,756 | 49 | 236 | 464 | 127 | 391 | 8 | 120 | 41 | | 114 | 323 |
| 2006 | jun | 5,281,500 | 1,609 | 3,497 | 47 | 217 | 455 | 87 | 276 | 7 | 110 | 40 | | 105 | 361 |
| 2006 | jul | 4,575,600 | 1,225 | 2,666 | 40 | 169 | 345 | 34 | 212 | 6 | 85 | 34 | | 82 | 426 |
| 2006 | aug | 4,193,600 | 1,098 | 2,467 | 33 | 159 | 309 | 36 | 195 | 5 | 81 | 28 | | 77 | 278 |
| 2006 | sep | 5,327,500 | 1,443 | 3,092 | 44 | 196 | 401 | 40 | 237 | 7 | 99 | 37 | | 95 | 475 |
| 2006 | oct | 5,541,500 | 1,798 | 3,781 | 47 | 243 | 451 | 53 | 297 | 8 | 122 | 40 | | 118 | 339 |
| 2006 | nov | 5,163,700 | 1,620 | 3,437 | 46 | 219 | 426 | 46 | 267 | 7 | 111 | 38 | | 107 | 407 |
| 2006 | dec | 3,741,600 | 1,709 | 3,609 | 46 | 231 | 438 | 50 | 282 | 8 | 116 | 39 | | 113 | 373 |

**Energy consumption and production (Kwh)**

| Year | Month | Consumed | Produced | Year | Month | Consumed | Produced | Year | Month | Consumed | Produced |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | Jan | 2,227,010 | 122,670 | 2003 | Jan | 2,411,570 | 78,040 | 2005 | Jan | 2,487,884 | 239,280 |
| 2001 | Feb | 2,090,040 | 121,300 | 2003 | Feb | 1,422,640 | 22,730 | 2005 | Feb | 2,232,800 | 251,110 |
| 2001 | Mar | 2,214,650 | 132,910 | 2003 | Mar | 2,198,220 | 281,060 | 2005 | Mar | 2,367,990 | 259,640 |
| 2001 | Apr | 2,288,800 | 229,590 | 2003 | Apr | 2,409,870 | 204,120 | 2005 | Apr | 2,460,130 | 175,240 |
| 2001 | May | 2,442,650 | 284,950 | 2003 | May | 2,493,660 | 232,820 | 2005 | May | 2,671,180 | 163,380 |
| 2001 | Jun | 2,547,160 | 248,400 | 2003 | Jun | 2,439,510 | 476,850 | 2005 | Jun | 2,588,190 | 182,780 |
| 2001 | Jul | 2,446,140 | 153,420 | 2003 | Jul | 2,587,670 | 519,480 | 2005 | Jul | 2,525,970 | 181,990 |
| 2001 | Aug | 2,236,080 | 176,400 | 2003 | Aug | 2,472,360 | 438,740 | 2005 | Aug | 2,299,730 | 140,000 |
| 2001 | Sep | 2,309,410 | 227,850 | 2003 | Sep | 2,480,480 | 165,710 | 2005 | Sep | 2,501,490 | 127,560 |
| 2001 | Oct | 2,541,570 | 272,370 | 2003 | Oct | 2,634,590 | 127,350 | 2005 | Oct | 2,499,150 | 116,730 |
| 2001 | Nov | 2,410,120 | 209,350 | 2003 | Nov | 2,546,550 | 130,240 | 2005 | Nov | 2,408,790 | 121,330 |
| 2001 | Dec | 2,491,630 | 179,840 | 2003 | Dec | 2,586,830 | 139,270 | 2005 | Dec | 2,288,237 | 140,130 |
| 2002 | Jan | 2,500,211 | 229,037 | 2004 | Jan | 2,472,190 | 55,800 | 2006 | Jan | 2,316,915 | 118,920 |
| 2002 | Feb | 2,116,740 | 138,630 | 2004 | Feb | 2,334,170 | 77,800 | 2006 | Feb | 2,083,962 | 110,180 |
| 2002 | Mar | 2,448,870 | 150,020 | 2004 | Mar | 2,260,280 | 52,350 | 2006 | Mar | 2,200,117 | 50,000 |
| 2002 | Apr | 2,442,460 | 79,410 | 2004 | Apr | 2,358,720 | 139,770 | 2006 | Apr | 2,386,256 | 65,437 |
| 2002 | May | 2,502,730 | 143,960 | 2004 | May | 2,413,670 | 76,690 | 2006 | May | 2,506,871 | 98,621 |
| 2002 | Jun | 2,467,240 | 113,660 | 2004 | Jun | 2,560,730 | 168,730 | 2006 | Jun | 2,506,648 | 119,209 |
| 2002 | Jul | 2,441,790 | 126,410 | 2004 | Jul | 2,542,780 | 179,140 | 2006 | Jul | 2,572,370 | 126,710 |
| 2002 | Aug | 2,284,350 | 38,190 | 2004 | Aug | 2,347,320 | 91,890 | 2006 | Aug | 2,274,580 | 73,390 |
| 2002 | Sep | 2,231,450 | 51,890 | 2004 | Sep | 2,336,470 | 226,420 | 2006 | Sep | 2,443,220 | 192,220 |
| 2002 | Oct | 2,516,780 | 75,930 | 2004 | Oct | 2,590,310 | 245,450 | 2006 | Oct | 2,608,917 | 188,770 |
| 2002 | Nov | 2,411,860 | 65,170 | 2004 | Nov | 2,321,780 | 212,760 | 2006 | Nov | 2,526,068 | 190,495 |
| 2002 | Dec | 2,323,540 | 194,820 | 2004 | Dec | 2,487,874 | 226,550 | 2006 | Dec | 2,567,493 | 189,633 |

