Abstract

Sustainable development indicators for urban water systems

Ulrika Palme
Environmental Systems Analysis
Chalmers University of Technology

The thesis investigates the Swedish urban water systems from a sustainable development perspective. It further analyses the combined findings from a case study on the construction of sustainable development indicators (SDIs) at a Swedish water company, and a literature survey on different applications of SDIs within companies in general.

The investigation of the Swedish urban water systems need to be further developed in the direction of increased sustainability, especially as concerns environmental sustainability. On the other hand, it is concluded that regarding environmental and sustainability awareness as well as accustomedness to the usage of indicators in these areas, Swedish water companies appear to be comparatively well-developed.

The thesis identifies a number of complicating aspects regarding sustainable development. It is concluded that many of the most urgent problems from a sustainability perspective cannot be handled solely at the level of urban water systems. Furthermore, sustainable development is complicated by its demand for far-reaching responsibilities and its non-compatibility with the prevalent individual short-term perspective.

SDIs appear to have a potential in helping to realise sustainable development in general. To make SDIs effective and efficient though, weaknesses identified in their present use concerning accommodation of stakeholder interests, credibility, benchmarking and future-orientation need to be addressed.

The thesis ends with some thoughts on future research, which will include case studies of water companies, and focus on information need.

Keywords: sustainable development indicators, urban water systems.

List of appended papers

This thesis is based on the following appended papers:

1. Palme, U., M. Lundin, A.-M. Tillman and S. Molander (Submitted). "A procedure for constructing sustainable development indicators for wastewater systems – researchers and indicator users in a co-operative case study." Submitted manuscript.

2. Palme, U. and A-M Tillman. "Sustainable development indicators and their applications: A literature survey." Manuscript.

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Preface and acknowledgements

When I started studying biology many years ago I thought that zoo-ecology would be a nice discipline for deeper studies. The courses in ecology I took, however, led me on a different path: environmental problems. Not because I felt that these were more interesting than zoo-ecology, only more urgent. I felt it impossible to sit around peacefully watching butterflies (or whatever) in a threatened world. Environmental problems are human problems in the sense that they are perceived by humans and most often caused by humans. Hence studying environment was not enough, and here I am with a licentiate thesis on sustainable development: the integration of environmental and social concerns. It has been a difficult journey for many reasons, and though I know the thesis has its shortcomings and imperfections, I feel content: I have built a platform.

I want to thank FORMAS for financing the project, the working group at Stockholm Water for participating in the case study, Henrikke Baumann for introducing me to management studies, Christine Räisänen for her inspiring assistance in the writing of the literature survey, and Henriette Söderberg for contributing to the ideas on future research.

Friends, family, colleagues: you all know your importance. I would not have achieved much without you giving me ideas and inspiration, listening and discussing, sharing your knowledge and experience, making me smile, looking after children, being children (**Per** och **Axel**: puss på er!). All in all I have received magnificent support: Thank you all!

Finally, my most profound and deeply felt gratitude go to three persons who in their own different ways have been particularly important to me in the process of building my platform: supervisor Anne-Marie Tillman, lifeline Karin Lega, my father Erik Palme.

1. Introduction

In combination with population growth, activities linked to production and consumption – resource depletion, waste generation and uneven distribution of wealth – are the aspects of human activity that contribute the most to the present unsustainable state of the earth. If we accept this, it is obvious that companies are important from a sustainability perspective. Companies can be regarded as the engines that generate wealth by transforming resources into products, services and waste (Fig 1). As such, they have the potential to lead development in the direction of further decreased sustainability by misusing resources, or in the direction of increased sustainability by the environmentally and socially sound production of wealth. It is sometimes argued that consumers are those in power, and thus are the "engines" of today's capitalistic society. Either standpoint could be defended, but the focus of this thesis is on companies, specifically in the water industry, and on their use of sustainable development indicators as a means to assess and promote sustainable development.

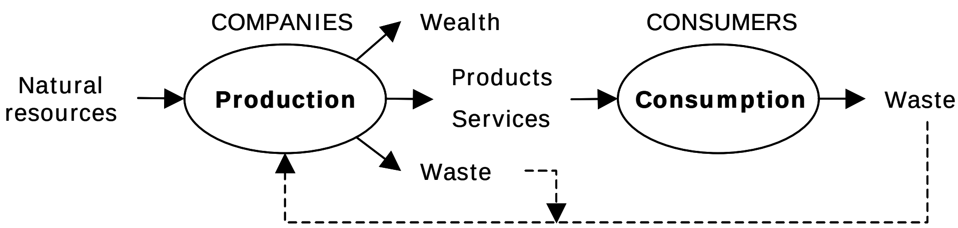

Figure 1. *Schematic drawing of the production–consumption chain*

I will return to the contents, aim and structure of the thesis at the end of this introductory chapter. First I will describe and define the key concepts of the thesis: sustainable development, sustainable development indicators and urban water systems.

Sustainable development

The classic definition of sustainable development that was formulated by the World Commission on Environment and Development (WCED) in their report "Our common future", also known as "the Bruntland report", in 1987 still seems to be the most widely known and accepted: "*Development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations*" (WCED 1987). The concept thus defined has been much criticised for being too vague and therefore too easy to use as an empty slogan (e.g. Leist and Holland 2000; Hanley and Atkinson 2003). A certain vagueness in a concept may, on the other hand, be necessary if it is to be accepted and used by people from various cultures (Bell and Morse 1999). The definition must be sharp enough to unite people towards a common goal, but fuzzy enough to accommodate a range of values, interests and cultural characteristics. Looked upon that way, the very vagueness of the concept is also its strength.

The concept of sustainable development has been variously interpreted since it was defined in the Bruntland report. Goodland's (1995) interpretation of the WCED definition leans towards the ecological perspective, dividing sustainable development into three distinct aspects: environmental, economic and social sustainability. The division made by Goodland is frequently used and is often depicted as a three-ringed sector model of sustainable development (Figure 2). As pointed out by Giddings et al. (2002), a weakness of this model is that it assumes separation of the three sectors, which distracts from the essential connections that actually exist between environment, economy and society. The same division, but not necessarily the three-ringed sector model, is also found in the "triple bottom line" referred to by many companies in their work towards sustainability (e.g. Bennett and James 1998; Grafé-Buckens and Beloe 1998; Schaltegger and Burritt 2000). Goodland divides the concept of sustainable development into social, economic and environmental sustainability in order to focus on the environmental aspect. He states, for example, that "Any consumption that is based on the depletion of natural capital is not income and should not be treated as such". When taken out of context, the Goodland division may appear to regard economic aspects as equally important to social and environmental aspects, especially if the schema is depicted by a symmetrical arrangement of three, equal-sized circles. This may be misleading, depending on how "economic" is interpreted. The definition of sustainable development made by Welford (1995), also frequently used, is clearer on this point. According to his definition, sustainable development is composed of three interrelated elements: environment, equity and futurity. "Equity" emphasises that the economic dimension of sustainable development concerns the distribution rather than the generation of wealth, and "futurity" that coming generations need to be considered as well as those now living.

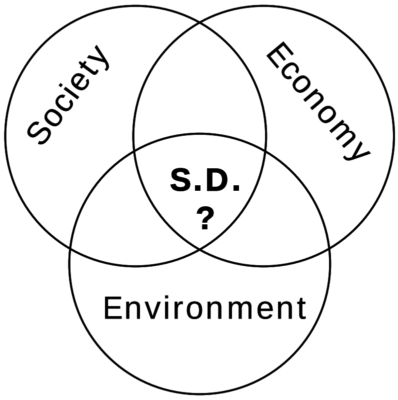

Figure 2. *The frequently used three-ringed sector view of sustainable development*

Both the interpretations of the Bruntland definition discussed above are simple and short, yet clarify a complex concept. Still neither of them singly, nor both in combination, provides a useful framework for this thesis. For this purpose I want to add the central structure of the "Daly triangle" (Figure 3) as interpreted by Meadows (1998) (Figure 4). In the Daly triangle, human economy is depicted as resting on the foundation provided by natural capital. Natural capital, including natural resources and ecosystem services, forms the ultimate means of development. Economy and technology are not ends in themselves, but intermediate means towards intermediate ends (including human and social capital) and the ultimate end of human well-being. My framework for discussing sustainable development will be the one created when Goodland's three aspects are mapped on the structure of the Daly triangle (Figure 5). The environment is thus the foundation and the limiting factor, economy and technology are the means, and social aspects, or human well-being (including welfare), are the aim of sustainable development. I prefer not to use the word "capital" and I choose to conflate the two levels of ends in the Daly triangle into one, as the distinction between human/social "capital" and human well-being is beyond the scope of this thesis.

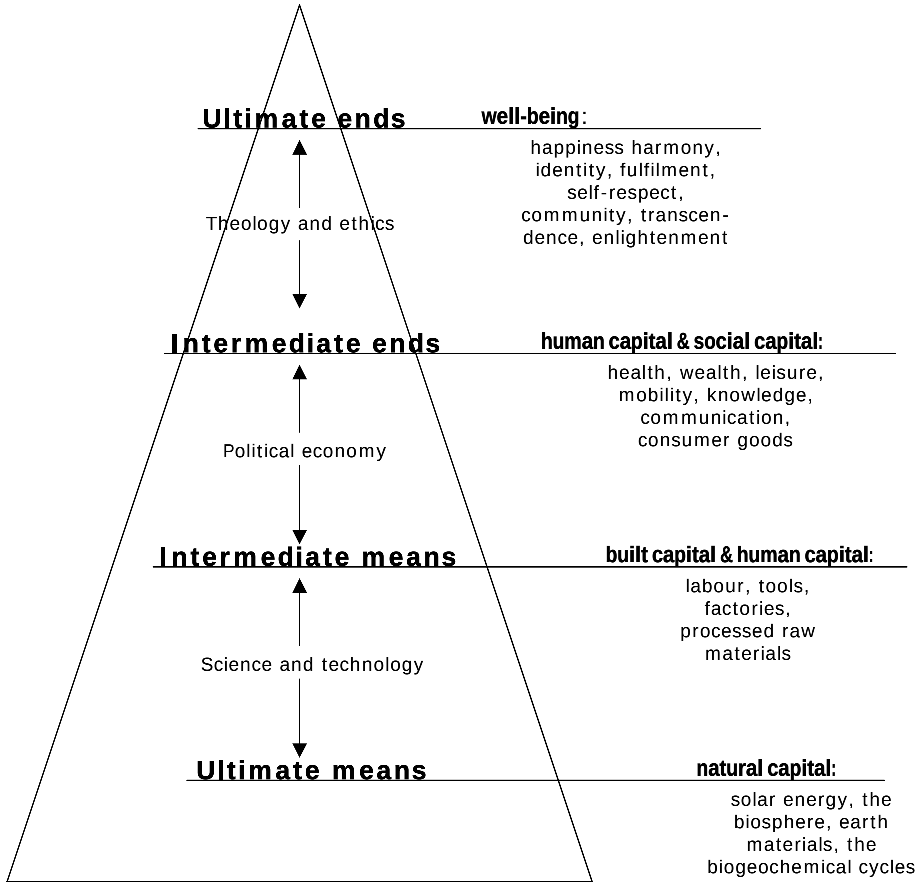

Figure 3. *The Daly triangle; from Daly (1973), as appearing in Meadows (1998)*

Like all models, this framework is a simplification and an abstraction of reality and has its weaknesses. One is that none of the sustainability aspects, environmental, techno-economic and social sustainability, is only foundation, means or end, but to some degree belong to all of these categories. I will discuss these "deviations" from the model in the appropriate sections in chapter 2. Furthermore, the futurity aspect from Welford's definition of sustainable development is a needed complement that adds the time perspective to the otherwise static triangle.

