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Modelling stormwater and evaluating potential solutions

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Abstract

Switching a city's stormwater management strategy from a "disposal mentality" towards a more sustainable, source control oriented approach is a difficult task. To convince decision makers, not only ecological but also financial arguments are necessary. One way to support the decision making process is to present the benefits of an alternative option in a so called decision matrix, a format which is well-known from product reviews in consumer magazines. The scope of this matrix is to compare different stormwater management options against relevant criteria like costs, impact on the environment, amenity, etc. In this paper the steps necessary to set up a decision matrix are described.

In addition two tools supporting the approach are presented. With STORM; a hydrological model for simulating stormwater runoff and pollution load, the effects of different stormwater management measures– especially SUDS - on different indicators can be quantified. The COFAS-method is a tool to compare the flexibility of alternative options (e.g. for stormwater management) regarding their adaptiveness to future changes.

Keywords: Stormwater Management, Multi-criteria assessment, Modeling, SUD, Decision matrix

1 Introduction

Stormwater management is becoming increasingly complex. A multitude of conflictive demands including social, economical and ecological aspects have to be considered concurrently. Pressures and impacts on water resource quantity and quality resulting from anthropogenic activities call for appropriate concepts of management and planning of mitigation measures. The European Water Framework Directive (WFD) asks for integrated river quality management of river basins. In addition, further objectives (e.g. flood protection, drainage of urban areas and recreational aspects) have to be considered in an integrated planning process.

One the other hand, many different techniques for managing stormwater runoff are available today. Conventional drainage systems (combined or separated systems) can be equipped with end-of-pipe solutions like retention ponds, clarifier, soil filter systems, real time control, etc. Alternatively a large variety of decentralized stormwater management measures (e.g. infiltration devices, swales, rainwater harvesting or green roofs) can be applied. Between these two general options a lot of combinations are thinkable. The challenge is now, to select an appropriate solution with respects to the various criteria under consideration of the local conditions. This is a multi-dimensional problem!

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2 Methodology of the Decision Matrix

Within two recent projects – Daywater, a FP5-project on stormwater source control (Förster et. al. 2004) and WSM300, a project funded by the German Foundation for the Environment DBU (Sieker 2005) – decision support systems for stormwater management have been developed. Core of both DSS is a "decision matrix", which has been implemented as a web based application (www.daywater.cz and www.wsm300.de).

The concept of a decision matrix is well known and widely accepted as a tool for comparing different alternatives regarding multiple criteria. One practical example for the use of decision matrices are product reviews in consumer magazines (Which? in UK, Stiftung Warentest in Germany, Consumentenbond in the Netherlands, etc.). In these reviews, different products (cars, computers, etc.) are compared against different indicators (price, environmental friendliness, performance, etc.). The values in the matrix are usually gained from multiples measurements. The results are presented in a highly aggregated form (++, --), so that non-experts can use the matrix as a base for decision making.

In stormwater management, decisions on different options are also often taken by non-experts (mayors, city council, investors, architects, etc.). To give decision makers the chance to make good decisions, a good decision making basis should be provided by the experts. One way to this is a decision matrix. The idea is to prepare a matrix similar to those in consumer magazines, comparing different stormwater management options against relevant criteria like costs, impact on the environment, amenity, etc. Figure 1 shows a flowchart of the steps necessary to prepare a decision matrix. For major steps have to be taken to prepare a decision matrix:

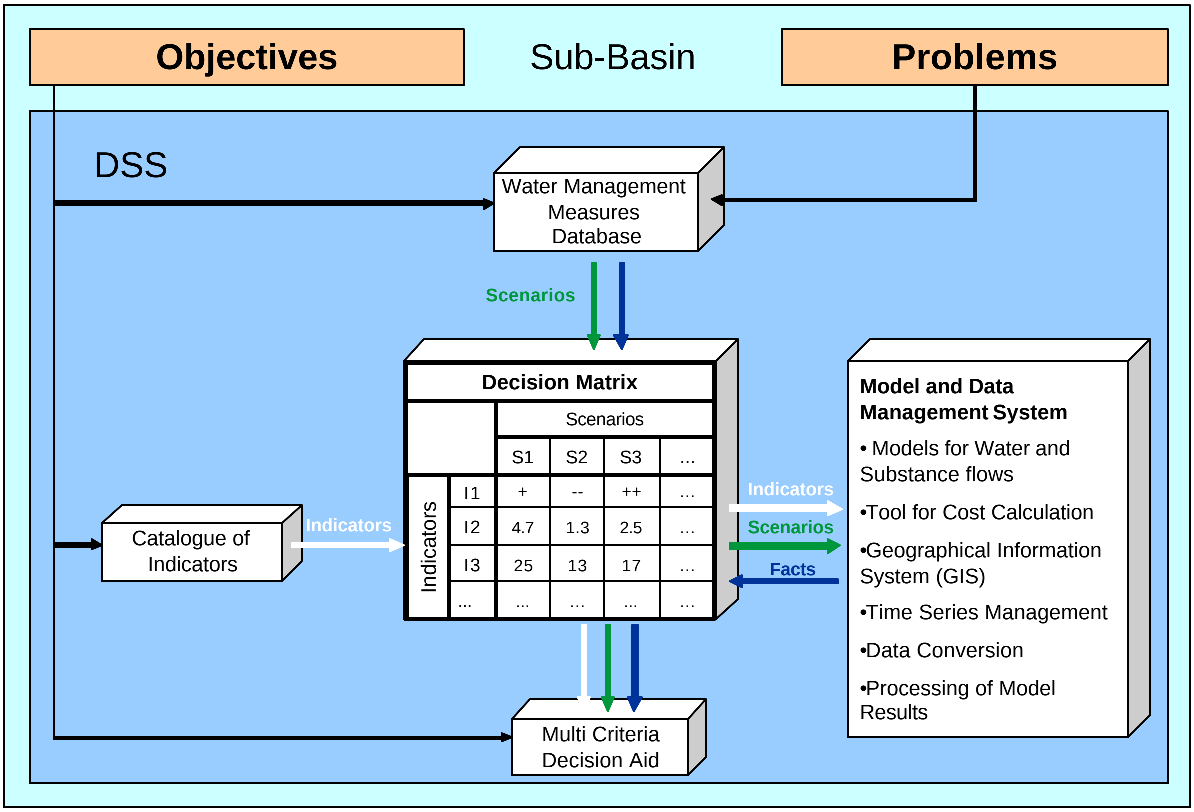

Figure 1: Flowchart for developing a decision matrix (Sieker et. al. 2005).

1. *Selecting appropriate indicators*
   Indicators play a central role in the comparison of different options as they represent the objectives of the planning process. Simulation models generate huge amounts of data that cannot be compared directly. For this reason it is necessary to process the data into a manageable number of significant indicators. The selection of indicators should be discussed and agreed on among the decision makers. Setting up a decision matrix is a group decision making process not pure office work!

2. *Developing alternative solutions*
   The second dimension of the matrix is spanned by the different alternative solutions. In the decision matrix approach it is necessary to include a variety of alternative solutions. It sounds trivial, but only those alternatives will be compared that not excluded beforehand. In practice it is very often the case, that some solutions (e.g. decentralized options) are excluded from the decision making process because of subjective judgments (*"that's not possible anyway…"*). If solutions are not suitable the indicators will confirm it. Including "bad" solutions makes the decision making process transparent and traceable. Like in consumer magazines, the identification of bad solutions/products can be very informative.