## Annex 6

## Raw Data for “Almozara” WWTP

| Year | Month | Inflow ($m^3$) | Energy consumption (Kwh) | Energy production (Kwh) | BOD in (ton) | Sludge (ton) | COD in (ton) | TP in (ton) | TN in (ton) | BOD out (ton) | COD out (ton) | TP out (ton) | TN out (ton) | TP sludge (ton) | TN sludge (ton) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | jan | 880,154 | 199,643 | 0 | 185 | 86 | 431 | 6.2 | 30.8 | 12.3 | 49.3 | 4.4 | 16.9 | 1.8 | 7.7 |
| 2001 | feb | 791,349 | 175,366 | 0 | 166 | 78 | 388 | 5.5 | 27.7 | 11.1 | 44.3 | 4.0 | 15.2 | 1.6 | 6.9 |
| 2001 | mar | 836,101 | 114,882 | 94,500 | 176 | 82 | 410 | 5.9 | 29.3 | 11.7 | 46.8 | 4.2 | 16.1 | 1.7 | 7.3 |
| 2001 | apr | 992,724 | 61,961 | 129,800 | 208 | 97 | 486 | 6.9 | 34.7 | 13.9 | 55.6 | 5.0 | 19.1 | 2.0 | 8.7 |
| 2001 | may | 1,089,864 | 65,510 | 149,400 | 229 | 93 | 534 | 7.6 | 38.1 | 15.3 | 61.0 | 5.4 | 21.0 | 2.2 | 9.5 |
| 2001 | jun | 1,099,278 | 55,502 | 144,400 | 231 | 101 | 539 | 7.7 | 38.5 | 15.4 | 61.6 | 5.5 | 21.2 | 2.2 | 9.6 |
| 2001 | jul | 1,126,241 | 64,013 | 142,600 | 237 | 91 | 552 | 7.9 | 39.4 | 15.8 | 63.1 | 5.6 | 21.7 | 2.3 | 9.9 |
| 2001 | aug | 1,063,140 | 93,152 | 111,600 | 223 | 85 | 521 | 7.4 | 37.2 | 14.9 | 59.5 | 5.3 | 20.5 | 2.1 | 9.3 |
| 2001 | sep | 980,892 | 59,566 | 132,000 | 206 | 93 | 481 | 6.9 | 34.3 | 13.7 | 54.9 | 4.9 | 18.9 | 2.0 | 8.6 |
| 2001 | oct | 1,040,235 | 54,437 | 140,600 | 218 | 106 | 510 | 7.3 | 36.4 | 14.6 | 58.3 | 5.2 | 20.0 | 2.1 | 9.1 |
| 2001 | nov | 927,665 | 33,761 | 157,400 | 195 | 91 | 455 | 6.5 | 32.5 | 13.0 | 51.9 | 4.6 | 17.9 | 1.9 | 8.1 |
| 2001 | dec | 907,957 | 37,575 | 163,300 | 191 | 76 | 445 | 6.4 | 31.8 | 12.7 | 50.8 | 4.5 | 17.5 | 1.8 | 7.9 |
| 2002 | jan | 965,126 | 70,334 | 140,200 | 203 | 94 | 473 | 6.8 | 33.8 | 13.5 | 54.0 | 4.8 | 18.6 | 1.9 | 8.4 |
| 2002 | feb | 902,025 | 36,589 | 147,200 | 189 | 88 | 442 | 6.3 | 31.6 | 12.6 | 50.5 | 4.5 | 17.4 | 1.8 | 7.9 |
| 2002 | mar | 1,006,272 | 45,266 | 156,400 | 211 | 99 | 493 | 7.0 | 35.2 | 14.1 | 56.4 | 5.0 | 19.4 | 2.0 | 8.8 |
| 2002 | apr | 991,907 | 47,158 | 147,400 | 208 | 97 | 486 | 6.9 | 34.7 | 13.9 | 55.5 | 5.0 | 19.1 | 2.0 | 8.7 |
| 2002 | may | 1,071,998 | 43,152 | 159,800 | 225 | 105 | 525 | 7.5 | 37.5 | 15.0 | 60.0 | 5.4 | 20.6 | 2.1 | 9.4 |
| 2002 | jun | 1,000,442 | 68,425 | 137,000 | 210 | 98 | 490 | 7.0 | 35.0 | 14.0 | 56.0 | 5.0 | 19.3 | 2.0 | 8.8 |
| 2002 | jul | 1,013,843 | 61,906 | 136,000 | 213 | 99 | 497 | 7.1 | 35.5 | 14.2 | 56.8 | 5.1 | 19.5 | 2.0 | 8.9 |
| 2002 | aug | 950,257 | 69,007 | 96,900 | 200 | 81 | 466 | 6.7 | 33.3 | 13.3 | 53.2 | 4.8 | 18.3 | 1.9 | 8.3 |
| 2002 | sep | 1,033,892 | 81,280 | 107,300 | 217 | 95 | 507 | 7.2 | 36.2 | 14.5 | 57.9 | 5.2 | 19.9 | 2.1 | 9.0 |
| 2002 | oct | 1,055,389 | 55,911 | 134,600 | 222 | 85 | 517 | 7.4 | 36.9 | 14.8 | 59.1 | 5.3 | 20.3 | 2.1 | 9.2 |
| 2002 | nov | 1,054,445 | 50,431 | 137,600 | 221 | 84 | 517 | 7.4 | 36.9 | 14.8 | 59.0 | 5.3 | 20.3 | 2.1 | 9.2 |
| 2002 | dec | 907,684 | 41,355 | 153,400 | 191 | 86 | 445 | 6.4 | 31.8 | 12.7 | 50.8 | 4.5 | 17.5 | 1.8 | 7.9 |