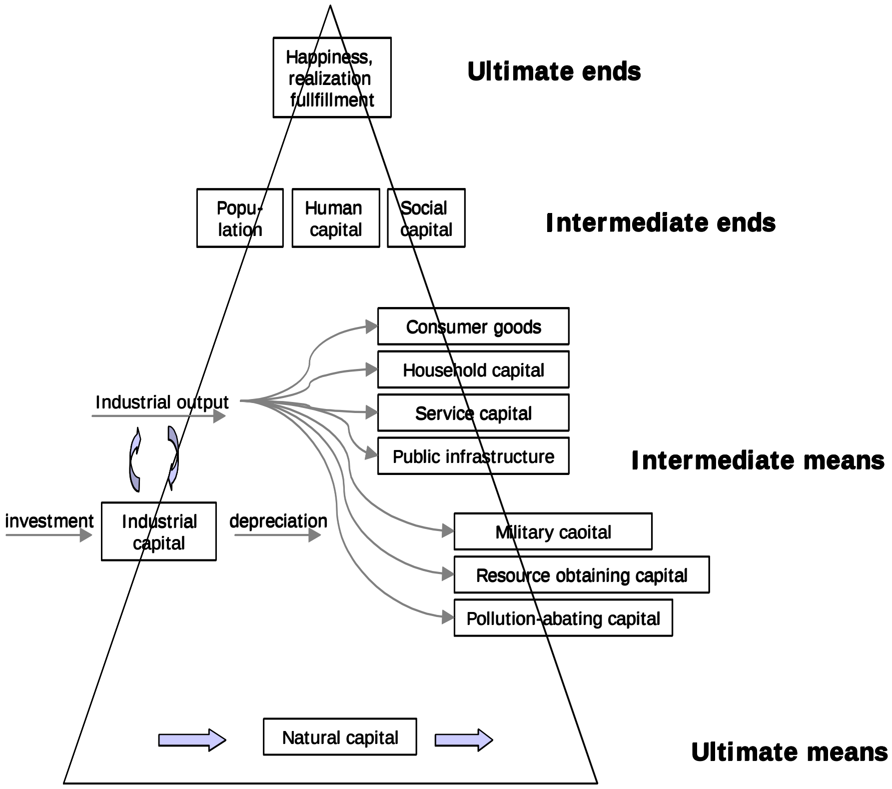

Figure 4. *The Daly triangle as interpreted by Meadows (1998).*

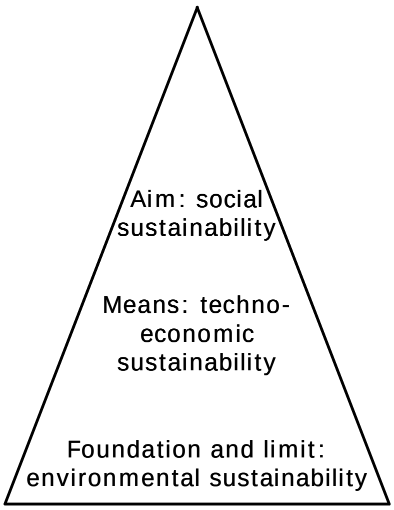

Figure 5*. Framework for sustainable development used in the thesis*

Sustainable development indicators

In striving for sustainability, indicators are frequently recommended to guide development in the desired direction. Indicators are used as tools in many different areas to give simplified but accurate information. An indicator generally has a broader significance than its immediate implication. For example, in ecology the presence of certain indicator species is used to judge the condition of an ecosystem, as the latter as such is difficult to measure. Correspondingly, it is difficult to measure sustainability directly. Instead, parameters relating to one or more of the dimensions or aspects of sustainability are identified and used as the basis for constructing sustainable development indicators (SDIs). According to Meadows (1998), the significant feature of an SDI is the connection to time, limit or target. It should enable an estimation of how long an activity can last, i.e. where we are with respect to our limits. I would like to add that as a complement to these "negative" indicators ("stop, here is the limit"), we also need "positive" indicators that show alternatives to the present unsustainable direction of development ("go here instead"). Whether "negative" or "positive", an SDI needs certain qualities, and most reports and papers on SDIs include a list of such qualities (see, e.g. Meadows 1998; Hodge and Hardi 1997; De Kruijf and Van Vuuren 1998; Kelly 1998; Graedel and Allenby 2002). In short, good SDIs should be effective and efficient, yet democratic and meet the needs of all stakeholders.

Following the U.N. conference on Environment and Development in Rio de Janeiro in 1992, a number of initiatives to measure different aspects of sustainability and select appropriate SDIs were launched. Initially, a majority of the SDIs proposed were intended for use at the international, national, regional or other administrative or geographical levels (see, e.g. Verbruggen and Kuik 1991; UNCSD 1996; OECD 1998). In the latter half of the 1990s the role and responsibility of companies in the implementation of sustainable development attracted increasing attention, leading to a new set of initiatives, now to develop SDIs for use at the company level. Ranganathan (1998), for example, lists 47 initiatives regarding sustainability reporting in companies. The use of SDIs within companies is also described by Bennett and James, 1999; Fiksel et al., 1999; Olsthoorn et al., 2000; Schaltegger and Burritt, 2000; Veleva et al., 2001; and Veleva and Ellenbecker, 2001. There have also been a number of SDI projects applying specifically to the water industry (for a review see, e.g. Balkema et al. 2002; Foxon et al. 2002).

Urban water systems

Theoretical academic discussions of sustainable development and its indicators seem to be endless, but do little good unless the ideas generated are implemented at some level of society. The focus of this thesis is on urban water systems in Sweden.

The main functions of an urban water system are to produce and deliver drinking water and to conduct and treat wastewater. These are vital functions in any society, hence securing them for current and future generations should be an important part of sustainable development. Another aspect of urban water systems that make them interesting from a sustainability point of view is their close linkage to society as a whole. Whatever chemical compound circulates in society sooner or later turns up in the wastewater and, although in lower concentrations, in the raw water that the drinking water system handles. In 1995 the Swedish EPA proposed a systems definition of an urban water system that is useful here (NVV 1995). According to this definition, an urban water system consists of the technical system itself and the organisation and technical functions needed to build, operate and maintain the urban water system functions – producing and delivering drinking water, and conducting and treating wastewater and urban run-off. Within the system boundaries are included water reserves and receiving waters, and also the products used in the treatment processes, such as chemical additives, and products extracted from these processes, such as energy and nutrients. To this I would like to add the users as parts of the system, as they affect as well as are affected by the functions of the urban water system.

Aim and structure of the thesis

A short summary

This licentiate thesis sums up the first phase of my doctoral research into indicators for the sustainable development of urban water systems. Initially, the project was based primarily on ideas pertaining to sustainable development at policy level, but with the intention of ultimately transferring these ideas to company level. Of the various aspects of sustainable development discussed in the introduction, the focus was predominantly on environmental sustainability. An important input to the project was the idea that life cycle assessment (LCA) would be useful in identifying important parameters for constructing SDIs. Furthermore, it was recognised that stakeholders need to be involved in sustainable development processes, including processes for constructing indicators. These ideas were fed into and further developed in a case study with the Stockholm Water Company (SWC) (Paper 1). The research journey then led on to studies in management, including the literature survey presented in Paper 2, as the case study made it clear that the corporate use of SDIs needs to be guided by management considerations as well as by scientifically generated principles. The broadened scope of the research thus came to encompass the applications and context of SDIs, as well as the original focus on process and policy.

Aim

The thesis aims to account for the knowledge gained thus far from the research into the use of SDIs within companies in general and within the water sector specifically, and to show how this knowledge has given rise to plans for further research.

Appended papers

Paper 1: A procedure for constructing sustainable development indicators for wastewater systems – researchers and indicator users in a co-operative case study

The Stockholm Water Company (SWC) case study used an existing iterative procedure (Lundin and Morrison 2002) for the construction of sustainability indicators as its point of departure. The study focused on sludge handling, but its aim was also to construct relevant indicators for the entire wastewater system. The study was multifaceted, using the multi-criteria analysis (MCA) of results from life cycle, risk, economic and uncertainty assessments in ranking technical options for sludge handling. The purpose of the MCA was to assess the various technical options, to assign values to various, and often conflicting, aspects of sustainability and to weigh the relative importance of various criteria. The MCA served these purposes well, and proved to be a useful framework for a structured discussion. On basis of the preferences expressed in the MCA, a number of SDIs and, when possible, targets for sustainable development, were formulated. At the beginning of the study the environmental and economic aspects of sustainability were the primary focus, but as the study progressed, technical and social aspects came to be included. The resulting SDIs consequently reflect economic, environmental, technical and social aspects of sustainable development. The SDIs were constructed to apply specifically to the sludge handling system, as this was the focus of all the assessments feeding into the study. When possible, however, the coverage of these indicators was broadened to encompass the entire wastewater system. The original procedure, used as a point of departure of the study, was developed into a co-operative procedure leading to the integration of both expert- and user-based knowledge, and with an increased focus on information needs. The main results of this case study were thus a number of indicators and a procedure, but the knowledge gained also concerned the importance of system levels, the usefulness of the various systems analysis tools used, and, as mentioned, the importance of considering sustainable development from a management perspective when studying it in the corporate setting.

