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THE CONCEPT OF SUSTAINABLE URBAN WATER MANAGEMENT

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ABSTRACT

Urban Water Management involves the fields of water supply, urban drainage, wastewater treatment and sludge handling. On the basis of the Agenda 21, principles and guidelines for sustainable urban water management are discussed. Sustainable technology leads to acceptable gradients in state variables. New technologies departing from an analysis of required services rather than stepwise improvement of existing technology is preferred. An efficient use of resources will lead to a minimal increase of entropy and will require an active rather than a reactive approach. The analysis of the transition period from today's to a sustainable situation is important. An example is introduced which deals with global cycling of nutrients and which may be approached on a regional scale. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Sustainable development; Brundtland Report; Agenda 21; urban water management; water supply; urban drainage; wastewater treatment; services; resources; research priorities; nutrients.

INTRODUCTION

Following the report of The World Commission on Environment and Development (1987), shortly referred to as the Brundtland Report, and the Rio Conference in 1992 on the same topic (United Nations, 1992), 'sustainable development' has been established as one of the major issues of our time. Amongst professionals within the fields of water supply, urban drainage and wastewater treatment - here summarized as *urban water management* - sustainable development has become an important topic. However, when it comes to practical engineering projects, it is not easy to agree on the content of the word 'sustainable'. On the contrary, from the literature it becomes clear that totally different approaches are declared sustainable, from 'ecological' wastewater treatment technology (e.g. Niemczynowicz, 1993) to genetic engineering solutions (Mannion, 1992).

It is not clear whether urban water management in its present form is sustainable or not. The nitrate problems in the ground water, the difficulties to recycle potentially limiting resources such as phosphorus from wastewater back to agriculture and the obvious problems we encounter in exporting our technology to the third world are only some examples which motivate us to investigate sustainable technology in urban water management.

We assume that the notion of preserving the world for today's as well as for future generations enjoys general acceptance. We also accept that a more equal distribution of wealth amongst the different parts of the world is necessary. We therefore do not question these basic ideas of sustainable development as they are expressed in the principles of the Agenda 21 (United Nations, 1992). However, carefully reading the parts of the Agenda 21 related to urban water management leads to the conclusion that no concept is proposed which is applicable in practice: The translation of the overall principles into operational criteria is still lacking.

In the following, we will discuss sustainable urban water management from the ideal position of an equal distribution of resources in time and space.

PRINCIPLES

Trying to structure the discussion on sustainable urban water management, we have identified the following four principles which may be generally applied to most anthropogenic activities.

Principle 1: The Goal - Anthropogenic Boundary Conditions

During the last years, it became generally accepted that sustainable development is only possible in the absence of extreme poverty (Impoverished humans do not have the means to take care of their future). This also implies that a minimum level of services from urban water management must be provided. It is important that this is accepted, not only by engineers, but also by ecologists. In areas with a lack of safe drinking water, biological diversity and other ecosystem requirements will not be given any priority.

Principle 2: The Means for Action - Resources

Resources, whether natural or anthropogenic, constitute our means for action. The notion of sustainable development is based on the idea that natural resources should be shared more equally in space and time. In many cases, we have the choice to use different resources for achieving comparable anthropogenic goals. The postulate of sustainable development may redirect our choice.

Principle 3: The System - Local Actions lead to Global Consequences

The Earth is a closed system which only exchanges energy, but no material with the surroundings. Although our field of action is not on a global scale, our local actions have to sum up to global sustainability. This goal can be achieved if every region does not require more than 'its own share'[1] of the limiting resources. The size of the relevant region depends on the problem to be solved.

Principle 4: The Methods

Considering equally the aspects of services to provide, the natural and anthropogenic resources to be managed and the eco-systems to be protected, the assignments of urban water management are rather complex. This leads us to suggest a step-by-step procedure in the development of new technology for providing the required services. In each step the overall increase in 'entropy' should be minimized. Since the increase of entropy is an irreversible process, action appears to be superior to reaction. In spite of the global considerations of principle 2, we claim that different local boundary conditions will give rise to different local technical solutions: E.g. in a cold, humid climate, water might be an excellent sun-powered and sustainable means for transporting pollutants whereas the direct use of sun energy for transport might be more appropriate in hot, water scarce climates.

