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# Sustainability Assessment of Göteborg Urban Water System using Stakeholder - Indicator combined approach

*Master of Science Thesis in Applied Environmental Measurement Techniques*

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SUMMARY

This thesis investigates Göteborg's urban water system from a sustainability point of view using a stakeholder - indicator combined approach.

The methodology uses Life cycle based Environmental Sustainability indicators. To complement the quantitative information obtained with the indicators, stakeholder interviews and a questionnaire survey was carried out. The questionnaire was designed to collect data regarding quality of the service and also to evaluate important issues related to future perspectives of the service. The questionnaire was targeted to both stakeholders and general public.

The results show that the UWS is moving towards sustainability in some of the indicators such as the concentration of P and N in the Ryaverket waste water treatment plant (RWWTP) effluent and in the sludge quality and stays stable without much variation in indicators such as leakage in the distribution of drinking water and energy consumption in the drinking water production. The questionnaire evaluation shown that in the area of sustainability issues, policies and management the answers didn't show a clear consensus among the stakeholders. Also shown that in the evaluation of the quality of the service and the drinking water quality the stakeholders supported the tap water that is produced and delivered by VA-Verket.

*Keywords:* urban water system; sustainable development; environmental sustainability indicators, stakeholders participation.

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## 1. Introduction

One of the most important resources for developing of all kind of economic and non-economic activities is water. Freshwater is used in several different activities and processes. We drink approximately 2 liters per day, but also we use water in our basic and common activities like cooking, washing, cleaning, flushing toilets and so on. The minimum required amount to cover all those activities is about 30 liters per day (Rydén, Lars 2000). The biggest consumer of freshwater in the Swedish modern society is the industrial activities with 70% of the withdrawal of freshwater. They consume water mainly in chemical and cooling processes. Among the other uses of water are: conveyance of wastes (from household and industries), recreation and aesthetics (Hultman, B. 1998).

In urban areas water systems are necessary to provide drinking water and collect the wastewater and stormwater. Those systems should provide reliable service and continuous in time as possible as the society depend on them. Urban water systems (UWS) like any other kind of system that uses natural resources and energy, should be long term sustainable. A sustainable urban water system should satisfy the needs of a community with the minimum economic, environmental and social impact. The service should be cost-effective and affordable for the costumer. In the social perspective UWS's should protect public health and also provide equitable access to drinking water. (White, S.; Turner, A. 2003).

Swedish UWS provides a high quality service of clean water, removal of wastewater and storm water. Yet current water and waste water systems and practices have lately been subjected to debate from the sustainability perspective (Hellström, D et al, 2000).

In order to evaluate the UWS from sustainability point of view is necessary to capture and understanding of both the service and consumer perspective, and the environmental systems perspective. These two perspectives combined are suggested to give comprehensive information of an UWS (Lundéhn C. et al, 2006). This master thesis carries out a holistic evaluation of the UWS in Göteborg, Sweden using a stakeholder dialogue and environmental sustainability indicators combined approach (ESI).

## 2. Aim and Objectives

The aim of this master thesis is to:

*"Carry out a sustainability assessment of the Urban Water System in Göteborg city using a stakeholder -indicator combined approach"*

The objectives are to:

- Carry out a literature review to understand methods and frameworks of UWS sustainability assessment in general and with the use of indicators in particular.
- Collect quantitative data of selected ESI (at treatment plants and relevant institutions) in order to view trends over time.
- Asses the results of a stakeholder and consumer questionnaire survey.
- Integrate ESI and questionnaire results to discuss Göteborg UWS from a sustainability point of view.

## 3. Background

### 3.1 Urban Water Systems and sustainability

There are many ways to define what Sustainable Development (SD) is. One of the most common used is the one that is in the Brundtland report (1987): "Development that meets the needs of the present without compromising the ability of the future generations to meet their own needs". This definition is, however, attached to the present state of technology and social organizations (Lundin M. 2003). A sustainable UWS can be defined by extending the definition of SD as follows: "A sustainable urban water system should be designed and managed to provide drinking water and conduct and treat wastewater in a long time perspective while maintaining the ecological, environmental, and societal integrity" (Loucks D. 2000, Lundin M. 2003, Palme U. 2004).

Water is and was one of the most predominant elements in the civilizations development. Having access to drinking water and the use of water for transport purposes were the main driving forces to establish the first settlements. The availability and the access to drinking water are essential for all societies and its significance involves almost every human activity. Water is a natural and renewable resource and is part of a closed cycle that means that the global water budget is limited (since it doesn't exist any external inputs of water). The water in the Earth is part of the same hydrological cycle, i.e. any perturbation, in large or small scale, will have repercussions in other parts of the globe (e.g. use of pesticides) (Lundin, L., 2000). A network of coast and marine areas, lakes, rivers, ground water, wetlands, streams, and estuaries constitutes the water system. The urban water system is part of the water system and is constituted by a network of pipes that delivers drinking water and conveys waste and storm water.  Also drinking water production plants and waster water treatment facilities are part of the urban water system. Both systems interact between them in different ways like energy, material flows, emissions etc. The interaction of both systems is shown in figure 3.1.

The urban water cycle begins in the catchment area (river, lake, dwell, etc) where the raw water is collected. Raw water is transported in different ways to the water works where is treated and distributed in a pipe network to the consumers (residential, industries, agricultural, etc). Wastewater is collected by a pipeline network that collects domestic and industrial wastewater.  Stormwater is removed and collected from urban areas by pipes and channels preventing flooding. Sometimes stormwater infiltrates the sewer system resulting in an extra pollution charge and an extra amount of water that goes to the wastewater treatment plants. After treatment the wastewater is discharged in different watercourses (rivers, streams etc.) and the ocean where it comes back to the water cycle. In some cases water ponds or wetlands are use as a buffer between treated wastewater and the environment. The treatment of wastewater produces treated wastewater and organic sludge. The sludge is possible to use to produce methane by sludge digestion, it can be disposed in landfills or used in soil enrichment processes (Huges, P. 2000).

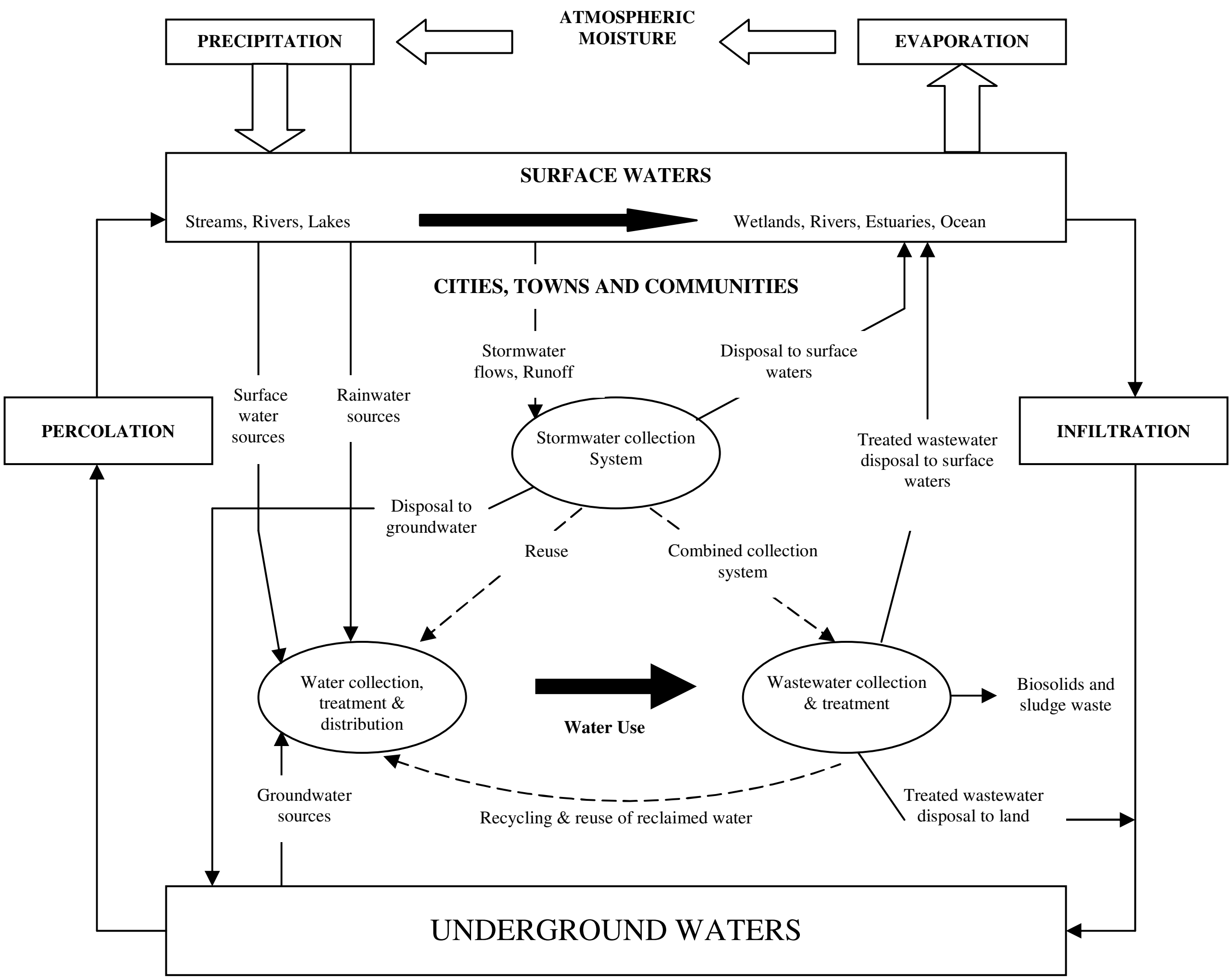



Figure 3.1 Urban and natural water systems interaction (adapted from Hughes, P. 2000)

### 3.1.1 Drinking water production and wastewater treatment

Commonly the process of drinking water production consists of a series of chemical and physical steps that start in the source of raw water (river, lake, etc.) and finish in the distribution pipe net. The process typically includes flocculation, sedimentation & flotation and rapid and slow filtration. The disinfection process is carried out using chlorine. The figure 3.2 shows the typical steps that are carried out in the drinking water production.

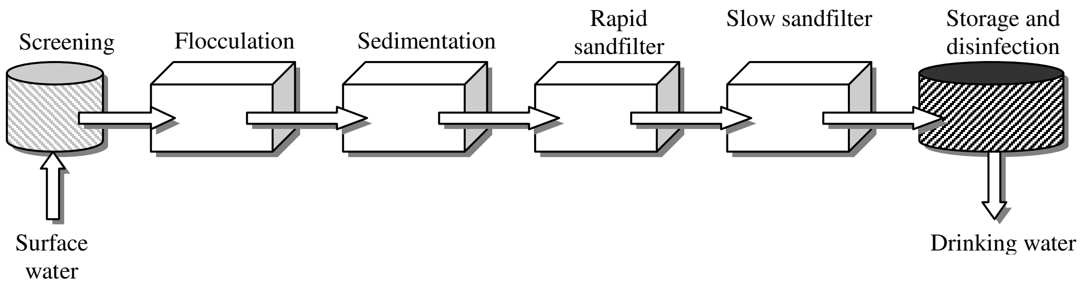



Figure 3.2 Typical drinking water production processes

Environmental aspects are related with the drinking water production such as energy consumption, emissions to air (lime burnt) and water contamination. Air emissions are related whit energy consumption and also to chemical production (Palme U., 2004). An alternative way to produce drinking water is that using a membrane filter system (figure 3.3). In this case raw water is taken and distributed directly to the filtration process. That process is carried out in two stages, in the first one the raw water is micro-filtered so after it can be used like service water, bathing or washing. Part of the flow (15% – 20%) is nano-filtered in order to be used for drinking and cooking. The whole process generates also residual water that can be used to flushing lavatories. This way to produce drinking water can be used under conditions of shortage or in situations where raw water is heavily contaminated (Urban Water Annual Report, 2000).

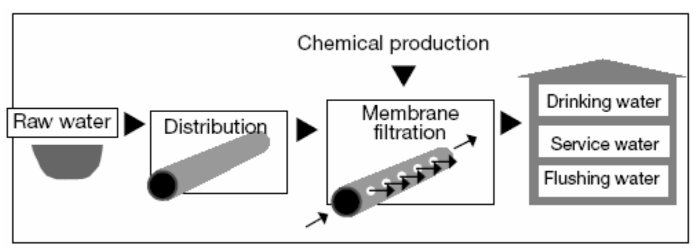



Figure 3.3: Membrane filter system for drinking water production

The treatment of wastewater in a conventional centralized system, where the wastewater from different sources (households, hospitals, industries, etc) is pumped to the sewer system, is carried out in three steps (figure 3.4):

1) Mechanical Treatment (primary treatment): The first step in the treatment of wastewater is the mechanical separation between the solid and the liquid part, for that, screens, grit chambers and settling tanks are used to separate the liquid part from the bigger solid part like sand, paper, stones, etc.
2) Biological Treatment (secondary treatment): After the mechanical process wastewater still contains solids that can be dissolved or floating on the surface. In order to remove those solids microorganism are used to trap and settle those particles.
3) Chemical Treatment (advanced treatment): In the final step the wastewater can be treated either chemically, physically or biologically in order to remove Phosphorus and Nitrogen and in some cases disinfecting it with Chlorine.

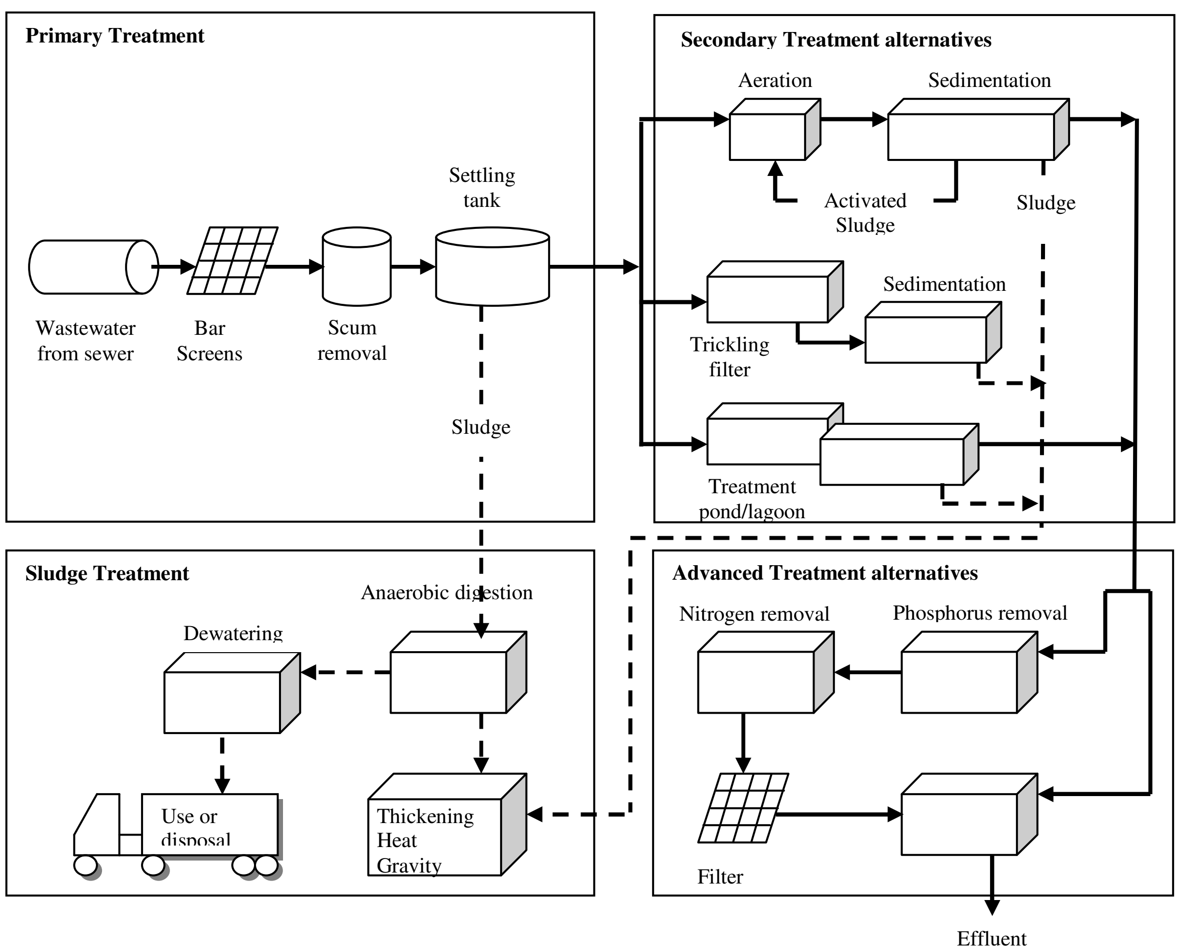



Figure 3.4 Typical wastewater treatment process (adapted from Water Environment Federation (2006))

The wastewater treatment process generates treated wastewater and sludge. Sludge is possible to use to produce methane, through anaerobic digestion, and also fertilizers that can be used for soil enrichment purposes.

Environmental aspects are related with the wastewater treatment process and the sludge process. Energy consumption and emissions of nutrients and heavy metals are important parameters to consider in order to identifying environmental aspects in the wastewater treatment process and the sludge process. Environmental aspects related those processes are: resource depletion of fossil fuels, acidification, eutrophication, stratospheric ozone depletion and the greenhouse effect (Palme U., 2004).

### 3.1.2 Policy and regulations.

Recently new tools have appeared to encourage environmental protection and the sustainability concept has started to shift in the way of thinking in public and private sectors. Agenda 21 and environmental labeling are ways for municipalities and companies to act more responsible and environmentally sound (Lundin, L., 2000).

Policy and regulation are a major drive force toward societal change. Currently the main pieces of legislation that regulates the urban water supply and sewage disposal in Sweden nowadays are:

- The public Water and Wastewater Plant Act (WWA)
- The Environmental Code (EC)
- The Food Act

The WWA states that the responsibility of supplying enough water and wastewater treatment services is to assure good health to the community is the municipality. The water services can be carried out by either the municipality or by private companies but under the supervision of the municipality. If a private company or operator is supplying the water services (supplying water or treatment of wastewater) their facilities, pipes etc can be declared public. WWA also declares that the water charges can not exceed the necessary cost of production of the service. Thus municipalities can not profit from supplying the service and use it in other sector. Consequently private sector can't profit either and they can't have profit-base dividends (Lannerstad, M. 2003, Holmqvist, A. 2004).