Paper 2: Sustainable development indicators and their applications: A literature survey

One of the difficulties in conducing the case study was to define the SWC objectives of the SDI program, i.e. how the SDIs were to be used and for what purpose. In response, the next phase of the project focused on various applications of SDIs within companies, and the resulting paper presents a survey of relevant literatures in both the social and natural sciences. The indicators included in the survey were those termed indicators of sustainable development, sustainability, sustainable production, environmental performance, social performance and eco-efficiency. The results showed that SDIs are used for a range of applications including accounting, internal and external reporting, benchmarking and planning. The use of SDIs for retrospective purposes, such as reporting, seems to dominate over the use of SDIs for prospective purposes, such as planning. Furthermore, there are weaknesses in the present use of SDIs concerning consideration of stakeholder interests, credibility and benchmarking. These issues need to be addressed in future research as well as by company management if SDIs are to become an effective tool in sustainable development at company level.

Structure

Chapter 2 describes urban water systems in Sweden from a sustainability perspective, taking as its points of departure the social, environmental and technical-economic aspects of sustainable development, which also correspond to the aim, foundation and means of sustainable development. These aspects will be illustrated with examples from the case study (Paper 1).

Chapter 3 describes the role of indicators in sustainable development from a managerial perspective. The first section deals with companies in general and is basically a summary of paper 2. The second section looks more specifically at the water sector and at results from the case study.

Subsequently, I will discuss the prerequisites for sustainable development of urban water systems, before ending the thesis with plans for future research.

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2. A sustainability perspective on urban water systems in Sweden

When looking at urban water systems from a sustainability perspective the situation in Sweden may seem unproblematic at a first glance. Sweden is both rich in fresh water and rich economically. In the year 2000 close to 90% of the population was connected to urban water systems. In most urban areas around the world the main problem is that people lack access to safe drinking water and basic sanitation. The main problem in Sweden, and in a number of other developed countries, is rather that the current design and function of water systems entail a waste of resources, as they do not enable recycling. The wastewater systems efficiently trap nutrients in the wastewater, stopping these from causing eutrophication of receiving waters. Beside nutrients, wastewater contains other potentially valuable resources, such as soil-conditioning substances and energy, but also harmful substances, such as heavy metals, persistent organic compounds and pathogens that can be transmitted to plants, livestock and humans. Pathogens have always been present in biological waste and are an inevitable reason why biological waste must be handled cautiously. The problem may have become more serious, however, with the large-scale infrastructure and long-distance transportation of modern society that has possibly helped spread pathogens. There are, however, techniques for hygienisation that can considerably diminish the risks associated with pathogens. It is different with heavy metals and persistent organic compounds. These are not inherently connected to biological waste and they cannot be destroyed. In the most sustainable society imaginable there would be no harmful substances other than pathogens to worry about, but considering the amount of chemicals circulating in society today, such a society is a long way off. A more realistic aim is to find a way to recycle the valuable resources, but not the harmful contaminants.

This chapter briefly describes the history and current condition of urban water systems in Sweden, followed by an analysis of these systems with regard to the different aspects of sustainable development, including examples from the case study.

History

In the middle of the nineteenth century severe outbreaks of cholera in Stockholm and Göteborg prompted the construction of networks of water mains conveying drinking water to the citizens. During this period, the expansion of the water supply system was determined by the need for drinking water and fire protection, and the first waterworks for distribution to private households were constructed in the 1860s. WCs were introduced around 1900.

These changes in the water system necessitated the upgrading of the existing sewer system, which had originally been built to protect buildings from moisture and mould by draining the city; stormwater and household wastewater, however, was conveyed in gutters. Consequently, in parallel with the development of water mains in the second half of the nineteenth century, new sewers were constructed. These were built to convey effluents as well as stormwater and drainage directly to the closest body of water. This exchanged the original acute health problem, outbreaks of cholera, for new ones: odour problems, health risks and eutrophication of receiving waters.

To come to grips with the new problems, sewage treatment plants were constructed. The first ones, using basic mechanical treatment only, were introduced in the 1930s. Wastewater was collected and conducted to the treatment plants by means of interceptors constructed in the existing sewer systems. The system carried wastewater, stormwater and drainage in one pipe. This so-called combined system was used in most places until the mid 1950s when separated systems, carrying wastewater and stormwater in separate pipes, became the preferred option for new developments. The separated system conducted wastewater to the wastewater treatment plant and stormwater directly to the receiving waters. This practice diminished the amount of wastewater overflow as a consequence of heavy rains, and stormwater was at that time considered clean enough not to require any treatment prior to discharge. Another novelty in the 1950s was biological treatment in wastewater treatment plants. The 1960s and 1970s was a period of intensive development and construction of wastewater treatment plants, including the introduction of chemical treatment by means of precipitation in the 1970s. This was followed by nitrogen reduction for all major coastal plants in the 1990s (VAV 2000; Johansson 1997). Discharges to aquatic ecosystems from urban areas decreased distinctly in response to these major steps in the development of wastewater systems. In the early 1960s the discharge of organic matter started to decrease sharply as a result of the extensive construction of plants with biological treatment. A few years later a similar decline could be seen in discharges of phosphorus, resulting from the introduction of chemical treatment. Not as sharp, but nonetheless obvious, was the decrease in discharges of nitrogen thanks to the introduction of nitrogen reduction in the 1990s (VAV 2000).

Over just 150 years urban water systems developed from simple drainage systems to advanced and effective systems that protect both human health and aquatic ecosystems. Partly connected to this development, the concurrent urbanisation entailed interrupted nutrient cycles. The three most important plant nutrients, nitrogen, phosphorus and potassium, can all be found in human waste, and rural populations once used both human and animal waste as fertiliser. Before industrialisation, access to nutrients was one of the most important limiting factors of agricultural yield. Urbanisation, however, increased the distance between "producers" of human waste and agricultural land where it could be used. City planners considered this problem in the late nineteenth century, and maps have been found of planned sewage systems that show pipes discharging in the vicinity of agricultural land. These ideas were abandoned in the early twentieth century, when it was recognised that the direct use of wastewater on arable land without hygienisation would entail great risks of spreading disease (Johansson 1997).

In today's urban water systems much of the nutrients in wastewater, about 95 % of the phosphorus and 20 % of the nitrogen, are trapped in sewage sludge (Johansson 1997). Wastewater treatment plants in Sweden generate about 230 000 metric tonnes of sewage sludge (measured as dry matter) yearly and large amounts of this sludge have been used as fertiliser on farmland. The advantages and disadvantages of the practice have been debated since the late 1960s (see Bengtsson 2002 for details).

In 1994 an agreement was made between the Swedish Environmental Protection Agency (NVV), the Federation of Swedish Farmers (LRF) and the Swedish Water and Wastewater Association (VAV) to promote the increased use of sewage sludge in agriculture. The agreement included limits and guideline values for heavy metals and a number of organic substances (NVV et al. 1995). However, in 1999 the LRF advised their members not to spread sewage sludge on agricultural land as traces of brominated flame-retardants were found in sewage sludge. As a result, the use of sewage sludge on arable land dropped from 25–30% of the total amount generated yearly in the late 1990s, to just over 10% in 2001 (Johansson 2002).

The major alternatives to use in agriculture are incineration and landfill. The latter will be prohibited starting 2005, while the former is comparatively expensive and not in agreement with the aim of increased nutrient recycling set forth in the Swedish Environmental Objectives. According to these, phosphorus should be recycled between urban and rural areas without risking the health of people or the environment (Government bill 2000/01:130). This is part of an overarching strategy for resource-efficient cycles free from hazardous substances. To solve the dilemma of whether to prioritise nutrient recycling or avoiding the risk of contaminating arable land with hazardous substances, technologies have been developed for recovering nutrients from wastewater and sewage sludge. I will return to these in the section on techno-economic aspects of sustainability (page).

Present

As of the year 2000, the public waterworks in Swedish urban water systems accounted for about 30% of total water withdrawal in Sweden, which amounted to 3.2 billion m^3 that year. *Private* water withdrawal accounted for the other 70%. Industrial use (excluding seawater used as cooling water in nuclear energy plants) accounted for 67% of the total water withdrawal, which explains the large amount of water withdrawal for private supply, households for 19% and agriculture for 4% (Statistics Sweden 2003).

In 2000, 7.7 million people, close to 90% of the Swedish population, depended on urban water systems for their drinking water supply and sanitation. Of the slightly more than 2000 public waterworks in Sweden, not quite 200 use surface water to produce drinking water. These waterworks are predominantly large and account for 50% of the total volume of drinking water produced in Sweden. Just over 1700 waterworks produce drinking water from groundwater, accounting for 25% of the drinking water production. The remaining 25% is produced by about 200 waterworks that use artificial groundwater, i.e. surface water purified through artificial infiltration (Svenskt Vatten 2004).

Production of drinking water is typically carried out in a series of steps including screening, flocculation, sedimentation, rapid and slow sand filters, storage and disinfection (see Figure 6). Disinfection is most often carried out by means of chlorination, but UV radiation or ozone may also be used.

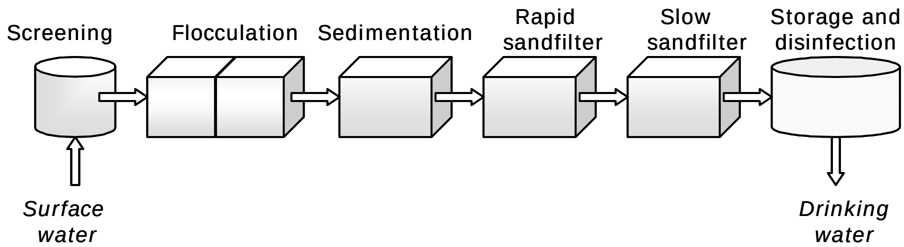

Figure 6. *Typical waterworks for producing drinking water from surface water (adapted from VAV, 2000)*

There are about 2000 public wastewater treatment plants in Sweden. Plants with biological and chemical treatment plus nitrogen removal serve 36% of the connected population. Plants with biological and chemical treatment serve 58%, and plants with only biological or chemical treatment serve the remainder (see Figure 7).

