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SUSTAINABLE TECHNOLOGICAL DEVELOPMENT FOR URBAN-WATER CYCLES

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ABSTRACT

Sustainable water management is a challenge for the future, as is the question what role technology may play in this. In the framework of the Netherlands interdepartmental research programme Sustainable Technological Development a pilot study has been carried out on the feasibility of a sustainable urban-water chain. Relevant unsustainability factors have been analysed to decide in what way sustainability of the water system might be increased. The starting point was a reduction by a factor of 20 for realisation in the year 2040. Relevant ideas have been processed into scenarios. In the four scenarios emphasis has been placed on reduction of emissions into the water chain, reduction of water consumption, minimal pollution (source reduction) and on small-scale. When the ideas have been realised in the 'zero emission' scenario, a substantial reduction of unsustainability may be realised. The attendant technological changes need to be developed.

KEYWORDS

Sustainable development; urban-water cycle; future; research program; backcasting.

BACKGROUND

In the Netherlands an interdepartmental research programme, called Sustainable Technological Development (STD), has been set up to try to find new ways to achieve a sustainable society. This programme aims at defining future production and consumption patterns within the environment. The 'Raad voor het Milieu- en Natuuronderzoek' in the Netherlands has further worked out this concept, which has resulted in the conclusion that for a sustainable society pressure on the environment should by reduced by a factor of 20. On the basis of these results the STD programme has formulated the challenge to increase the environmental efficiency of production and consumption by a factor of 10 to 50 and investigate what technological options may be developed for this purpose. In order to assess the future environmental situation the backcasting method has been used. This method translates the desirable future situation into current challenges to new policy and technological developments. This starting point has also been the main motive for the 'Pilot study STD Water'.

In June 1993 STD organised a workshop on the subject of water. Problems of sustainable water management as to agriculture, industry, drinking water supply, urban-water system and nature conservation were discussed. After this workshop STD decided to have a pilot study made in which the urban-water system was the central focus of attention. As a reference an urban agglomeration of 100,000 inhabitants and a period of 50 years from now were selected. The urban-water system can be defined clearly and the various water themes, such as collection, consumption and discharge may be studied in the integrated framework of a small cycle. It concerns both the quality and the quantity of water. In October 1993 the study assignment was defined, it was started in December 1993 and concluded in October 1994. The study was carried out by a (core) project team of Witteveen+Bos Consulting engineers in which experts in the field of drinking water, wastewater, sewage, surface water and environmental policy were represented. The project has been overseen by a steering committee consisting of Messrs E.J. Vles (STD, Chairman), W.A. Bruggeman (DG Rijkswaterstaat RIZA), B.A. Heide (TNO), H. van de Honing (Water Board Regge and Dinkel) and F.L. Schulting (Kiwa).

METHODOLOGY

The methodology has been based on a model and schematic approach in which the backcasting method has been applied. The year 2040 has been selected as a point of reference. After defining the system a model has been developed for the urban-water chain, which illustrates the present and future unsustainability. Then it has been investigated whether a reduction by a factor of 20 is feasible. For this purpose ideas have been developed. Not one single idea will solve all problems, it needs a clustering by means of scenarios. The ideas are, for the greater part, still in a preliminary stage and need further study and development. The study answers the three following questions:
a. What will be the future unsustainability (when current developments are continued)?
b. Is an unsustainability reduction by a factor of 20 at all feasible?
c. What techniques need to be developed in order to achieve this?

An agglomeration of 100,000 inhabitants and the year 2040 have been selected to study the urban-water cycle. The 'internal water cycle' of this town is not completely closed and that is why it is more like a water chain, shown from beginning to end. The water chain includes all urban water; inflow and outflow of groundwater and surface water do not belong to the system and have therefore been put at zero. The sources are the households, the small industries and offices; big companies and agriculture have been excluded from this urban-water system.

The water chain for an urban agglomeration of 100,000 inhabitants reflects the typical present situation in the Netherlands; it may be divided into:
- drinking water production; groundwater as raw material;
- drinking water distribution; very complex structure with high reliability;
- water consumption; domestic and (minor) industrial; (125 l/d per capita);
- sewerage; combined system with overflows; high degree of connection (> 97 %);
- wastewater treatment; full biological treatment with nutrient removal; sludge dewatering and incineration;
- effluent discharge into a small watercourse;
- costs; investment costs NLG 850 m, total operation costs NLG 40 m p.a.

When drawing up the model use has been made of various data, which are practical standards in the Netherlands. The total investment per capita is approx. NGL 8,500 and the total operation costs are approx. NGL 4 per m^3 of water.

