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Realising sustainable stormwater management in existing systems – evaluation of different implementation options

Réaliser une gestion durable des eaux pluviales urbaines dans les systèmes existants - évaluation de différents scénarios

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RÉSUMÉ

Le développement de solutions durables de gestion des eaux pluviales fait suite au constat des limites des systèmes conventionnels basés sur le drainage. Une conception proche de l'état naturel vise à la réintroduction locale des eaux pluviales urbaines dans le cycle naturel de l'eau. L'adaptation des systèmes vers des infrastructures plus flexibles et des systèmes plus durables nécessiterait des efforts importants de travaux sur les systèmes existants. Cette communication présente le développement d'une approche mathématique d'optimisation afin d'élaborer une stratégie alternative de développement de systèmes durables d'assainissement et de drainage. Les fonctions-objectifs du modèle sont les coûts économiques et écologiques. On simule l'impact de la transformation des infrastructures sur l'évolution de la partie naturelle du cycle de l'eau. Le modèle a été appliqué à différents scénarios sur un bassin versant particulier. Les résultats montrent que l'adaptation des systèmes vers un cycle plus naturel de l'eau est possible. Les transformations ne causeront pas une approche linéaire des valeurs cibles, mais plutôt des tendances différentes selon les périodes de transformation : des effets importants sont constatés au début ou à la fin de la période, selon la pondération des fonctions-objectifs. Le modèle développé peut être considéré comme un outil au service des décideurs. Il constitue une première étape pour établir la stratégie optimale, en simulant le détail des impacts financiers et écologiques des processus de transformation du système existant des gestions des eaux urbaines.

ABSTRACT

Sustainable rainwater management developed from the realisation of deficits in conventional, drainage based concepts. A near-natural planning aims at a local diversion of rainwater into natural water cycle. The demand for an adaptation of existing water infrastructure to flexible and sustainable systems will cause extensive construction efforts in existing systems. The paper shows the implementation of a mathematical optimisation approach to realise an extensive implementation of sustainable urban drainage and sanitation. Objective functions are economic and ecologic costs. When transforming systems the adaptation to a near-nature water balance is assessed. For a catchment in Germany, the model was applied in different scenarios. The results show, that an adaptation towards a near-natural water balance is possible. The transformations will not cause linear adaptations to target values. Rather, changing trends result during transformation periods, which show high effects at the beginning or end of the period of consideration subject to the weighting of objective functions. The approach can very well support decision makers in finding optimal implementation strategies when showing all impacts of transformation processes in detail. All in all, the developed model can be seen as a first step in strategy finding for transformations in existing urban water systems.

KEYWORDS

Assessment, Decision support, Development of strategies, Near-natural water balance, Optimisation, Sustainable stormwater management, System transformation
1 BACKGROUND

1.1 Background and aim of the study

Near-natural rainwater management developed from the realisation of deficits in conventional, drainage based concepts. In Germany, main objective is the preservation of local water balance in undeveloped state (e.g. DWA, 2006, 2007; Sieker et al., 2006; WHG, 2009). This reference condition will show the highest part of water balance in evaporation and a high component of infiltration, depending on slope, ground conditions and vegetation. A near-natural planning aims at a local diversion of rainwater into natural water cycle, when qualitative and physiographic conditions are fulfilled. The order of priority should be avoiding, use and retention, infiltration and evaporation, treatment and drainage of remaining runoff. The aim is to find the right tools for the particular application, used in the best combination. The demand for adapting existing water infrastructure to flexible and sustainable systems will cause extensive construction efforts in present systems. Such a retrofitting can only be realised successively over a long period and requires new strategies for transition.