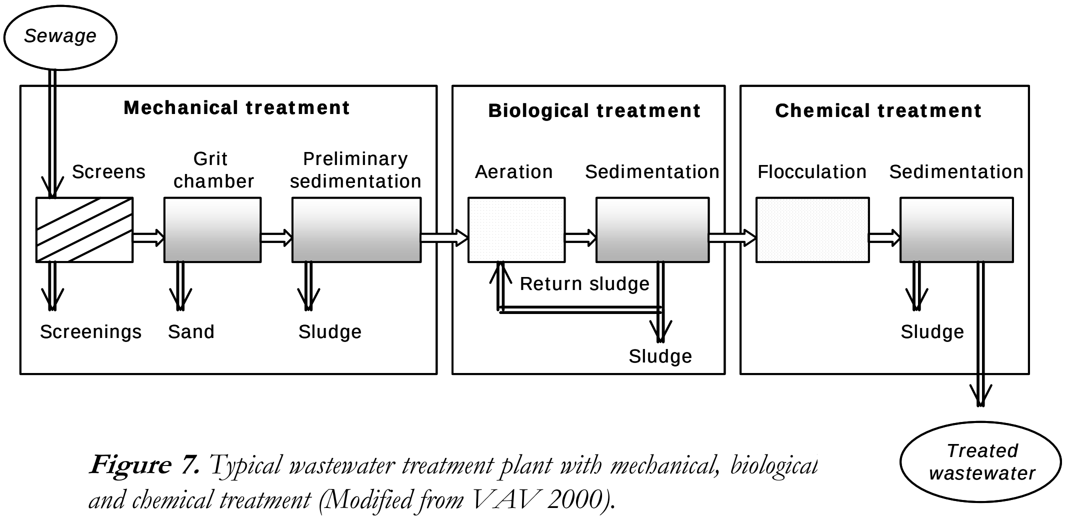

Figure 7. *Typical wastewater treatment plant with mechanical, biological and chemical treatment (Modified from VAV 2000).*

The water infrastructure is an important aspect of urban water systems, although it is rarely seen and hence easily forgotten. There is a total of 67 000 km of water mains and 92 000 km of sewers in Sweden, both figures exclusive of private house connections. Of the pipes comprising the water mains, 55% are made of cast iron, 19% of PVC, 14% of polyethylene and the rest of other materials. Water pipes in private houses are most often made of copper. Of the pipes conducting wastewater and stormwater, 80% are made of concrete, 13% of PVC, 3% of polyethylene and the rest of other materials (VAV 2000).

Aim of sustainable development: human well-being

A problem with the framework of sustainable development that I have chosen for this thesis is that its aim, the well-being of people, is extremely subjective. On the other hand, so are freedom, security, tolerance, beauty and many other concepts that we use to describe important aspects of life. We know intuitively whether these qualities are present or not, even if they cannot be measured, and even if perceptions of these qualities vary from one person to another. The aim of sustainable development must then be to give to as many people as possible a sense of well-being, whatever that may be. Although it may sound as if this excludes all other species on earth from the aim of sustainable development, such is not the intention. However, no matter how large an intrinsic value we assign other living species, they are not able to speak for themselves. Their well-being will be the aim of sustainable development only if there are enough people on earth who consider their well-being important, whether on utilitarian or deontological grounds. Sustainable development remains a human concept and a human challenge, hence the formulation of the aim.

In this section I will discuss some aspects of urban water systems that I, subjectively, consider important and part of the social dimension of sustainable development, i.e. affecting the well-being of people.

Other aspects of sustainable development are social in nature, but can hardly be considered ends in themselves; these are institutional aspects, such as laws and regulations. In some frameworks for sustainable development the institutional aspects form a fourth dimension beside environment, economy and society. One such framework is the "Prism of Sustainability" developed at the Wuppertal Institute, where the institutional dimension is defined as "human interactions and the rules by which they are guided, i.e. to the institutions of society" (Valentin and Spangenberg 2000). In the framework of this thesis, however, institutional aspects will be regarded as a means of sustainable development (page 21).

Access to drinking water and sanitation

Access to safe drinking water and functioning sanitation are basic human needs. Though there are people in Sweden today who do not get these needs met, the cause is most likely social maladjustment, not some physical aspect of the urban water system. Most of the population enjoy the comforts of hot and cold running water, water closets and drainage, probably without paying them much attention in daily life – these are the kinds of things that we tend to notice only when they do not function properly. Consequently, in the development of Swedish urban water systems towards increased sustainability, the aim would be to maintain the present level of service to the population, even when the systems have to be changed to include greater consideration for the well-being of people in other parts of the world, or to adjust to the limits set by the environment.

Health

The most obvious health aspect connected to urban water systems, – drinking water delivery as well as sanitation included – is whether they exist or not. In Sweden they exist and normally function well. A fundamental and health-related aspect of a functioning water system is that of distributing safe drinking water. With few exceptions this requires disinfection, and, as described earlier, in Sweden this is most often achieved by chlorination. Hence, chlorine compounds are added to secure health, but there is evidence that chlorine, especially in combination with high organic content in the water, poses a health risk due to the formation of carcinogenic compounds (Johansson 1997). This is not a big problem in Sweden as we have a comparatively cold climate and good quality raw water, both circumstances that contribute to a reduced need for chlorination. Still, the example illustrates the complexity of sustainable development: one activity, chlorination, with one purpose, health protection, can give rise to a conflict. Newer disinfection methods, possibly more aligned with the demands of drinking water safety, and consequently more in accord with sustainable development, are being developed (see page 24).

The bacteriological status of receiving waters is also an important health aspect, especially during the warm season when people go swimming. Untreated wastewater is occasionally discharged from wastewater systems, either as a consequence of failure in the wastewater treatment plant, or due to combined sewer overflows caused by heavy rains. Whatever the reason, untreated wastewater increases the amounts of nutrients, organic matter and contaminants, including potentially harmful micro-organisms, in receiving waters. Normally the public can be warned in time on these occasions. Hence, this is rarely a health problem, but rather an inconvenience – "the beach is closed".

There are also health aspects to be considered when discussing the fate of sewage sludge, as it contains chemical as well as biological contaminants. Still, in the case study, health was removed from the criteria used to assess the different sludge-handling options. This was done not because health issues were considered unimportant *per se*, but because all the options in question were regarded as safe in that aspect. As is often the case, health risks and environmental risks coincide. In the case of the sludge-handling options discussed here, the fate of contaminants in sewage sludge was assigned to the environmental aspect, and that is also how it will be handled in this chapter, i.e. under the section on environmental aspects.

The growing problem of pesticides in ground water can also be regarded as a risk to human health as well as to the environment. In this case, however, the source of the impact lies outside the water system, in the use of pesticides in agriculture, and therefore only the health aspects will be discussed here. At present, pesticides have been found primarily in private wells in Sweden, but the problem is spreading and may eventually affect municipal water sources as well. This shows clearly how dependant the sustainability of water systems is on the condition of adjacent systems, in this case agriculture.

Working environment

The working environment is an important contributor to well-being. This was confirmed in the case study where the working environment was ranked the fourth most important criteria in assessing various handling options, more important than, for example, the use of natural resources or social acceptance. Also worth mentioning is that SWC was not only concerned with the working environment of its own employees, but of everybody in the sludge handling and wastewater treatment chains.

Social acceptance

Social acceptance refers in this context to the opinions of various stakeholders in society on activities within the urban water systems. This may include the opinions of users on a new technology, but also the opinions of people in general and of representatives of certain sectors, such as the food industry, on the use of, for example, nutrients from wastewater. This is a large and diffuse matter, but basically it comes down to a call for stakeholder engagement in sustainable development. Any action taken needs to be entrenched among and accepted by all stakeholders, or it will not be sustainable. This is simple in theory, but more complicated in practice. An example of the importance of social acceptance is the 1999 recommendation of the Federation of Swedish Farmers that its members not spread sewage sludge on agricultural land. This was caused by the widespread alarm regarding the presence of brominated flame-retardants in sludge that attracted much attention, and the result was an immediate drop in the use of sewage sludge in agriculture.

The well-being of "others"

So far this section has only been concerned with the well-being of the Swedish population. Obviously Swedish urban water systems mainly affect Swedish people, but there are international connections too. I will discuss one such connection here, because it is central to the ongoing debate on recycling nutrients from wastewater and was discussed in the case study. The discussion of whether to prioritise the recycling of phosphorus from wastewater or not is primarily a resource issue, as extractable phosphorus is a finite resource (see next section). Thus, there are equity and futurity aspects to this question. The supply of extractable phosphorus is limited. A large proportion of these resources have been used to fertilise arable land in developed countries (Steen 1998; Smil 2000). We could potentially contribute to the increased well-being of people in developing countries now, and of future generations, by leaving extractable phosphorus resources for use on their arable land.

Foundation for sustainable development: functioning ecosystems

Environmental sustainability is about ensuring that humanity lives within the limits of the earth's carrying capacity. The environment is the foundation of development, and needs to be maintained in order to supply mankind with resources as well as with ecosystem services, such as waste assimilation, protection from ultraviolet rays and the biogeochemical cycling of, for example, water, nitrogen and carbon. This foundation is currently degrading as a consequence of resource depletion and pollution. Regarding the environment as the foundation of development has the advantage of making the importance of environmental issues obvious: if the foundation is allowed to crumble, the superstructure will collapse. There are, however, other aspects of the environment and nature that should be mentioned – beauty and recreation. These may not be crucial to our survival, but are among the aspects of life that many people find essential to their well-being. Thus the environment is not only the foundation and limiting factor of development, but also represents values that belong to the upper half of my sustainability framework – i.e. to the social realm of sustainable development – as they create human well-being. Yet another way of looking at nature is to claim, on grounds of deontological ethics, that it has the right to exist because it has a value in its own, irrespective of human attitudes towards it. This may be so, but it still takes a human to express the notion, and hence I would allocate also that attitude to the social domain.

The following sections will concentrate on the role of the environment as the foundation for sustainable development. Life cycle assessment (LCA) as a tool for modelling the environmental aspect of sustainability will be described, followed by a summary of what the most important environmental impacts of urban water systems are according to a number of LCA studies.

LCA

Life cycle assessment (LCA) is a structured method used to collect and process environmentally relevant information related to a system function. A product or process is followed through its life cycle, and all energy and material flows and their links to potential environmental impacts are modelled. This means taking into consideration the extraction and processing of raw materials, manufacturing of chemicals, operations, distribution/transportation, recycling and final disposal. For a comprehensive description of the method, see Baumann and Tillman (In press) and the internationally agreed standards on LCA developed by the International Organisation for Standardisation (ISO) (ISO 14040 1997; ISO 14041 1998; ISO 14042 2000; ISO 14043 2000). Among the advantages of LCA is that the life cycle perspective is systemic as a model.