3. *Computing facts*
   The third step (even if the steps are numbered here, the process of setting up a decision making matrix is not straight forward but more an iterative work) is to fill the matrix. Filling the matrix involves two tasks:
   - Quantification: the effect of each different alternative solution has to be quantified for each indicator. This can be done by measurements, simulation (e.g. rainfall-runoff-modeling) or other calculations (e.g. cost calculations). In some cases (e.g. for an indicator amenity) expert judgment may also be necessary.
   - Aggregation: measurements or modeling results usually give a lot of very detailed data which cannot be directly used to fill a matrix. Therefore it is necessary to aggregated the results over time, space and sometimes also over sub-indicators (like the EU-WFD aggregates different water quality parameter to a ecological status).

4. *Multi-Criteria-Assessment*
   Finally, when the matrix is complete it provides a good base for decision making. If decision matrices are very complex Multi-Criteria-Assessment (MCA) as a mathematical tool to identify optimal solutions can be applied. However, practical application of the decision matrix approach has shown that often decision makers want to make their decision on their own. Computer assistance for identifying the optimal solution is usually not asked for. Nevertheless, the classical Multi-Criteria-Assessment methodologies like Utility Value Analysis (UVA) can also be applied to identify "bad" solutions or to carry out a sensitivity analysis.
   One step of MCA is always needed, independent of applying mathematical routines or not: weighting the indicators. If indicators are not weighted it automatically implies an equal weighting. The weighting should be done – like the selection of indicators – by the group of decision makers together. A decision matrix is a tool to support a group decision making process.

In this paper, two tools for supporting the process described above are presented. STORM is a simulation tool which can be used to fill the matrix (step 3). COFAS is a special tool, which allows to include flexibility as an indicator and to carry out multi-criteria assessment (step 4) on future scenarios. With the Life-Cycle-Cost-Analysis-Tool Eco.SWM another tool for supporting the decision matrix approach has been developed within SWITCH (Sieker 2007).

3 STORM

A very important step in the process of developing a decision matrix is the computation of facts ("filling the matrix"). In consumer tests, this step is mainly based on measurements and reviews. For stormwater this cannot be the only source for the facts as many effects are long-term processes and probability plays an important role. Therefore it is necessary to apply simulation models to gain the information for filling the matrix.

With STORM the effects of stormwater management on a large variety of indicators can be quantified. It is possible to compute peak flows in sewers and rivers, storage volumes in retention ponds, overflow frequencies of overflow structures or water balances for single plots or whole river catchments. As STORM is also a pollution load model, substance related information like event mean concentration or annual loads can also be modeled (IPS, 2008).

A unique feature of STORM in comparison with other rainfall-runoff-models is the availability of modules for a variety of SUDS (sustainable urban drainage, a term used in UK for decentralized stormwater management, like infiltration devices, rainwater harvesting or green roofs. STORM can be used to design SUDS and also to model the impact of SUDS on existing urban drainage systems – a scenario which should be considered in a stormwater master plan. By using the add-on-module SEWSYS, developed by Chalmers University within the Daywater project, source and flux modeling for urban stormwater is possible (Ahlmann, 2007).