| Year | Month | Inflow ($m^3$) | Energy consumption | Energy production | BOD in (ton) | Sludge (ton) | COD in (ton) | TP in (ton) | TN in (ton) | BOD out (ton) | COD out (ton) | TP out (ton) | TN out (ton) | TP sludge (ton) | TN sludge (ton) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | jan | 948,925 | 66,363 | 124,786 | 199 | 96 | 465 | 6.6 | 33.2 | 13.3 | 53.1 | 4.7 | 18.3 | 1.9 | 8.3 |
| 2003 | feb | 485,334 | 73,547 | 111,914 | 102 | 48 | 238 | 3.4 | 17.0 | 6.8 | 27.2 | 2.4 | 9.3 | 1.0 | 4.2 |
| 2003 | mar | 980,254 | 99,758 | 128,400 | 206 | 82 | 480 | 6.9 | 34.3 | 13.7 | 54.9 | 4.9 | 18.9 | 2.0 | 8.6 |
| 2003 | apr | 1,127,111 | 85,595 | 139,800 | 237 | 110 | 552 | 7.9 | 39.4 | 15.8 | 63.1 | 5.6 | 21.7 | 2.3 | 9.9 |
| 2003 | may | 1,053,971 | 64,046 | 135,100 | 221 | 103 | 516 | 7.4 | 36.9 | 14.8 | 59.0 | 5.3 | 20.3 | 2.1 | 9.2 |
| 2003 | jun | 1,070,652 | 66,636 | 126,800 | 225 | 105 | 525 | 7.5 | 37.5 | 15.0 | 60.0 | 5.4 | 20.6 | 2.1 | 9.4 |
| 2003 | jul | 1,042,771 | 52,572 | 106,700 | 219 | 102 | 511 | 7.3 | 36.5 | 14.6 | 58.4 | 5.2 | 20.1 | 2.1 | 9.1 |
| 2003 | aug | 995,021 | 66,868 | 104,000 | 209 | 98 | 488 | 7.0 | 34.8 | 13.9 | 55.7 | 5.0 | 19.2 | 2.0 | 8.7 |
| 2003 | sep | 1,085,220 | 42,926 | 121,600 | 228 | 106 | 532 | 7.6 | 38.0 | 15.2 | 60.8 | 5.4 | 20.9 | 2.2 | 9.5 |
| 2003 | oct | 1,108,179 | 57,714 | 126,900 | 233 | 108 | 543 | 7.8 | 38.8 | 15.5 | 62.1 | 5.5 | 21.3 | 2.2 | 9.7 |
| 2003 | nov | 979,397 | 49,285 | 132,200 | 206 | 83 | 480 | 6.9 | 34.3 | 13.7 | 54.8 | 4.9 | 18.9 | 2.0 | 8.6 |
| 2003 | dec | 954,764 | 94,797 | 128,600 | 201 | 88 | 468 | 6.7 | 33.4 | 13.4 | 53.5 | 4.8 | 18.4 | 1.9 | 8.4 |
| 2004 | jan | 877,727 | 42,926 | 167,300 | 184 | 71 | 430 | 6.1 | 30.7 | 12.3 | 49.2 | 4.4 | 16.9 | 1.8 | 7.7 |
| 2004 | feb | 997,799 | 57,714 | 121,100 | 210 | 79 | 489 | 7.0 | 34.9 | 14.0 | 55.9 | 5.0 | 19.2 | 2.0 | 8.7 |
| 2004 | mar | 913,210 | 49,285 | 126,900 | 192 | 87 | 447 | 6.4 | 32.0 | 12.8 | 51.1 | 4.6 | 17.6 | 1.8 | 8.0 |
| 2004 | apr | 1,103,135 | 94,797 | 68,500 | 232 | 112 | 541 | 7.7 | 38.6 | 15.4 | 61.8 | 5.5 | 21.2 | 2.2 | 9.7 |
| 2004 | may | 1,044,630 | 60,329 | 126,100 | 219 | 102 | 512 | 7.3 | 36.6 | 14.6 | 58.5 | 5.2 | 20.1 | 2.1 | 9.1 |
| 2004 | jun | 1,329,772 | 52,123 | 111,400 | 279 | 111 | 652 | 9.3 | 46.5 | 18.6 | 74.5 | 6.6 | 25.6 | 2.7 | 11.6 |
| 2004 | jul | 1,255,278 | 69,079 | 98,700 | 264 | 123 | 615 | 8.8 | 43.9 | 17.6 | 70.3 | 6.3 | 24.2 | 2.5 | 11.0 |
| 2004 | aug | 1,138,363 | 93,452 | 75,700 | 239 | 112 | 558 | 8.0 | 39.8 | 15.9 | 63.7 | 5.7 | 21.9 | 2.3 | 10.0 |
| 2004 | sep | 1,110,816 | 57,469 | 110,800 | 233 | 109 | 544 | 7.8 | 38.9 | 15.6 | 62.2 | 5.6 | 21.4 | 2.2 | 9.7 |
| 2004 | oct | 1,265,582 | 41,008 | 137,400 | 266 | 124 | 620 | 8.9 | 44.3 | 17.7 | 70.9 | 6.3 | 24.4 | 2.5 | 11.1 |
| 2004 | nov | 1,051,128 | 156,556 | 35,400 | 221 | 103 | 515 | 7.4 | 36.8 | 14.7 | 58.9 | 5.3 | 20.2 | 2.1 | 9.2 |
| 2004 | dec | 1,103,158 | 41,910 | 154,500 | 232 | 108 | 541 | 7.7 | 38.6 | 15.4 | 61.8 | 5.5 | 21.2 | 2.2 | 9.7 |