UNSUSTAINABILITY FACTORS

In order to realise a more sustainable society it is necessary to change the non-sustainable activities and processes in such a way that their consequences put less pressure on the environment. The sustainable environmental conditions have been defined as remaining within the limits of the environmental resources. To analyse a sustainable urban-water chain unsustainability factors have been developed, such as emission into surface water, production of solid waste, use of chemicals, energy, use of building materials, water balance, space and nature. Next to sustainability also hygiene aspects are important, because a well-functioning water chain is of essential importance for public health. Reliability is also an essential factor in this respect.

All unsustainability factors for the water chain model have been further quantified. In this respect it was important to find out what weight the factors in question placed on the whole. A picture has been drawn of a desirable situation. Certain unsustainability factors of the water chain are of great importance, because they are (practically) the only source of unsustainability in a certain situation; in fact, there is then a very direct relation between the water chain and the effect. Due to all sorts of reasons a drastic reduction of an unsustainability factor may be necessary, irregardless of the contribution of the various chains to this aspect. Of the studied unsustainability factors the share of the water cycle in the total of the urban model has been assessed. So this method of quantifying does not concern the relative share of the factor studied within the Netherlands or in the world. On the basis of this an order of priority of the various unsustainability factors has been drawn up.

Therefore **very important** are: the emission of heavy metals into surface water (A1), the emission of organic micro-pollutants into surface water (A2), the sludge production (A3), the groundwater management (A4), the emission of oxygen-binding materials via overflows (peak discharge) (A5). Care must be taken that the current level for hygiene (A6) and reliability (A7) are maintained or improved.

Group B is considered **important**; it includes the emission of oxygen-binding materials into surface water (B1), the emission of nutrients into surface water (B2), the emission into soil (B3), the production of drinking water sludge (B4), the electricity consumption (B5).

Group C is considered **relatively important**; it consists of the production of sewerage deposits (C1), the production of other waste materials (C2), the use of chemicals (C3), the use of building materials, more especially PVC (C4), the surface water management (C5).

Group D is considered **less important** and includes the CO_2 emission (D1), space and natural environment (D2).

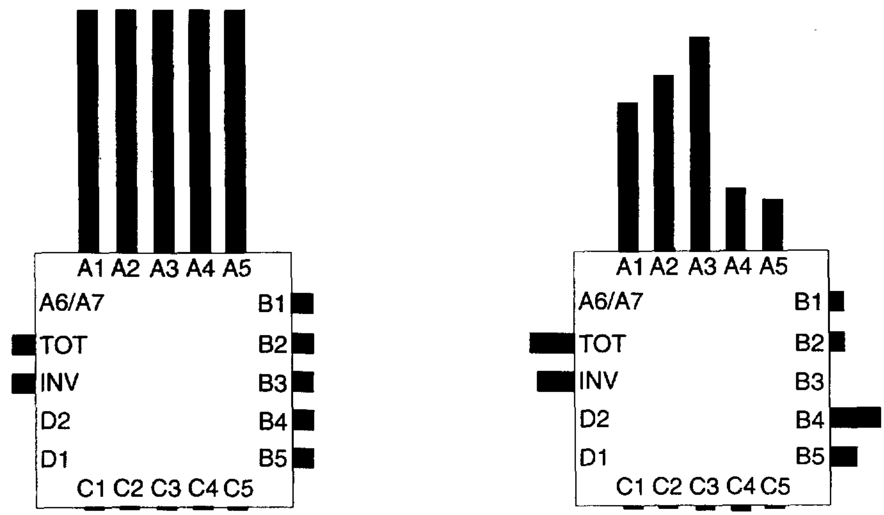
It has been indicated now that some unsustainability factors are very important and others are important, relatively important or less important, respectively. In the study the unsustainability factors have been assessed and translated into figures for reasons of comparison. All A factors have been attributed a value of 1000, B factors a value of 100, C factors a value of 10 and D factors a value of 1. So the present situation has a total unsustainability of 5552.
Measures yielding drastic changes in group A will be most effective in reducing the total unsustainability, without having negative effects on the other factors, or with simultaneous reduction of other pressure on the environmental resources. It may be said of most factors that their unsustainability is linear to their importance. An emission reduction of a certain material by a factor of 20 usually implies a similar unsustainability reduction for that part. The factor 20 has been, rather arbitrarily, determined by STD because sustainability may then become feasible. This starting point has not been influenced by the nature of the urban-water system nor the location of the urban agglomeration. This means that the remaining emissions into f.i. surface water have not been assessed on their local or regional effects. The actual distance to the current environmental targets in the Netherlands has not been included in the study, either.