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[1] We are aware that this is an ideal claim that cannot be controlled. However, as technicians we may try to develop pragmatic common-sense solutions which consider the limited nature of resources. It is an easy task to multiply per capita requirements for our technical solutions with the number of world inhabitants (6-10 billions) and investigate the consequences. As an example, the direct electric power requirements for urban water management in Zürich is around 20 W per person (which does not include production of hot water). This is in fact very modest, but multiplied by 10 billions it adds up to more than half of the existing world nuclear power production.

Although the concept of entropy is difficult to apply directly in engineering computations, we should generally incorporate more consciously the principle of the second law of thermodynamics into our considerations.

THE ANTHROPOGENIC BOUNDARY CONDITIONS

Every anthropogenic activity has two sides: on one side is the demand for the services (the desired benefit), on the other the allocation of resources to this specific activity (the cost).

Tischner and Schmidt-Bleek (1993) argue that in order to create sustainable innovation in technology, we must not focus on the technology itself, but rather investigate the function or services provided by a given technology. Without focusing on known conventional solutions, one may be able to develop more sustainable, 'lean' technologies with minimum requirements for resources. The success is measured by the 'service units' obtained per unit of resource used. A comparable approach is found in the SETAC guide of Life Cycle Assessment where 'the environmental friendliness' of different goods is compared on the basis of 'functional units' (SETAC, 1992). At the moment, no consensus has been found with respect to the methods of evaluation.

In TABLE 1, we define the services that urban water management has to provide. Such definitions may be controversial. As one example, we have included urban agriculture in the services of urban water management. The quantification is even more difficult: what is a 'unit of hygiene' or a 'unit of storm water protection'? However, even two 'unit pairs of shoes' may have such different qualities that they cannot easily be compared. Even if one includes physical quality and reduces the comparison to 'walked kilometers', non-scientific aspects such as the change of fashion may totally reverse the result obtained by any scientific evaluation of resource efficiency.

Table 1. The functions of urban water management

1. Urban Hygiene

Traditionally, urban hygiene meant solving the problem of *removing fecal matter from urban areas* and thereby minimizing the transfer of infectious agents. We want to extend urban hygiene also to the *supply of water* for production and cleaning purposes within households, trade and industry, including *handling of the wastewater.*

2. Drinking Water and Personal Hygiene

Water for drinking, for cooking and for personal hygiene is subject to strict quality requirements. Urban water management must supply such quality water and protect the appropriate water resources.

3. Prevention of Flooding / Draining of Urban Areas

Urban drainage is fundamental for preventing flooding of many urban areas. Although urban drainage has serious consequences for the water cycle and for the quality of receiving waters during storm events, it is not possible to maintain present population densities in urban areas without this service. In many urban areas a continuous draining of ground water is necessary.

4. Integration of Urban Agriculture into Urban Water Management

Traditionally, urban water management was assigned responsibility for recycling the nutrients between city and countryside. With the introduction of cheap fertilizers, this responsibility was lost. Urban agriculture is a new phenomenon with a large potential for increasing at the same time life quality and the possibility of nutrient recycling in urban areas (Brown et al., 1990). Urban water management is regaining importance in this area.

5. Providing water for pleasure and for recreational aspects of urban culture

Water has always been an important aspect of urban culture: Without fountains, ponds, public parks, etc. urban life would loose important qualities. In some parts of the world, the *pleasure* of taking a shower causes a much larger water demand than personal hygiene does.

For urban water management, we suggest to include the *preferences of the users* into the definition of a functional unit: it only makes sense to compare different systems if they are all publicly acceptable.

RESOURCES: THE MEANS FOR ACTION

Traditionally, we have been used to express our possibilities of action in terms of money. With the notion of sustainable development, it has become clear that this concept is inadequate as long as the consumption of the environment is not included in the prices (von Weisäcker, 1992). On the long run, anthropogenic activities will be limited by the natural resources available, including the capacity of the environment to cope with the waste products of these activities.