| Year | Month | Inflow ($m^3$) | Energy consumption | Energy production | BOD in (ton) | Sludge (ton) | COD in (ton) | TP in (ton) | TN in (ton) | BOD out (ton) | COD out (ton) | TP out (ton) | TN out (ton) | TP sludge (ton) | TN sludge (ton) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | jan | 1,059,861 | 48,682 | 162,600 | 223 | 104 | 519 | 7.4 | 37.1 | 14.8 | 59.4 | 5.3 | 20.4 | 2.1 | 9.3 |
| 2005 | feb | 1,020,743 | 43,290 | 134,000 | 214 | 100 | 500 | 7.1 | 35.7 | 14.3 | 57.2 | 5.1 | 19.6 | 2.0 | 8.9 |
| 2005 | mar | 1,152,335 | 50,801 | 165,500 | 242 | 113 | 565 | 8.1 | 40.3 | 16.1 | 64.5 | 5.8 | 22.2 | 2.3 | 10.1 |
| 2005 | apr | 1,229,784 | 43,628 | 162,600 | 258 | 120 | 603 | 8.6 | 43.0 | 17.2 | 68.9 | 6.1 | 23.7 | 2.5 | 10.8 |
| 2005 | may | 1,323,417 | 58,051 | 144,500 | 278 | 66 | 648 | 9.3 | 46.3 | 18.5 | 74.1 | 6.6 | 25.5 | 2.6 | 11.6 |
| 2005 | jun | 1,295,058 | 45,184 | 150,600 | 272 | 119 | 635 | 9.1 | 45.3 | 18.1 | 72.5 | 6.5 | 24.9 | 2.6 | 11.3 |
| 2005 | jul | 1,205,506 | 71,949 | 125,500 | 253 | 97 | 591 | 8.4 | 42.2 | 16.9 | 67.5 | 6.0 | 23.2 | 2.4 | 10.5 |
| 2005 | aug | 1,132,556 | 83,718 | 97,700 | 238 | 90 | 555 | 7.9 | 39.6 | 15.9 | 63.4 | 5.7 | 21.8 | 2.3 | 9.9 |
| 2005 | sep | 1,268,415 | 70,067 | 133,200 | 266 | 121 | 622 | 8.9 | 44.4 | 17.8 | 71.0 | 6.3 | 24.4 | 2.5 | 11.1 |
| 2005 | oct | 1,151,756 | 41,330 | 159,400 | 242 | 117 | 564 | 8.1 | 40.3 | 16.1 | 64.5 | 5.8 | 22.2 | 2.3 | 10.1 |
| 2005 | nov | 1,038,621 | 52,563 | 138,400 | 218 | 102 | 509 | 7.3 | 36.4 | 14.5 | 58.2 | 5.2 | 20.0 | 2.1 | 9.1 |
| 2005 | dec | 995,838 | 49,308 | 153,100 | 209 | 83 | 488 | 7.0 | 34.9 | 13.9 | 55.8 | 5.0 | 19.2 | 2.0 | 8.7 |
| 2006 | jan | 919,103 | 44,421 | 165,600 | 193 | 77 | 450 | 6.4 | 32.2 | 12.9 | 51.5 | 4.6 | 17.7 | 1.8 | 8.0 |
| 2006 | feb | 722,666 | 32,712 | 150,100 | 152 | 71 | 354 | 5.1 | 25.3 | 10.1 | 40.5 | 3.6 | 13.9 | 1.4 | 6.3 |
| 2006 | mar | 741,875 | 46,344 | 160,700 | 156 | 73 | 364 | 5.2 | 26.0 | 10.4 | 41.5 | 3.7 | 14.3 | 1.5 | 6.5 |
| 2006 | apr | 941,944 | 50,437 | 149,000 | 198 | 92 | 462 | 6.6 | 33.0 | 13.2 | 52.7 | 4.7 | 18.1 | 1.9 | 8.2 |
| 2006 | may | 1,081,790 | 58,563 | 158,400 | 227 | 106 | 530 | 7.6 | 37.9 | 15.1 | 60.6 | 5.4 | 20.8 | 2.2 | 9.5 |
| 2006 | jun | 1,132,300 | 51,360 | 151,500 | 238 | 111 | 555 | 7.9 | 39.6 | 15.9 | 63.4 | 5.7 | 21.8 | 2.3 | 9.9 |
| 2006 | jul | 980,963 | 57,142 | 137,700 | 206 | 96 | 481 | 6.9 | 34.3 | 13.7 | 54.9 | 4.9 | 18.9 | 2.0 | 8.6 |
| 2006 | aug | 899,066 | 58,584 | 113,200 | 189 | 88 | 441 | 6.3 | 31.5 | 12.6 | 50.3 | 4.5 | 17.3 | 1.8 | 7.9 |
| 2006 | sep | 1,142,162 | 49,258 | 136,900 | 240 | 97 | 560 | 8.0 | 40.0 | 16.0 | 64.0 | 5.7 | 22.0 | 2.3 | 10.0 |
| 2006 | oct | 1,188,042 | 62,932 | 147,600 | 249 | 109 | 582 | 8.3 | 41.6 | 16.6 | 66.5 | 5.9 | 22.9 | 2.4 | 10.4 |
| 2006 | nov | 1,107,045 | 56,307 | 155,100 | 232 | 89 | 542 | 7.7 | 38.7 | 15.5 | 62.0 | 5.5 | 21.3 | 2.2 | 9.7 |
| 2006 | dec | 802,161 | 62,450 | 153,320 | 168 | 64 | 393 | 5.6 | 28.1 | 11.2 | 44.9 | 4.0 | 15.4 | 1.6 | 7.0 |