AUTONOMOUS DEVELOPMENT

In order to determine the future unsustainability in a number of situations we used of a specially developed model. To begin with, we calculated the 'autonomous development' scenario. In this scenario various aspects of the water chain are improved, such as connections of various remote discharges, renovating sewerage systems and optimising wastewater treatment and drinking water production, f.i. by switching to surface water as a raw material. Autonomous development may be characterised as a continuation of the current policy, supplemented with the application of various optimalisations. For this scenario it may be calculated via the model how unsustainability factors and costs, too, will change.

As a starting point the 'current situation' has been shown. The length of the poles illustrates the unsustainability. A similar illustration has been made for the 'autonomous development' scenario; here especially factors A4 and A5 (groundwater management and peak emissions of oxygen-binding materials) decrease. The future unsustainability is decreasing, but still remains considerable, approx. 70 % of the current level. The A factors continue to be very important as well as B4 (drinking water sludge) (Fig. 1).

Figure 1 Unsustainability factors (A1-D2) and costs (INV = investment, TOT = total operation) of the 'current situation' (left) and the 'autonomous development' (right).



current situation
total unsustainability 5552 (100 %)

autonomous development
total unsustainability 3749 (68 %)

SUSTAINABILITY-INDUCING IDEAS

How can unsustainability or unsustainability factors be reduced? Many initiatives have been developed so far. Most of them, however, focus on one part or one aspect of the water chain. They do not provide an integrated approach of the issue. Extensive improvement of the sustainability of the water chain necessitates introduction of more integrated technological improvements. For this purpose the project team has been brainstorming and the resulting ideas are in various stages of development, from new to project form in stages from demonstration to application. The ideas gathered from extensive literature study have then been discussed with various interviewees and discussions have been organised in workshops.

For each relevant idea the following aspects have been characterised: the definition, the relation with the water chain and the geographic scale, the experience and applicability, the effects on unsustainability, the costs and various items, such as special boundary conditions, state of development, combination possibilities.

Some examples of ideas are filtrating asphalt, bottled drinking water, biological membrane reactor, dry cleaning, completely closed sewerage system, large-flux membranes and selective ion exchange.

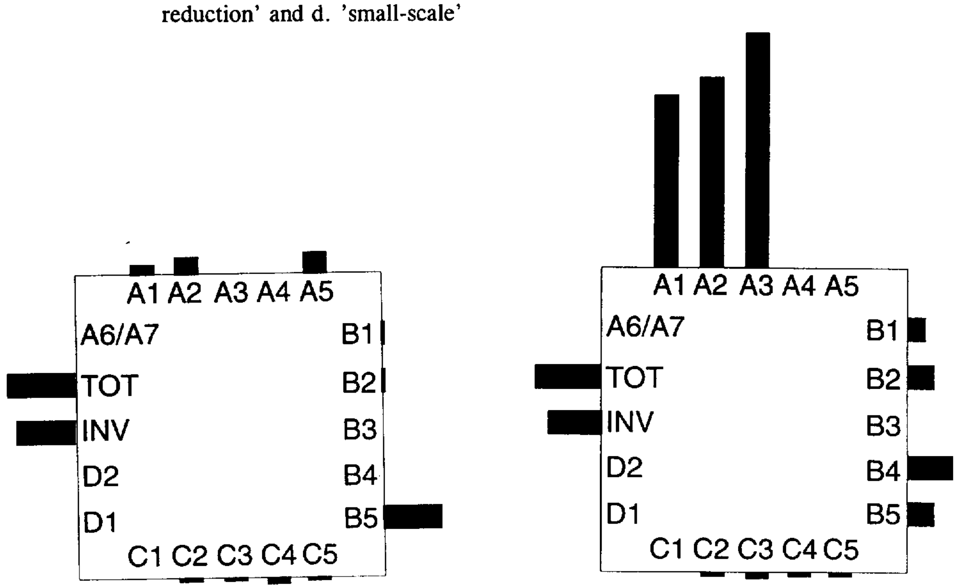
More than 80 ideas were identified. A first selection produced some 25 suitable ideas. Ideas very often only affect one or two unsustainability factors. They may, however, enhance or exclude each other. A combination of ideas by means of scenarios proved an interesting option and has therefore been further worked out. The ideas have been joined in a scenario in a logical way.