It covers the whole life cycle of the process or product under study, and can be extended to cover all or part of adjacent systems if needed. It is also systematic as a *process*, and the methods of model construction, data gathering and data processing can all be made clear, transparent and standardised. The various potential environmental effect categories, as well as specific assumptions and simplifications, can be made explicit, facilitating rational debate and decision-making. All these traits make LCA useful as a basis for constructing resource and environment related SDIs, as recommended by Lundin and Morrison (2002) and used in the case study in Paper 1.

Environmental impacts of wastewater systems

A number of studies have used LCA to estimate the environmental loads of wastewater systems (for a review see Lundin 2003). It is hard to draw any general conclusions from these studies, as the design and assumptions differ between them. There are, however, some similarities: most of these studies show that energy and emissions of nutrients and heavy metals are important parameters. This is consistent with the results of the LCA performed in our case study, and also confirms that the ongoing Swedish debate on whether or not to prioritise nutrient recycling is relevant. The results of the LCA studies of wastewater systems are not that surprising. Wastewater systems handle nutrients and wastewater is contaminated with heavy metals, this much is known. Energy is central in most LCA studies, likely because so many important environmental problems are associated with the energy system, although not necessarily caused primarily by it: resource depletion (fossil fuels), acidification, eutrophication, ground-level ozone, stratospheric ozone depletion and the greenhouse effect. Surprising or not, the results of LCA studies scientifically reveal what environmental impacts need to be reduced in order to increase the sustainability of urban wastewater systems.

Eutrophication

The raison d'être of wastewater treatment plants is the protection of human health and the environment. As described in the first section of chapter 2, discharges to aquatic ecosystems from urban areas have decreased since the 1960s thanks to improved treatment plants. In spite of this, the largest source of anthropogenic phosphorus in Sweden in 1995 was still sewage water. Municipal and private effluents were at that time responsible for about half of the phosphorus emissions to water, while agriculture and industry each contributed about one quarter (SOU 2000:52 2000). Phosphorus is the main concern in eutrophication of freshwater ecosystems, while in the marine environment, nitrogen is believed to be equally or more important. In 1995, almost half of all anthropogenic nitrogen emissions to the sea originated from agriculture, and about one third from sewage water (SOU 2000:52 2000).

Recycling of nutrients

Swedish discussion of nutrient recycling mainly focuses on phosphorus. In the case study in Paper 1, an extra study of phosphorus was performed as a complement to the LCA. This study revealed that apart from extractable phosphorus being a finite resource, extraction of virgin phosphorus is connected to large environmental impacts, mainly due to the large amounts of raw material needed and of waste material produced in the process. The production of one kilo of phosphorus requires almost 20 kilos of phosphate rock, and generates large amounts of waste rock and gypsum that are most often contaminated with heavy metals, especially cadmium, and radio nuclides (Davis and Höglund 1999; Smil 2000). Also potassium and sulphur are mentioned with increasing frequency in the debate on nutrient recycling (NVV 2002a; Fredriksson and Karlsson 2002; Palm et al. 2002; Jönsson 2003). Both elements are important plant nutrient and are, like phosphorus, regarded as finite resources. They were not, however, discussed in the case study in Paper 1; the reason for this may be the explicit goal of phosphorus recycling expressed in the Swedish Environmental Objectives (Government bill 2000/01:130).

Nitrogen is not a finite resource. Atmospheric nitrogen (N_2) can be fixed by biological or industrial processes and used as fertiliser. Industrial nitrogen fixation is, however, an energy-intensive process, and hence increased recycling of nitrogen in wastewater as a fertiliser is desirable to save energy. The process of nitrogen fixation implies a transformation of inert nitrogen (N_2) to reactive nitrogen species such as NO^{2-}, NO^{3-} and NH^{4+}. These reactive nitrogen species cause eutrophication as well as acidification, and some are also greenhouse gases. The dramatically increasing pool of reactive nitrogen species is hence an important environmental problem. The introduction of nitrogen reduction in the wastewater treatment plants is a way to counteract this increase.

Heavy metals and persistent organic compounds

LCA studies have identified the heavy metal contamination of soil as a potentially important environmental impact. This problem is primarily linked to the use of sewage sludge on arable land and in forestry. As well, persistent organic compounds such as dioxins, brominated flame-retardants and DDT are of concern. Chemicals circulating in society sooner or later turn up in the wastewater systems. From a sustainability perspective, this is not primarily a problem of the water industry, but one belonging to society as a whole. This is also well recognised. One of the Swedish Environmental Objectives is the eventual achievement of a *non-toxic environment*. In the meantime, which will most likely be quite long, the water industry needs to handle contaminants in wastewater as safely as possible with respect to environmental and human health.

Environmental impacts of drinking water production

There have been fewer LCA studies of water supply systems than of wastewater systems. A recent South African study (Friedrich 2002) traces all the significant environmental impacts of the production of potable water to the generation of electricity. A Swiss study from 1999 (Crettaz et al. 1999) likewise identifies energy consumption and related emissions to air and water as the most important environmental aspects of drinking water production. A Swedish study, also from 1999 (Wallén 1999), reaches a similar conclusion, but in this case the production of chemicals, especially burnt lime and aluminium sulphate, is identified as the major source of emissions to air. As in the case of the LCA studies performed on wastewater systems, these studies vary somewhat with regard to system boundaries and other methodological aspects, so the results are not comparable. This is not a problem in this case, as all the results point in the same direction. The identification of energy consumption as the dominant source of environmental impacts appears logical, considering that water supply systems handle neither nutrients nor heavy metals, the other two important parameters when considering wastewater systems. Emissions to air are related to energy consumption and also to chemical production, and both these aspects are linked to water use. Smaller volumes require less pumping which saves energy. Smaller volumes also decrease the use of chemicals in water treatment. There is however a limit to how small the water distribution can be. The system is dimensioned for the present use of water and requires a certain circulation of water in order to keep the water quality intact.

Means of sustainable development: techno-economic and institutional aspects

The preceding two sections looked at Swedish urban water systems from the social and the environmental perspectives of sustainable development. In the commonly used division of sustainable development into three dimensions, the third dimension is that of economy. In the "prism of sustainability" the third and fourth dimensions are the economic and institutional ones, technology not being mentioned (Valentin and Spangenberg 2000). In their suggested definitions of these dimensions, however, Goodland (1995) as well as Valentin and Spangenberg (2000) use the same economic language as does Daly: they all refer to various kinds of capital. In the Daly triangle, economy and technology are integrated at the second level of the pyramid as built capital. Goodland, in defining the economic dimension, refers to human-made capital, Valentin and Spangenberg to man-made capital. These words are all synonymous, and hence

Meadows' definition of built capital (1998) seems appropriate for all: "Built capital is the physical stock of productive capacity of an economy. It is steel mills, buildings, chainsaws…the most solid measures of economic development". Against this background, economic sustainability should be a matter of keeping the productive capacity of built capital at a level where it contributes to the fulfilment of human needs, without any detrimental impact on the environment – natural capital to use economic language – upon which it depends.

I have chosen to regard technology and economy as means of sustainable development, as neither is an end in itself. Nevertheless, just as with the environmental dimension, both technology and economy have social aspects. Some kinds of technology serve as hobbies that make life worth living for some people, and there is an old and established connection between economy and social status.

Under "means of sustainable development" I have also included laws and regulations, as these are useful and probably necessary tools for achieving sustainable development. For example, several investigations have identified the important influence of regulations on the environmental impacts of industry (Ammenberg 2004).

Next, in this section, I will briefly discuss laws and regulations that are relevant to the Swedish water industry from a sustainability perspective. I will then return to techno-economic aspects to discuss the current problems as well as possible sustainability strategies of urban water systems.

The institutional perspective

During the 1970s complying with laws and regulations guided the environmental work of most organisations and companies (see Paper 2). Since then a proactive approach to sustainability issues has become more prevalent, and voluntary initiatives, such as the Global Reporting Initiative and standardised environmental management systems (EMS), are now widespread and established (Paper 2 and Ammenberg 2004). Laws and regulations are, nevertheless, still important means of control.

The basic features of the Swedish water industry, such as effluents from wastewater treatment plants and drinking water quality, are regulated by legislation expressed in the Environmental Code, the Health Act, the Public Water and Wastewater Plant Act and the Food Act (VAV 2000). In addition to these, the Swedish water industry is also controlled by a number of EU directives (Hakeman and Karlsson 2003). Of the institutional aspects that have been discussed heatedly over the last few years, two are connected to EU legislation: the demand for nitrogen reduction (directive 91/271/EEG), and the implementation of the EU Water Framework Directive (2000/60/EG). The third issue that has been much debated and investigated is the Swedish Environmental Objective concerning phosphorus recycling.

Reduction of nitrogen is important from a sustainability perspective (see page 20). It is, however, a very costly way of coming to grips with the increasing pool of reactive nitrogen species, especially in northern Sweden where conditions do not favour the biological processes used in nitrogen reduction.

The EU Water Framework Directive aims at improving and protecting aquatic ecosystems and promoting the sustainable use of water resources. The problems connected to the implementation of the Water Framework Directive in Sweden are partly administrative. The Directive prescribes that old administrative boundaries be exchanged for boundaries based on water catchments, and that these new administrative units be under the control of new water authorities. The Swedish government has recently proposed that the country be divided into five water districts, with five county administrative boards serving as the water authorities for these districts (Miljödepartementet 2004).

The Committee on Environmental Objectives originally proposed that 75% of the phosphorus from wastewater should be returned to arable or other productive land without jeopardising human health or the environment by 2010. As already discussed, the contamination of sewage sludge has made this an unrealistic objective under present circumstances. In 2001 the Swedish Environmental Protection Agency was commissioned to examine, in consultation with stakeholders, the health and environmental protection requirements for sewage sludge and its use, as well as for the restoration of phosphorus to arable land. The assignment resulted in a comprehensive action plan (NVV 2002a) which suggests a less ambitious but more realistic interim target for phosphorus recycling: "By 2015, 60% of the phosphorus in wastewater shall be restored to productive soil, of which half should be returned to arable land". The long-term objective proposed concerns not only phosphorus: "Nutrients in wastewater are returned to the soil, where they are needed and without jeopardising health and the environment".

The techno-economic perspective

Urban water systems, including treatment plants, water reservoirs, pipes and pumps, constitute techno-economic systems, or built capital, referring to Meadows' definition (1998) as presented in the introduction to this section.