Decision support approaches for the selection of sustainable urban drainage systems (SUDS) or sanitation concepts have been investigated in a number of studies including assessment methods for comparing different options (e.g. Icke et al., 1999; Niederer et al., 2007; Thévenot, 2008; Pearson et al., 2010). Most published decision support approaches are used to choose an appropriate future system solution. Research on a complete transformation of water infrastructure systems seems to be rather rare. Most studies (e.g. listed in Duffy & Jeffries, 2012) focus on organizational and financial aspects, whereas the technical part is not investigated profoundly.

It would be of interest in what succession sustainable stormwater management devices can be installed and how the effects can be evaluated. The strategy for retrofitting should ensure a minimisation of financial efforts and environmental impact. As these two criteria have to be minimised, the development of a mathematical optimisation model seems obvious.

2 METHODOLOGY

2.1 Mathematical optimisation model

2.1.1 Model aim and formulation

The objective is to find an optimised transformation strategy from present state to a favoured more sustainable future state. That means that the required installation and retrofitting steps for integrating near-natural storm water management or resource orientated sanitation have to be provided by the developed method in their optimal temporal and spatial succession. Possibly realisable and expedient techniques of resource orientated drainage and sanitation have to be represented for all subcatchments according to specific conditions. Due to installation periods and life-spans a succession of construction work can be chosen. All implemented devices will cause economic costs and will influence the (hydraulic) functioning of the systems. Therefore, the feasibility of the systems is a decisive factor for the precedence of activities. The effect on the environment is assessed by introducing ‘ecologic costs’. These costs and the economic costs should both be minimised at the choice of activities constrained by numerous conditions for design and feasibility.

For this purpose a bi-criteria linear mixed integer program was formulated based on a complex model structure. This network allows the simultaneous consideration of mathematical project scheduling and network flow problems. For the network flow problem defined flow variables are: maximum design rainfall, mean dry weather flow with its components, runoff contribution area and pollution loads in dry weather flow and stormwater runoff. These flows are “led” through the network, which is expanded by and by as new elements are built and reduced if elements are shut down respectively. Flows are restricted by constraints which guarantee the feasibility of the systems and allow the evaluation of environmental impact. In the project scheduling problem, calculating of investment and operational costs is done. Here, specifications for starting times of activities, construction periods, useful life spans as well as budget and resource restrictions are formulated in linear (un)equations.

2.1.2 Objective functions of the model

The objective functions of the model, which concurrently have to be minimised are the economic costs (financial efforts) and ecologic costs (environmental impact).
The economic costs $K(1)$ at every time step are the sum of:

- $K_1(1)$: investment costs of devices with beginning of construction in the regarded time step (€);
- $K_2(1)$: rehabilitation and reinvestment costs respectively (€);
- $K_3(1)$: operating costs (€/year) of all installed measures and existing drainage elements;
- $K_4(1)$: extra costs for sewer flushing if dry weather flow velocity is below minimum flow velocity (€/year);
- $K_5(1)$: flow depending costs e.g. for WWTP effluent charge (€/year)

The economic costs $K(1)$ for the whole period under consideration are calculated as total project costs referring to starting date of period of consideration.

The assessment of the environmental impact in the context of the optimisation model is a complex field. The model includes mass balances for water and for the parameter Chemical Oxygen Demand (COD) as reference parameter for all major components of the urban water cycle. For evaluation of ecologic costs $K(2)$ a kind of benefit-analysis was chosen. Not the benefit was assessed but the detriment, introduced as ‘ecologic costs’.

The fields for evaluation of ecologic costs in the model are:

- $K_1(2)$: reaching a near-natural water balance (adaptation of rates for natural evaporation, infiltration, runoff and rainwater utilisation);
- $K_2(2)$: conservation of natural resources (adaptation of desired rates for greywater recycling, fertiliser and energy recovery and direct reduction of potable water demand)
- $K_3(2)$: emissions (pollution loads discharged to receiving waters, evaluation of discharge rate and dilution rate in CSOs)
- $K_4(2)$: immissions (peak flows to receiving waters)