The Environmental Code is a framework of Swedish environmental legislation with its main purpose to regulate activities with and environmental impact to promote a sustainable development i.e. to ensure the present and future generations a pleasant and healthy environment. The EC also stipulates the measures that have to be taken in order to prevent and minimize environmental impacts. In the second chapter the EC includes a number of general rules of consideration like:

- The polluters pay principle
- Knowledge of environmental effects
- Principles of good management and re-circulation

In relation with urban water services the EC regulates the environmental impacts that could provoke the water abstractions and the effluent that comes from the wastewater treatment plants (Lundin, Lars-Christer 2000; Lannerstad, M. 2003).

As water is a food product it also falls under the Food Act and must to be handled with the same standards as other of food product.

#### 3.1.3 Private or public management?

The main motivation to privatize public goods and services is the lack of efficiency. One of the characteristics of the public goods market is that it behaves like a monopoly. In this case the lack of substitute products and competition leads to less incentive to keep prices down. Also the decisions are politically based instead of economically driven. Other characteristic is that is that the public sector is producer-oriented instead of consumer-oriented (Holmqvist, A. 2004).

The process of privatization can made through different approaches, it can be partial or total, can be in a management level or construction and maintenance of facilities and pipe lines, or other kind of combinations. Water involves a wide range of activities and is essential to develop economic activities, improving individual and social well being, life and health and has cultural and religious significance. Due to the importance of water, finding the best alternative or combination of public or private control is not an easy task (Suleiman, R. 2002) there are different arguments for and against the privatization process, some of those are listed below:

“Pros” of privatization:

- The private sector has more financial resources to invest and maintain the water infrastructure than the government.
- The private sector has economic driving forces that lead to improved performance of the service.
- The private sector has proper technical resources to manage water operations and its decisions are not politically influenced.

“Cons” of privatization

- Privatization unties the responsibility to the government of assure adequate access to water for everyone, regardless any circumstances.
- The privatization process may be irreversible.
- The access to water may be just for those who can pay for it.
- The feasibility to provide water services may be restricted by profitable and economic reasons that could be unattractive to invest in rural areas.
- The risk of corruption due to the commercialization of water supply.

Regardless of the “pros” and “cons” related to privatization of water services, governments should assure adequate access to water services to the population using private or public approaches. Also the privatization process is a different situation in developing countries where economical conditions are different than in developed countries (Holmqvist, A. 2004; Suleiman, R. 2002).

In Sweden, a privatization tendency of water services and sewage disposal started in 1998 through Public-Private-Partnership, multinational management contracts and facilities with private ownership. In the opinion of professor Jan-Erik Gustafsson, (Royal Institute of Technology, Stockholm) the process of privatization of water services (WS) and sewage disposal in Sweden is a reaction to the European/global ideological desire to transform the society according to neo-liberal ideas (Lannerstad, M. 2000). The strongest argument against the privatization is that water is a life necessity and the water supply constitutes a natural monopoly. The anti-privatization position is supported by the Chief Engineer Sven-Erick Kristenson in Gothenburg and Sverker Westman at Stockholm Water. Kristenson and Westman argue that although many people think that public are cost-ineffective negative economical charge for the same, but on the other hand all the cost are cover with the water tariffs. Also they criticize the privatization lawyers for not include all in their calculations. Even though doesn't exist a strong support for privatization, water professionals in the private sector argue that politicians less capable of taking the right decisions in order to promote an efficient management of water services. The representatives of Sydkraft, which is a private company that runs the water services in Norrköping (Sweden), also criticize the non-profit policy of the Swedish government. The leading political party in Sweden since World War II is the Social Democratic Party. Because of that Their decisions are thus relevant in the process of privatization. It seems that they have different opinions about privatizing WS, since the decision of privatizing WS in Norrköping was made by local social democrats yet very criticized by other members of the Social Democrats party traditional level. The WS and sludge disposal in Sweden is from having a definitive solution or way to manage water services. The two possible scenarios for the future, are either private operation or municipal cooperation (Lannerstad, M. 2000).

### 3.2 Sustainability Assessment

One thing that is constant in time is change, the uncertain thing is "what" will change over the time. Changes in one way or another will occur and surely they will have influence, positive or negative, in the physical, biological and social dimensions. The anticipation of change is an important aspect in any planning process (Loucks, D. 2000). The idea of sustainability has different meanings for different people but commonly involves the future and therefore planning. Trends and tendencies are important to have in mind in the process of planning in order to anticipate futures changes, establish goals and aims and develop new policies. Therefore assessment of sustainability lies in the concept of sustainable development. It is not enough measuring productivity, efficiency or effectiveness in an economic point of view, is also necessary to incorporate the social and environment dimensions. Several frameworks and tools are available to assess if a system is going towards sustainability or not. This chapter presents some of the most common frameworks that have been applied to evaluate UWS in a sustainability perspective.

### 3.2.1 Environmental Accounting

Environmental accounting is a method that quantify and evaluates costs and benefits of environmental activities, used at company level or national level to evaluate the use of natural resources. Companies that provide either services or products will incur in direct and indirect costs. One type of cost is the environmental costs (USA, EPA 1995; Lundin, M. 1999). Environmental costs should be taken in account in a managerial perspective because:

- They can be reduced trough the incorporation of better technology or the redesigning of processes or products
- They can be balanced with revenues that they can generate (sale of waste or by-products)
- They can be used like a competitive advantage to show to the costumers

From a business perspective it is possible to find different types of environmental costs that are otherwise hidden to the managers:

- Upfront Environmental Costs: related with costs that is possible to incur before the operation of a process, system or facility such as site studies, R&D, installation, etc
- Regulatory and voluntary Costs (beyond compliance): related with costs incur in the operation such as remediation, inspections, reports insurance.
- Back end Environmental Costs: related with operation that eventually will occur in a defined future such as closure/decommission, closing a landfill cell, replacing tanks with hazardous substances.

- Contingent Costs: These kinds of costs are related with situations that may or may not occur in the future, like remediation and compensation of spills or accidents related with the environment.
- Image and relationship Costs: these kind of cost are less “tangible” than the others because depends on the perception of the managers, communities and regulators. Examples are environmental reports, awards, environmental initiatives that can affect the relationship with costumers, investors, lenders regulators etc.

### 3.2.2 Sustainable Development Records (SDR)

SDR is used to evaluate the economic and environmental performance of a system that produces a service or a product. The model is composed by three parts: Resource Base, System and Service. Figure 3.5 shows the SDR model.

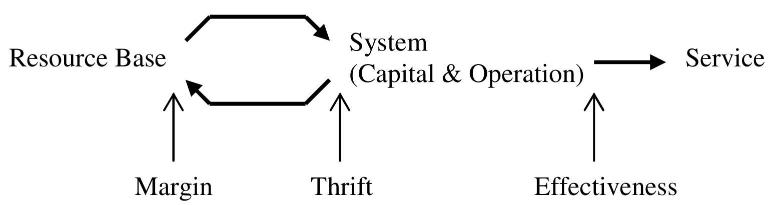



Figure 3.5 The SDR model

The SDR model evaluates the flow of resources (financial, social and material) through a system to produce a service. It includes three different kinds of indicators: Effectiveness Ratio (Service/operation) relationship between the service and the size of the operation, Thrift Ratio (operation/throughput) that relates the operation with the use of resources and the Margin Ratio (throughput/resource base) that links the use of resources with the total resources base (Nillson, J; Bergström, S. 1995; Sjöström, C.; Stang, K. 2002).

### 3.2.3 Pressure-State-Response (PSR) model

The PSR model is based on Cause-Effect links and was developed by the Organization for Economic Cooperation and Development (OECD) among other institutions. This model is composed by three different sets of indicators: Pressure, State and Response indicators. The figure 3.6 shows the conceptual frame of PSR model

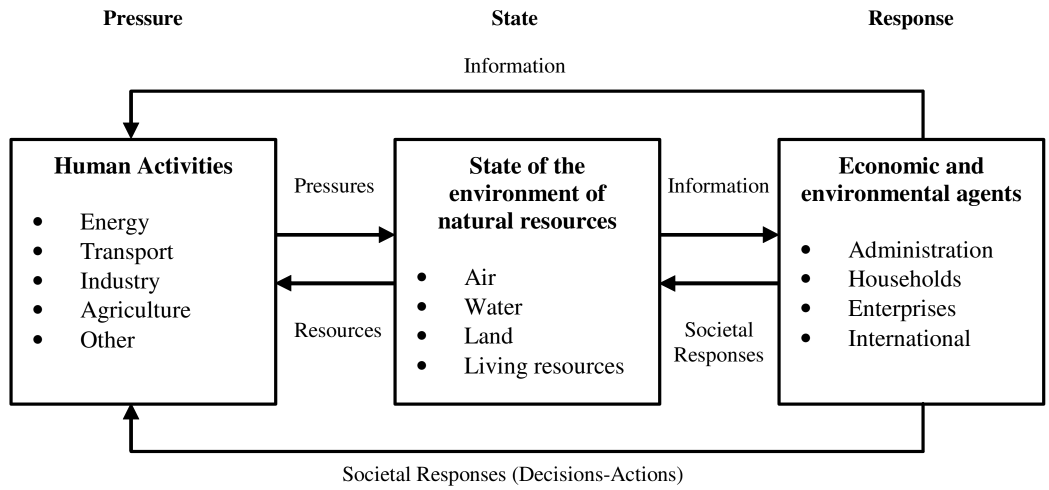



Figure 3.6 Conceptual framework of PSR model.

The pressure indicators are related with human activities like use of natural resources, energy consumption, green house gases etc. that exert a pressure in the environment, this pressure give as a result a change in the state of the environment (air pollution, land degradation, etc) that generates a response from the society. This response can be individual or collective and can be to prevent, remediate or conserve the environment (Pierini, N. 2005).

### 3.2.4 Life Cycle Assessment

The Life Cycle Assessment (LCA) is a tool that is used to evaluate and analyze the environmental impacts and the resource consumption in either the production of goods or services. The LCA encompasses the whole “history” of the product since its origin as raw material till the end as debris. In the assessment all the activities that involve the activity such as transportation, raw material extraction and preparation, manufacture, distribution etc are taken in account (Antón, M.A. 2004; Menke, D. Davis, G.; Vigon, B. 1996).

The LCA method can be resumed in four steps defined by ISO 14040, 1997(figure 3.7)

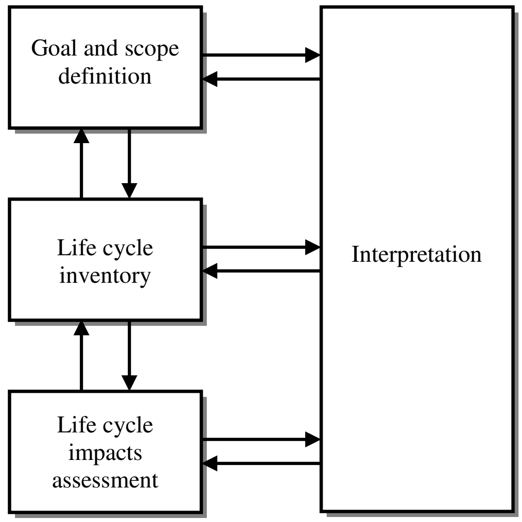



Figure 3.7 methodological framework of LCA as described by ISO 14040 (from Tillman, A. et al 1997)

In the *goal and scope definition* step the subject, objectives and boundaries are defined. In this step the functional unit that describes the main function of the system that will be analyzed is also defined. The next step is the *life cycle inventory.* Here, data collection and calculation procedures are identified in order to quantify all the adverse effects in the environment related with the functional unit. The *Life cycle impacts assessment* step has been defined by ISO 14042 and distinguished mandatory and optional elements, in this part of the LCA the environmental loads of the *life cycle inventory* are assessed.

### 3.2.5 Socio-Ecological Indicators

Socio-ecological indicators are indicators that are focused in cause rather than in the environmental effect, to provide an earlier warning. The indicators are based on four sustainability principles:

1. Substances extracted from the crust of the Earth must not increase their concentrations in the ecosphere, like lead
2. Substances produced by the society must not be accumulated in the ecosphere like toxic waste

3. Nature must not be subject of systematic degradation by physical means, like soil erosion.
4. The use of resources must be done in terms that not undermine the ability to meet the human needs in the future, like clean air.

These four principles have been used by different kind of companies, municipalities, governments, NOG's in order to define the basic requirements for a sustainable society and economy (Lundin, M. 2000; Pierini, N. 2005).

**3.3 Public and Stakeholder participation.**

After the Rio meeting 1992, public participation in environmental issues gained high priority and over the last 10 years it has been on the policy agenda in the local government (Åberg H; Söderberg, H. 2003). The Århus convention was held in the Danish city of Århus in 1998 and enforced in 2001. This convention was organized by United Nations Economic Commission for Europe (UNECE) with the goal of promoting Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters. The convention states that:

*"In order to contribute to the protection of the right of every person of present and future generations to live in an environment adequate to his or her health and well-being, each Party shall guarantee the rights of access to information, public participation in decision-making, and access to justice in environmental matters in accordance with the provisions of this Convention"*(UNECE 2001).

Increased public participation and access to information is expected to lead to:

- Enhanced quality of environmental decisions.
- Public awareness of environmental issues.
- Opportunities for the public to express its concerns.

The public participation in the decision making process is important in a democratic system as it forces authorities take the concerns of the population into account building trust in public institutions.

Sustainable decision making includes stakeholders' involvement (Åberg H; Söderberg, H. 2003). One way to interact between stakeholders is by using an Institutional Base Map (IBM). Figure 3.8 shows the Institutional Base Map. Once the stakeholders are recognized and identified their representation in the local situation of a system is necessary to analyze the issues that involve the local situation of a system. An example of an IBM for the city of Göteborg is shown in figure 3.9.

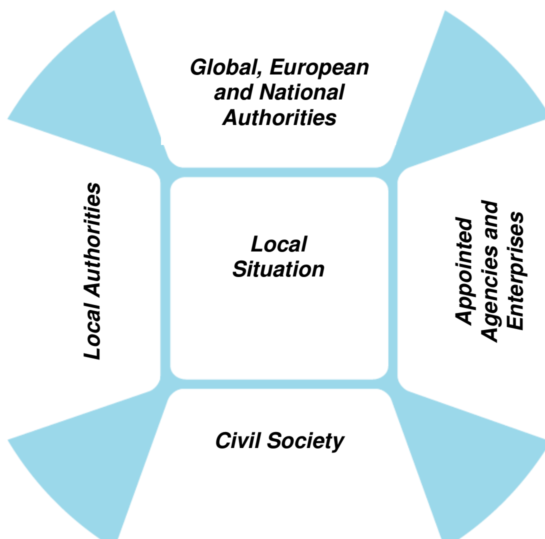



Figure 3.8: Institutional Base Map adapted from Kain, 2003


Figure 3.9: Institutional Base Map from Göteborg (adapted from Kain, 2003)

## 4. Methodology

The evaluation of the UWS in this case study is based on using a stakeholder - indicator combined approach developed by Christina Lundéhn and Greg Morrison at Chalmers University of Technology. This approach is based on two perspectives:

- Service supply and consumer perspective
- Life cycle assessment perspective

These two points of view will generate a wide perspective view of the system.

### 4.1 Case Study Procedure

The case study procedure is shown in figure 4.1.

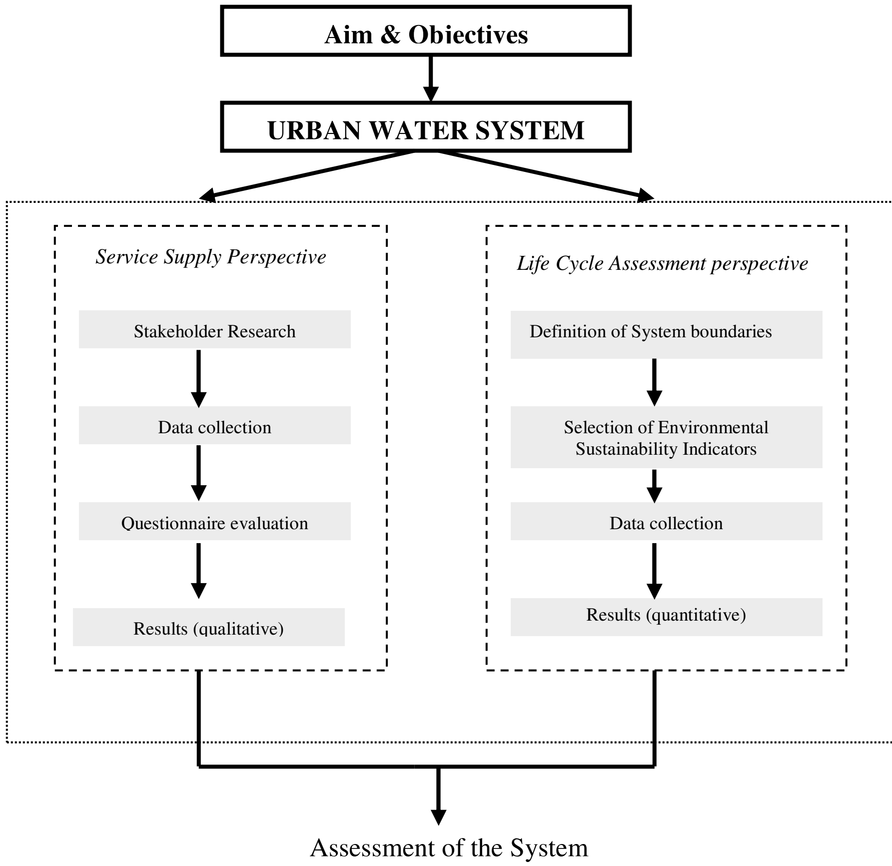



Figure 4.1 Case study procedure.

## 4.2 Service supply perspective

### 4.2.1 Participatory approach

Through interviews and the questionnaire survey the UWS in the service supply perspective will be evaluated. The key stakeholders involved in the UWS including Academics, employees, general public, local politicians, private sector and Non governmental organizations.

### 4.2.2 Data collection

The stakeholders included in the study are:

1. Academics: Chalmers university of technology, Gothenburg university.
2. Professional Employees:

    i. County administration
    ii. RWWTP
    iii. Water and Sanitation
3. General Public
4. Local Politicians:
    i. Board of sustainable waste and wastewater management
    ii. Gryaab board
    iii. VA-V water & Sanitation committee
5. Private Sector.

