A FRAMEWORK FOR SYSTEMS ANALYSIS OF SUSTAINABLE URBAN WATER MANAGEMENT

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ABSTRACT

There is, in society in general, an increasing demand for sustainable development. This will have a profound impact on all types of urban infrastructures. However, within many fields there is a lack of knowledge of how sustainable development should be attained and how sustainability of various technical systems should be assessed. This paper describes the framework of a systems analysis project dealing with the above issues, which focus on urban water and wastewater systems. The project is carried out within a six-year national research programme entitled "Sustainable Urban Water Management". A set of sustainability criteria – covering health and hygiene, social and cultural aspects, environmental aspects, economy and technical considerations – are defined and will in the future be applied together with a number of analysis methods for evaluating different water and wastewater system solutions. Computer simulation, risk assessment and life cycle assessment are examples of promising tools for analysis. For the validation of model behaviour and assessment results, measurement campaigns in existing systems will be carried out.

To promote the practical use of a set of sustainability criteria it must be concise and related to quantifiable indicators that are easily measured. The paper suggests suitable indicators for the proposed criteria. It also contains a brief analysis of the contribution to various environmental effects and resource utilisation of the Swedish urban water system in relation to the impact of Swedish society in total. The purpose of this comparison is to correctly prioritise which the most important criteria are for a sustainable development with regard to urban water management. A priority list of eight sustainability criteria/indicators is suggested.

Introduction

In order to improve and raise the knowledge with regard to sustainable water and wastewater management, the Swedish Foundation for Strategic Environmental Research (MISTRA) in 1999 initiated a six-year Swedish research programme entitled "Sustainable Urban Water Management"

The systems analysis project within the programme is carried out by a group of senior researchers. However, the complete research programme covers both technical and integrated projects, which have been set up for PhD students (14 projects altogether). The technical projects deal primarily with: 1) drinking water – treatment and distribution; 2) storm water management; and 3) wastewater and sludge – recovery of products. The integrated projects focus on: 1) social-economical aspects; 2) hygienic aspects; 3) risk assessment and communication technologies; and 4) use of products from the urban water system.

The systems analysis is the core of the programme, aiming at synthesising results from the other research projects and analysing results with respect to the overall visions and the goals of the programme. The work procedure of the systems analysis involves studies of different combinations of model cities, system structures (technical systems) and scenarios (future events in society directly or indirectly affecting the water and wastewater systems). A complete description of the systems analysis project is given in Jeppsson *et al.* (1999).

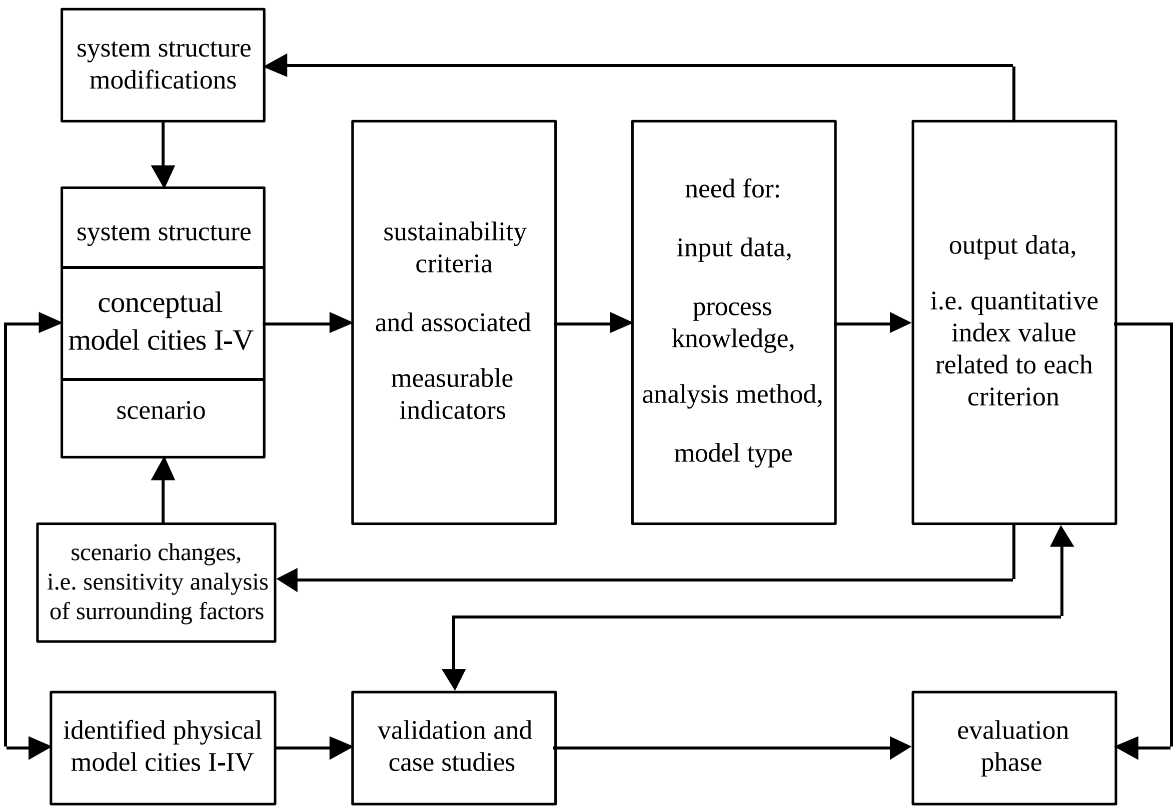

Figure 1. Schematic description of the systems analysis work procedure within the Swedish research programme “Sustainable Urban Water Management”.