$K_1(2)$ to $K_3(2)$ result from annual mean values, $K_4(2)$ from maximum runoff. Most criteria comprise an adaptation of actual values to goal values. Therefore a monetary quantitation is not appropriate for evaluation. The ecologic costs for each criterion can directly be accounted as differences of these values or sums in case of emissions or can be scaled to an interval $[0,1]$ by transformation functions. For two components these are shown in Figure 1. Within, 1 represents the highest detriment (can be chosen to characterise present state) and 0 being the matching of a target value (no detriment). The criteria can be individually weighted. The sum of the weights should be 1 for comparison reasons. Some criteria are conflicting, e.g. the minimisation of pollution loads to receiving waters and a target value for infiltration rate. If stormwater would be infiltrated exceeding the favoured infiltration rate, the receiving waters would be loaded less. Therefore, the more criteria are selected to contribute to the objective function $K(2)$, solving the problem is getting more complex.

![Figure 1. Examples of transformation functions for criteria of ecologic costs (distance from natural infiltration rate (left) and rate of reused greywater (right)) (Kaufmann Alves, 2013)](image-url)

The solution of the LP represents an optimal strategy towards the future state, which could not be enhanced in both criteria (economic and ecologic costs). Generally, not only one solution of the optimisation problem exists but numerous reasonable Pareto-optimal solutions (see e.g. Ehrngott, 2005). Pareto solutions are those for which improvement in one objective can only occur with the worsening of the other objectives. Therefore, a “compromise” either by weighting the objective functions (weighted sum method) or by limiting one objective ($\varepsilon$-constraint method) has to be found.
2.2 Sustainable stormwater management in the concept of the model

Possible measures and adaptations for reaching particular future states have to be analysed and evaluated with regard to economic costs and impacts on existing systems and the environment. Within the scope of the optimisation model it is not required to design the devices in detail. This has to be done in a planning and engineering work for the specific application. For the model, simplified design rules are necessary to define the dimension of plants as this is relevant for investment and operational costs. Costs are calculated as €/m² of connected paved area for different plant sizes and constraints guarantee the selection of the adequate size and allow the consideration of appropriate costs.

For the mathematical modelling, possible combinations of techniques were reduced to standard cases. Table 1 shows the used measures with their fields of application, the specific costs and installation periods which were assessed by literature survey. The spans in the table represent the costs according to subcatchment’s characteristics. A local infiltration device in a subcatchment with low soil permeability has to be designed as filled drain trench rather than as an open swale and the higher costs would result. Furthermore, the considered devices refer to a retrofitting of systems as transformation strategies starting from existing systems are evaluated. Therefore e.g. the device ‘green roof’ represents an extensively vegetated roof, as the replacement of roof materials should not considerably increase weight.

Table 1: devices for rainwater management in mathematical model based on literature review

<table>
<thead>
<tr>
<th>devices</th>
<th>surface types</th>
<th>building costs [€/m²cpa]</th>
<th>operational costs [€/(m²cpa year)]</th>
<th>installation period [days/m²cpa]</th>
<th>useful life span [years]</th>
</tr>
</thead>
<tbody>
<tr>
<td>green roofs</td>
<td>roofs, steep</td>
<td>-</td>
<td>40</td>
<td>0,5</td>
<td>0,1</td>
</tr>
<tr>
<td></td>
<td>roofs, flat</td>
<td>+</td>
<td></td>
<td>0</td>
<td>0,13</td>
</tr>
<tr>
<td></td>
<td>terraces, private paved areas</td>
<td>+</td>
<td></td>
<td>0,05</td>
<td>0,05</td>
</tr>
<tr>
<td></td>
<td>streets</td>
<td>+</td>
<td></td>
<td>2 - 15</td>
<td>0,05</td>
</tr>
<tr>
<td></td>
<td>parking lots</td>
<td>+</td>
<td></td>
<td>1 - 5</td>
<td>0,01</td>
</tr>
<tr>
<td>infiltration devices</td>
<td></td>
<td>+</td>
<td></td>
<td>2 - 15</td>
<td>0,05</td>
</tr>
<tr>
<td>centralised infiltration pond</td>
<td></td>
<td>+</td>
<td></td>
<td>1 - 5</td>
<td>0,01</td>
</tr>
<tr>
<td>rainwater utilisation</td>
<td></td>
<td>+</td>
<td></td>
<td>30 (50)</td>
<td>0,75</td>
</tr>
<tr>
<td>for watering (and in household)</td>
<td></td>
<td>+</td>
<td></td>
<td>5</td>
<td>0,07</td>
</tr>
<tr>
<td>other retention devices</td>
<td></td>
<td>+</td>
<td></td>
<td>(-)</td>
<td>5</td>
</tr>
<tr>
<td>treatment</td>
<td></td>
<td>-</td>
<td>5 - 50</td>
<td>0,05-0,5</td>
<td>0,02-0,1</td>
</tr>
</tbody>
</table>