The service supply and consumer perspective will be evaluated through questionnaires that will be sent through regular mail. The questionnaire used in the service supply perspective was designed and distributed in May 2005 by Christina Lundéhn (PhD – candidate, WET department, Chalmers) and is composed by 3 sections (Appendix I). This questionnaire was sent to the 6 identified groups. The questionnaire was distributed by regular mail to approximately over 300 people.

### 4.2.3 Questionnaire survey

A total of 159 questionnaires were received. The distribution among the stakeholders of the 159 received questionnaires is shown in table 4.1.

Table 4.1: Handed in questionnaires among the stakeholders

| Stakeholder Group | Handed in | Distributed | Response rate % |
|---|---|---|---|
| Academics | 11 | 21 | 52,4 |
| Local politicians | 17 | 20 | 85,0 |
| Professional Employees | 31 | 74 | 41,9 |
| Private Sector | 10 | 17 | 58,8 |
| General Public | 85 | 214 | 39,7 |
| NGO's | 0 | 22 | 0 |

The information was sorted and tabbed among the different groups in order to analyze the answers. The percentage of participation in the total answers is shown in the Figure 4.2.

The questionnaire is divided in 3 sections. Section A is related with the quality of the service. Section B is related with the future perspectives of the service and section C is related with the evaluation of environmental issues in the Municipal area of Göteborg.

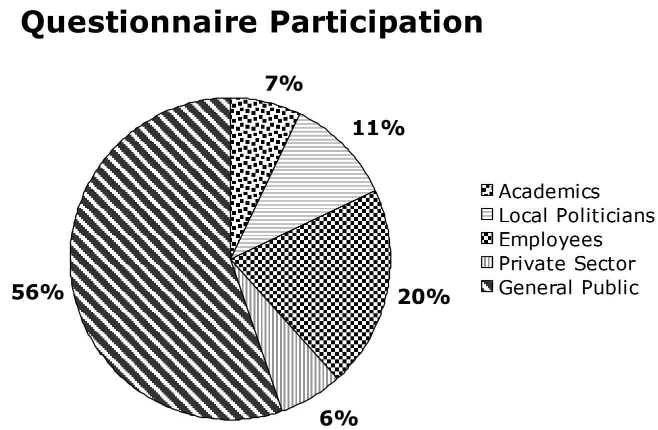



Figure 4.2: percent of participation of the stakeholders in the received questionnaires

### 4.3 Life cycle assessment perspective

The Sustainable System Perspective will be evaluated using Sustainability Development Indicators (SDI). The first step is defining physical and time boundaries based on the LCA method.

#### 4.3.1 Study Boundaries

Establishing the system boundaries is essential for sustainability and environmental assessment because they delimiting the system and the processes that are involved and also facilitate the identification of the inputs and outputs of the system. The UWS is defined in terms of physical (energy/materials and inputs/outputs) and time boundaries. The time boundaries are related with a time perspective that of 5-30 years for the assessment of sustainability indicators. The physical boundaries are defined from the intake of water from Göta Älv river (cradle) till the discharge of treated wastewater in the Göta Älv river (grave) and the sludge deposition in the sludge land catchment. Three boundaries are defined:

1. Technical System
2. Urban Water System

3. Catchment and Life Cycles

Sketching the frontiers of the system (figure 4.3) and adding the main inputs and outputs in each boundary is possible to have a more detailed picture of the system. The following sketch shows schematically the components of the UWS in Göteborg

**The technical system**

The technical system is conformed by the Drinking Water Plants (Lackarebäck and Alelyckan) and the Wastewater treatment plant (Ryaverket) **1a** and **1b** respectively. Both production of drinking water and treatment of wastewater have inputs and outputs. In **1a** the main input is the raw water that is obtained from the Göta Älv river and the main output is drinking water that is distributed through pipes. In the production of drinking water sludge is obtained a sub product. In the **1b** system the main input is wastewater that is collected through the sewer system. Stormwater and sludge that comes from the drinking water production process are collected and treated too. The main output is treated wastewater and sludge. Both (**1a** & **1b**) consume energy and different kinds and amounts of chemicals.

**The urban water system**

The Urban Water System includes both processes (**1a** & **1b**) and usage of drinking water, heat drinking water, wastewater and stormwater collection, also the sludge that is produced in the drinking water production and the sludge that is produced by the treatment of wastewater. Inputs and outputs of energy are also considered in this part of the system. The process of production of drinking water does not include any energy recovering whatsoever but in the wastewater treatment process it does through the generation of biogas and the recovering of heat trough the heating pumps. Both processes consume energy through production/treatment, drinking/wastewater respectively and in the distribution process.

**Catchment and Life Cycles**

Catchment and life cycle is the third system boundary of the system. Set by the catchment area (where the life cycle ends); the final discharge of the treated water in the Göta Älv river and the disposal of sludge. In this part of the system is included the use of sludge (part of it in soil enrichment) and the obtaining of sludge sub-products (biogas).

**Göteborg Urban Water System**

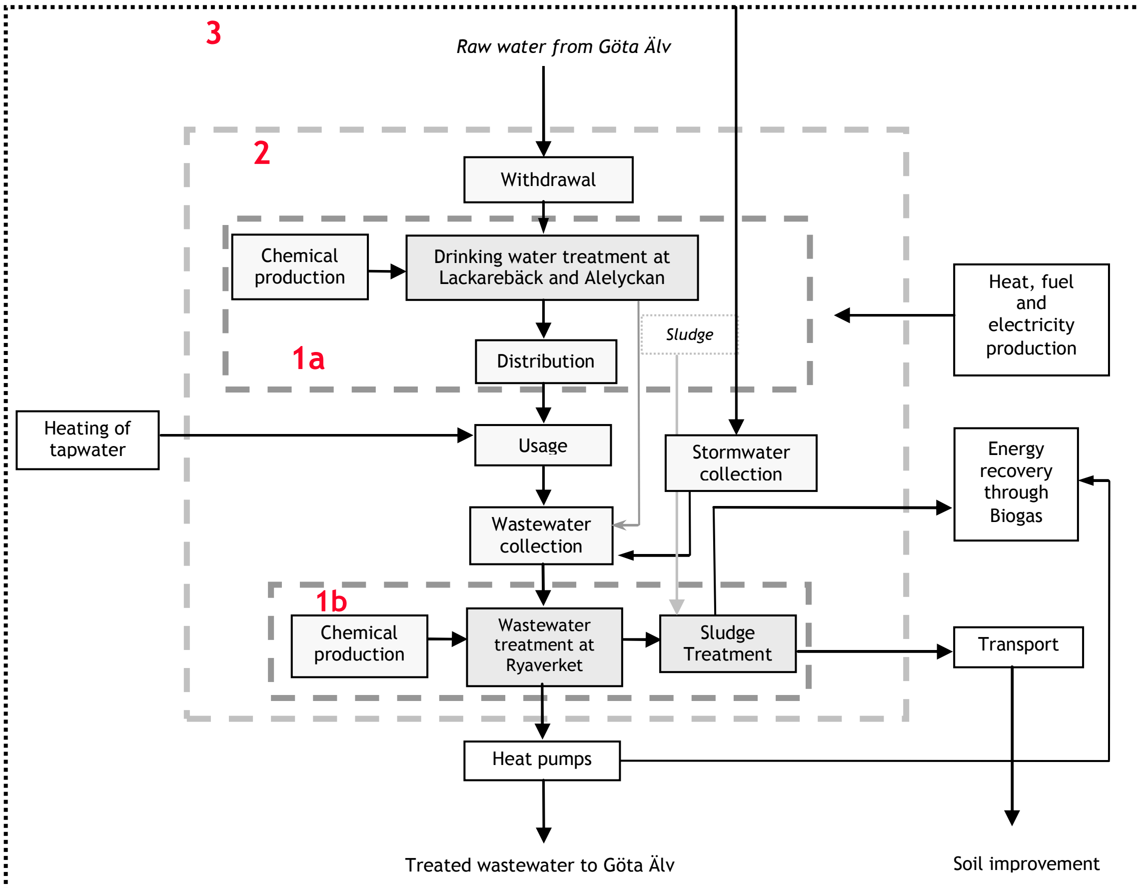



Figure 4.3 Göteborg UWS boundaries

### 4.3.2 Selection of Environmental Sustainability Indicators (ESI)

The selection of SDI was made through a literature review and defined in the different burdens of the system. Sixteen SDI were used and they were grouped (table 4.2). The ESI utilized in the case study are grouped in 5 section depending in which part of the UWS are located.

### 4.3.4 ESI Data collection

The data necessary to assess the SDI will be collected using the VA-Verket and GRYABB annual reports and also with interviews with relevant people related with both companies.

Table 4.2 Selected Environmental Sustainability Indicators.

| Urban water cycle | Study boundary level | Environmental System Perspective<br>Environmental Sustainability Indicators [1]<br>Indicator | <br><br>Units |
|---|---|---|---|
| Freshwater resources | 3,1 | Raw water protection<br>Raw water quality<br>Freshwater availability | % protected water resources<br>mg/l (COD, P, N)<br>% (withdrawal/available volume) |
| Drinking water production and distribution | 1 | Chemical and energy consumption<br>Drinking water production<br>Leakage | Kg and kWh per produced $m^3$ drinking water<br>L per capita and day<br>% |
| Usage | 2 | Drinking water consumption | per capita and day |
| Wastewater collection and treatment | 1,3 | Wastewater collection<br>Treatment performance<br>Chemical and energy consumption<br>Loads to receiving water | per year<br>% removal of BOD, P and N<br>per treated $m^3$ water<br>amount of P and N per year |
| Handling of by-products | 1,3 | Sludge disposal or reuse<br>Nutrient recycling<br>Loads to receiving soils | % reused<br>% amount of N. P recycled<br>Amount of Cd per year |

[1] measured through data collection (modified from Lundin 2003)

## 5. Study Area description

The case study has been carried out in Göteborg the second largest city in Sweden. The study comprises the whole urban water cycle in Göteborg.

### 5.1 Göteborg (Sweden)

Göteborg is located on the west coast of Sweden and is part of the Västra Götaland province (figure 5.1). Göteborg is the second largest city after Stockholm and has a population of 495.849 inhabitants (2000 census). Göteborg Metropolitan Area is conformed by 11 municipalities with 816.931 inhabitants in total and with a population density of 279.3 hab/km$^2$.


Figure 5.1 Map of Sweden.

### 5.2 Freshwater resources

The urban water cycle starts in the catchment area of the Göta Älv River (figure 5.2). This river is one of the longest rivers in Europe and it is the longest in Sweden with a longitude of 90 km. With an average flow of 550 m$^3$/s the Göta Älv serve as drainage for Lake Vänern into the Kattegat.

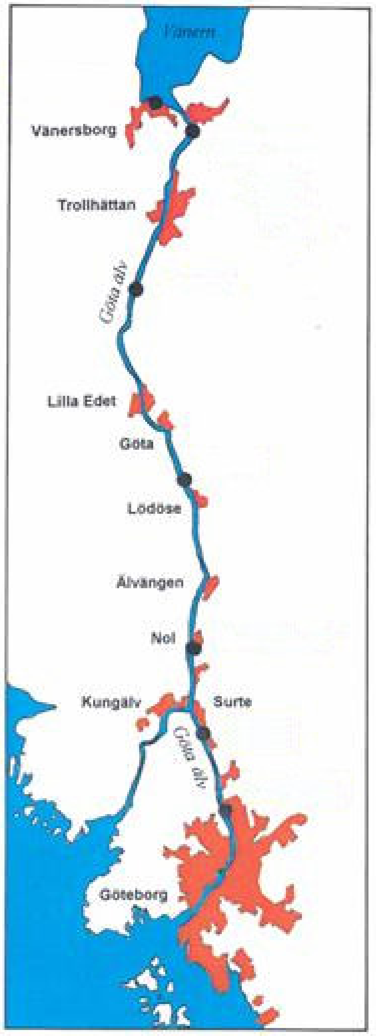



Figure 5.2 Göta Älv River.

Almost every species of fish that live in the lakes in Sweden is possible to find in Göta Älv. The Göta Älv River provides raw water for Göteborg, Öckerö and parts of the municipalities of Ale, Partille and Mölndal for the production of drinking water, totalizing approximately 700.000 inhabitants. Raw water is taken from the Göta River and pumped to the Alelyckan Water Treatment Plant, where is process and distributed. Water quality is monitored by 7 monitoring stations along Göta Älv between Vänern (where the river starts) and the catchment point at Lärjeholm. Part of the water that is taken flows via tunnel systems to the lake Lilla Delsjön that is connected via a channel with lake Stora Delsjön where Lackarebäck water treatment plant takes the raw water, for drinking water production. Currently a backup system exists that allows Lackarebäck water plant to supply drinking water in case that raw water can not be taken from lake Delsjön. It so raw water is taken from Rådasjön using a supply line.

### 5.3 Drinking water production

The process of drinking water production in Lackarebäck and Alelyckan is similar. Basically they have three main steps: chemical precipitation, sedimentation, filtration and absorption using activated carbon (flocculation, sedimentation and filtration). Before the raw water begins the purification process it passes through a turbine that generate 1% of the energy necessary in the production process. The purification process start by adding aluminium sulphate ($Al_2(SO_4)_3$) to the raw water. The aluminum sulphate is prepared and mixed with drinking water before use in raw water. The chemical precipitation can be accelerated using sodium silicate ($Na_2SiO_3$) that helps the coagulation process. All the particles that are heavier than water precipitate in the bottom of the sedimentation tanks. The sludge generated in this part of the process is pumped to Ryaverket wastewater treatment plant. At this point of the process the water still contains flocculent matter that is not heavy enough to be separated in the sedimentation process. To remove it the water passes through a rapid filter process where the water is filtered using a one meter thick activate carbon filter. The activated carbon also traps substances that can smell or taste. The activated carbon is flushed every 4 days to keep it clean. Before the water is pumped in the pipe system the drinking water has to reach appropriate pH and disinfection levels. In order to reach those levels calcium hydroxide and chlorine or chlorine dioxide are added. Figure 6.3 shows the main processes of drinking water production.

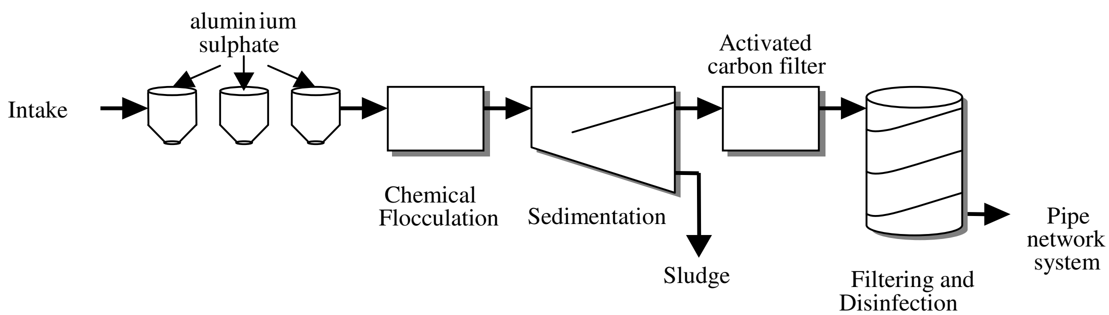



Figure 5.3 Drinking water production processes.

### 5.4 Wastewater collection and treatment

Wastewater collection is made by a centralized pipe system. Wastewater is pumped by VA-Verket to RWWTP. RWWTP has been working since 1972 and nowadays collects the wastewater of 6 municipalities that also are the owners of the company. The six municipalities are Ale, Göteborg, Härryda, Kungälv, Mölndal and Partille. Seventy-two people work there and the company had an income of 192.3 Msek for the year 2004. Figure 5.4 shows in general terms, the process that is carried out at RWWTP.

The process (figure 5.4) can be divided in two sub processes, one that treats the liquid part and the other one that treats the solid part of the wastewater that is collected. When the wastewater arrives to the system it is pumped with 4 pumps through the primary settling where most of the organic material settles in the bottom. In this process iron sulphate is added to partially remove phosphorous. Then the water is pumped to the biological process to break down the organics and remove nitrogen through aerobic and anaerobic processes. In this part artificial bacterial colonies are created to later bind with a flocculant polymer. The water then passes through the secondary settling where the last part of the organic matter settles in the bottom. Finally, the effluent waste passes through a turbine that generates electricity and through a heat pump that reduces the temperature of the water to 8° C approximately. This energy is used in the combined heat power system of the city. The treatment of the sludge (figure 5.5) is basically a series of mechanical processes like the gravity thickener and the gravity belt thickener in the beginning of the process to decrease the volume of sludge, separating it from the water. When the sludge gets a determined density it goes to the digester where is stored during 21 days to produce biogas. The digested sludge passes through two more mechanical processes (centrifuge and belt filter press) to finally be used for soil enrichment. The biogas produced passes through a pressure regulator and is then used in different ways. Part of it is used to produce electricity (gas motors) and heat, other part goes to the gas city network, other for vehicles that works with methane and the final part, that is not used, is burned.

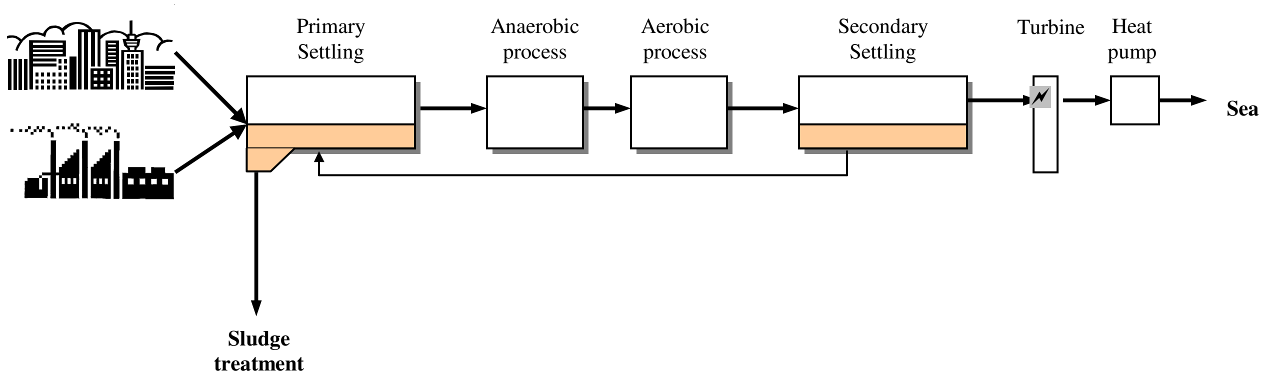



Figure 5.4 Wastewater and stormwater treatment processes.