In TABLE 2, we structure the resources involved in urban water management. Our purpose for doing so is to emphasize that different types of resources give rise to different possibilities of action. A more cautious handling of the primary resources may enhance our possibilities of action (saving of water, recycling of nutrients, better exploitation of energy) whereas focusing on secondary resources may reduce the area of potential action. The recipient as a resource includes both the traditional aspect of environmental protection as well as the conscious exploitation of the natural self-purification capacity. The anthropogenic resource number one, money, is normally considered the most limiting resource for our possibility to act. However, man- and brain-power may be of extreme importance for extending our possibilities in the future.

When we use different resources for a specific anthropogenic activity, we would of course like to compare different scenarios and evaluate which one is the most favorable from the point of view of resource economy. A lively discussion of the relevant methods for such comparisons is found in the publications of the Society of Environmental Toxicology and Chemistry (e.g. SETAC, 1993). Since the evaluation involves social values and preferences, SETAC (1992) suggest the use of different techniques of decision theory. A main distinction is made between quantitative and qualitative procedures. In the quantitative methods, the aggregation of different aspects is based on different 'factors' which can then be added up. This allows for an easy and uncomplicated comparison of different technologies. In the qualitative method, verbal arguments lead to the final decision. The second method has the advantage that the political process finally leading to the evaluation is more transparent whereas the first one may pretend to be objective where objectivity is not possible.

Table 2. The resources of urban water management

1. Primary Resources of urban water management

We define primary resources as natural resources being directly taken care of by urban water management. These are primarily *water, nutrients and energy (in the form of organic chemicals as well as potential energy)*. There might be situations where for instance heavy metals should also be considered as a primary resource (e.g. in heavily loaded industrial wastewater).

2. Secondary Resources of urban water management

We define secondary resources as natural resources used for fulfilling the assignments of urban water management. These are *energy, space and material* of all sorts (construction and operating material, chemicals, etc.).

3. Recipients as Resources

The recipients, *ground and surface waters, soil and air* are regarded as resources on the same level as the primary and secondary resources.

4. Anthropogenic Resources

Sustainable development requires anthropogenic resources such as *capital, qualified labor, public acceptance, etc.* Without theses resources sustainable or any other form of development is not possible..

Even more interesting than the different methods of evaluation is the question how we may successfully develop technology with substantially improved life-cycle profiles. One strategy is the steady improvement of the efficiency of conventional technology, such as energy- and material-efficiency of existing infrastructure. From Swiss experience, we know that at least the energy efficiency can be considerably improved (Müller *et al.*, 1994). In urban water management this strategy would e.g. lead to the development of even more favorable process schemes for wastewater treatment plants or more extensive use of existing storage capacity in the sewer system.

Another strategy is to re-analyze the services to provide (TABLE 1) as suggested in the previous chapter, and based on this analysis re-develop a system according to the principles of sustainable development. The idea behind this procedure may be illustrated by the (mathematical) picture of multiple 'local minima' in the landscape of technologies. Departing from a 'local minimum', it is not possible to develop the system step by step into a different local minimum: it is too expensive to cross the 'hill'. Several difficulties are inherent to this strategy. First of all we have to believe that at least one other 'local minimum' exists, secondly we have to identify where it might be and finally we have to find a way which may lead from the present situation to the new and better one. Considering today's urban water systems, we believe that the search for technological alternatives, more in accordance with the principle of closing cycles and using resource and energy cascades rather than relative improvement of presently available technology, is a research obligation.

SYSTEM DEFINITION

The system which we define, for research or for problems to be solved, will significantly influence the solutions which we finally develop. For the considerations of sustainable urban water management, we suggest that not only the spatial resolution, but also the time scale is important when we define the system of interest (Fig. 1).

Typical problems within the field of urban water management arise on a regional scale with relatively short time constants (This might be the main reason why water pollution control preceded air and soil pollution control). The eutrophication of lakes which led to the booming construction of phosphorus removal wastewater treatment plants is a good example. Eutrophication has a typical time constant in the order of a year and its regional scale makes it relatively easy to agree on the causal relationship between wastewater emissions and the problem. The response to eutrophication was the application of end-of-pipe technology: treatment plants with processes subject to time constants of hours, days and weeks. The space scale of the solution relates to the sewer system which made it possible to concentrate the technical solution of a regional problem on a very limited space: the treatment plant. Intensive research on nutrient removal technology takes place in the laboratory. Here we deal with details reaching into the scales of molecular size and the corresponding time-scales. It is an important fact that the fame of many engineering and especially natural scientists is based on these rather small time and space scales. From the point of view of optimizing a scientific carrier, it is reasonable today to define the system of interest within the lower left corner of Fig. 1.