+ applicable for surface type  - not applicable / affordable for surface type  (+) due to pollution  cpa: connected paved area

References (extract): DWA, 2012; Gantner, 2002; Geiger et al., 2010; Herbst, 2008; Londong, 2000; Schütze, 2005; UACDC, 2010

Costs and useful lifespans are perceived including supply pipes and as mean value for constructional and machine equipment, if existing. Resulting effluents can be conducted to further devices of SUDS, which then have to be adequately designed. Furthermore, elements for drainage of remaining runoff are provided, such as open channels, trenches or sewers. Installations of SUDS devices make an impact on runoff rates and the distribution of infiltrated, evaporated and harvested parts of rainfall. These specifications are made for each possible measure in each subcatchment.

3 CASE STUDY

3.1 Catchment and characteristics

The model has been applied to a suburb of Kaiserslautern in Germany, a rural catchment of about 3,000 inhabitants. The entire catchment has a drainage area of about 90 ha and implies 35 ha of paved area. About 70% are drained by combined sewer systems whereas newer developed areas are drained by separate sewer systems. Two combined sewer overflow devices and one final sewer over-
flow tank are installed in the sewer system. Dry weather flow amounts to 11.4 L/s and consists of 8.2 L/s foul sewage and 3.2 L/s infiltration water. The pollution of Chemical Oxygen Demand (COD) in dry weather flow is 560 mg O₂/L. Wastewater is led to central waste water treatment plant (WWTP) of Kaiserslautern.

3.2 Future state and conditions

For the presented approach, the future state itself with a general decision for a sustainable concept is known. Moreover, goal values for more natural water balance (based on values before development) or resources protection have to be defined. For this paper, the chosen specifications for one possible sustainable future state are summarized in Table 2. The goal values for water balance and resources protection in future state are used for calculating ecologic costs in the respective fields. They are not given as constraints, that means they must not be reached exactly in future state.

Table 2. Specifications for favoured future state.

<table>
<thead>
<tr>
<th>overall specifications</th>
<th>stormwater</th>
<th>stormwater runoff and wastewater should not be mixed any more near-nature and source-controlled management</th>
</tr>
</thead>
<tbody>
<tr>
<td>greywater</td>
<td></td>
<td>greywater should completely be treated centrally at WWTP</td>
</tr>
<tr>
<td>blackwater</td>
<td></td>
<td>blackwater completely decentralised treatment</td>
</tr>
</tbody>
</table>

| specific goal values   | evaporation rate as a percentage of mean precipitation height 55 %                                   |
|                       | infiltration rate 30 %                                                                                  |
|                       | rate of rainwater utilisation 10 %                                                                     |
|                       | rate of greywater recycling* 0 %                                                                       |
|                       | rate of fertiliser and energy recovery 20 %                                                           |
|                       | rate of direct reduction of use of potable water 40 %                                                   |

* not chosen for objective function as greywater should be treated centrally at WWTP