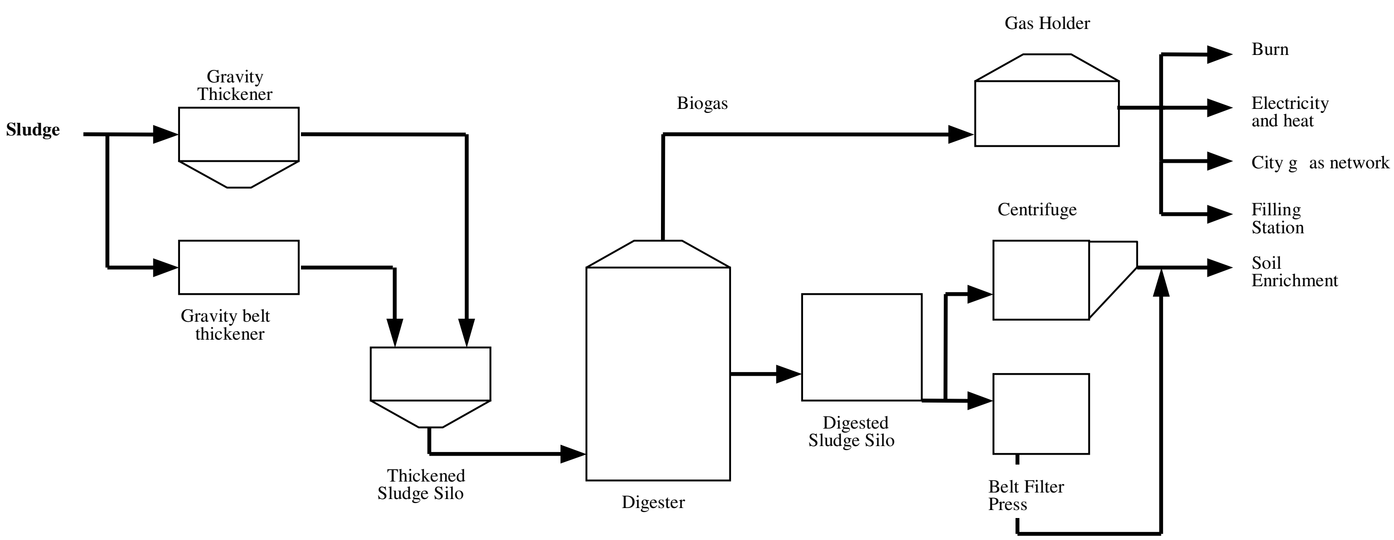



Figure 5.5 Sludge treatment processes.

### 5.5 Identified stakeholders

Different stakeholders are involved in the urban water cycle in Göteborg. The stakeholders have different interests in the water system and can be divided in the following groups:

- Academics
- Employees
- General Public
- Local Politicians
- Private Sector
- Non governmental organizations

#### 5.5.1 Academics

The academics through universities and institutes are related with the UWS through all sort of investigations and research related to the water and sanitation, sector supporting the decision making process with scientific results.

#### 5.5.2 Professional employees

This group refers to the personnel and expertise working at or with water and sanitation in Göteborg. They are directly related with both drinking water production and wastewater treatment processes. They are in charge of the production process and also supervise that the UWS fulfill the quality standards and laws. This group is composed by employees from the county administration of Västra Götaland, Committee of sustainable waste and wastewater management, Municipality environment department, Water and sanitation and RWWTP.

#### 5.5.3 General Public

This group is composed by people of different age, sex and that live in different sectors of Göteborg. Their opinion as a consumer has the relevance that represents part of the opinion of common people that is not involved directly with the production of drinking water neither the treatment of waster.

### 5.5.4 Local Politicians

This group has the objective to administrate the UWS and watch over for the government interests related with water and sanitation sector.

- Committee of sustainable waste and wastewater management
- Water and sanitation
- RWWTP

### 5.5.5 Private Sector

The private sector is composed mainly for large industries, real-estate owners and agriculture. Their water consumption is high and also their wastewater production. The quality of the effluent from this sector is different in volume and quality compared with households. They also are important part of the local economy and providing jobs to the people of Göteborg and surrounding localities.

### 5.5.6 Non governmental organizations

Environmental agencies such local communities organizations, community councils etc. are part of the NGO's. They can represent the way of thinking of a determined group of people and safeguard the public concerns and interests with the local authorities and their representatives.

## 6. Results

The results are reported in two sections, one with the environmental sustainability indicators and the other one with the questionnaire evaluation.

### 6.1 ESI results

Indicator data collection and calculation are found in appendix III and IV respectively.

#### 6.1.1 Freshwater resources

As described in section 3.4 protection of resources such as water, is a stated goal in the Swedish Strategy for Sustainable Development and in the Swedish Environmental Objectives (Regringskansliet, Government Communication 2003). National Sustainability Indicators show that the share of protected water areas in Sweden has increased with 156 00 hectares of water between 1991 (5.5% of all water resources) and 1999 (6.5% of all water resources). High-quality raw water is one of the preconditions for obtaining good drinking water and increased water protection is both a stated short term (5 years) and long term (one generation) target also in the Göteborg Eco-cycle Plan (Göteborg Eco-cycle Plan 2003). The Göta Älv water-protection area currently covers 28 square kilometers from the raw-water intake (Figure 6.1). For the lakes Delsjöarna, the protection area comprises the lakes entire catchment area of 8.9 square kilometers. Large portions of the area are also a nature reserve (Figure 6.1). Thus, protection of resources is high.

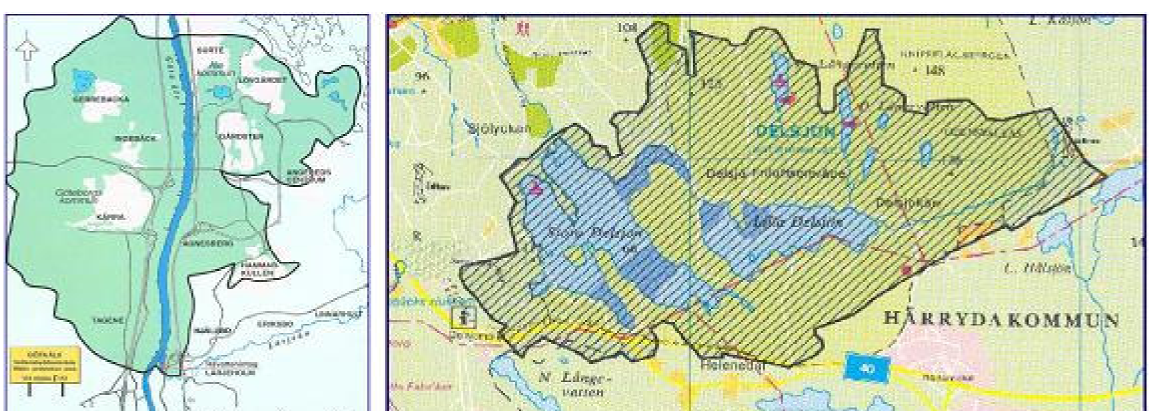



Figure 6.1 The Göta Älv water protection area and the lakes Delsjöarna water-protection area (VA-Verket Report Göteborg 2003).

The initial water protection regulation for the river was approved in 1998. By establishing water protection areas for the water supplies awareness of their importance has increased among the stakeholders and others (VA-Verket Report, 2003). The quality of the river water is normally good and continuous monitoring takes place coordinated by the Göta-Älv Water Conservation Committee. Chemical Oxygen Demand (COD) is used as indicator for the long term quality trend and show that current levels are back to the same levels as in the end of the 19th century (figure 6.2).

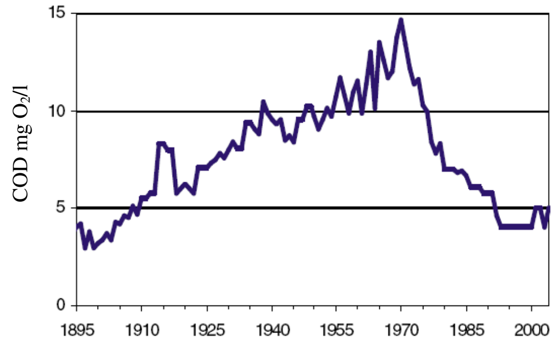



Figure 6.2 Göta Älv river COD trend.

During the 20th century the river has suffered significant environmental impacts. In the early 1970's the situation was at its worst but since then river water quality has improved greatly. The highest phosphorus (P) content was observed in 1980 then dropped with the introduction of chemical treatment at the wastewater treatment plants along the river. During the 1990's the P content increased slightly and was around 20 µg/l (Lundin, M. 2004). Between 2001 and 2003 the average amount of P was 15µg/l, indicating a further decrease (Göta Älv's Vattnvårdsföbund, 2004). Figure 6.3 shows data collected on total P levels for the water intake at Lackarebäck and Alelyckan water works during the past 5 years. At Alelyckan a decrease is seen while Lackarebäck has been rather stable. P levels <12.5 µg/l in lakes is classified by the Swedish Environmental Protection Agency as Low P Level while levels between 12,5 and 25 µg/l are classified as Moderately High P Level. Thus, Lackarebäck fall into the Low Level category and Alelyckan into the Moderately High level category.

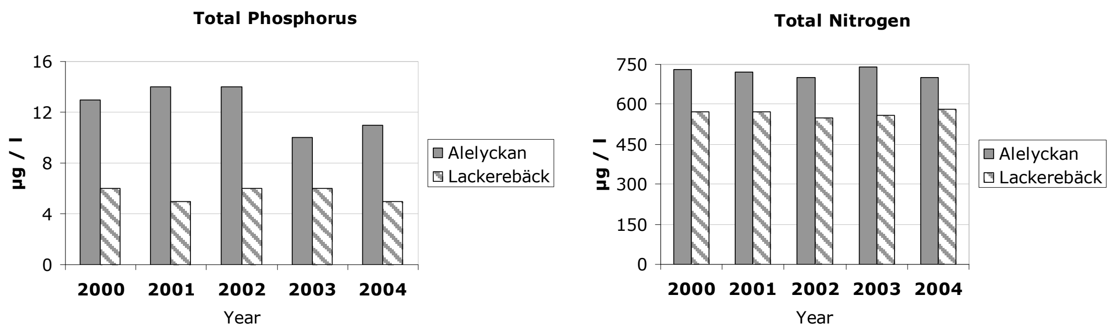



Figure 6.3 Total P and N concentration levels for the water intake at Lackarebäck and Alelyckan.

Between 1965 and 1995 the nitrogen (N) content in lake Vänern increased by 30% and consequently affected the Göta Älv River water quality. During 1990's the N content in the river stabilized at a level of 800 µg/l (Lundin, M. 2004). Data collection for the years between 2001 and 2003 show an average total N of 785 µg/l in Göta Älv (Göta Älv's Vattnvårdsföbund, 2004). Rather stable N levels are found at both water works intakes Figure 6.1.3 where Lackarebäck falls within the category of Moderately High N Level (between 300 and 625 µg/l) while Alelyckan falls in the category of High N Level (between 625 and 1250 µg/l), based on the Swedish Environmental Protection Agency classification. Göta Älv river has a flow of 550 $m^3$/s. Between 2000 and 2004 the average withdrawal for drinking water production was calculated to 2,2 $m^3$/s, thus water scarcity is not an issue.

Waterborne disease due to microbial contaminants is at present considered the main risk of using the surface water in Göta Älv river for drinking water production. Risk analysis has proven good safety against bacteria but there is a need to improve the protection against viruses and parasites (Friberg J.; Rosén L. 2003). New technologies such as membrane filtration are been tested. To further secure water supply and quality the use of ground water infiltration is being discussed and is a target defined in the Göteborg Eco-cycle Plan (VA-Verket Göteborg Årberättelse, 2003). This would not only serve as an alternative raw water source and reduce the dependence of Göta Älv for water supply, but increase raw water quality and thereby decrease the chemical consumption for drinking water production.

### 6.1.2 Drinking water production and distribution

Together with urban development the use of water for households and industries increase and Göteborg water production level (per capita, including industry) increased from 170 to 410 liter/day between the year 1945 and 1970. Water consumption then stagnated as population growth rate decreased and water prices increased (Lundin 2004). Data collected between the year 1994 and 2004 show a slight decrease in water production per capita, with an average water production calculated to 273 liter/cap/day (including industry) (figure 6.4). However, a substantial amount of water is lost when distributed. Leakage levels between the year 1994 and 2004 ranged between 16 and 22%, indicating a need for continuous pipe network maintenance (figure 6.5).

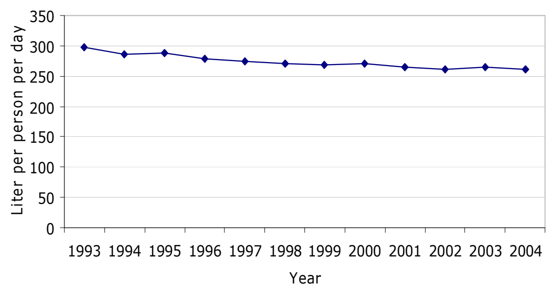



Figure 6.4 Drinking water consumption.

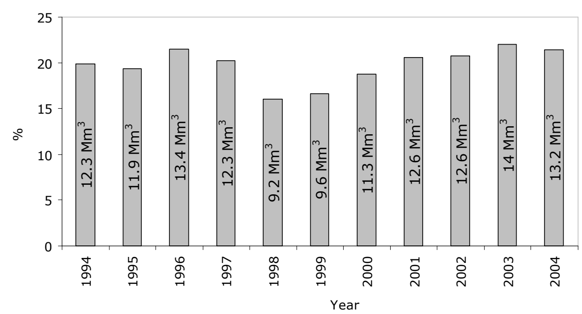



Figure 6.5 Leakage trend.

Comparing raw water withdrawal volumes with the amount of drinking water produced show a high (91%) efficiency in the process (average during the past 5 years).

The total net energy efficiency for water production (including energy recovery) decreased with an increasing of 37% on the energy use per $m^3$ produced between 1991 and 1997. Since 1996, energy efficiency has increased and in the year 2004 0.66kWh/$m^3$ was consumed (figure 6.1.6). The average cost for energy consumption during the past 5 years is calculated to 0.052 USD/$m^3$. The use of chemicals has also varied over time. Since 2001 chemical consumption varied between 8801 tonnes/year and 9751 tonnes/year but with stability in consumption efficiency (figure 6.6). The average cost for chemical consumption during the past 10 years is calculated to 0.021 US$/$m^3$. The total amount of energy necessary to produce drinking water is composed by 7 different activities. The main activity that consumes the biggest amount of energy is the process itself, the renewal of the

Activated Carbon Filters (ACF) and the warming of the facilities. Figure 6.7 shows the distribution of energy use in drinking water production.

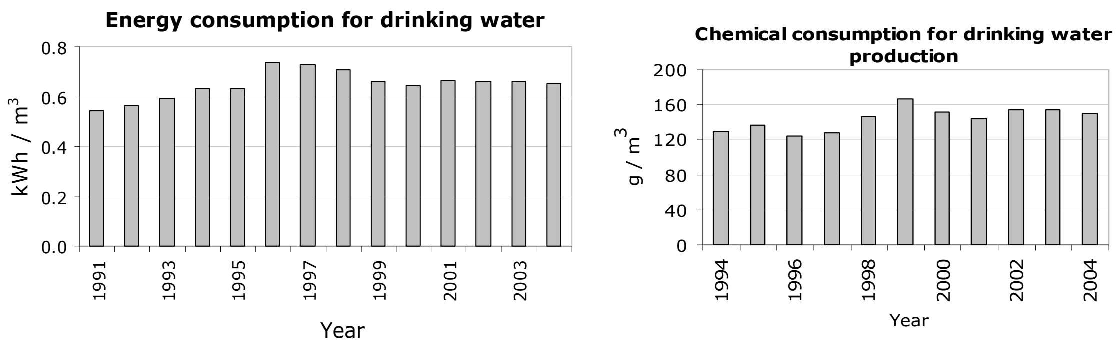



Figure 6.6: Energy and chemical consumption per $m^3$

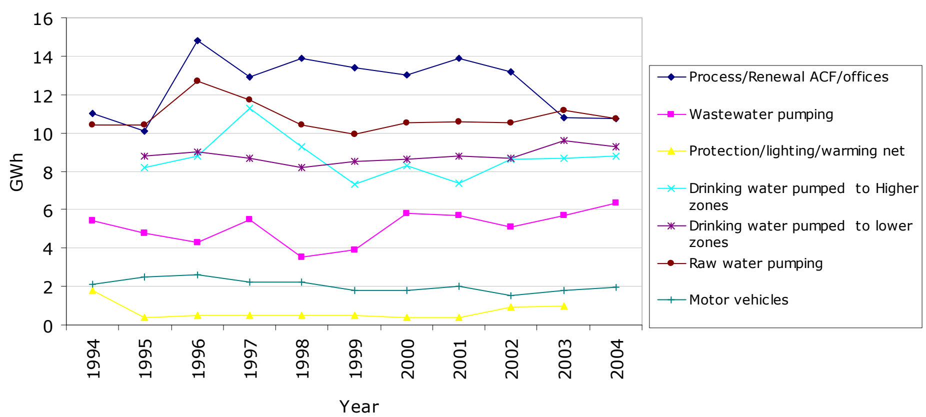



Figure 6.7: Distribution of energy use in drinking water production

### 6.1.3 Water Usage

Figure 6.8 shows the distribution of water consumption between consumers. The biggest consumer of tap water is the household sector. In terms of efficient resource use it is understood that heavily reduction of cold water consumption, due to piping network dimensions in certain areas, may lead to quality deficiencies in consumer drinking water. Also, the energy consumption to produce and deliver drinking water for one person in Göteborg equals 12 W whereas households hot water saving measures (such as efficient washing machines, dishwashers etc.) creates energy savings of 15 to 20%. Thus the greatest resource saving is through reduced warm water use 0.052 USD/$m^3$ (Ecocycle plan 2004).

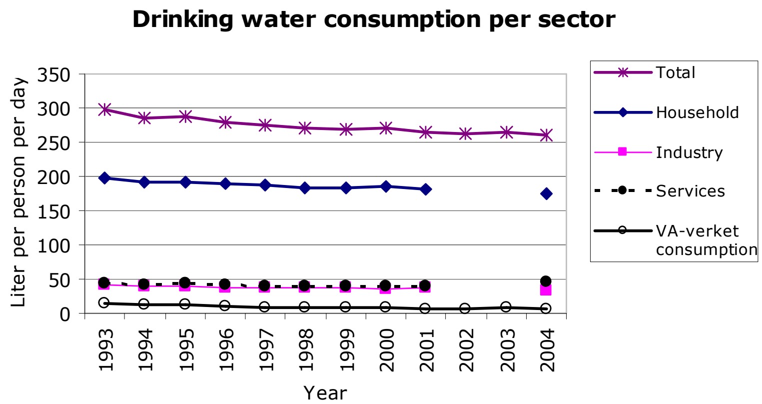



Figure 6.8 Drinking water consumption patterns among the consumers.