# Annex 7
## Raw Data for “Paper mills” WWTP
## Source: Report submitted by Paper mills to Local agenda 21 Office in 2005

| Parameter | Value |
|---|---:|
| Inflow ($m^3$ $year^{-1}$) | 14,400,000 |
| Energy consumption (Kwh) | 744,971 |
| Energy production (Kwh) | 1,539,236 |
| BOD in (kg) | 2,596,051 |
| Sludge (ton) | 1,139 |
| COD in (kg) | 6,057,453 |
| TP in (kg) | 86,535 |
| TN in (kg) | 432,675 |
| Heavy metals in (kg) | 11,730 |
| BOD out (kg) | 173,070 |
| COD out (kg) | 692,280 |
| TP out (kg) | 61,811 |
| TN out (kg) | 237,971 |
| Heavy metals out (kg) | 3,499 |
| TP sludge (kg) | 24,724 |
| TN sludge (kg) | 108,169 |
| Heavy metals sludge (kg) | 8,231 |

## Annex 8
## Calculations of $CO_2$ emissions from electricity consumption

| Energy source | Relative proportion of each source in Spain | | Factors for $CO_2$ emissions (g/kWh) | Resulting emissions (g/Kwh) | |
|---|---|---|---|---|---|
| | Current | Projections form National Energy Plan (2020) | | Current | Projections form National Energy Plan (2020) |
| Coal | 0.40 | 0.20 | 980 | 395.4 | 196.0 |
| Hydropower | 0.19 | 0.22 | 9 | 1.7 | 1.9 |
| Combined cycles | 0.09 | 0.33 | 362 | 33.3 | 119.5 |
| Wind | 0.04 | 0.06 | 7 | 0.3 | 0.4 |
| Nuclear | 0.27 | 0.19 | 20 | 5.4 | 3.7 |
| Gas Thermal | 0.00 | 0.00 | 653 | 0.0 | 0.0 |
| Resulting factors for Spain | | | | 436.1 | 321.5 |

Source for Spain: Ministerio de Industria, Turismo y Comercio de España (2007)
Source for Emission Factors: European Commission (1995)

From previous annexes electricity consumptions per year can be obtained:

| Total energy consumption per year (Gwh) | | | | | | |
|---|---|---|---|---|---|---|
| Year | DWTP | Distribution network | Cartuja | Almozara | Groundwater extraction | Paper mills |
| 2001 | 5.07 | 1.01 | 28.25 | 1.02 | 0.38 | 0.74 |
| 2002 | 5.08 | 0.91 | 28.69 | 0.67 | 0.38 | 0.74 |
| 2003 | 5.43 | 0.82 | 28.68 | 0.82 | 0.38 | 0.74 |
| 2004 | 6.51 | 0.65 | 29.03 | 0.82 | 0.38 | 0.74 |
| 2005 | 7.02 | 0.62 | 29.33 | 0.66 | 0.38 | 0.74 |
| 2006 | 6.74 | 0.60 | 28.99 | 0.63 | 0.38 | 0.74 |