In this example, only the cost portion $K_1(2)$, which evaluates the adaptation of a near-natural water balance is chosen to contribute to the objective function of ecologic costs and the components are weighted equally. Using the weighted sum method for solving the mathematical problem, different weights of $K(1)$ and $K(2)$ in objective function are examined. Table 3 shows the three different investigated scenarios to reach the future state specified in Table 2. The high factor in the column of ecologic costs $K(2)$ is due to different dimensions and scales of the two cost types. At economic costs $K(1)$ values in the range of several million € will result for transformation strategies, whereas ecologic costs will sum up to about 10 when scaling into an interval [0,1]. An equal weight of $K(1)$ and $K(2)$ thus can be reached by a weighting factor for $K(2)$ of about 2-3$\cdot 10^6$. The actual ratio of both objective functions can only be determined after solution finding.

Table 3. Specifications for objective functions in the different scenarios.

<table>
<thead>
<tr>
<th>weights in weighted sum method</th>
<th>economic costs $K(1)$</th>
<th>ecologic costs $K(2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>scenario S0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>scenario S1</td>
<td>1</td>
<td>$2.5 \cdot 10^6$</td>
</tr>
<tr>
<td>scenario S2</td>
<td>1</td>
<td>$4.0 \cdot 10^6$</td>
</tr>
</tbody>
</table>

If weights of 1:0 are chosen (scenario S0), an optimal strategy for reaching the future state with minimal economic costs, regardless environmental impact, has to be found. To still advance a local natural water balance, it was given, that in every subcatchment at least one out of all possible measures of SUDS has to be implemented.

In this example, a total period of consideration of 80 years is chosen. Within, the transformation to the favoured future state has to be achieved in a period of 50 years and a period of 30 years afterwards is investigated to evaluate the ‘maintenance costs’ of the future state. The economic costs are calculated as total project costs with an interest rate of 3 % relating to starting point of consideration. This interest rate is recommended for cost calculations in water management by DWA (2012), where also neglecting of inflation is proposed. In addition, a budget of 2.5 million € per time-step ($\Delta T = 5$ years) is given.
4 RESULTS AND DISCUSSION

4.1 Objective functions’ values

The different weightings of $K(1)$ and $K(2)$ in the three scenarios lead to different strategies with different objective functions values. The higher the weight for ecologic costs, the more financial efforts are made in transformation strategy. The three introduced scenarios show costs $K(1)$ and $K(2)$ in total as presented in Table 4. The conditions of this specific case result in 33.4 million € as minimum economic cost $K(1)$ to achieve and maintain the future state (Scenario S0). The rather high value results due to the fact, that numerous measures are required anyway to reach the future state. E.g., rainwater and blackwater have to be separated from remaining wastewater. If ecologic costs $K(2)$ have a high weight in the objective function (Scenario S2), 40 million € (20 % higher economic costs than in S0) are spent to reach a value of 7.0 in ecologic costs (a score of 40 % less than in S0). As sum of $K(2)$ a maximum of 16 (for 16 time steps in 80 years) could result, if no new elements were implemented. The assessed environmental impact thus can be reduced to a great extent.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total Economic Costs $K(1)$ [million €]</th>
<th>Total Ecologic Costs $K(2)$ [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario S0</td>
<td>33.4</td>
<td>11.3</td>
</tr>
<tr>
<td>Scenario S1</td>
<td>35.7</td>
<td>10.4</td>
</tr>
<tr>
<td>Scenario S2</td>
<td>39.8</td>
<td>7.0</td>
</tr>
</tbody>
</table>

4.2 Investment costs for realising sustainable stormwater management

The part of investment costs $K_{1}(1)$ and reinvestments / rehabilitations $K_{1}(1)$ for SUDS is shown in Figure 2 for the whole period of consideration. Costs in years 0 to 45 are installation costs and rehabilitation costs when indicated, after that period only rehabilitation and reinvestment costs will incur.