They represent a certain economic value and require continuous investment to keep their capacity intact. For example, Sweden's entire network of mains and pipes has an estimated replacement value of SEK 350 billion (ca. 37 billion Euros) (Svenskt Vatten 2003). From a sustainability perspective, the main task of technology and economy is, very simply, to keep the system functional, preferably for a long time. This is a matter of effectiveness – "doing the right thing" – and of efficiency with regard to natural resource use. Though Swedish urban water systems are effective in the sense that they do supply drinking water and sanitation, their efficiency, especially in terms of nutrient recycling, could be improved. Furthermore, they are durable. Consequently they have a considerable capacity to keep "doing the right thing" in an inefficient way for a long time. This is a so-called "lock-in" effect: because of the large economic value the infrastructure represents, it would be extremely costly to replace it all at once, and it is technically difficult to replace it a little at a time. This is one of the main challenges in making urban water systems meet the demands of sustainable development.

Economic reality

One of the inputs into the assessment of sludge handling options in the case study was an economic assessment of the options in question, performed within the same system boundaries as the LCA. Data from this assessment supported the economy criterion used beside eight other criteria in ranking these options by use of multi-criteria analysis. The economy criterion was clearly considered the most important, i.e. the economic performance of an option was valued higher than its environmental performance. I will get back to the plausible reason and likely consequences of this in the concluding chapters of the thesis.

Sustainability strategies: technical means and opportunities

Researchers and practitioners are currently working in many different areas relating to urban water systems in order to find solutions that would contribute to the sustainable development of these systems. I will summarise the most important trends in drinking water and stormwater management, and discuss wastewater treatment in more detail, as this was the focus of Paper 1.

Drinking water

In the field of drinking water, there is much focus on finding alternatives to disinfection by use of chlorine compounds. Ultraviolet radiation and ozone disinfection are being tested in Sweden, and membrane techniques could also potentially be used (Winnfors 2003). The quality of drinking water is not only a matter of water treatment, but of distribution, and thus of circulation time (as mentioned in the section "Environmental impacts of drinking water production", page 21) and of what material to use in water pipes. Copper in pipes (mainly in pipes beyond the point of private house connections) leads to increased copper concentrations in sewage sludge, which is an argument for replacing copper with, for example, stainless steel (Johansson 1997). Protection of groundwater is another important aspect of sustainable urban water systems.

Stormwater

When the separated system conducting wastewater and stormwater in separate sewers was introduced in the 1950s it was regarded as an environmental improvement. At the time, stormwater was generally regarded as clean enough to be discharged into receiving waters without any treatment; by taking care of stormwater separately, less untreated wastewater entered receiving waters as a consequence of combined sewers overflow. Stormwater probably was considerably cleaner in the 1950s than it is today. Much of the contaminants in urban run-off originate from traffic, which has increased dramatically since the 1950s, but also from the facades of buildings (NVV 2002b).

For sustainable urban water systems, "stormwater management", as opposed to "stormwater disposal", is increasingly recommended. This includes the application of "source control", where stormwater runoff is stored, treated or re-used locally, close to the point of generation (Butler and Davies 2000). Technologies recommended are infiltration and local collection of stormwater as means of avoiding contamination as much as possible. These technologies can be combined with retention in ponds and wetlands where contaminants are deposited before the water is discharged. There are still many questions to be answered with regard to source control; such as how long a surface can be used for infiltration before becoming "saturated" with contaminants, and what the long-term effects are of using ponds and wetlands for the retention of contaminated stormwater. Whatever the answers to these questions are, they concern the effects of a problem, not its root cause. From a sustainable development perspective the question ought to be, "How do we avoid contaminating stormwater?" rather than "How do we take care of contaminated stormwater?" The former question is, however, not the responsibility of the water industry.

Wastewater

There are two main lines of research and development and suggested solutions to the problem of wastewater. One has its point of departure in the existing infrastructure and looks at how to use nutrients and other valuable resources in the present mixture of waste streams. The other focuses on separating the waste streams in order to make better use of the system from a resource perspective. The situation is reminiscent of that of waste handling in Sweden in the 1980s. In the late 1970s, advanced facilities for separation of metals, plastics, glass etc from unsorted waste for subsequent recycling, were developed and operated for a number of years. Today these facilities have been replaced by widespread source separation of waste; it proved just too difficult to recycle materials from mixed waste (Berg 1993). An important difference between the waste and wastewater systems is, however, that source separation of waste has been possible using existing infrastructure. Source separation of wastewater requires changes in existing infrastructure in order to enable conduction of separate wastewater streams for collection or treatment. Still, urine separation, often in combination with local treatment of "grey water" from baths, showers and washing, is being tested in small areas, and has also been the subject of a number of LCA studies. Generally, wastewater options based on separating wastewater fractions have a lower potential environmental impact in these studies (Tillman et al. 1998; Lundin et al. 2000; Sonesson et al. 2000).

Technical options for recycling phosphorus and other resources using existing infrastructure include technologies for recycling phosphorus either from wastewater by use of precipitation, or from sewage sludge by use of hydrolysis. In the case study in Paper 1, two technologies for separating phosphorus from sewage sludge, Bio-Con and Cambi-CREPRO, were assessed. These options also enable energy recovery and the recycling of certain chemicals (see Paper 1). Recovery of phosphorus directly from wastewater by precipitation was not considered viable due to low efficiency in the Swedish climate.

Case study experiences on technical options for sludge treatment

The other two options included in the case study apart from Bio-Con and Cambi-CREPRO were the use of sewage sludge in agriculture and co-incineration with household waste. The advantage of the new technologies was a lower potential environmental impact as assessed in the LCA; their disadvantages were high cost and uncertainties regarding reliability and the working environment. The preferred option in the case study, sustainable development considered, turned out to be the use of sludge in agriculture. This preference furthermore seems to be in agreement with the dominant opinion in the Swedish water sector (Bergström 2003).

Summary

Technologies are at hand to develop urban water systems in the direction of increased sustainability. Except for the technologies for drinking water treatment, they are all solutions to problems that do not originate in the urban water systems themselves, but in society at large. Many of these solutions are costly and require more or less extensive modifications of existing urban water infrastructure.

3. The role of indicators in sustainable development of urban water systems

The preceding chapter described and discussed the performance of Swedish urban water systems from a sustainable development perspective in terms of what aspects need to be improved, why this is needed and how this can be achieved. As stated in the introduction, SDIs are frequently and generally recommended as a tool to promote development in the direction of sustainability. The aim of this chapter is to examine how SDIs are used in companies in order to explore whether and how such indicators contribute to sustainable development. The first section examines the findings of the literature survey of companies in general (Paper 2), while the second examines the findings of the case study with SWC (Paper 1).

Different applications for indicators within companies

In companies, development towards sustainability is achieved through management, especially through the managerial functions of planning and control (Figure 8). The other two functions, organising and leading, are most probably very important to the sustainable development of companies, but they are not frequently discussed in the indicator context. According to Robbins and Coulter (2002), a standard management textbook, the planning process includes the formulation of objectives, goals and strategies. The control process, in turn, is a three-step process including measuring actual performance, comparing actual performance to a standard, and taking managerial action to correct deviations or inadequate standards.

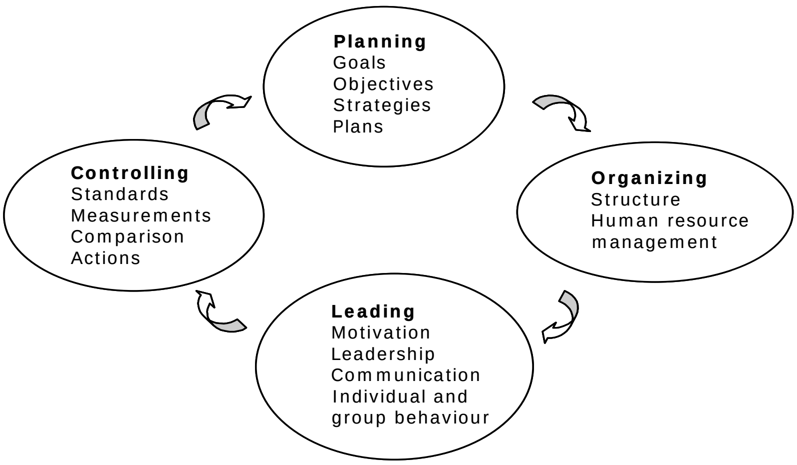

Figure 8. *The control-planning loop in management (from Robbins and Coulter, 2002)*

Related to the managerial functions of planning and control is the application of SDIs in indicator target formulation, accounting, reporting and benchmarking (Figure 9). It could be argued that the formulation of indicator targets is not actually an area where SDIs can be applied, but this is not so. In setting targets it is necessary to consider what the needs are and what can realistically be achieved in terms of sustainable development. Doing that is, in my view, a way of applying an indicator. Furthermore, with targets follow the need to measure performance in order to assess to what extent the targets are being met: this is how the planning function links to the control function (measurement). At least that is how it should be according to management theory; in practice, less attention seems to have been paid to the use of SDIs in planning than to SDIs in the control function. The literature survey in Paper 2 showed that there is a vast amount of literature on reporting and accounting, comparatively little on benchmarking, and even less on strategic planning towards sustainability.

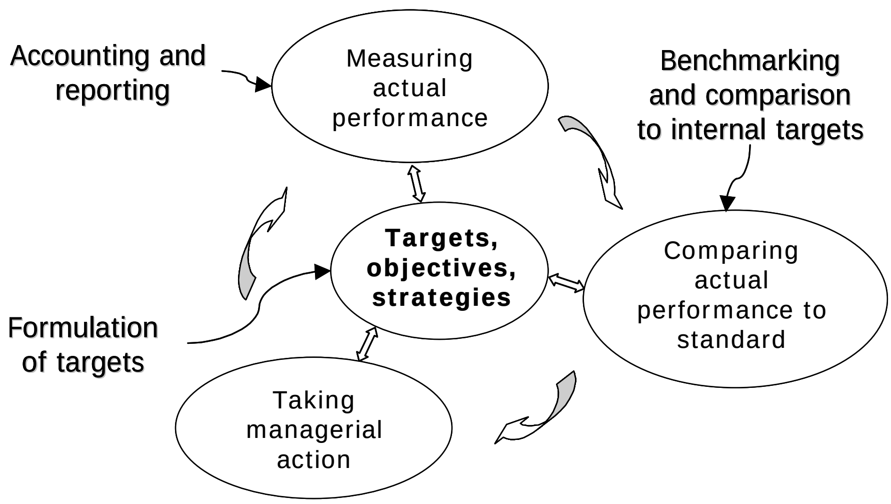

***Figure 9**. Common SDI applications (shaded text) in the planning and control functions of management (adapted from Robbins and Coulter, 2002)*

The following paragraphs briefly describe the various SDI applications and their use in companies today will be. A more thorough description is found in Paper 2.