SCENARIOS AS COHERENT SOLUTIONS

In this study the urban-water system of the future has been formulated in four scenarios.
The first one, the 'zero emission' scenario focuses on reducing emissions into the water chain; the cycles and the material flows have been kept closed as much as possible. The second scenario, 'flux reduction', focuses on reduction of water consumption, whereas the third one, the 'source reduction' centres its attention on minimal pollution. Finally, there is the 'small-scale' scenario which represents a direct relation to man, the environment and water. These four scenarios all are considered a continuation as well as a supplement to the autonomous development.

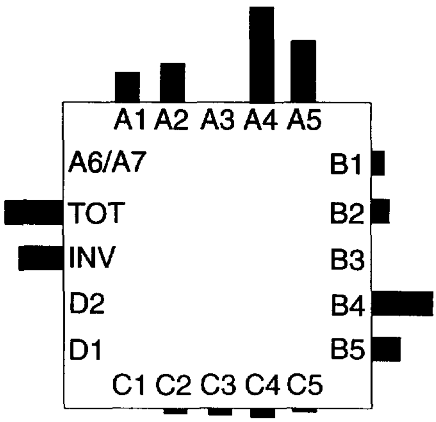
In the 'zero emission' scenario emissions of undesirable materials into surface water have been drastically reduced or are absent. The urban-water chain is virtually closed. All used water is collected and transported to the wastewater treatment plant. There are no more overflows from the sewerage system. The wastewater treatment plant produces good quality water which is comparable to the surface water into which it is discharged. Drinking water production makes full use of surface water as a raw material, so that the groundwater balance may be spared. The produced wastewater and drinking water sludges are recycled and reused as building material. Many factors decrease substantially, such as all A factors and factors B1-B4; only B5, electricity consumption, increases (Fig. 2a).

Figure 2 Unsustainability factors and costs of a. 'zero emission', b. 'flux reduction', c. 'source reduction' and d. 'small-scale'

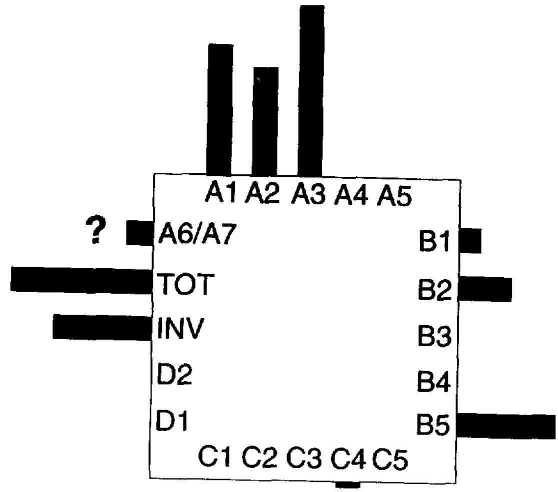


zero emission
total unsustainability 377 (7 %)

flux reduction
total unsustainability 2573 (46 %)



source reduction
total unsustainability 1427 (26 %)



small-scale
total unsustainability 2287 (41 %)

In the 'flux reduction' scenario we see that in many places in the water cycle water consumption is reduced. Reducing water flows, especially quantitatively, may decrease unsustainability. This is the essence of the 'flux reduction' scenario. Multiple use of water is aimed at, domestical water saving is already realised to a great extent and the sewerage system may be relieved by deviating rainwater. Only A4 and A5 are affected. Factors A1, A2 and A3 only change little (fig. 2b).

The 'source reduction' scenario tries to achieve a drastic improvement of the wastewater quality by means of pollution prevention: control at the source. In this way all sorts of emissions are reduced substantially. End-of-pipe techniques will then require less development and application. Besides, all sorts of subsystems, such as reuse, may be set up differently. This scenario assumes that, in principle, all pollutants are traceable and reducible, if not, they are uncontrollable (fig 2c).

In the 'small-scale' scenario central amenities are drastically abandoned on the basis that when the water chain is set up locally, there is a much directer and more conscious relationship between people, nature and environment. In addition, all sorts of disadvantages of large scale, such as oversizing, high and vague costs and dependency are avoided. Central themes in this scenario are the lack of central distribution and collection structures. The necessary water for one house is collected and processed locally. The water used is then reused as much as possible. The unsustainability effect is disappointing. The factors A1, A2 and A3 do not decrease, B2 and B5 even increase substantially. This also goes for the costs, which are even 2 to 3 times higher than in the other scenarios (fig. 2d).