### 6.1.4 Wastewater collection and treatment

Between the year 2000 and 2004 an average of 121 $Mm^3$/year (equals 499 l/cap/day) was collected and treated at Rya Waste Water Treatment Plant where about 50% of the influent is surface-, drain- and groundwater that has leaked into the system. System overload e.g. due to heavy rains, is an issue as it causes detriment in the wastewater treatment and untreated wastewater is discharged directly over water courses.

Approximately 7000 tons of iron sulphate per year is used to remove phosphorus from the wastewater, this figure has not change significantly in the last 10 years. Between 2000 and 2004 energy consumption for wastewater treatment was in average 36,8 GWh (figure 6.9). The energy efficiency of the process has increased over the last decade even though the amount of power was approximately the same, mainly because of improvements in the BOD removal (Lundin, M. 2003).

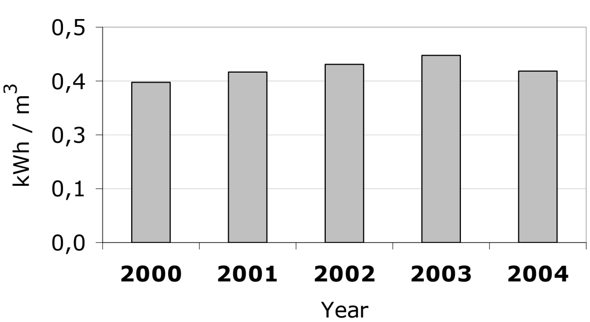



Figure 6.9 Energy consumption trend for wastewater treatment.

Eutrophication of coastal and open sea areas around southern and central Sweden and has lead to stricter standards for nitrogen removal at large sewage treatment plants. New target and limit values for discharge of total P (not exceeding 0.3 g/m$^3$), total N (10 gN/m$^3$ as target value yearly average) and $BOD_7$ (10 $gO_2/m^3$) are being enforced in 2007 (GRYAAB, 2004).

The eradication of anthropogenic eutrophication is included in the Swedish Environmental Objectives. The target is to by 2015, decrease waterborne anthropogenic phosphorus compounds emissions in to lakes, streams and coastal waters with at least 20% (based on the 1995 values). Since 1972 the loads of nutrients to receiving waters has decreased with an increased treatment performance. The wastewater treatment efficiency can be measured by the percentage of removal of N, P and BOD (figure 6.1.10). Other useful indicators to observe are the average amounts of nitrogen and phosphorus discharged per year because those elements can provoke eutrophication problems.

Figure 6.11 shows the $BOD_7$, N and P discharge to receiving waters and the removal percentage from the wastewater inflow. Between the years 1999 and 2004 an average of 95.2% of BOD removal was achieved.

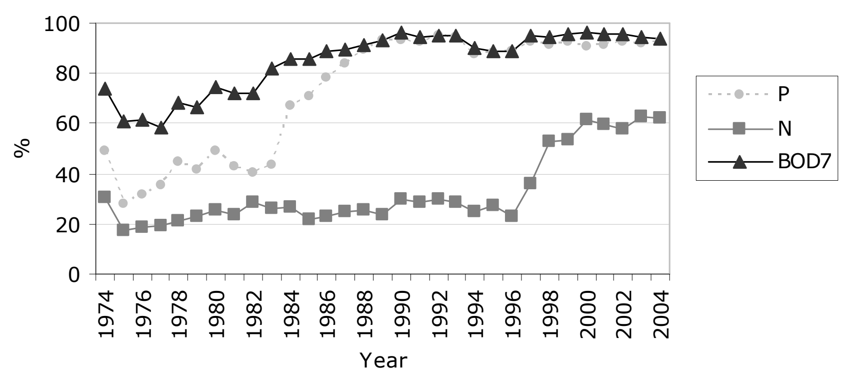



Figure 6.10: % of Removal of P, N and $BOD_7$ between 1974 and 2004

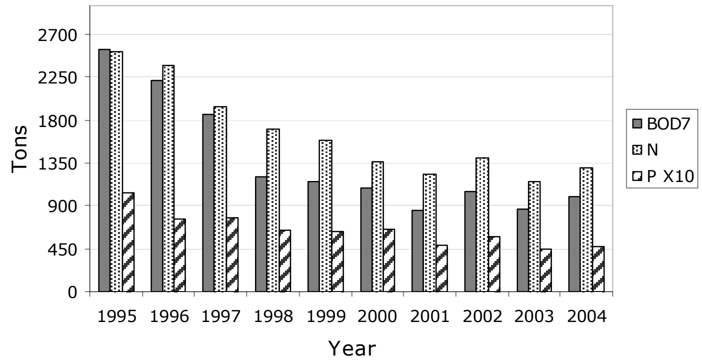
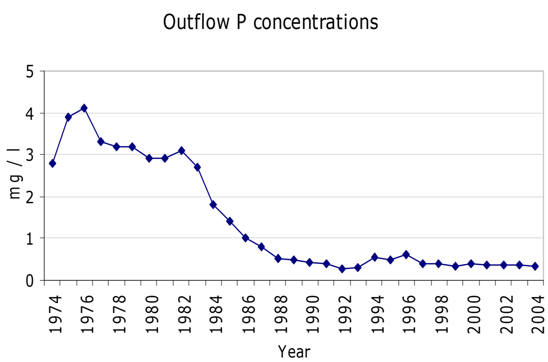



Figure 6.11: Discharges of $BOD_7$, N and P between the years 1995 and 2004.

Figure 6.10 and 6.11 show the results of 30 years of continuous effort and dedication in the reduction in the removal and thus the reduction on the total Tons of BOD, N and P in the effluent of GRYABB. The charts bellow (figure 6.12 and 6.13) show the trends in the outflow of P, N and $BOD_7$ between the years 1974 and 2004.



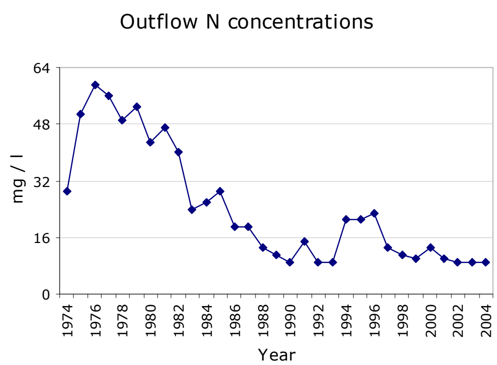




Figure 6.12: Outflow P and N concentrations

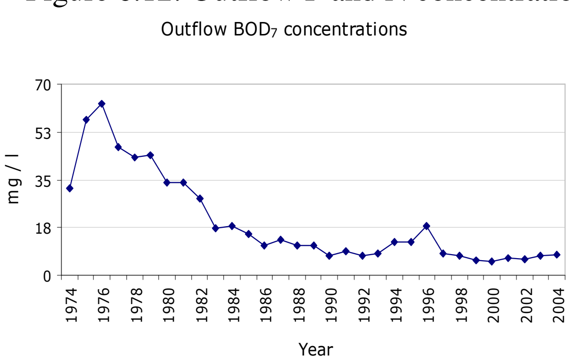



Figure 6.13: Outflow $BOD_7$ concentration

### 6.1.5 Handling of By-products

The main disposal of the treated sludge in Sweden is in agriculture, urban soil improver or landfill (Lundin, M. 2004), similar practice is used in the European Union. The sludge is possible to use on agricultural lands only if it lives up to certain requirements concerning in the concentration levels of heavy metals and key organic substances (Hultman B., 1999). The European Union (EU) has established medium and long terms goals for the maximum levels of concentrations of heavy metals present in sludge. The table shows the EU standards for de next 20 years and the Swedish standards in 2001.

| | Medium term (about 2015) | | Long term (about 2025) | | Swedish standards |
|---|---|---|---|---|---|
| Elements | Limit values for concentrations of heavy metals in sludge for use on land (mg/kg dm) | Limit values for amounts of heavy metals which may be added annually to soil, based on a ten year average (g/ha/y) | Limit values for concentrations of heavy metals in sludge for use on land (mg/kg dm) | Limit values for amounts of heavy metals which may be added annually to soil, based on a ten year average (g/ha/y) | mg/kg TS |
| Cd | 5 | 15 | 2 | 6 | 2 |
| Cr | 800 | 2400 | 600 | 1800 | 100 |
| Cu | 800 | 2400 | 600 | 1800 | 600 |
| Hg | 5 | 15 | 2 | 6 | 2,5 |
| Ni | 200 | 600 | 100 | 300 | 50 |
| Pb | 500 | 1500 | 200 | 600 | 100 |
| Zn | 2000 | 6000 | 1500 | 4500 | 800 |

Table 6.1: The European Union standards for de next 20 years; maximum concentrations levels of heavy metals present in sludge.

The total amount of sludge generated during one year at Swedish sewage works contains nearly 6000 tons of phosphorus. Around 60% of Swedish sludge meets the required standard. In 1998, an estimated 25% of sludge was used on arable land, while 50% was disposed of to landfill. At present, the food industry does not accept the use of sludge as a fertilizer for Swedish raw materials, so only a small portion of the sludge produced is used to spread on arable land. This is due to concerns about contamination with heavy metals and other substances. Sludge is still used as a soil conditioner in parks and on golf courses and for landscaping (SEPA, 2001).

Gryaab produced an average of 49 thousand tons of sludge per year between the years 2000-2004. The trends of Pb and Cd concentrations in the sludge show that the situation has improved since 1975, figure 6.14. The sludge is mainly used in composting and landscaping where is possible to reincorporate the N and P to their natural cycles. Figure 6.15 shows the amounts (in tons) of N and P that is re-used.

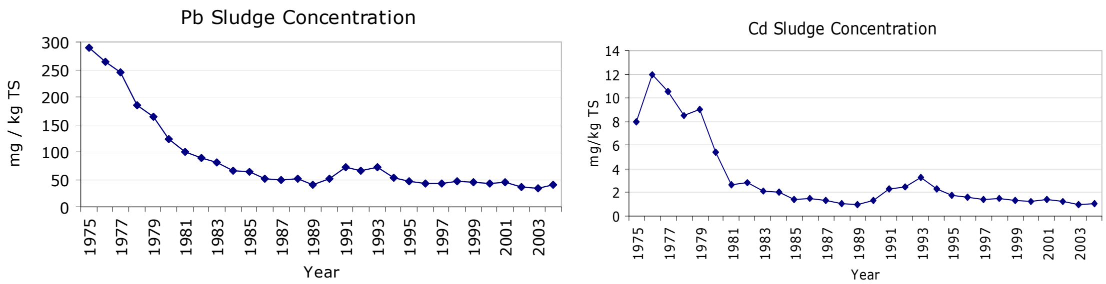



Figure 6.14: Pb and Cd sludge concentrations between 1975 and 2004

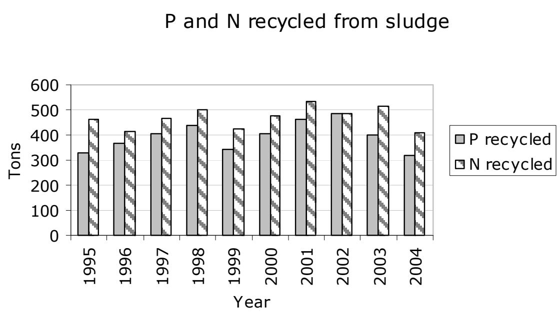



Figure 6.15: P and N recycled from sludge between 1995 and 2004

### 6.2 Questionnaire results

All questionnaire results are listed in Appendix II.

#### 6.2.1 Questionnaire Results Section A

The goal of section A was to evaluate, through a questionnaire survey, aspects that arose in stakeholders interviews. In terms of quality deficiency of the drinking water that is delivered, just an 8% of the respondents had problems such as bad odor or taste in the past years. 21% experienced cuts off in the service. In terms of acceptance toward quality deficiency, cuts offs and health related deficiency, results are shown in figure 6.16 only a

7% of the participants answers that it is acceptable with health related water quality deficiencies in a period of a year.

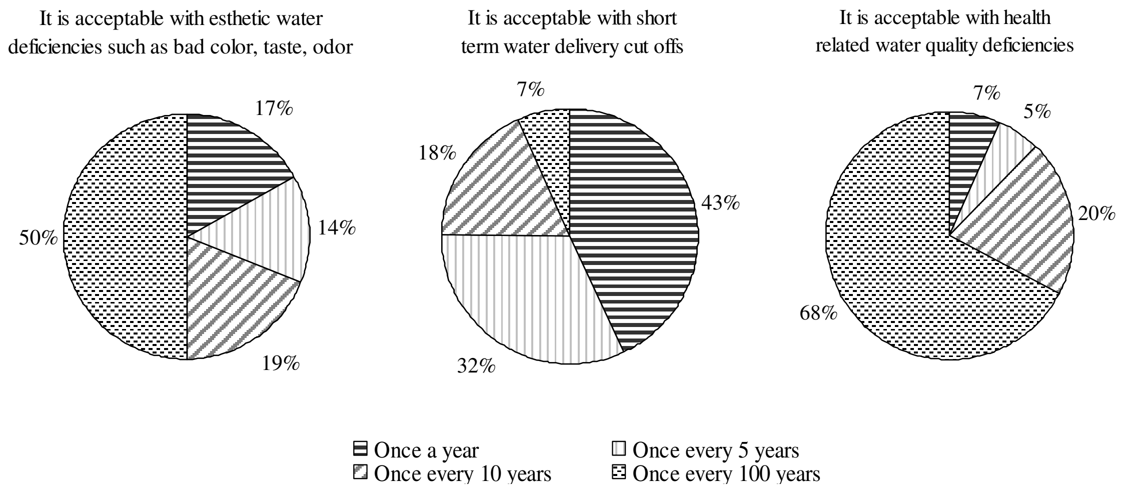



Figure 6.16: Acceptance levels related with esthetics, cuts off and health

Over 40% of the answers shown that is acceptable to have cuts off once a year. In long terms cuts off a 25% of the answers shown that is acceptable every 10 years. Over 70% of the participants find that more should become ill due to water quality deficiency. Is possible to observe through the results that in these three water quality aspects (esthetic deficiencies, cut offs and health related water quality deficiencies) different level of acceptance, but the lower value of acceptance was in health related water quality deficiencies.

### 6.2.2 Questionnaire Results Section B

In order to understand which the most important criterion related with UWS are in the future, 9 statements were given to construct a ranking with them. The results show that the most important issues concerning to the UWS are "Healthy water" and "Safe access to water". The results show also that the middle part of the ranking somewhat varies among stakeholders, but not in a big range. Table 6.2 shows the final rank.

Table 6.2: Ranking of the issues related with the UWS in the future

| Rank | Criterion | Total reply's | Highest reply value |
|---|---|---|---|
| 1 | Healthy water | 154 | 118 |
| 2 | Safe access to water | 144 | 62 |
| 3 | Good water taste | 150 | 43 |
| 4 | Low water tariffs | 147 | 28 |
| 5 | Limited environmental burden to lakes and watersheds | 153 | 34 |
| 6 | Low energy consumption for water treatment and distribution | 153 | 33 |
| 7 | Integrated water and sanitation planning in the municipality | 154 | 36 |
| 8 | Sludge re-use | 151 | 28 |
| 9 | Public awareness on water related issues | 150 | 51 |

"Public awareness on water related issues" and "Sludge re-use" are the less important issues that was considered by the stakeholders in the future. These results reflect that the respondents' attitudes are more related with quality and access issues than the statements related with sustainability issues.

### 6.2.3 Questionnaire Results Section C

In the C section of the questionnaire 25 statements related with sustainability were given related to drinking water quality, raw water extraction, treatment of wastewater, UWS policy & management. The respondents had to answered if they were agreeing, disagree or have no opinion in each statement. In a general context the results of the section C showed more differences in attitudes among stakeholders than was found in section A and B. Just in 2 statements the General Public group showed a support bigger than 50% of their answers and just in 1 against with a percentage over 50%. Most of the answers of this group were centered in the option "I have no opinion". Local politicians and Professional Employees showed a clearer tendency to be in accord or have a clear opinion on the statements and showed less tendency to pick the "I have no opinion" option.

**Drink water quality**

Results show that there is a great trust in the quality and hygiene of tap water produced by VA-Verket. Figure 6.17 and 6.18 show the answers from the questionnaire participants.

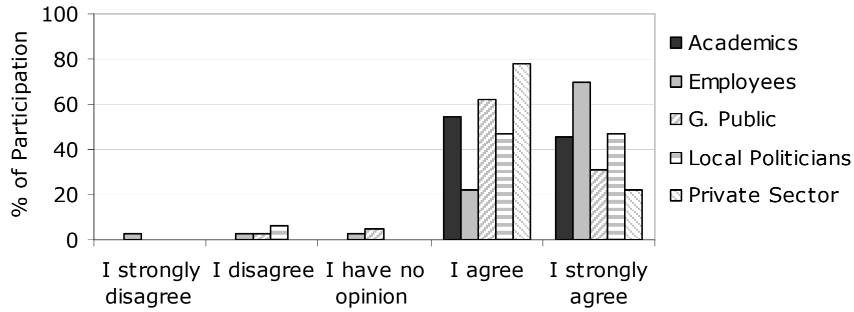



Figure 6.17: "I feel safe drinking tap water"

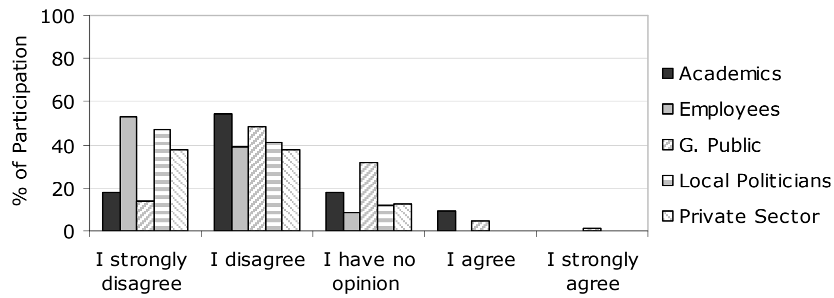



Figure 6.18: "Bottled water is healthier than tap water"

When participants were asked if Gothenburg water and sanitation system is "good and long term sustainable", in average over 50% of the total answers among the participants supported the idea with the and just a 13% rejected it. The biggest support came from the Local politicians with over 60% of support. The table 6.3 shows the results of that statement. The perception of the water and sanitation system in Gothenburg among the participants is that the system is in long term sustainable, furthermore taking in account only the answers that support the statement the average rate rise till 61% against 13% that rejects the statement.