TABLE 1. Sustainability criteria and associated indicators (continued on next page). If not specified, data in column three by courtesy of Stockholm Water Co. and data in column four (Swedish national values) from SCB (1996). Empty cells in column two: indicators not formulated; empty cells in column three and four: data not available; grey cells: indicator cannot easily be related to a total anthropogenic impact.

CRITERION	INDICATOR	Impact from water supply and sanitation	Total anthropogenic impact (in Sweden)	Rel. impact from water supply and sanitation, %
Health and hygiene criteria				
Availability to clean water	Acceptable drinking water quality[1] (% of samples)	> 99.5		
	Non-access to drinking water (h/p,yr)	3.5		
Risk of infection	Number of waterborne outbreaks[2] (no/100000 p,yr)	0.05-0.1		
	Number of affected persons[2] (no/100000 p,yr)	5-10		
Exposure to toxic compounds	Drinking water quality			
Working environment	Number of accidents			
Social and cultural criteria				
Easy to understand				
Work demand				
Acceptance	Violation			
	Omission			
	Ignorance			
Availability				
Environmental criteria				
Groundwater preservation	Groundwater level			
Eutrophication[3]	N to water (kg/p,yr)	1.3	9.8	14
	P to water (g/p,yr)	23	280	8.2
	OCP* (kg O_2/p,yr)[4]	21 (sea) 7.9 (lake)	150 (sea) 62 (lake)	14 13
Contribution to acidification[3]	H^+-eqv. (moles/p,yr)	15	1600	0.9
Contribution to global warming[3]	CO_2 -eqv. (g/p,yr)	43	8300000	0.0
Spreading of toxic compounds to water	Cd, Hg, Cu, Pb (g/p,yr)	Cd: < 0.008 Hg: < 0.02 Cu: 0.8 Pb: < 0.08	Cd: 0.2 Hg: 0.1 Cu: 60 Pb: 1.5	Cd: < 4 Hg: < 16 Cu: 1.4 Pb: < 5
Spreading of toxic compounds to arable soil[5]	Cd, Hg, Cu, Pb (g/p,yr)	Cd: 0.041 Hg: 0.061 Cu: 9.0 Pb: 1.2	Cd: 0.43 Hg: 0.11 Cu: 13 Pb: 8.2	Cd: 10 Hg: 54 Cu: 70 Pb: 15
Use of natural resources	Utilisation of available land[6] (m^2/p)	< 0.1	500-700	< 0.02
	Use of electricity and fossil fuels (MJ/p,yr)	400	160000	0.2-0.3
	Total exergy consumption[7] (MJ/p,yr)	3000-4000		
	Use of fresh water (m^3/p,yr)	120		
	Use of chemicals: Fe, Al (kg/p,yr)	Fe: 2.0 Al: 0.3		
	Use of materials for construction of infrastructure (m pipe/p)	2.0 (water pipe) 3.5 (sewer)		
	Potential recycling of phosphorus[8] (g/p,yr)	720	2300	31

CRITERION	INDICATOR	Impact from water supply and sanitation	Total anthropogenic impact (in Sweden)	Rel. impact from water supply and sanitation, %
Economical criteria				
Total cost	Capital cost (Euro/p,yr)	33	22200 (GNP/p)	0.15
	Operation and maintenance (Euro/p,yr)	61	22200 (GNP/p)	0.28
Functional and technical criteria				
Robustness	Overflow (m^3/p,yr)	0.4 (0.3% of flow)		
	Non-access to clean water (h/p,yr)	3.5		
	Sewer stoppage (no/100000 p,yr)	70		
	Flooding of basements (no/100000 p,yr)	5		
Performance	Out-leakage (m^3/p,yr)	20 (16% of flow)		
	In-leakage (m^3/p,yr)	13 (10% of flow)		
Flexibility				

*) OCP – *oxygen consumption potential*, based on amount of organic material, nitrogen and phosphorus.
1) Restrictions of drinking water quality from SLV (1995).
2) Data on the risk of infection from Jong and Andersson (1997).
3) Data on the impact from water and sanitation of a conventional system from Kärrman *et al.* (1999).
4) Fresh water situation and marine water situation respectively according to Ødegaard (1995).
5) Data on the total anthropogenic impacts calculated from average concentrations in mineral fertilisers (Andersson, 1992), usage of mineral P-fertiliser in 1995 (SCB, 1997) and the usage and concentrations in lime (Andersson, 1992).
6) Data of land use in Sweden from SCB (1993).
7) Estimations of exergy consumtion based on data from Hellström and Kärrman (1997).
8) Data on the total anthropogenic impacts based on the purchase of mineral fertilisers from SCB (1996).

TABLE 2. The priority set of criteria and the associated methods for evaluation for the systems analysis project of the research programme “Sustainable Urban Water Management”.

CRITERION	METHOD FOR EVALUATION
Health and hygiene criteria	
Risk for infection	Microbial risk assessment
Social and cultural criteria	
Acceptance	Action research and assessment scales
Environmental criteria	
Eutrophication	Life-cycle assessment, computer-based modelling, material-flow analysis and exergy analysis
Spreading of toxic compounds to water	
Spreading of toxic compounds to arable soil	
Use of natural resources	
Economical criteria	
Total cost	Cost-benefit analysis
Functional and technical criteria	
Robustness	Functional risk analysis