![Figure 2: economic costs for the implementation of SUDS in scenario S0, S1 and S2](image-url)
In S0, where ecologic costs are secondary for reaching the future state, main investments are done at the end of the period for transformation (year 35 to 45). This is mainly due to the calculation of $K^{(1)}$ as total project costs, were lower costs result, the later a measure is implemented. Imposing a measure earlier leads to higher costs $K^{(1)}$ while reducing ecologic costs $K^{(2)}$ more efficiently as the sum has to be minimised. This is done with high weight on $K^{(2)}$ as in scenario S2. Here, many devices are implemented at the beginning of the period of consideration where a key aspect lies on realising rainwater utilisation devices. These are rather expensive in comparison to e.g. infiltration swales (see Table 1). The cost schedule is also due to the fact, that a budget of 2.5 million € per time step for new investments is given and to reach the future state many devices, also out of the fields of drainage elements and new sanitation techniques, are necessary.

### 4.3 Ecological costs

#### 4.3.1 Minimisation of cost portions $K^{(2)}$

Figure 3 allows a closer look at the aspects of the ecologic costs $K^{(2)}$, that are evaluated by the model. Although only the criteria of a natural water balance were selected for minimization in objective function, the impact on all criteria can be shown for the solutions produced by the model. For the total period of consideration in every axis of the radar chart the sum of costs for each criterion is shown. The resulting costs per criterion are scaled without the weight for the respective component (these would be 1/3 for $K_{1i}^{(1)}$ and 0 for the other criteria). In this example, e.g. the “costs” for adaptation to a near-nature infiltration rate in scenario S2 sum up to 4. Scenario S2 shows considerably lower costs as S1 for the three water balance criteria, which are minimised in objective function. Also impacts on emission and immission criteria are less than in S1, as these components are mainly compliant with water balance criteria. However, costs for resources protection $K_{2i}^{(2)}$ are even worse than in S0.

For comparison, the results for a scenario S3, where all fields of ecologic costs contribute to objective function, are shown. The weighting of $K^{(1)}$: $K^{(2)}$ is $1:2.5 \times 10^6$ as in scenario S1. Here, with the same economic costs $K^{(1)}$ as in S2, an additional reduction of costs for resource based criteria $K_{2i}^{(2)}$ is achieved. Above all, potable water demand is reduced more efficient by installing water saving fittings and washing machines or dish washers earlier. In comparison to the scenario S2, which was calculated for the same weights for objective functions, with 10 % higher ecologic costs, cost parts of economic costs are lower or equal except of utilisation rate $K_{1c}^{(2)}$. The influence of this criterion is very high, as a high rate of rainwater should be used to substitute drinking water in households. In fact, the reduction of costs for this criterion can only be achieved by worsening other criteria.

The choice of only one criteria field of ecologic costs for objective function is often not expedient, as impacts in other fields can crucially worsen. A definition for the specific application often has to be done in iterative way. Preferences and paradigms can change during long transformation periods, for which reason an adaptation to one single goal value should not be weighted to high.
4.3.2 Adaptation of a near-natural water balance

For varied combinations of ecological criteria in objective function and different weightings of $K(1)$ and $K(2)$ possible adaptations to near-natural water balance as shown in Figure 4 result. Altogether, 35 calculations for reaching the future state specified in Table 2 were analysed. Beside the ranges for every time step the median values are shown. For all components of water balance a scale of 30 %-points is chosen. So the components evaporation, infiltration and utilisation are about 10 %-points away from goal values in present state. The discussed scenarios S1 and S2 are shown as lines.

In all regarded scenarios the target values are approached by and by. The lower boundaries of the ranges for evaporation, infiltration and utilisation result from scenarios were ecologic costs in general or the respective criterion has a low weight. Upper values are achieved when a high weight is put on ecologic costs or the single criterion. For the percentage of runoff the effects are contrary. The scenario S1 is for this purpose a “middle” variant to adapt a more natural water balance on the way to future systems, scenario S2 lies at the upper boundary because of the high weight on ecologic costs.