Control

The first step in the control process (Figure 8) is that of measuring performance. This includes accounting and reporting, two linked areas that have attracted considerable attention with regard to achieving corporate sustainability.

Accounting

Accounting is basically a matter of bookkeeping. Conventional accounting dates back to the sixteenth century and involves the systematic development and analysis of information about the economic affairs of an organisation. Environmental impacts were not dealt with, but to the extent they were recognised, written off as "externalities". Today the field of accounting is generally regarded as divided into two disciplines: management accounting and financial accounting. Management accounting is the basis for internal management decisions, while financial accounting is directed towards the external stakeholders of firms with respect to financial impacts (Schaltegger and Burritt 2000). With increasing environmental awareness, the need for including "externalities" in the accounting systems is being gradually recognised.

There are two major ways of incorporating environmental data into accounting systems. The approach that appeared first was that of valuing the environment in monetary terms so as to include environmental impacts in the accounting system, as described by, for example, Atkinson (2000) and Bailey (1999). This has been termed "environmentally differentiated information" (Schaltegger and Burritt 2000). The other approach, now increasingly recommended, is that of introducing non-financial terms (e.g. tonnes of CO_2) in the accounting system as a complement to "environmentally differentiated information" (Gao 1995; Birkin 1996; Evans 1996; Rikhardsson 1998; Richards and Gladwin 1999; Birkin 2000; Schaltegger and Burritt 2000; Gray and Bebbington 2001; Edwards et al. 2002).

The SDIs associated with accounting are primarily those of eco-efficiency. These indicators combine economic figures (in the numerator) with environmental figures (in the denominator), forming a ratio for measuring economic-ecological efficiency – "eco-efficiency" (Schaltegger and Burritt 2000). This obviously omits the social dimension of sustainable development. According to Schaltegger and Burritt (2000) and Dyllick and Hockerts (2002), eco-efficiency is the guiding principle most frequently selected by firms in working towards sustainable development.

The advantage of environmental accounting is its connection to conventional accounting. Developing and extending an existing system is probably more appealing and practical than inventing a completely new system for handling information on sustainable development. According to Schaltegger and Burritt (2000), the emergence of environmental accounting has also been motivated by the poorly co-ordinated environmental data most companies currently possess; accounting may bring some order into this.

Reporting

Reporting is a way for companies to tell the world how and what they are doing. As with accounting, this activity formerly focused entirely on financial data, with shareholders being the principal target group. Today the number of companies that complement their financial reports with environmental or sustainability data is increasing rapidly.

In 1998, Ranganathan listed 47 different sustainability reporting initiatives (Ranganathan 1998), including the global reporting initiative (GRI) launched in 1997 by CERES – the Coalition for Responsible Economies. In 1999 the first GRI draft guidelines were issued (Bavaria 1999; Ranganathan and Willis 1999). GRI has since revised the draft guidelines twice, and they are now the most frequently used framework for sustainability reporting, being used by almost 400 organisations in 33 countries (GRI 2002; GRI 2004).

Several authors have commented on the potential of the GRI guidelines to help organisations improve their sustainability performance (Bavaria 1999; Hussey et al. 2001; Andrews 2002; Morhardt et al. 2002), but also warn against a gap between what large companies find appropriate to report and the recommendations in the guidelines, especially as pertains to economic and social aspects (Hussey et al. 2001; Morhardt et al. 2002). This may sound strange, considering that reporting was originally focused on financial data, but financial data does not necessarily equal economic sustainability data.

External reporting is a requirement within EMAS (the European Eco-management and Audit Scheme) but not within the ISO 14001 environmental management standard. However, according to Freimann and Walther (2001) also most ISO 14001 companies publish environmental or sustainability reports. Furthermore, the guidelines for environmental and sustainability reporting within the EMAS regulation are very weak (Freimann and Walther 2001; Ammenberg 2003). Freimann and Walther recommend that "the scientific community must define as exactly as possible figures and indicators that are appropriate to measure the phenomenon of corporate sustainability", if environmental and sustainability reports are to become a valid base for corporate sustainability evaluation.

Several authors have drawn attention to deficiencies in the practice of external environmental and sustainability reporting in companies today, whether these reports are based on the GRI guidelines or not. Among these deficiencies are lacks of economic data and insufficient accommodation of stakeholder needs (Azzone et al. 1996; Noci 2000) a lack of objectivity (Niskanen and Nieminen 2001), insufficient commitment to sustainability issues (O'Dwyer 2003), little information on projected future performance (Marshall and Brown 2003) and insufficient quality and credibility of reports (Edwards et al. 2002; Laufer 2003).

Comparing performance against standard

The next step in the control process is that of comparing actual performance to a standard, normally selected among available standards or formulated as a goal or target in the planning function of management. For sustainability issues there is as yet no external standard to adopt, and operational goals and targets are often missing. Consequently, comparison to a standard or to internal targets is most often impossible. Another kind of comparison is benchmarking: "the search for the best practices among other companies that lead to superior performance" (Robbins and Coulter 2002). The need to increase the possibility of benchmarking sustainability performance through standardising sustainability data is frequently expressed in the literature (Davis-Walling and Batterman 1997; Young and Welford 1998; Characklis and Richards 1999; Delfgaauw 2000; Veleva and Ellenbecker 2000; Freimann and Walther 2001; Johnston and Smith 2001; Kolk et al. 2001; Wehrmeyer et al. 2001; Tyteca et al. 2002).

SDIs for planning – future-oriented indicators

As mentioned earlier in this section, less work has been done in the planning function than in the control function of management. Development towards increased sustainability is not easy; it requires planning. Consequently, companies need to define clearly their sustainable development aims and to formulate future-oriented indicators. This has been argued by many authors, including Azzone et al. (1996), Fiksel et al. (1999), Hopkinson et al. (2000), Veleva and Ellenbecker (2000), Johnston and Smith (2001), Graedel and Allenby (2002), and Marshall and Brown (2003).

At present there seem to be three potential frameworks for future-oriented indicators, the balanced scorecard (BSC), the Global Reporting Initiative (GRI) and standardised environmental management systems (EMS).

The balanced scorecard

The BSC was developed in the early 1990s in response to the "short-termism" and past orientation of management accounting. The BSC is a framework that links performance measures in four different perspectives to business strategy. The four perspectives are the financial, innovation and learning, internal business and customer perspectives, and targets and indicators are formulated for each of these. The BSC "complements the financial measures with operational measures … that are the drivers of future financial performance" (Kaplan and Norton 1992).

Environmental and sustainability measures can be regarded as "drivers of future financial performance", and hence be integrated into the BSC. A way of doing this is to add a fifth perspective to the scorecard. Epstein and Wisner (2001) suggested "sustainability", Figge et al. (2002) "non-market" and Bieker and Waxenberger (2002) "society". Dias-Sardinha et al. (2002) enlarge the scope of the financial and customer perspectives to encompass sustainability and stakeholders, respectively. The important thing here is not what the different perspectives are called, but what targets are formulated and how far in the future "future financial performance" extends.

Global Reporting Initiative

The GRI guidelines include advice on planning for sustainability. The guidelines state that a GRI report should include a section on the vision and strategy of the company. This section should present a formulation of the main sustainability issues of the company, as well as objectives related to these issues. Hussey et al. (2001) and Veleva and Ellenbecker (2000), however, have identified a lack of direction and targets as a weakness of GRI reports from companies in the late 1990s. An explanation of this finding, and possibly also of the generally expressed "lack of targets and planning" found by many researchers, may be either that the strategy part of the GRI recommendations is not being followed (most companies only use part of the guidelines), or that "vision" and the like is so vaguely formulated as to have no real substance.

Environmental management systems

The formulation and follow up of targets is a central feature of EMS. Neither ISO 14001 nor EMAS give recommendations as to the level of these targets, except to state that existing legislation must be followed and that continuous improvement of environmental performance is required. Frequently used indicators in EMS are inverted eco-efficiency ratios (environmental figures in the numerator and economic figures in the denominator). These can signal improved environmental performance in spite of increased environmental impact. For example, emissions per item produced may decrease by half, but if the number of items produced simultaneously triples the total environmental impact will still have increased (Ammenberg 2004). This is problematic from a sustainable development point of view.

These were the main findings of Paper 2 on SDI applications by companies in general. The next section will look at the experiences from the case study with Stockholm Water described in Paper 1.

An example from the water industry

The company where the case study was performed, Stockholm Water Company, like many other water companies has a long tradition of using indicators in its operations. These indicators are used primarily for accounting, and some of them are also used for external reporting as they are included in the "Environmental accounts and annual report" published by the company (Frank et al. 2001). Other indicators are used for internal monitoring and for management by objectives; indicators in this latter group are related to targets to be accomplished by a specific year (Eriksson 2000). SWC also takes part in a regional benchmarking initiative, the "six-cities group", including the water authorities of Stockholm, Göteborg, Malmö, Køpenhamn, Oslo and Helsinki (Stockholm Water Company 2002; Lundin 2003). Many of the indicators mentioned in this paragraph carry information relevant to sustainable development, although no indicators termed "SDIs" existed at SWC before the case study (Paper 1).

The aim of the case study was to identify SDIs having special applicability to the choice of technical options for sludge handling, and with a general bearing on the development of the entire wastewater system. Thus, the case study had to cover two different SDI objectives: support of choice among technology options, and guidance of long-term development towards sustainability. Furthermore, these two different objectives referred to two different system levels: the technology options concerned the sludge handling system, while long-term development concerned the entire wastewater system (Palme and Lundin 2002).

The process of SDI identification was approached through the evaluation of four sludge handling alternatives in terms of their environmental, economic, technical and social performance. The sludge handling options were:

- Spreading of pasteurised sludge on agricultural land
- Co-incineration with household waste
- Separate incineration followed by phosphorus recovery by the Bio-Con process
- Fractionation by acid hydrolysis for recovery of phosphorus with the Cambi-KREPRO process.

The evaluation of these options was based on data obtained from a number of assessments performed in the case study: LCA (Pettersson 2001), economic assessment (Zetterlund 2001), risk assessment (mainly qualitative) and uncertainty assessment (purely qualitative). In addition, a literature study on the production and availability of phosphorus was performed to complement the LCA.

The results of the assessments were compiled and presented to the members of the SWC working group. These results were subsequently used as input in a multi-criteria analysis (MCA) that ranked the sludge handling options above with regard to their long-term demands on the system and their function as part of a sustainable society.