Table 6.3: Gothenburg water and sanitation system is good and long term sustainable.

| | I strongly disagree | I disagree | I have no opinion | I agree | I strongly agree |
|---|---|---|---|---|---|
| **Academics** | 0,0 | 9,1 | 27,3 | 63,6 | 0,0 |
| **Employees** | 0,0 | 27,8 | 8,3 | 47,2 | 16,7 |
| **G. Public** | 1,2 | 6,2 | 28,4 | 55,6 | 8,6 |
| **Local Politicians** | 0,0 | 11,8 | 5,9 | 64,7 | 17,6 |
| **Private Sector** | 0,0 | 11,1 | 55,6 | 22,2 | 11,1 |

**Raw water extraction**

The main source of raw water to produce drinking water is surface water. Other alternative to produce drinking water is using ground water. The advantages of use ground water (depending in the availability) are in general that groundwater is significantly less costly to develop than surface water, it is less susceptible to contamination than surface water, and quite often requires little or no treatment to be used as drinking water (Hydrosources Associates, Inc. 2006). Under the statement "Today surface water is used as raw water but in the future we should use more groundwater" 40% of the respondents answers that they have no opinion, only the Local politicians say that they don't support the idea of using more groundwater instead surface water (55% of their answers). In the same line of statements was consulted if it is better for the environment to increase the portion of groundwater used as raw water. The results shown that the group that disagreed with the highest percentage (over 70%) was the Local politician group followed by the Academic with 45%. Also the group with the highest percentage (67%) of answers in the category "I have no opinion" was the General public.

**Treatment of wastewater and sustainability**

One important sustainability issue related with the wastewater collection is that the pipe network can be centralized, decentralized or a combination of both systems. The actual UWS in Gothenburg has a centralized system that collects all the wastewater in the same pipe network and processes it in one central facility. When was asked to the different groups of stakeholder if the actual way to treat the wastewater (centralized) is better than decentralized system the opinions were diverse. It seems to be that there isn't consensus in the Professional employees group. The results show that in 20% of the answers the Professional employees group didn't have an opinion about it and at the same time they are agree to shift the system from centralized to decentralized (23% agree and 34% disagree). The Local Politician group had less dispersion in their answers. They reject in a 56% of the total answers in shifting the actual system. The Private sector has the highest supporting percentage of shifting the system with a 67%. The figure 6.19 shows those results.

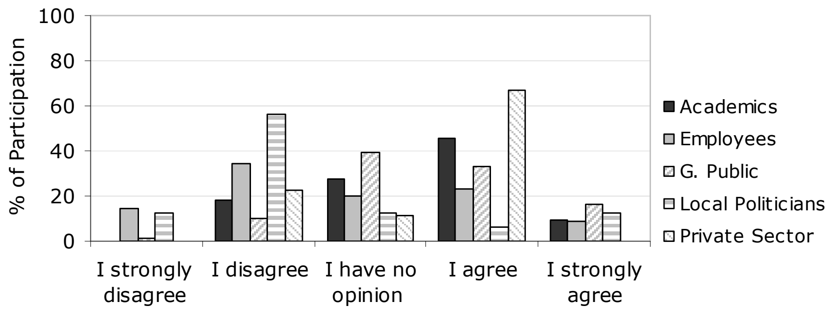


Figure 6.19: Results from the statement "Shifting from a centralized water system toward a decentralized system, is a prerequisite for a sustainable urban water system"

**UWS Policy & management**

Lack of opinion was the common factor in the answers related with policies and the management of the UWS. Academics, General public and the Private sector were the participants that picked the alternative "I have no opinion" in almost all the statements related with UWS Policy & management.

However, in the statement "The political water and sanitation decisions being made are characterized by holistic view and a sustainability perspective" most of the participants either agreed or strongly agreed as shown in table 6.3.

Table 6.4: Results from the statement "The political water and sanitation decisions being made are characterized by holistic view and a sustainability perspective"

| | I strongly disagree | I disagree | I have no opinion | I agree | I strongly agree |
|---|---|---|---|---|---|
| **Academics** | 18,2 | 63,6 | 18,2 | 0,0 | 0,0 |
| **Employees** | 63,9 | 27,8 | 5,6 | 2,8 | 0,0 |
| **G. Public** | 30,4 | 51,9 | 11,4 | 2,5 | 3,8 |
| **Local Politicians** | 35,3 | 58,8 | 5,9 | 0,0 | 0,0 |
| **Private Sector** | 33,3 | 44,4 | 22,2 | 0,0 | 0,0 |

The statement were "I have no opinion" was the most frequently selected was "The institutional organization structure promotes a sustainable development of the urban water and sanitation system". The highest percentage was Academics with 72,7%, (General Public 76,3% and Private Sector 66,7%). Another aspect related to policy and management is the role that the municipality plays as the manager of the UWS. The results in of this questionnaire show support to the municipality as the manager of the UWS and they do not support the idea of privatization.

## 7. Discussion and conclusions

The idea of sustainable development has different meanings depending on the context where it is founded. Urban water systems, as for any other kind of system that use raw materials and energy to produce goods or services, should be able to be sustainable in a long time perspective.

The evaluation of an UWS under the concept of sustainable development is a complex task. The existence of different tools and frameworks to assess the system is wide and based on diverse criterion. One method that is proven useful as a framework to assess the progress towards sustainability is the use of LCA-based indicators. The LCA-based indicator method provide useful information and trends that can highlight issues to address to improve the system and underpin the decision making process. The combination of the ESI obtained from the LCA-based method and the stakeholder approach, provides a holistic view of the UWS. The integration of the information of those two approaches has proven to be useful in relate the critical issues (from the interviews and the questionnaire evaluation) and quantitative results (ESI trends) of the UWS. Furthermore with the questionnaire evaluation was possible to understand how different sectors understand the concept of sustainability and the importance of drinking water as an economic and vital resource and their responsibility as a consumer.

In general the ESI trends found for Göteborg's UWS indicates that over the last four decades have had a constant concerning about the environmental impacts of the operation of the UWS in their impacts on the environment. The results show a positive tendency towards sustainability status. One example is that in the last 40 years the quality of the water in the Göta Älv River has improved substantially. The levels of P and N in the raw water used for both water works have decrease or remained stable (low) in the past 5 years. In terms of production and distribution of drinking water the trends shown positive improvements, as drinking water consumption has decreased and leakage has remained stable around (20% per year) between the years 1994 and 2004. The energy and chemical consumption use per $m^3$ produced has also shown stability or a decrease which means that the system is becoming more efficient.

The wastewater treatment process has shown positive trends indicating that the process is moving towards sustainability. The energy consumption per $m^3$ of treated wastewater has remained stable in the between the years 2000 and 2004 but the processes has increased it performance tremendously between the years 1974 and 2004 mainly because of improvements in the percentage of removal of P, N and BOD7. The quality of the sludge has been improved between 1975 and 2004 and today the concentrations of Pb and Cd are very low.

The questionnaire evaluation reveals interesting results. In a general context there exists a big trust in the UWS in terms of drinking water quality delivery and hygiene. These aspects were also identified as the most important criterion for the future ("Healthy water" and "Safe access to water"). The issues related with the treatment of wastewater and sustainability the answers were dispersed and the lack of opinion was the common factor found in their answers. Same situation was found with the questions related with UWS policy & management. One possible reason for that is there is a lack of information available or there is no interest in knowing about it. Other reasons could be that the questions were too much technical for the general knowledge of the participants.

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**Personal Communication**

The wastewater treatment process at Ryaverket waste water treatment plant according David Ions (personal communication, November 2005).

The sludge treatment process at Ryaverket waste water treatment plant according David Ions (personal communication, November 2005)

APPENDIX I : The Questionnaire

*Water and sanitation survey Gothenburg*
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## Questionnaire

This questionnaire is part of a research project with the ambition to assess the sustainability of the urban water system in Göteborg. The term "water system" refers here to the complete water path from raw water to recipient including drinking water production, distribution and wastewater handling. The results will be published in a PhD thesis regarding sustainable water and wastewater systems.

**A)** How many people are you in your household? ___
Type of housing? ___ apartment ___ terrace house ___house
How much do you pay for water each month? ___kr/month
How much do you pay for food each month? ___ kr/month
How much do you pay for energy (electricity and heating) each month? ___ kr/month

I have experienced water quality deficiency (such as bad odor, taste) during the past years.

- ☐ Yes, *(How often: ____)*
- ☐ No

It is acceptable with esthetic water deficiencies such as bad color, taste, odor…

- ☐ Once a year
- ☐ Once every 5 years
- ☐ Once every 10 years
- ☐ Once every 100 years

It is acceptable with health related water quality deficiencies …

- ☐ Once a year
- ☐ Once every 5 years
- ☐ Once every 10 years
- ☐ Once every 100 years

I have experienced cut offs in water delivery during the past years.

- ☐ Yes, *(How often: ____)*
- ☐ No

It is acceptable with short term water delivery cut offs….

- ☐ Once a year
- ☐ Once every 5 years
- ☐ Once every 10 years
- ☐ Once every 100 years

It is acceptable with long term water delivery cut offs for 100 000 people….

- ☐ Once every 10 years
- ☐ Once every 50 years
- ☐ Once every 100 years
- ☐ Once every 1000 years

It is acceptable that …

- ☐ 100-1000
- ☐ 10-100
- ☐ 1-10
- ☐ 0

… people per year become ill due to water quality deficiency.

It happens that I flush waste (other than toilet paper) into the WC….

- ☐ Every day
- ☐ Every week
- ☐ Every month
- ☐ Every year
- ☐ Never

From environmental point of view, it is reasonable that the amount of energy it takes to produce drinking water for one household is…

- ☐ 0.1 %
- ☐ 1 %
- ☐ 5 %
- ☐ 10 %

… of a normal sized households electricity consumption.

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**B)** What do you consider most important for the future? Please rank below from 1 (most important) to 9 (least important)

___ Healthy water
___ Sludge re-use
___ Good water taste
___ Integrated water and sanitation planning in the municipality
___ Safe access to water
___ Low water tariffs
___ Limited environmental burden to lakes and watersheds
___ Low energy consumption for water treatment and distribution
___ Public awareness on water related issues

Other: ______________________

**C)** Below you will find a number of statements referring to your situation in Gothenburg municipality. Please grade the statements below on a scale of 1 to 5 where:

1 – I strongly disagree
2 – I disagree
3 – I have no opinion
4 – I agree
5 – I strongly agree

___ Bottled water tastes better than tap water.

___ Bottled water is healthier than tap water.

___ Drinking bottled water is better for the environment than tap water.

___ Gothenburg water and sanitation system is good and long term sustainable.

___ I feel safe drinking tap water.

___ The water price (1 öre per liter) is cheap in comparison to the importance of the resource.

___ The fact that we rely on Göta Älv as our source of drinking water in Gothenburg is long term sustainable.

___ Stormwater ought to be separated from wastewater in as large extent as possible.

___ Polluted stormwater ought to be treated in as large extent as possible.

___ For a sustainable development consumers ought to be on-site water and sanitation solutions should be encouraged.

___ It is acceptable that consumer water and sanitation costs are raised to reach sustainable water criteria according to national or international objectives.

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| |
|---|
| 1 – I strongly disagree |
| 2 – I disagree |
| 3 – I have no opinion |
| 4 – I agree |
| 5 – I strongly agree |

___ The centralized urban water system of today is the best for the future.

___ Shifting from a centralized water system *(where wastewater and stormwater are in the same piping)* toward a decentralized system *(where urine, blackwater, greywater and stormwater is separated from wastewater)*, is a prerequisite for a sustainable urban water system.

___Water which today is produced, distributed and collected by the municipality ought to be privately managed, like other technical infrastructures in society.

___ Today surface water is used as raw water but in the future we should use more groundwater.

___ It is better for the environment to increase the portion of groundwater used as raw water.

___ The recycling of nutrients from sewage sludge either through agricultural application or extraction should be prioritized to reduce the burdens on natural resources.

___ Potential human health and environmental risks associated with the use of sewage sludge on agricultural land are acceptable tradeoffs to meet nutrient recycling goals.

___ The best way of managing sewage sludge in the future is to continue the production of soil amendment of sludge so that it ends up in parks etc.

___ To make use of the nutrient content in sewage sludge we should strive to separate nutrients at the source through collection of organic material and urine for example.

___ The best way to make use of nutrients in sewage sludge is to invest in development and implementation of new separation technologies at treatment plants.

___ There is a strategy for sustainable development of Gothenburg urban water system that I am aware of.

___ The political water and sanitation decisions being made are characterized by holistic view and a sustainability perspective.

___ The institutional organization structure promotes a sustainable development of the urban water and sanitation system.

___ The stakeholders responsible for urban water and sanitation systems work towards common goals.

**D)** This questionnaire is being distributed to a number of stakeholders. Which category of stakeholder do you represent?

- ☐ Politician/government
- ☐ Employee within water and sanitation
- ☐ Industry/corporation
- ☐ Consumer/ The general public
- ☐ Academics
- ☐ Organization related to water *which?:* ________________

Other Comments:

*Thank you for your participation!*

*Christina Lundéhn & Greg Morrison*

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APPENDIX II : Questionnaire results

| | Section A | Academics | Employees | General Public | Private Sector | Politicians |
|---|---|---|---|---|---|---|
| 1 | I have experienced water quality deficiency (such as bad odor, taste) during the past years. | | | | | |
| | Yes | 0 | 4 | 6 | 1 | 1 |
| | No | 11 | 32 | 79 | 5 | 16 |
| 2 | It is acceptable with esthetic water deficiencies such as bad color, taste, odor… | | | | | |
| | Once a year | 3 | 10 | 25 | 0 | 6 |
| | Once every 5 years | 2 | 12 | 18 | 2 | 2 |
| | Once every 10 years | 5 | 11 | 22 | 4 | 7 |
| | Once every 100 years | 1 | 1 | 19 | 0 | 2 |
| 3 | It is acceptable with health related water quality deficiencies … | | | | | |
| | Once a year | 0 | 1 | 7 | 0 | 2 |
| | Once every 5 years | 0 | 0 | 6 | 0 | 2 |
| | Once every 10 years | 4 | 10 | 12 | 2 | 2 |
| | Once every 100 years | 7 | 24 | 53 | 4 | 11 |
| 4 | I have experienced cut offs in water delivery during the past years. | | | | | |
| | Yes | 2 | 14 | 15 | 1 | 1 |
| | No | 9 | 21 | 70 | 5 | 16 |
| 5 | It is acceptable with short term water delivery cut offs…. | | | | | |
| | Once a year | 5 | 14 | 38 | 1 | 8 |
| | Once every 5 years | 3 | 16 | 23 | 1 | 6 |
| | Once every 10 years | 3 | 5 | 14 | 3 | 3 |
| | Once every 100 years | 0 | 0 | 9 | 1 | 0 |
| 6 | It is acceptable with long term water delivery cut offs for 100 000 people…. | | | | | |
| | Once every 10 years | 4 | 6 | 21 | 1 | 4 |
| | Once every 50 years | 3 | 16 | 25 | 2 | 8 |
| | Once every 100 years | 2 | 8 | 17 | 2 | 2 |
| | Once every 1000 years | 2 | 4 | 16 | 1 | 2 |
| 7 | It is acceptable that X number of people per year become ill due to water quality deficiency | | | | | |
| | 100-1000 | 0 | 0 | 1 | 1 | 0 |
| | 10-100 | 0 | 3 | 1 | 0 | 0 |
| | 1-10 | 4 | 10 | 11 | 2 | 4 |
| | 0 | 6 | 22 | 71 | 3 | 13 |
| 8 | It happens that I flush waste (other than toilet paper) into the WC…. | | | | | |
| | Every day | 0 | 0 | 0 | 0 | 0 |
| | Every week | 0 | 0 | 0 | 0 | 1 |
| | Every month | 0 | 2 | 2 | 2 | 0 |
| | Every year | 0 | 8 | 4 | 0 | 2 |
| | Never | 11 | 26 | 79 | 4 | 14 |
| 9 | From environmental point of view, it is reasonable that the amount of energy it takes to produce drinking water for one household is… | | | | | |
| | 0,1% | 2 | 6 | 15 | 3 | 2 |
| | 1% | 6 | 17 | 26 | 2 | 9 |
| | 5% | 3 | 7 | 18 | 1 | 3 |
| | 10% | 0 | 0 | 3 | 0 | 1 |

## Academics

| | (%) I strongly disagree | (%) I disagree | (%) I have no opinion | (%) I agree | (%) I strongly agree |
|---|---|---|---|---|---|
| 1 | 0,18 | 0,64 | 0,00 | 0,18 | 0,00 |
| 2 | 0,18 | 0,55 | 0,18 | 0,09 | 0,00 |
| 3 | 0,64 | 0,36 | 0,00 | 0,00 | 0,00 |
| 4 | 0,00 | 0,09 | 0,27 | 0,64 | 0,00 |
| 5 | 0,00 | 0,00 | 0,00 | 0,55 | 0,45 |
| 6 | 0,00 | 0,00 | 0,00 | 0,55 | 0,45 |
| 7 | 0,00 | 0,27 | 0,55 | 0,18 | 0,00 |
| 8 | 0,00 | 0,00 | 0,27 | 0,55 | 0,18 |
| 9 | 0,00 | 0,00 | 0,18 | 0,55 | 0,27 |
| 10 | 0,09 | 0,18 | 0,45 | 0,27 | 0,00 |
| 11 | 0,00 | 0,00 | 0,27 | 0,64 | 0,09 |
| 12 | 0,00 | 0,27 | 0,36 | 0,36 | 0,00 |
| 13 | 0,00 | 0,18 | 0,27 | 0,45 | 0,09 |
| 14 | 0,18 | 0,64 | 0,18 | 0,00 | 0,00 |
| 15 | 0,18 | 0,36 | 0,45 | 0,00 | 0,00 |
| 16 | 0,18 | 0,45 | 0,36 | 0,00 | 0,00 |
| 17 | 0,00 | 0,00 | 0,18 | 0,64 | 0,18 |
| 18 | 0,09 | 0,18 | 0,18 | 0,55 | 0,00 |
| 19 | 0,09 | 0,00 | 0,45 | 0,36 | 0,09 |
| 20 | 0,00 | 0,09 | 0,27 | 0,55 | 0,09 |
| 21 | 0,09 | 0,09 | 0,55 | 0,18 | 0,09 |
| 22 | 0,18 | 0,27 | 0,45 | 0,09 | 0,00 |
| 23 | 0,09 | 0,09 | 0,73 | 0,09 | 0,00 |
| 24 | 0,09 | 0,09 | 0,73 | 0,09 | 0,00 |
| 25 | 0,18 | 0,09 | 0,73 | 0,00 | 0,00 |

| | I strongly disagree | I disagree | I have no opinion | I agree | I strongly agree |
|---|---|---|---|---|---|
| 0% - 25% | 24 | 16 | 9 | 12 | 22 |
| 26% - 50% | 0 | 6 | 11 | 4 | 3 |
| 51% - 75% | 1 | 3 | 5 | 9 | 0 |
| 76% - 100% | 0 | 0 | 0 | 0 | 0 |