CONCLUSIONS FROM THE SCENARIOS

The 'zero emission' scenario offers most perspective to achieve a sustainable urban-water chain. Total unsustainability will decrease by 93 % compared with the present situation. If special attention is paid to the remaining unsustainability factors, viz. the remaining emissions of heavy metals and organic micro-pollutants, and the relatively high energy consumption, an even better situation may be achieved. For this scenario question B, whether an unsustainability reduction by a factor of 20 is feasible, may be answered positively. For many factors this reduction is feasible in the given circumstances, it is only for a few that it is not.
After the 'zero emission' scenario, the 'source reduction' scenario is most effective. Total

unsustainability decreases by 74 % versus the present situation, the remaining unsustainability is especially caused by relatively high groundwater consumption, continuing peak discharges and a relatively high production of drinking water sludge. In the 'flux reduction' scenario and the 'small-scale' scenario unsustainability is only reduced in some parts of the water chain. The 'zero emission' scenario, the 'source reduction' scenario and the 'flux reduction' scenario will be 50-100 % more expensive than the current situation. The 'small-scale' scenario involves a higher price increase.

FEEDBACK TO THE IDEAS

At this stage of the study we may wonder which ideas match which scenarios.
- Many ideas fall within 'autonomous development', but they very often have only limited impact. They may be considered partly as optimalisations of the current system and have often been reasonably developed. Further development or stimulation does not seem obvious.
- Within the three alternative developments especially the ideas that fit in the 'zero emission' scenario merit further attention. These ideas may be clustered into two groups: one group concerns advanced wastewater treatment so that emissions of heavy-metals and organic micro-pollutants (A1 and A2) will be reduced. The second group solves the sludge problem (A3) by useful reuse.
- Some of the remaining ideas yield a reasonable impact within the other scenarios, especially 'source reduction'. These are especially domestic ideas.

SOME METHODIC NOTES

This study focuses on the urban-water chain. For this purpose a model has been developed in which current and future data have been introduced. A number of hypotheses have been put forward, such as current and future water consumption, the structure of the sewerage and overflow frequency and the method of wastewater treatment and drinking water production. Changes in the present as well as the anticipated hypotheses will affect the results of the model calculation.

In the model weighing factors have been allocated to the unsustainability factors. In order to find out to what extent a different allocation of weighing factors to the A, B, C and D factors would affect the final merits of the scenarios, a number of additional calculations were made. When maintaining the unsustainability factors within the categories (A, B, C and D) it appeared that variation in the weighing factors did not lead to different results. The 'zero emission' scenario continued to be the most effective scenario.

In some places there is a direct relation between a single measure and a single unsustainability factor. Groundwater management demonstrates this. The quantity of groundwater to be extracted has been considered as the representative unsustainability factor. Obviously, when groundwater is not used (when surface water is used as a raw material), its unsustainability factor is reduced to zero. In practice, the relation is, of course, more complicated and partial reduction of the use of groundwater may allready imply a sustainable situation.

TECHNOLOGICAL DEVELOPMENT

What ideas need further development? What should be done to be prepared for the year 2040?
On the basis of the preceding conclusions the successful ideas have been grouped around three main themes:
- advanced wastewater treatment;
- sludge processing;
- application of inert materials.

Concerning advanced wastewater treatment we are thinking of techniques to remove heavy metals and organic micro-pollutants. Membrane technology, selective ion exchange, pertraction and selective micro-organisms are examples of these. Studies along these lines should be stimulated.

Sludge processing may involve vitrification and other immobilisation techniques. It is wise to gain practical experience in these subjects.

Application of inert materials, such as ceramic and synthetic materials means less emission of, among other things, heavy metals. This needs little development, it is more a matter of policy to stimulate this.

The last item is the dry toilet, which fits in a number of scenarios. Use of the dry toilet may decrease water consumption as well as emissions of pollutants. The development of such a system could mean a drastic change in the total system of the urban-water chain.

GENERAL REMARKS

Next to the technological solutions attention should also be paid to policy measures and organisational steps. In this respect water saving should be endeavoured and all kinds of pollution prevention should be stimulated. A decline in hygienic reliability and safety of the water system is not acceptable in our modern society. Furthermore, it is necessary not to overlook the many small improvements as they can also contribute usefully. Finally, it is vital that there should continue to be support for all amenities within the water chain.

CONCLUSIONS

The three main questions which were formulated at the beginning of the study have been answered. To begin with, the unsustainability of the urban-water chain appears to decrease by only 30 % if the current policy is continued.

However, it is possible, in principle, to reduce the total unsustainability by a factor of 20. Emissions into surface water need to be tackled extensively and a sustainable solution must be found for waste-water sludge. As many techniques to achieve this imply increased energy consumption it is necessary from a sustainability point of view to develop techniques to control this.

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