Based on the preferences expressed in the MCA, which included the valuation of different and often conflicting aspects of sustainability and the weighting of various criteria, SDIs were formulated. The choice of technical options as such was not considered of prime importance in constructing SDIs, but rather the arguments brought forward for making that choice – arguments also reflected in the weighting of various criteria. The resulting SDIs covered economic, environmental, technical and social aspects of the sustainable development of sludge handling systems. Where possible, the coverage of the indicators identified through evaluating the sludge handling options was extended to the entire wastewater system. The case study consequently resulted in two sets of SDIs. The study also included the formulation of SDI targets at both the sludge handling and overall wastewater system levels. This was a difficult part of the study that required many hours of communication in meetings and by mail and telephone. That targets were finally formulated for all SDIs was, possibly because of the challenge the task constituted, experienced as one of the strengths of the study, even if some of these targets were only formulated in terms of "as low as possible" and the like.

In addition to a list of SDIs and targets, the case study produced knowledge relating to the SDI identification process. This included knowledge of the advantages of co-operation between researchers and indicator users, of the contributions of the various assessments performed (most notably on the application of a life cycle perspective) and of the importance of a thorough problem definition. The problem definition in this case amounted to defining the purpose of the SDIs and to exploring the SWC working group's view of the meaning of sustainable development for the company. Defining the objectives of the SDI program, i.e. how the SDIs were to be used and for what purpose, proved to be a particular difficulty in this study, although this was only fully recognised after the fact. SWC wanted the case study to support the choice of technology for sludge handling and, at the same time, to be relevant for the development of SDIs for the management by objective of the entire wastewater system. The results of this double objective were one set of SDIs that covered the important sustainable development aspects of the sludge handling system, and another set that covered *some* of the sustainable development aspects relating to the wastewater system. The conclusions drawn from this are that a) SDIs need to be identified at the level of intended use and b) there is a need for purposefulness regarding indicator application.

4. Prerequisites for sustainable development of urban water systems

The preceding chapters show that Swedish urban water systems need to be further developed in the direction of increased sustainability, especially as concerns environmental sustainability. The problem is not so much technical, as there are technologies at hand, as it is one of cost and organisation: the water systems are extensive and intricately connected to society at large and hence take time to change. Furthermore, SDIs appear to be potentially useful tools in the sustainable development of urban water systems.

Facilitating conditions

Interestingly, a correlation between comparatively high environmental performance and the use of indicators appears to exist in the Swedish water sector. In comparing SWC's sustainability performance and commitment to sustainable development issues, to that of companies in general (as determined in the literature study – Paper 2), SWC was found to perform well above average. The same is probably true for most Swedish water companies, as they by definition work with health and environmental protection. This, in turn, has encouraged the use of indicators through the need to monitor processes and report to authorities. Furthermore, Swedish water companies operate according to the principle of prime cost, i.e. they are not allowed to make any profit. This has encouraged the use of indicators for benchmarking as an alternative to regular competition. Consequently, speaking of environmental and sustainability awareness as well as of accustomedness to the use of indicators in these areas, Swedish water companies appear to be comparatively well-developed. This ought to facilitate their further development towards sustainability.

Complicating aspects

Urban water systems may appear comparatively suited to sustainable development in many ways, but there are complicating factors. I believe these factors affect sustainable development at the level of individual companies or sectors in general, but I will discuss them primarily from the urban water system perspective.

Dependence on adjacent systems

As noted in the section on the environmental aspects of urban water systems, many of the problems that water systems must handle, such as contaminations in wastewater that complicates nutrient recovery, the increasing pool of reactive nitrogen species that necessitates nitrogen reduction and the increasing contamination of ground water and stormwater, originate outside the water systems. One conclusion from this is that many of the most urgent problems from a sustainability perspective cannot be handled solely at the level of urban water systems. This does not, however, diminish the need for SDIs in these areas. On the contrary, SDIs may be effective in communicating the need for action to concerned stakeholders such as authorities and users.

Little responsibility across system boundaries

The decision as to how far-reaching the responsibilities of a company should be is important from a sustainability perspective. Extended responsibilities mean that effects on surrounding systems are taken into consideration. A simple recommendation to promote sustainable development would be: the further responsibility extends in time and space, the better. This basically corresponds to the *equity* and *futurity* aspects in Welford's interpretation of sustainable development (1995) mentioned in the introduction.

In the SWC case study the issue of far-reaching responsibility was discussed apropos the working environment ("we care about other than our own employees") and the recovery of phosphorus ("leave some extractable phosphorus resources to those that need them more than we do"), and these standpoints were reflected in the formulation of SDIs and targets for sustainable development. Yet, even though urban water systems may do their utmost to recycle phosphorus, to what extent this will affect the import of virgin phosphorus also depends on, for example, the agricultural system and the fertiliser industry. The next step in the causal chain, which concerns the fate of virgin phosphorus *not* imported to Sweden in the event of increased recycling, is *very* uncertain.

The case of phosphorus demonstrates how uncertain the effects are of action aiming to increase sustainability outside one's own decision domain. Only the prerequisites for effects in surrounding, or future, systems can be created. The further away from one's own decision domain, the more actors are involved and the more difficult it is to predict the outcome of the action taken. Other actors may not assume their responsibilities; they may behave as *free riders*, i.e. sharing in the benefits (in the case of phosphorus a slightly more sustainable world) produced by the sacrifice of others without contributing themselves, and thus gaining competitive advantage (Ammenberg 2004). This is a phenomenon that complicates sustainable development in general: "Why should I take responsibility for poor people, whales or the ozone layer if nobody else does?" It is also part of the explanation for the apparent conflict between the economic and environmental dimensions of sustainable development, which is in actual fact a conflict between different time perspectives.

It was clearly demonstrated in the SWC case study that economy was the most important criterion used in ranking technical options by means of multi-criteria analysis. The environmental performance of an option would not be assigned a greater weighting than its economic performance. A likely explanation for this is that the money belongs to the water company, while the potential environmental benefits belong to everybody – they are common goods. A biologist, Garett Hardin, stated in 1968 that if a resource can be used freely there are no mechanisms that prevent its overexploitation. He named the phenomenon "the tragedy of the commons". This tragedy stems from the fact that the short-term benefit to the individual of his increased exploitation of the commons is solely his own, and is therefore larger than the resulting negative *shared* effects he experiences. As long as the commons are not in scarce supply there is no problem, but with increasing scarcity, which brings in the time perspective, the problem is aggravated and the results may be devastating. Hardin (in Pihl 1992) wrote "Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all". The problem and its effects are well established in environmental economics (Ammenberg 2004) and I will not venture further into a discussion of the subject. I would like, however, to point to an example that illustrates the importance of legislation in counteracting the tragedy of the commons. Wastewater treatment plants along the coasts of Sweden have implemented nitrogen reduction as a means of ridding society of reactive nitrogen species that originate from various combustion processes and from agriculture, and have extensive environmental impacts through processes such as eutrophication, acidification and the greenhouse effect. Nitrogen reduction is a costly process that entails no direct benefit to the water company or to the customers who pay its expenses, and would consequently not have been realised without legislation.

The role of the SDIs

Confronted with the difficulties connected to the sustainable development of urban water systems, one wonders whether using SDIs can actually help. This could have led to a general discussion as to whether sustainable development is possible or not. I will, however, avoid any discussion of that matter by simply quoting another cheerful contributor to the sustainability literature, Goodland (1995):

> The world will in the end become sustainable, one way or another. We can select the timing and nature of that transition and the levels of sustainability to be sought, or we can let depletion and pollution dictate the abruptness of the final transition. The former will be painful; the latter deadly.

I believe he is right, that the painful way is worth trying, and that this painful way may involve the use of indicators.

Judging from both the literature and the case study, SDIs do appear to have the potential to help in the realisation of sustainable development in general. To make SDIs effective and efficient, however, the weaknesses in their present application concerning accommodation of stakeholder interests, credibility, benchmarking and future-orientation, identified in Paper 2, need to be attended to.

At the beginning of the SWC case study and my doctoral project my focus was on procedures for identifying SDIs. At this point, summing up the knowledge gained from my empirical and theoretical studies, I have come to believe that the important question to set out from is "Who needs what information for what purpose?" This question appeared as a difficulty in the case study, and we could find no clear answer to it. The importance of focusing on information needs is also articulated in the literature (Rikhardsson 1998; Seager 2001; Burström Von Malmborg and Lindqvist 2002). If information, whether in general or encapsulated in an indicator, is not experienced as needed, it will not be used and will hence be ineffective. And if information is not adjusted to its purpose, or application, it will not be efficient. Taking information needs as a point of departure, the "best practice" for identifying SDIs, as well as improved understanding of the weaknesses in the present use of these indicators, will surely follow.

5. Future research

I end Paper 2 by underlining the importance of case studies in building understanding of the corporate perspective on sustainable development, as well as in developing SDIs into efficient tools. Case studies will consequently comprise an important part of my future research into the subject of the sustainable development of urban water systems. My aim is to investigate further the preconditions for the sustainable development of the water sector and the role of SDIs as information carriers in this context.

SDIs have a function as information carriers, but, as stated in the preceding discussion, it is necessary to investigate who needs what information for what purpose in order to formulate effective and efficient SDIs. Furthermore, effectiveness requires that the indicators be genuinely connected to actual impacts on ecological and social conditions. This implies narrowing the gap between the perceived needs for action in the company, the natural science and the societal perspective on sustainable development.

The preconditions for sustainable development and useful SDIs in the water sector will arise from interpretation within the organisation of the concept of sustainable development: what the three dimensions of sustainable development – economy, environment and social issues – mean to the people in the organisation, how these dimensions are interrelated and how far the responsibility of the organisation should extend (only to employees, to the local community, to the third world, etc). Taking this interpretation as point of departure, the preconditions will then be sought in terms of:

1. The need for sustainability information for water industry activities such as reporting to authorities and other external stakeholders, and for internal applications such as control, planning, benchmarking, formulating targets and decision-making support. Information needs will be sought not so much in terms of format as in terms of information content: what parameters, what system boundaries, what time horizon, etc.
2. The existing information formats for various applications and the demands these place on the information system.
3. The competence of the people and organisations receiving the information.
4. The extent to which the sustainability information is already integrated in economic technical and/or other existent information systems.
5. The need for flexibility in different parts of the information system(s), as new demands for sustainability information arise.

When these preconditions have been investigated, the specification of requirements for effective and efficient SDIs within the water industry can, I hope, finally proceed.

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