When current emission factor for Spain (436.1 g/Kwh) is applied to the values of total energy consumption per year the $CO_2$ emissions are obtained:

| $CO_2$ emissions (ton) | | | | | | |
|---|---|---|---|---|---|---|
| | DWTP | Distribution network | Cartuja | Almozara | Groundwater extraction | Paper mills |
| 2001 | 2,210 | 442 | 12,315 | 443 | 164 | 325 |
| 2002 | 2,215 | 399 | 12,508 | 292 | 166 | 325 |
| 2003 | 2,369 | 355 | 12,506 | 358 | 165 | 325 |
| 2004 | 2,840 | 284 | 12,655 | 356 | 166 | 325 |
| 2005 | 3,059 | 271 | 12,789 | 287 | 164 | 325 |
| 2006 | 2,939 | 262 | 12,641 | 275 | 165 | 325 |

## Annex 9. Calculation of Environmental Impacts from Transportation
## Energy consumed and $CO_2$ emissions

Total mass of chemical products and sludge per year at the different UWS facilities can be obtained from previous annexes.

Factors for $CO_2$ emissions and energy consumption derived from transportation of products in Heavy trucks where obtained from Thonstad (2005):

$CO_2$ emission factor (g/ton/km) = 69
Energy consumption factor (Kwh/ton/km) = 0.22

Distances between facilities and production companies (for chemical products) and between facilities and disposal sites (for sludge) were provided by the Local Agenda 21 Office of Zaragoza.

| **Total annual mass (ton)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **DWTP** | | | | **Cartuja** | | **Almozara** | **Paper mills** |
| **Year** | **Chlorine** | **Alum** | **PAC** | **Sludge as Dry matter** | **Iron Chloride** | **Sludge as ash** | **Sludge** | **Sludge** |
| 2001 | 3,365 | 10,045 | 0 | 0 | 5,065 | 4,754 | 1,077 | 1,139 |
| 2002 | 2,974 | 9,090 | 0 | 3,489 | 4,843 | 4,640 | 1,112 | 1,139 |
| 2003 | 2,909 | 9,331 | 45 | 7,594 | 4,692 | 5,113 | 1,129 | 1,139 |
| 2004 | 3,074 | 9,840 | 337 | 5,995 | 4,681 | 3,698 | 1,240 | 1,139 |
| 2005 | 2,237 | 7,526 | 178 | 5,974 | 5,042 | 4,048 | 1,231 | 1,139 |
| 2006 | 2,456 | 5,989 | 179 | 7,674 | 4,763 | 4,135 | 1,073 | 1,139 |
| Distance (km) | 25 | 32 | 18 | 21 | 18 | 21 | 15 | 21 |
| **Resulting factors from multiplying distances** | | | | | | | | |
| $CO_2$ | 1725 | 2208 | 1242 | 1449 | 1242 | 1449 | 1035 | 1449 |
| Energy | 5.5 | 7.04 | 3.96 | 4.62 | 3.96 | 4.62 | 3.3 | 4.62 |

The values for Energy consumption are the following:

| **Total energy consumption from transportation of sludge and chemical products (Kwh)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **DWTP** | | | | **Cartuja** | | **Almozara** | **Paper mills** |
| **Year** | **Chlorine** | **Alum** | **PAC** | **Sludge as Dry matter** | **Iron Chloride** | **Sludge as ash** | **Sludge** | **Sludge** |
| 2001 | 18,508 | 70,714 | 0 | 0 | 20,057 | 21,965 | 3,555 | 5,264 |
| 2002 | 16,356 | 63,992 | 0 | 16,120 | 19,177 | 21,439 | 3,669 | 5,264 |
| 2003 | 15,997 | 65,692 | 178 | 35,082 | 18,579 | 23,622 | 3,726 | 5,264 |
| 2004 | 16,906 | 69,274 | 1,333 | 27,696 | 18,539 | 17,084 | 4,093 | 5,264 |
| 2005 | 12,305 | 52,984 | 704 | 27,600 | 19,968 | 18,701 | 4,064 | 5,264 |
| 2006 | 13,506 | 42,162 | 708 | 35,454 | 18,863 | 19,104 | 3,539 | 5,264 |

The values for $CO_2$ emissions are the following:

| Total $CO_2$ emissions from transportation of sludge and chemical products (ton) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **DWTP** | | | | **Cartuja** | | **Almozara** | **Paper mills** |
| **Year** | **Chlorine** | **Alum** | **PAC** | **Sludge as Dry matter** | **Iron Chloride** | **Sludge as ash** | **Sludge** | **Sludge** |
| 2001 | 5.8 | 22.2 | 0.0 | 0.0 | 6.3 | 6.9 | 1.1 | 1.7 |
| 2002 | 5.1 | 20.1 | 0.0 | 5.1 | 6.0 | 6.7 | 1.2 | 1.7 |
| 2003 | 5.0 | 20.6 | 0.1 | 11.0 | 5.8 | 7.4 | 1.2 | 1.7 |
| 2004 | 5.3 | 21.7 | 0.4 | 8.7 | 5.8 | 5.4 | 1.3 | 1.7 |
| 2005 | 3.9 | 16.6 | 0.2 | 8.7 | 6.3 | 5.9 | 1.3 | 1.7 |
| 2006 | 4.2 | 13.2 | 0.2 | 11.1 | 5.9 | 6.0 | 1.1 | 1.7 |