It is obvious that the adaptation to a natural evaporation rate has the smallest margin. This is due to the fact, that the evaporation is improved by all measures of natural storm water management (except underground facilities or treatment in a technical site). Rain water utilisation rate is only affected by applications that allow a reuse in household, whereas infiltration rate is increased substantially by infiltration systems and also considerably by unpaving activities (pervious pavements).

![Graphs showing water balance values for scenarios with different weightings and choice of ecological criteria.](image)

All in all, an adaptation towards a near-natural water balance is possible. Above all, direct runoff can be reduced to a great extent. The regeneration of a natural water balance in existing developments is difficult and it has to be kept in mind, that in the shown scenarios economic costs are restricted by a budget.
The transformations will not cause linear adaptations to target values. In fact, during the transformation period changing trends will result, which show high effects at the beginning or end of the period of consideration subject to the weighting of objective functions. This weight as well as the choice of ecologic criteria has a high influence on optimal transformation strategies. Recommendations for the definition of optimisation criteria result from the respective objective of a system transformation. The discussion with local deciders will lead to the definite choice of an optimal strategy for application.

4.4 Discussion and summary of results

To sum up these results, it can be seen, that different optimal solutions are possible to reach one future state. The introduced approach can support local decision makers as making possible to show all impacts in detail when calculating different scenarios.

A problem is to specify the weights of the two introduced costs. Different dimensions and scales make it difficult to choose a predefined value. Also, diverse characteristics of ecological criteria complicate choice and weighting of cost portions $K(2)$. In the result, a lower value of $K(2)$ can imply on the one hand a better adaptation to goal values or lower emissions respectively. On the other hand, it can stand for a “faster” adaptation with the same final values in future state. The definition of ecologic costs for transformation phases thus remains difficult. Nevertheless, new knowledge about time-dependent demonstration of environmental impact and effects on infrastructures is of great value.

Strategies for transformation with varied weights of $K(1)$ and $K(2)$ or optimisation criteria do not differ severely in choice of implemented devices. With a given future state (e.g. complete decentralised treatment of stormwater and blackwater) many retrofitting steps are necessary in either case. In fact, the dates of implementation during the transformation period and the plant sizes especially for SUDS are the significant differences when choosing different optimisation criteria. With high weight on ecologic costs, effective measures are implemented at the beginning of transformation period even though investment costs are high. Strategies that should result in low financial efforts (high weight on economic costs) initially show an implementation of measures with low expense.

5 CONCLUSION AND OUTLOOK

An extensive integration of new systems for stormwater drainage and/or sanitation in existing infrastructures requires besides a suitable choice of techniques an optimal strategy for implementation. For development of such strategies mathematical optimisation methods can be an adequate instrument. In this paper it was shown, that:

- solutions for transformation strategies are Pareto-optimal, as conflicting criteria have to be minimised,
- weighting of introduced costs and choice of ecologic criteria has a high influence,
- a sustainable stormwater management can be evaluated by adaptations to a near-natural water balance at system transformations,
- the interaction with local deciders is important and will lead to the definite choice of an optimal strategy for application.

If a temporal and spatial sequence of activities and measures should be included in long-term-planning, the willingness for a system change in municipal and private level and the financial framework would be a decisive factor. Existing disposal systems will be continually modified by upcoming transformation processes. A need for action to adopt (technical) rules and regulations for centralised drainage or treatment arises during such a transformation as input and calculation parameters will change.

All in all, the developed model can be seen as a first step in strategy finding for transformations in existing urban water systems. It cannot replace engineering design studies but gives an important indication for strategies for extensive transformations. The exclusive planning and consideration of a favoured sustainable future state of systems is inadequate for assessment of effects of extensive implementation of resource orientated storm and waste water management.
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