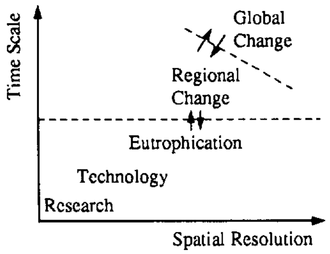

Fig. 1. Time scale and spatial resolution for system definition.

Sustainable development relates to global change and long time-horizons. Our realistic options for activity lie on a regional scale. Regional change having a chance of leading towards global sustainability is typically judged to occur in the order of decades. An active approach with a reasonable chance of success therefore requires larger time scales to be taken into account.

We believe that the most important challenge of sustainable urban water management is to establish the connection across the lines indicated in Fig. 1. Environmental engineers have successfully gained experience in working in the lower left part of the diagram. Establishing an *active* rather than a *reactive* connection to the upper right part of the diagram requires considering a longer time horizon. Below we will discuss an example of practical linking of technology to regional and global change.

Like all system definitions, also the definition of appropriate regional scales depends on the problem to be solved (discussing wastewater treatment plants, we would never ask the question of system boundaries before defining the problem). For the larger scale problems relevant to sustainable development, the hierarchical structure of most countries and the added supranational organizations like the European Union or the UN are the practical models which we have available. For urban water management it is obvious that relative to the global scale practical problem solving will be on a very small local scale, often starting with the local municipality. However, as discussed by Krebs and Larsen (1997, this volume), for sustainable solutions these municipality borders rapidly become too narrow. For the problems addressed by Boller (1997, this volume), we would typically expect to define a national solution (source control of contaminants in storm water via technical specifications) whereas certain problems may even require international cooperation (air pollution).

METHODS: MINIMIZING THE INCREASE IN ENTROPY

Sustainable development is a global issue whereas the physical reality of urban water management will always remain regional or local. Here we will use the example of nutrients in wastewater in order to discuss how global requirements *(extended spatial resolution)* may lead to changes in technology on the regional level. The concept presented may be described as an example of *waste design*, an active approach well suited for minimizing the increase in entropy.

We have categorized nutrients in wastewater as primary resources. Different, mainly global reasons for wanting to recycle these resources are listed below.

1. By some authors, the natural phosphorus resources are considered limited (Frederikson, 1994). Although other authors claim that for practical purposes, the phosphorus reserves are unlimited (Van Kauwenbergh, 1992), their quality will decline in the future and e.g. the removal of cadmium will become mandatory in order to maintain soil fertility (Bøckman *et al.*, 1990).

2. It may be possible to develop systems with a better global 'life-cycle profile' than our present systems. It is obvious that the life-cycle profiles depend heavily on changing boundary conditions: If denitrification becomes mandatory (for global or regional reasons), traditional wastewater treatment processes will become more resource intensive. If heavy metals have to be removed from the fertilizer, the same will happen to fertilizer production, etc.

3. With the present level of nutrient losses from urban water management to receiving waters, ecological agriculture (without synthetic fertilizers) is not possible on a large scale. With a global commitment to ecological agriculture, nutrient recycling may again become one of the major services provided by urban water management.

The macro nutrients stemming from the human metabolism are mainly contained in urine and not in feces as often anticipated by lay people. Concise data on the actual distribution are difficult to obtain, but for nitrogen, phosphorus, potassium and sulfur (N, P, K and S) more than 75 % are found in urine (Ciba-Geigy, 1977). N, P and K make up the conventional fertilizer, sulfur is increasingly used as a fertilizer in Europe, probably due to reduced anthropogenic emissions (Bøckman *et al.*, 1990). Of course, also the nutrients mainly contained in feces will be limiting with time. However, there are good reasons for considering urine as a primary target of interest.