## Annex 10. Calculations for Storm water overflows to the Ebro River

| Year | Month | Precipitation (mm) | Precipitation * Inpervious area | Expected from precipitation + consumption | Total Inflow WWTPs | Expected from consumption minus Total inflow WWTPs | Overflows to the river |
|---|---|---|---|---|---|---|---|
| 2001 | **Jan** | 30 | 837,480 | 5,893,629 | 5,283,654 | 227,505 | 609,975 |
| 2001 | **Feb** | 4 | 105,840 | 4,561,242 | 4,750,549 | 295,147 | 0 |
| 2001 | **Mar** | 24 | 665,280 | 5,564,739 | 5,019,201 | 119,743 | 545,537 |
| 2001 | **Apr** | 7 | 198,800 | 4,854,963 | 5,959,424 | 1,303,262 | 0 |
| 2001 | **May** | 50 | 1,405,880 | 6,418,318 | 6,542,564 | 1,530,126 | 0 |
| 2001 | **Jun** | 8 | 213,080 | 5,869,981 | 6,599,078 | 942,178 | 0 |
| 2001 | **Jul** | 46 | 1,300,320 | 6,882,947 | 6,760,941 | 1,178,315 | 122,005 |
| 2001 | **Aug** | 4 | 113,400 | 5,522,964 | 6,382,140 | 972,577 | 0 |
| 2001 | **Sep** | 73 | 2,047,640 | 7,377,521 | 5,888,392 | 558,510 | 1,489,130 |
| 2001 | **Oct** | 17 | 482,440 | 5,743,443 | 6,244,635 | 983,632 | 0 |
| 2001 | **Nov** | 12 | 326,480 | 5,431,775 | 5,568,865 | 463,570 | 0 |
| 2001 | **Dec** | 0 | 0 | 5,411,588 | 5,450,557 | 38,968 | 0 |
| 2002 | **Jan** | 31 | 879,480 | 6,074,230 | 5,567,126 | 372,376 | 507,104 |
| 2002 | **Feb** | 6 | 177,240 | 4,488,013 | 5,203,145 | 892,372 | 0 |
| 2002 | **Mar** | 37 | 1,029,840 | 5,830,599 | 5,804,472 | 1,003,713 | 26,127 |
| 2002 | **Apr** | 26 | 731,360 | 5,095,437 | 5,721,607 | 1,357,530 | 0 |
| 2002 | **May** | 1 | 33,600 | 4,700,258 | 6,183,598 | 1,516,940 | 0 |
| 2002 | **Jun** | 14 | 397,600 | 5,434,335 | 5,770,842 | 734,107 | 0 |
| 2002 | **Jul** | 16 | 448,000 | 5,704,241 | 5,848,143 | 591,902 | 0 |
| 2002 | **Aug** | 9 | 252,000 | 4,989,296 | 5,481,357 | 744,061 | 0 |
| 2002 | **Sep** | 23 | 644,000 | 5,476,632 | 5,963,792 | 1,131,160 | 0 |
| 2002 | **Oct** | 38 | 1,052,800 | 5,908,543 | 6,087,789 | 1,232,046 | 0 |
| 2002 | **Nov** | 10 | 268,800 | 5,072,870 | 6,082,345 | 1,278,275 | 0 |
| 2002 | **Dec** | 21 | 599,200 | 5,368,205 | 5,235,784 | 466,778 | 132,422 |