## Professional Employees

| | (%) I strongly disagree | (%) I disagree | (%) I have no opinion | (%) I agree | (%) I strongly agree |
|---|---|---|---|---|---|
| 1 | 0,44 | 0,25 | 0,14 | 0,11 | 0,06 |
| 2 | 0,53 | 0,39 | 0,08 | 0,00 | 0,00 |
| 3 | 0,89 | 0,11 | 0,00 | 0,00 | 0,00 |
| 4 | 0,00 | 0,28 | 0,08 | 0,47 | 0,17 |
| 5 | 0,03 | 0,03 | 0,03 | 0,22 | 0,69 |
| 6 | 0,00 | 0,00 | 0,00 | 0,08 | 0,92 |
| 7 | 0,06 | 0,56 | 0,08 | 0,19 | 0,11 |
| 8 | 0,03 | 0,17 | 0,17 | 0,36 | 0,28 |
| 9 | 0,00 | 0,00 | 0,17 | 0,56 | 0,28 |
| 10 | 0,26 | 0,53 | 0,15 | 0,06 | 0,00 |
| 11 | 0,03 | 0,03 | 0,08 | 0,50 | 0,36 |
| 12 | 0,03 | 0,17 | 0,31 | 0,37 | 0,11 |
| 13 | 0,14 | 0,34 | 0,20 | 0,23 | 0,09 |
| 14 | 0,64 | 0,28 | 0,06 | 0,03 | 0,00 |
| 15 | 0,00 | 0,25 | 0,44 | 0,19 | 0,11 |
| 16 | 0,06 | 0,40 | 0,37 | 0,06 | 0,11 |
| 17 | 0,03 | 0,06 | 0,14 | 0,61 | 0,17 |
| 18 | 0,11 | 0,37 | 0,23 | 0,26 | 0,03 |
| 19 | 0,03 | 0,37 | 0,31 | 0,26 | 0,03 |
| 20 | 0,06 | 0,25 | 0,42 | 0,22 | 0,06 |
| 21 | 0,03 | 0,20 | 0,66 | 0,11 | 0,00 |
| 22 | 0,03 | 0,17 | 0,17 | 0,49 | 0,14 |
| 23 | 0,08 | 0,31 | 0,22 | 0,33 | 0,06 |
| 24 | 0,19 | 0,19 | 0,28 | 0,19 | 0,14 |
| 25 | 0,11 | 0,47 | 0,14 | 0,25 | 0,03 |

| | I strongly disagree | I disagree | I have no opinion | I agree | I strongly agree |
|---|---|---|---|---|---|
| 0% - 25% | 20 | 14 | 18 | 15 | 20 |
| 26% - 50% | 2 | 9 | 6 | 7 | 3 |
| 51% - 75% | 2 | 2 | 1 | 3 | 1 |
| 76% - 100% | 1 | 0 | 0 | 0 | 1 |

## General Public

| | (%) I strongly disagree | (%) I disagree | (%) I have no opinion | (%) I agree | (%) I strongly agree |
|---|---|---|---|---|---|
| 1 | 0,15 | 0,47 | 0,12 | 0,20 | 0,06 |
| 2 | 0,14 | 0,48 | 0,32 | 0,05 | 0,01 |
| 3 | 0,46 | 0,36 | 0,17 | 0,01 | 0,00 |
| 4 | 0,01 | 0,06 | 0,28 | 0,56 | 0,09 |
| 5 | 0,00 | 0,02 | 0,05 | 0,62 | 0,31 |
| 6 | 0,01 | 0,03 | 0,08 | 0,48 | 0,41 |
| 7 | 0,04 | 0,09 | 0,40 | 0,39 | 0,09 |
| 8 | 0,00 | 0,05 | 0,11 | 0,40 | 0,44 |
| 9 | 0,00 | 0,04 | 0,10 | 0,38 | 0,49 |
| 10 | 0,19 | 0,28 | 0,40 | 0,09 | 0,05 |
| 11 | 0,04 | 0,29 | 0,30 | 0,29 | 0,07 |
| 12 | 0,04 | 0,10 | 0,41 | 0,30 | 0,15 |
| 13 | 0,01 | 0,10 | 0,39 | 0,33 | 0,16 |
| 14 | 0,30 | 0,52 | 0,11 | 0,03 | 0,04 |
| 15 | 0,08 | 0,19 | 0,54 | 0,19 | 0,01 |
| 16 | 0,04 | 0,22 | 0,67 | 0,05 | 0,03 |
| 17 | 0,01 | 0,10 | 0,28 | 0,50 | 0,11 |
| 18 | 0,05 | 0,38 | 0,34 | 0,23 | 0,00 |
| 19 | 0,00 | 0,04 | 0,53 | 0,40 | 0,04 |
| 20 | 0,01 | 0,08 | 0,47 | 0,36 | 0,08 |
| 21 | 0,00 | 0,01 | 0,52 | 0,36 | 0,10 |
| 22 | 0,04 | 0,20 | 0,70 | 0,06 | 0,00 |
| 23 | 0,07 | 0,09 | 0,78 | 0,05 | 0,01 |
| 24 | 0,03 | 0,04 | 0,76 | 0,17 | 0,00 |
| 25 | 0,03 | 0,08 | 0,82 | 0,07 | 0,01 |

| | I strongly disagree | I disagree | I have no opinion | I agree | I strongly agree |
|---|---|---|---|---|---|
| 0% - 25% | 23 | 19 | 7 | 12 | 21 |
| 26% - 50% | 2 | 5 | 10 | 11 | 4 |
| 51% - 75% | 0 | 1 | 5 | 2 | 0 |
| 76% - 100% | 0 | 0 | 3 | 0 | 0 |

## Local Politicians

| | (%) I strongly disagree | (%) I disagree | (%) I have no opinion | (%) I agree | (%) I strongly agree |
|---|---|---|---|---|---|
| 1 | 0,35 | 0,59 | 0,06 | 0,00 | 0,00 |
| 2 | 0,47 | 0,41 | 0,12 | 0,00 | 0,00 |
| 3 | 0,41 | 0,59 | 0,00 | 0,00 | 0,00 |
| 4 | 0,00 | 0,12 | 0,06 | 0,65 | 0,18 |
| 5 | 0,00 | 0,06 | 0,00 | 0,47 | 0,47 |
| 6 | 0,00 | 0,00 | 0,06 | 0,41 | 0,53 |
| 7 | 0,12 | 0,12 | 0,06 | 0,41 | 0,29 |
| 8 | 0,00 | 0,00 | 0,12 | 0,65 | 0,24 |
| 9 | 0,00 | 0,12 | 0,12 | 0,47 | 0,29 |
| 10 | 0,29 | 0,53 | 0,12 | 0,06 | 0,00 |
| 11 | 0,12 | 0,24 | 0,18 | 0,29 | 0,18 |
| 12 | 0,06 | 0,12 | 0,00 | 0,59 | 0,24 |
| 13 | 0,13 | 0,56 | 0,13 | 0,06 | 0,13 |
| 14 | 0,35 | 0,59 | 0,06 | 0,00 | 0,00 |
| 15 | 0,00 | 0,59 | 0,18 | 0,12 | 0,12 |
| 16 | 0,00 | 0,71 | 0,24 | 0,00 | 0,06 |
| 17 | 0,12 | 0,06 | 0,06 | 0,47 | 0,29 |
| 18 | 0,12 | 0,47 | 0,12 | 0,29 | 0,00 |
| 19 | 0,06 | 0,24 | 0,12 | 0,47 | 0,12 |
| 20 | 0,00 | 0,35 | 0,35 | 0,24 | 0,06 |
| 21 | 0,13 | 0,25 | 0,44 | 0,13 | 0,06 |
| 22 | 0,00 | 0,06 | 0,29 | 0,47 | 0,18 |
| 23 | 0,18 | 0,12 | 0,18 | 0,41 | 0,12 |
| 24 | 0,24 | 0,29 | 0,18 | 0,24 | 0,06 |
| 25 | 0,06 | 0,47 | 0,18 | 0,18 | 0,12 |

| | I strongly disagree | I disagree | I have no opinion | I agree | I strongly agree |
|---|---|---|---|---|---|
| 0% - 25% | 20 | 13 | 22 | 12 | 20 |
| 26% - 50% | 5 | 5 | 3 | 10 | 4 |
| 51% - 75% | 0 | 7 | 0 | 3 | 1 |
| 76% - 100% | 0 | 0 | 0 | 0 | 0 |

# Private Sector

| | (%) I strongly disagree | (%) I disagree | (%) I have no opinion | (%) I agree | (%) I strongly agree |
|---|---|---|---|---|---|
| 1 | 0,00 | 0,38 | 0,25 | 0,25 | 0,13 |
| 2 | 0,38 | 0,50 | 0,13 | 0,00 | 0,00 |
| 3 | 0,63 | 0,38 | 0,00 | 0,00 | 0,00 |
| 4 | 0,00 | 0,11 | 0,56 | 0,22 | 0,11 |
| 5 | 0,00 | 0,00 | 0,00 | 0,78 | 0,22 |
| 6 | 0,00 | 0,00 | 0,00 | 0,67 | 0,33 |
| 7 | 0,00 | 0,22 | 0,33 | 0,44 | 0,00 |
| 8 | 0,00 | 0,00 | 0,11 | 0,56 | 0,33 |
| 9 | 0,00 | 0,00 | 0,11 | 0,56 | 0,33 |
| 10 | 0,13 | 0,00 | 0,50 | 0,25 | 0,13 |
| 11 | 0,00 | 0,38 | 0,38 | 0,25 | 0,00 |
| 12 | 0,00 | 0,33 | 0,44 | 0,22 | 0,00 |
| 13 | 0,00 | 0,22 | 0,11 | 0,67 | 0,00 |
| 14 | 0,33 | 0,44 | 0,22 | 0,00 | 0,00 |
| 15 | 0,00 | 0,33 | 0,56 | 0,11 | 0,00 |
| 16 | 0,00 | 0,33 | 0,44 | 0,22 | 0,00 |
| 17 | 0,00 | 0,22 | 0,11 | 0,56 | 0,11 |
| 18 | 0,00 | 0,56 | 0,22 | 0,11 | 0,11 |
| 19 | 0,00 | 0,00 | 0,44 | 0,44 | 0,11 |
| 20 | 0,00 | 0,11 | 0,33 | 0,44 | 0,11 |
| 21 | 0,00 | 0,22 | 0,44 | 0,33 | 0,00 |
| 22 | 0,11 | 0,22 | 0,56 | 0,11 | 0,00 |
| 23 | 0,00 | 0,11 | 0,67 | 0,22 | 0,00 |
| 24 | 0,00 | 0,11 | 0,67 | 0,22 | 0,00 |
| 25 | 0,00 | 0,11 | 0,89 | 0,00 | 0,00 |

| | I strongly disagree | I disagree | I have no opinion | I agree | I strongly agree |
|---|---|---|---|---|---|
| 0% - 25% | 22 | 17 | 11 | 15 | 22 |
| 26% - 50% | 2 | 7 | 7 | 4 | 3 |
| 51% - 75% | 1 | 1 | 6 | 5 | 0 |
| 76% - 100% | 0 | 0 | 1 | 1 | 0 |

# APPENDIX III : Indicator data collection

| **DATA COLLECTION** | **GÖTEBORG** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water production level Mm$^{3}$/year | | | | | | | | | 60,4 | 61,2 | 61,1 | 63,5 | 69 |
| Water Asset m$^{3}$/s | **Lärjeholm** | | | | | | | | | | | | |
| | Max | | | | | | | | 394 | 315 | 769 | 197 | 186 |
| | Min | | | | | | | | 111 | 100 | 110 | 120 | 124 |
| | Average | | | | | | | | 194 | 236 | 161 | 145 | 149 |
| | **Göta Älv** | | | | | | | | | | | | |
| | Max | | | | | | | | 1268 | 1262 | 855 | 787 | 743 |
| | Min | | | | | | | | 142 | 142 | 141 | 160 | 171 |
| | Average | | | | | | | | 730 | 905 | 511 | 366 | 427 |
| Oxygen demand COD mlO$_{2}$/l | Alelyckan | | | | | | | | 4 | 5 | 4 | 4 | 4 |
| | Lackarebäck | | | | | | | | 5 | 5 | 5 | 4 | 5 |
| | | | | | | | | | | | | | |
| Raw water withdrawal Mm$^{3}$ per year | Alelyckan | | | | | | | | 34 | 34,3 | 34,6 | 37,4 | 35,3 |
| | Lackarebäck | | | | | | | | 32 | 32,1 | 32,1 | 33,8 | 33,7 |
| | *Total* | | | | | | | | 66 | 66,4 | 66,7 | 71,2 | 69 |
| | m3/s | | | | | | | | 2,09 | 2,11 | 2,12 | 2,26 | 2,19 |
| Intake cutoff | frequency | | | | | | | | 40 | 59 | 52 | 73 | 55 |
| | hours | | | | | | | | 2093 | 1475 | 2139 | 2123 | 2851 |
| Chlorine Ton/year | | | | | | | | | 48,5 | 49,3 | 52,1 | 58,2 | 55,3 |
| Piping Network length km | length | | | | | | | | 1754 | 1760 | 1768 | 1774 | 1702 |
| | new lines | | | | | | | | 13 | 5,6 | 9,2 | 6,5 | 9,4 |
| | replacement | | | | | | | | 6,3 | 14,6 | 11,5 | 7,3 | 6,1 |
| Leakage m$^{3}$/km per day | | | | | | | | | 17,7 | 19,6 | 19,6 | 21,6 | 19,8 |
| Waste water piping network km | length | | | | | | | | 2448 | 2462 | 2477 | 2487 | 2503 |
| | new lines | | | | | | | | 15,5 | 14,3 | 14,6 | 13,1 | 16,8 |
| | replacement | | | | | | | | 2,1 | 2,4 | 1,6 | 3,2 | 2,2 |
| Waste water to Ryaverket Mm$^{3}$ | | | | | | | | | 44,5 | 41,4 | 41,4 | 41,3 | 41 |
| Waste water cut off | Frequency | | | | | | | | 394 | 383 | 316 | 331 | 280 |
| Waste water treated | Mm$^{3}$ | | | | | | | | 131 | 115 | 120 | 111 | 121 |
| | m$^{3}$ | | | | | | | | 0,131 | 0,115 | 0,12 | 0,111 | 0,121 |
| Discharge amount per industry m$^{3}$/year | Arla Mejeri | | | | | | | | 333303 | 343472 | 318106 | 303626 | |
| | Eka Chemicals | | | | | | | | 577600 | 456250 | 475000 | 457000 | |
| | Sahlgreska sjukhuset | | | | | | | | 405820 | 325485 | 295604 | 314925 | |
| | Volvo Personvagnar AB | | | | | | | | 1930000 | 1680000 | 1900000 | 2020000 | |
| Energy consumption VA-Verket GWh | | | | | | | | | 46,5 | 48,8 | 46,1 | 49,1 | 48,9 |
| Source of energy GWh | Oil/Gas | | | | | | | | 5,8 | 5,8 | 5,5 | 4,7 | 3,4 |
| | Turbine | | | | | | | | 0,4 | 0,4 | 0,4 | 0,4 | 0,5 |
| | Electric | | | | | | | | 39,4 | 39,5 | 39,5 | 40,6 | 41,6 |
| | Heat Pump | | | | | | | | 1,1 | 1,1 | 1,1 | 1,1 | 1,5 |
| | Fuel | | | | | | | | 1,8 | 2 | 1,5 | 1,8 | 2,0 |
| | **Total** | | | | | | | | **48,5** | **48,8** | **48,0** | **48,6** | **48,9** |

| | | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Use of Energy GWh | Process/Renewal ACF/offices | | 11 | 10,1 | 14,8 | 12,9 | 13,9 | 13,4 | 13 | 13,9 | 13,2 | 10,8 | 10,8 |
| | Wastewater pumping | | 5,4 | 4,8 | 4,3 | 5,5 | 3,5 | 3,9 | 5,8 | 5,7 | 5,1 | 5,7 | 6,4 |
| | Protection/lighting/warming net | | | 1,8 | 0,4 | 0,5 | 0,5 | 0,5 | 0,5 | 0,4 | 0,4 | 0,9 | 1,0 |
| | Drinking water pumped to Higher zones | | 17,8 | 8,2 | 8,8 | 11,3 | 9,3 | 7,3 | 8,3 | 7,4 | 8,6 | 8,7 | 8,8 |
| | Drinking water pumped to lower zones | | | 8,8 | 9 | 8,7 | 8,2 | 8,5 | 8,6 | 8,8 | 8,7 | 9,6 | 9,3 |
| | Raw water pumping | | 10,4 | 10,4 | 12,7 | 11,7 | 10,4 | 9,9 | 10,5 | 10,6 | 10,5 | 11,2 | 10,8 |
| | Motor vehicles | | 2,1 | 2,5 | 2,6 | 2,2 | 2,2 | 1,8 | 1,8 | 2 | 1,5 | 1,8 | 2,0 |
| | **Total** | | **46,7** | **46,6** | **52,6** | **52,8** | **48,0** | **45,3** | **48,5** | **48,8** | **48,0** | **48,7** | **48,9** |
| Total drinking water distribution Mm$^{3}$ | | | | | | | | | 60,4 | 61,2 | 61,1 | 63,5 | 61,5 |
| Chemical consumption & cost per year | Total tons | | | | | | | | 9134,1 | 8801,2 | 9403,4 | 9751,1 | 9259 |
| | Total cost | | | | | | | | 9654 | 9460 | 10475 | 10592 | 10307 |
| | öre per m$^{3}$ | | | | | | | | 15,95 | 15,5 | 17,25 | 16,7 | 16,65 |
| Tariff taxes included kr/m$^{3}$ | drinking water | | | | | | | | | 4,21 | 4,21 | 4,21 | 4,21 |
| | waste water | | | | | | | | 5,38 | 5,38 | 5,38 | 5,38 | 5,38 |
| Drinking water consumption (household+industry+ public services) | Liter per person per day | | | | | | | | 261 | 258 | 256 | 257 | 254 |
| | Household | 198 | 191 | 192 | 189 | 188 | 184 | 183 | 186 | 181 | | | 175 |
| | Industry | 41 | 40 | 40 | 38 | 38 | 38 | 37 | 36 | 37 | | | 33 |
| | Services | 44 | 42 | 43 | 41 | 39 | 40 | 39 | 39 | 40 | | | 46 |
| | VA-Verket consumption | 14 | 13 | 13 | 11 | 9 | 8 | 9 | 9 | 7 | 6 | 8 | 7 |
| | | | | | | | | | | | 256 | 257 | |
| | Total | 297 | 286 | 288 | 279 | 274 | 270 | 268 | 270 | 265 | 262 | 265 | 261 |