Based on the concept of waste design, it is logical to seek to separate urine at the source, preventing the increase in entropy due to dilution. *Spatial segregation* of the different fractions of wastewater has been discussed for more than a century: it is still up for debate whether separate or combined sewers are the best solution for urban wastewater management. Industrial wastewater is often successfully separated from domestic wastewater and the separate handling of feces - and in recent times also of urine - based on spatial segregation is an important topic in ecological engineering (Niemczynowicz, 1993).

For the specific conditions in Western Europe, we suggest to investigate the principle of *time segregation* as an interesting alternative to spatial segregation. Instead of organizing a separate transport system for urine, we suggest that urine should be stored locally (at the source) and during night hours be simultaneously transported to the treatment plant. The existing sewer system could be used for this transport causing only a minimal 'dilution' of the urine. In the early stages of transition with only parts of the catchment being involved, the arriving 'nutrient solution' may be used for optimizing nitrification at the treatment plant - the final vision would be a separate treatment of concentrated urine with the possibilities of nutrient recycling.

We believe that the possibilities of organizing the transition period *and* the degrees of freedom (nutrient removal/nutrient extraction) offered by the system are very important advantages which support a sustainable development. With limited initial investment, the existing infrastructure can be developed into a different direction. A detailed description of the technology and of possible transition scenarios is found in Larsen and Gujer (1996).

DISCUSSION AND CONCLUSION:
GUIDELINES FOR FUTURE DEVELOPMENT

In this paper, we have discussed how the four basic principles initially presented may lead to considerations on different levels. Here we extract six guidelines which might help us to find options for a sustainable urban water management in the future.

Guideline no. 1:. In order to develop a sustainable urban water management, we must first define the services to provide and should not fix our mind on improving existing technology.

This first guideline is directly adopted from Tischner and Schmidt-Bleek (1993). However, we pointed out that some of the services - or functions - of urban water management may be controversial and might change with the changing preferences of the people involved.

Guideline no. 2:. Research in the field of urban water management should investigate the possibility of other 'local minima', possibly not relying on presently applied technology.

A 'local minimum' is achieved if the necessary services are accomplished with a minimum requirement of resources. The definitions of the 'necessary services' and the aggregation of the required resources are both dependent on subjective evaluation and involve a political process.

Guideline no. 3:. In order to prevent that problems are 'exported' in time and space, the spatial dimension as well as the time scale of the relevant systems should be drastically extended.

The extended system definition excludes the possibility of achieving locally favorable solutions at the cost of exporting the problems in time and space. Since the export of problems is inherent to traditional urban water management (from the urban areas to the receiving waters, from the receiving waters to the agriculture (in the context of sludge utilization and end-of-pipe solutions), etc.), we expect the extended system definition to lead to the trend of solving problems closer to the source of the waste. It should be noted that this is a purely 'logical' identification of the expected trend (where free export is allowed, this will always be the cheapest solution), not based on taking position in the discussion of centralized versus decentralized technology.

Guideline no. 4:. Acceptable gradients of state variables are important indicators for sustainable development.

The 'export in time' of problems is most easily detected when we watch the dynamics or the *gradients of the state variables.* A constant increase of nitrate, a constant decrease of a water table, etc. are signs that some condition changes are in an undesirable direction. History teaches us that such sustained changes may have very negative consequences. However, as engineers we must be aware that state variables are not always directly visible: As an example biodiversity must be considered as the ultimate state variable of most natural systems.

Guideline no. 5:. In order to simultaneously minimize the exploitation of different types of resources, the reactive approach of urban water management should be changed into an active approach. The concept of wastewater design is an important step in this direction.

Under 'Methods' we identified how the criterion of minimizing the increase in entropy could lead to the concept of wastewater design. We would like to emphasize that in our opinion 'step-by step' solutions take their point of departure in the services to be provided and not in existing technology.

Guideline no. 6:. With the introduction of new technology, the organization of the transition period becomes essential. The possibility of 'using up' existing infrastructure is essential to the success of new technologies. Since future developments are difficult to predict and the infrastructure of urban water management has a long life expectancy, we should prefer transition scenarios with high degrees of freedom.

With the practical example of nutrient handling, we further identified the organization of the *transition period* as an important aspect of achieving sustainable changes of large infrastructures with a substantial amount of inertia.

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