**Formula**

**Estimated storm water**
**= Precipitation * impervious area**

**Overflows = Estimated storm water + Expected WWTPs inflow – Actual inflow to WWTPs**

**Impervious area (km$^2$) = 28,000**

| Year | Month | Precipitation (mm) | Precipitation * Inpervious area | Expected from precipitation + consumption | Total Inflow WWTPs | Expected from consumption minus Total inflow WWTPs | Overflows to the river |
|---|---|---|---|---|---|---|---|
| 2003 | **Jan** | 15 | 414,400 | 5,120,255 | 5,710,425 | 1,004,570 | 0 |
| 2003 | **Feb** | 33 | 918,400 | 4,978,424 | 4,953,460 | 893,436 | 24,964 |
| 2003 | **Mar** | 18 | 498,400 | 4,847,781 | 5,898,954 | 1,549,573 | 0 |
| 2003 | **Apr** | 29 | 812,000 | 4,805,901 | 6,782,711 | 2,788,810 | 0 |
| 2003 | **May** | 46 | 1,282,400 | 5,767,313 | 6,342,571 | 1,857,658 | 0 |
| 2003 | **Jun** | 39 | 1,103,200 | 5,954,054 | 6,442,952 | 1,592,098 | 0 |
| 2003 | **Jul** | 1 | 39,200 | 5,173,981 | 6,275,171 | 1,140,391 | 0 |
| 2003 | **Aug** | 4 | 112,000 | 5,034,663 | 5,987,821 | 1,065,159 | 0 |
| 2003 | **Sep** | 33 | 924,000 | 5,601,800 | 6,530,620 | 1,852,820 | 0 |
| 2003 | **Oct** | 44 | 1,226,400 | 5,982,163 | 6,668,779 | 1,913,016 | 0 |
| 2003 | **Nov** | 35 | 980,000 | 5,445,823 | 5,893,797 | 1,427,974 | 0 |
| 2003 | **Dec** | 16 | 448,000 | 5,073,223 | 5,745,564 | 1,120,341 | 0 |
| 2004 | **Jan** | 10 | 291,200 | 4,586,785 | 4,659,927 | 364,342 | 0 |
| 2004 | **Feb** | 34 | 957,600 | 4,925,772 | 5,297,399 | 1,329,227 | 0 |
| 2004 | **Mar** | 42 | 1,164,800 | 5,653,661 | 4,848,310 | 359,449 | 805,351 |
| 2004 | **Apr** | 35 | 968,800 | 5,076,606 | 5,856,635 | 1,748,829 | 0 |
| 2004 | **May** | 47 | 1,316,000 | 5,860,213 | 5,546,030 | 1,001,817 | 314,183 |
| 2004 | **Jun** | 10 | 274,400 | 5,344,331 | 7,059,872 | 1,989,941 | 0 |
| 2004 | **Jul** | 24 | 672,000 | 5,668,454 | 6,664,378 | 1,667,924 | 0 |
| 2004 | **Aug** | 2 | 44,800 | 4,587,888 | 6,043,663 | 1,500,574 | 0 |
| 2004 | **Sep** | 6 | 179,200 | 4,955,382 | 5,897,416 | 1,121,234 | 0 |
| 2004 | **Oct** | 28 | 784,000 | 5,449,262 | 6,719,082 | 2,053,820 | 0 |
| 2004 | **Nov** | 1 | 16,800 | 4,483,808 | 5,580,528 | 1,113,520 | 0 |
| 2004 | **Dec** | 0 | 0 | 4,439,115 | 5,856,758 | 1,417,643 | 0 |

| Year | Month | Precipitation (mm) | Precipitation * Inpervious area | Expected from precipitation + consumption | Total Inflow WWTPs | Expected from consumption minus Total inflow WWTPs | Overflows to the river |
|---|---|---|---|---|---|---|---|
| 2005 | **Jan** | 10 | 275,800 | 4,787,355 | 5,630,561 | 1,119,006 | 0 |
| 2005 | **Feb** | 8 | 218,400 | 4,355,780 | 5,422,743 | 1,285,363 | 0 |
| 2005 | **Mar** | 17 | 476,000 | 4,932,419 | 6,121,835 | 1,665,416 | 0 |
| 2005 | **Apr** | 14 | 397,600 | 4,649,740 | 6,533,284 | 2,281,144 | 0 |
| 2005 | **May** | 50 | 1,394,400 | 5,799,473 | 7,030,717 | 2,625,644 | 0 |
| 2005 | **Jun** | 46 | 1,288,000 | 5,862,983 | 6,880,058 | 2,305,076 | 0 |
| 2005 | **Jul** | 0 | 5,600 | 4,633,128 | 6,404,306 | 1,776,778 | 0 |
| 2005 | **Aug** | 6 | 156,800 | 4,285,596 | 6,016,756 | 1,887,959 | 0 |
| 2005 | **Sep** | 22 | 610,400 | 4,902,997 | 6,738,515 | 2,445,918 | 0 |
| 2005 | **Oct** | 40 | 1,131,200 | 5,183,344 | 6,118,756 | 2,066,611 | 0 |
| 2005 | **Nov** | 33 | 912,800 | 4,836,312 | 5,517,721 | 1,594,209 | 0 |
| 2005 | **Dec** | 6 | 156,800 | 4,540,264 | 5,290,438 | 906,975 | 0 |
| 2006 | **Jan** | 16 | 453,600 | 4,834,733 | 5,206,163 | 825,030 | 0 |
| 2006 | **Feb** | 27 | 767,200 | 4,251,890 | 4,093,466 | 608,776 | 158,424 |
| 2006 | **Mar** | 13 | 364,000 | 4,258,136 | 4,202,275 | 308,139 | 55,861 |
| 2006 | **Apr** | 26 | 722,400 | 4,299,035 | 5,335,544 | 1,758,909 | 0 |
| 2006 | **May** | 16 | 453,600 | 4,718,791 | 6,127,690 | 1,862,499 | 0 |
| 2006 | **Jun** | 41 | 1,136,800 | 5,614,742 | 6,413,800 | 1,935,859 | 0 |
| 2006 | **Jul** | 38 | 1,052,800 | 5,567,399 | 5,556,563 | 1,041,963 | 10,837 |
| 2006 | **Aug** | 6 | 173,600 | 4,144,170 | 5,092,666 | 1,122,096 | 0 |
| 2006 | **Sep** | 61 | 1,719,200 | 5,876,446 | 6,469,662 | 2,312,416 | 0 |
| 2006 | **Oct** | 25 | 688,800 | 4,703,978 | 6,729,542 | 2,714,364 | 0 |
| 2006 | **Nov** | 43 | 1,204,000 | 5,028,348 | 6,270,745 | 2,446,397 | 0 |
| 2006 | **Dec** | 0 | 0 | 4,110,740 | 4,543,761 | 433,022 | 0 |