## Wastewater outflow quality

| *Outflow concentrations* | *$BOD_7$ mg/l* | *COD mg/l* | *$P_{tot}$ mg/l* | *$N_{tot}$ mg/l* | *SS mg/l* | *Pb µm/l* | *Cd µm/l* | *Cr µm/l* | *Hg µm/l* | *Ni µm/l* | *Cu µm/l* | *Zn mg/l* |
|---:|---|---|---|---|---|---|---|---|---|---|---|---|
| 1974 | 32 | 97 | 2,8 | 19,1 | 29 | 29 | 0,6 | 10 | 0,3 | 31 | 22 | 0,14 |
| 1975 | 57 | 138 | 3,9 | 20,2 | 51 | 22 | 1 | 17 | 0,2 | 22 | 33 | 0,19 |
| 1976 | 63 | 151 | 4,1 | 21,3 | 59 | 20 | 1,1 | 20 | 0,4 | 23 | 43 | 0,22 |
| 1977 | 47 | 117 | 3,3 | 18,1 | 56 | <10 | 1,2 | <10 | 0,3 | <23 | 32 | 0,14 |
| 1978 | 43 | 109 | 3,2 | 20,2 | 49 | <7 | 0,7 | <9 | 0,4 | <22 | 29 | 0,1 |
| 1979 | 44 | 109 | 3,2 | 19,1 | 53 | <7 | 0,7 | <7 | 0,6 | <18 | 29 | 0,11 |
| 1980 | 34 | 102 | 2,9 | 18,2 | 43 | <5 | <0.4 | <5 | <0.3 | <17 | 20 | <0.07 |
| 1981 | 34 | 109 | 2,9 | 16,9 | 47 | <5 | <0.3 | <6 | 0,3 | <13 | 26 | 0,09 |
| 1982 | 28 | 99 | 3,1 | 17,2 | 40 | <5 | <0.3 | <7 | <0.2 | <18 | 25 | <0.08 |
| 1983 | 17 | 68 | 2,7 | 15,1 | 24 | <5 | <0.3 | <6 | <0.2 | <14 | 25 | <0.08 |
| 1984 | 18 | 59 | 1,8 | 17,9 | 26 | <5 | <0.2 | <5 | <0.1 | <13 | 22 | <0.07 |
| 1985 | 15 | 77 | 1,4 | 15,4 | 29 | <5 | <0.2 | <5 | <0.1 | <14 | <17 | <0.07 |
| 1986 | 11 | 73 | 1 | 16,8 | 19 | <6 | <0.3 | <6 | <0.2 | <13 | 14 | <0.06 |
| 1987 | 13 | 81 | 0,8 | 17 | 19 | <5 | <0.2 | <6 | <0.1 | <12 | <13 | <0.06 |
| 1988 | 11 | 65 | 0,51 | 15,7 | 13 | <5 | <0.2 | <5 | <0.1 | <13 | <8 | <0.06 |
| 1989 | 11 | 71 | 0,49 | 18,3 | 11 | <3 | <0.2 | <3 | <0.1 | <12 | <5 | <0.03 |
| 1990 | 7 | 69 | 0,43 | 18,1 | 9 | <3 | <0.2 | <3 | <0.1 | 13 | <5 | <0.04 |
| 1991 | 9 | 60 | 0,41 | 20,7 | 15 | <5 | <0.3 | <6 | <0.2 | 16 | <7 | <0.04 |
| 1992 | 7 | 46 | 0,28 | 18,5 | 9 | <3 | <0.2 | <3 | <0.2 | 11 | <6 | <0.03 |
| 1993 | 8 | 50 | 0,3 | 21 | 9 | <3 | <0.2 | <10 | <0.2 | 14 | <8 | <0.03 |
| 1994 | 12 | 56 | 0,56 | 19 | 21 | <3 | <0.2 | <3 | <0.2 | 11 | 11 | <0.02 |
| 1995 | 12 | 63 | 0,49 | 20,2 | 21 | <3 | <0.2 | <3 | <0.2 | 10 | 13 | <0.04 |
| 1996 | 18 | 69 | 0,6 | 24,1 | 23 | <3 | <0.2 | <4 | <0.2 | 12 | 14 | <0.02 |
| 1997 | 8 | <46 | 0,41 | 19,2 | 13 | <3 | <0.2 | <4 | <0.2 | 10 | 11 | <0.02 |
| 1998 | 7 | <40 | 0,39 | 12,7 | 11 | <3 | <0.2 | <4 | <0.2 | 11 | 10 | <0.02 |
| 1999 | 5,3 | <37 | 0,34 | 11,6 | 10 | <3 | <0.2 | <3 | <0.2 | 10 | 10 | <0.02 |
| 2000 | 5,1 | <33 | 0,41 | 9,4 | 13 | <3 | <0.2 | <3 | <0.2 | 6 | 10 | 0,02 |
| 2001 | 6,4 | 36 | 0,38 | 10,6 | 10 | <3 | <0.2 | <4 | <0.2 | 6 | 10 | <0.02 |
| 2002 | 5,7 | <36 | 0,36 | 11,8 | 9 | <0.8 | <0.1 | <1.3 | <0.18 | 6 | 8 | <0.01 |
| 2003 | 7,3 | <37 | 0,36 | 10,4 | 9 | <0.2 | <0.1 | <1 | <0.1 | 5 | 8 | <0.02 |
| 2004 | 7,6 | 38 | 0,34 | 10,2 | 9 | 0,4 | <0.1 | <1 | <0.1 | 4 | 11 | <0.01 |

# Wastewater inflow quality

| Inflow concentration | Q $m^3$/d x 1000 | $BOD_7$ mg/l | COD mg/l | $P_{tot}$ mg/l | SS mg/l | $N_{tot}$ mg/l | Pb µm/l | Cd µm/l | Cr µm/l | Hg µm/l | Ni µm/l | Cu µm/l | Zn mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1974 | 243 | 124 | 314 | 5,5 | - | 27,4 | 61 | 1,8 | 37 | 0,5 | 42 | 69 | 0,44 |
| 1975 | 316 | 146 | 322 | 5,4 | - | 24,4 | 43 | 2 | 33 | 0,5 | 30 | 66 | 0,37 |
| 1976 | 289 | 164 | 353 | 6 | - | 26,2 | 41 | 2,2 | 40 | 0,7 | 26 | 75 | 0,44 |
| 1977 | 357 | 113 | 289 | 5,1 | 178 | 22,5 | 26 | 2,4 | 25 | 0,5 | 31 | 65 | 0,32 |
| 1978 | 325 | 137 | 327 | 5,8 | 207 | 25,7 | 24 | 1,6 | 32 | 0,7 | 36 | 60 | 0,28 |
| 1979 | 322 | 130 | 325 | 5,5 | 204 | 24,8 | 19 | 2,2 | 18 | 0,9 | 25 | 56 | 0,25 |
| 1980 | 301 | 134 | 366 | 5,7 | 222 | 24,5 | 18 | 1,1 | 18 | 0,7 | 26 | 58 | 0,21 |
| 1981 | 309 | 123 | 311 | 5,1 | 196 | 22,1 | 11 | 0,7 | 13 | 0,4 | 20 | 58 | 0,21 |
| 1982 | 320 | 100 | 288 | 5,2 | 188 | 24 | 12 | 0,8 | 18 | 0,5 | 25 | 67 | 0,17 |
| 1983 | 271 | 94 | 268 | 4,8 | 195 | 20,5 | 10 | 0,6 | 13 | 0,4 | 20 | 78 | 0,19 |
| 1984 | 292 | 128 | 316 | 5,5 | 239 | 24,4 | 11 | 0,6 | 12 | 0,3 | 19 | 76 | 0,2 |
| 1985 | 346 | 107 | 323 | 4,8 | 209 | 19,7 | 9 | 0,6 | 12 | 0,3 | 20 | 58 | 0,16 |
| 1986 | 336 | 98 | 322 | 4,6 | 194 | 21,9 | 7 | 0,4 | 12 | 0,2 | 18 | 56 | 0,14 |
| 1987 | 342 | 126 | 364 | 4,9 | 226 | 22,7 | 9 | 0,5 | <11 | 0,2 | 15 | 52 | 0,15 |
| 1988 | 372 | 128 | 344 | 4,7 | 235 | 21,1 | <8 | <0.5 | <9 | <0.2 | <13 | 52 | 0,14 |
| 1989 | 298 | 165 | 427 | 6,9 | 289 | 24 | 14 | 0,6 | <6 | 0,3 | <18 | 54 | 0,14 |
| 1990 | 351 | 195 | 435 | 6,5 | 292 | 25,9 | 15 | 0,5 | <6 | <0.3 | 21 | 59 | 0,15 |
| 1991 | 313 | 157 | 394 | 5,7 | 310 | 29 | 19 | 0,6 | 12 | 0,4 | 26 | 68 | 0,23 |
| 1992 | 344 | 146 | 386 | 5,5 | 313 | 26,4 | 18 | <0.7 | 13 | <0.4 | 27 | 90 | 0,26 |
| 1993 | 324 | 152 | 391 | 5,3 | 308 | 29,3 | 14 | 0,9 | 53* | 0,3 | 50* | 108 | 0,29 |
| 1994 | 372 | 123 | 308 | 4,5 | 253 | 25,2 | 10 | 0,6 | 8 | 0,3 | 15 | 80 | 0,14 |
| 1995 | 358 | 108 | 295 | 4,1 | 242 | 27,7 | 8 | 0,4 | 7 | 0.2 @ | 11 | 69 | 0,16 |
| 1996 | 283 | 161 | 370 | 5,4 | 257 | 31,4 | 8 | 0,4 | 10 | 0,3 | 15 | 79 | 0,12 |
| 1997 | 333 | 156 | 376 | 5,5 | 297 | 30,1 | 9 | 0,5 | 7 | 0,3 | 16 | 87 | 0,13 |
| 1998 | 386 | 131 | 304 | 4,5 | 237 | 26,8 | 7 | 0,4 | 18 | 0,3 | 16 | 76 | 0,13 |
| 1999 | 388 | 121 | 304 | 4,5 | 238 | 24,9 | 6 | 0,3 | 12 | 0,2 | 13 | 78 | 0,12 |
| 2000 | 372 | 129 | 306 | 4,5 | 229 | 24,6 | 7 | 0,3 | 8 | <0.2 | 10 | 70 | 0,11 |
| 2001 | 319 | 143 | 306 | 4,5 | 199 | 26,3 | 5 | 0,24 | 11 | <0.2 | 10 | 70 | 0,1 |
| 2002 | 327 | 135 | 308 | 4,8 | 201 | 27,8 | 6 | 0,2 | 8 | <0.2 | 10 | 83 | 0,14 |
| 2003 | 304 | 132 | 301 | 4,5 | 210 | 27,7 | 5 | <0.2 | 8 | <0.2 | 9 | 88 | 0,1 |
| 2004 | 332 | 123 | 296 | 4,4 | 190 | 27,1 | 5 | 0,17 | 7 | 0,18 | 6 | 75 | 0,08 |

## Sludge quality

| | Sludge ton/year | Pb mg/kg TS | Cd mg/kg TS | Cu mg/kg TS | Cr mg/kg TS | Hg mg/kg TS | Ni mg/kg TS | Zn mg/kg TS |
|---|---|---|---|---|---|---|---|---|
| 1975 | 13837 | 289 | 8 | 317 | 97 | 3,2 | 45 | 1538 |
| 1976 | 11495 | 263 | 12 | 375 | 119 | 4 | 39 | 2093 |
| 1977 | 12559 | 245 | 10,5 | 340 | 81 | 3,8 | 49 | 1600 |
| 1978 | 12559 | 185 | 8,5 | 320 | 111 | 3,6 | 40 | 1280 |
| 1979 | 15258 | 163 | 9 | 294 | 95 | 3,6 | 39 | 1100 |
| 1980 | 16520 | 124 | 5,4 | 304 | 92 | 3,9 | 34 | 1009 |
| 1981 | 15423 | 100 | 2,7 | 282 | 65 | 3,4 | 28 | 870 |
| 1982 | 17759 | 89 | 2,8 | 266 | 63 | 2,8 | 36 | 724 |
| 1983 | 21004 | 80 | 2,1 | 250 | 50 | 2,7 | 31 | 688 |
| 1984 | 23501 | 66 | 2 | 237 | 39 | 2,1 | 22 | 577 |
| 1985 | 23233 | 63 | 1,4 | 231 | 36 | 2,7 | 22 | 520 |
| 1986 | 23897 | 52 | 1,5 | 218 | 44 | 1,9 | 20 | 487 |
| 1987 | 26015 | 49 | 1,3 | 201 | 29 | 1,9 | 14 | 435 |
| 1988 | 30344 | 51 | 1,1 | 227 | 24 | 1,6 | 16 | 448 |
| 1989 | 31436 | 41 | 1 | 212 | 24 | 1,4 | 16 | 426 |
| 1990 | 26533 | 51 | 1,3 | 236 | 26 | 1,4 | 17 | 548 |
| 1991 | 18216 | 72 | 2,3 | 315 | 43 | 1,8 | 29 | 848 |
| 1992 | 17236 | 65 | 2,5 | 388 | 34 | 2,4 | 32 | 1015 |
| 1993 | 16300 | 73 | 3,3 | 520 | 27 | 2,4 | 23 | 1430 |
| 1994 | 15052 | 53 | 2,3 | 474 | 32 | 1,6 | 25 | 1000 |
| 1995 | 12830 | 46 | 1,8 | 435 | 38 | 1,8 | 20 | 733 |
| 1996 | 14100 | 43 | 1,6 | 430 | 46 | 1,4 | 26 | 644 |
| 1997 | 14852 | 43 | 1,4 | 408 | 53 | 1,3 | 24 | 694 |
| 1998 | 14806 | 47 | 1,5 | 413 | 51 | 1,1 | 21 | 725 |
| 1999 | 15500 | 44 | 1,3 | 386 | 34 | 0,9 | 18 | 644 |
| 2000 | 14390 | 42 | 1,2 | 440 | 36 | 0,8 | 17 | 666 |
| 2001 | 13512 | 44 | 1,4 | 508 | 33 | 1 | 19 | 753 |
| 2002 | 14463 | 37 | 1,2 | 448 | 29 | 1,1 | 23 | 640 |
| 2003 | 14204 | 34 | 1 | 407 | 29 | 1 | 24 | 625 |
| 2004 | 13501 | 40 | 1,1 | 421 | 30 | 1,2 | 23 | 663 |

APPENDIX IV: Indicator calculations

**Fresh water resources**

1. Raw water protection: percentage of increasing or decreasing on the protected water areas.

2. Raw water quality: average per year measured by the concentration in the raw water of COD, P, N in µg/l.

3. Freshwater availability: ratio between the withdrawal and the available volume for drinking water production.

$$\text{Freshwater availability} = \frac{\textit{water production level } Mm^3 \textit{ per year}}{\textit{raw water withdrawal } Mm^3 \textit{ per year}}$$

**Drinking water production and distribution**

4. Chemical and energy consumption: amount of chemicals (Tons) and energy (GWh) per $m^3$ of drinking water produced.

$$\text{Chemical consumption} = \frac{\textit{water production per year}}{\textit{total chemical consumption per year}}$$

$$\text{Energy consumption} = \frac{\textit{water production per year}}{\textit{Energy Consumption}}$$

5. Drinking water production: amount of drinking water produced (l) per person per day.

$$\text{Drinking water production} = \frac{\textit{drinking water produced}}{\textit{per person per day}}$$

6. Leakage: % calculated by the leakage ($m^3$) divided by total amount of drinking water produced ($m^3$).

$$\text{Leakage} = \frac{\textit{water production } Mm^3 \textit{ per year}}{\textit{leakage } Mm^3 \textit{ per year}}$$

**Usage**

7. Drinking water consumption: amount ($m^3$) of drinking water consumed per person per day. Population estimated considering the total in the Göteborg commune.

$$\text{Drinking water consumption} = \frac{\textit{water consumed } m^3}{\textit{population}}$$

**Wastewater collection and treatment**

8. Wastewater collection: volume ($m^3$) collected per person per year. Considering the people that live in the connected communes. (Ale, Göteborg, Härryda, Kungälv, Mölndal, Partille)

$$\text{Wastewater collection} = \frac{\textit{volume } m^3}{\textit{population per year}}$$

9. Treatment performance: % removed of BOD, P and N calculated by the concentration (mg/l) in the inflow divided by the concentration (mg/l) in the outflow average per year.

$$\text{Treatment performance} = \frac{\textit{concentration of BOD, P, N Inflow}}{\textit{concentration of BOD, P, N Outflow}}$$

10. Chemical and energy consumption: amount of chemicals (Tons) and energy (GWh) per $m^3$ of wastewater treated.

$$\text{Chemical consumption} = \frac{\textit{treated wastewater per year}}{\textit{total chemical consumption per year}}$$

$$\text{Energy consumption} = \frac{\textit{treated wastewater per year}}{\textit{Energy Consumption per year}}$$

11. Loads to receiving water: total concentration (Tons) of N and P that receives the water bodies per year.

**Handling By-products**

12. Sludge disposals or reuse: % of the sludge that is reused per year.

13. Energy consumption: amount energy (GWh) per Tons of P and N that is produced.

14. Nutrient recycling: amount (Tons) of P and N that is recycled from sludge per year.

15. Loads to receiving soils: amount (Tons) of cadmium that the soil receives per year.