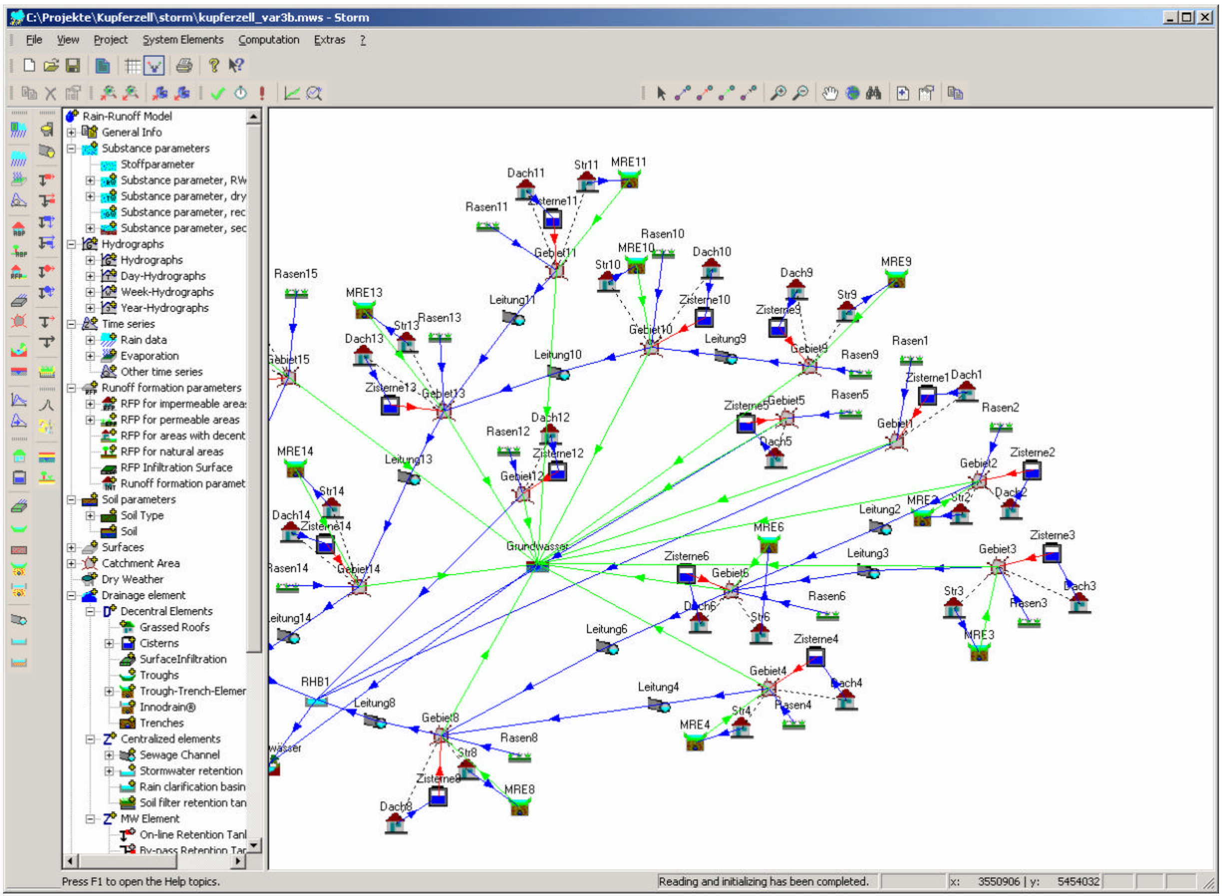
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Figure 2: Screenshot of the STORM-Software

STORM is a modern 32-bit software developed in Microsoft® Visual C++, an object-oriented programming language that facilitates further development and allows for rapid simulations. Some modules for STORM have been developed within the Daywater project, funded by the EU.

The main window of STORM is shown in Figure 2. To the left is an “explorer window” where parameters and drainage elements are listed. The drainage structure of the studied catchment(s) is built up in a graphical way in the window to the right using nodes and links. STORM is available in both English and German versions. A demo version of STORM can be downloaded from the website www.sieker.de.

4 COFAS

A major advantage of small-scale decentralized measures for stormwater management such as infiltration devices is their ability to respond more flexible to changes in boundary conditions. Conventional systems such as storm sewers are much less flexible as the diameter of pipe cannot be enlarged; instead the pipe has to be replaced or a retention tank built. Although this general advantage of small-scale BMPs is well known and widely accepted, as yet no method is available by which such benefits may be quantified.

It is in response to this identified need that the COFAS methodology has been developed which enables the flexibility of different BMP options to be identified and compared (Sieker et. al. 2008). The method is based on classical utility value analysis (UVA) using a hierarchy of indicators for environmental, economical and social aspects (Peters et al. 2005). To overcome the difficulty of comparing alternatives regarding different aspects, the assessment for an indicator (e.g. cost, emissions or water quality parameter) is standardized by using so called utility functions.

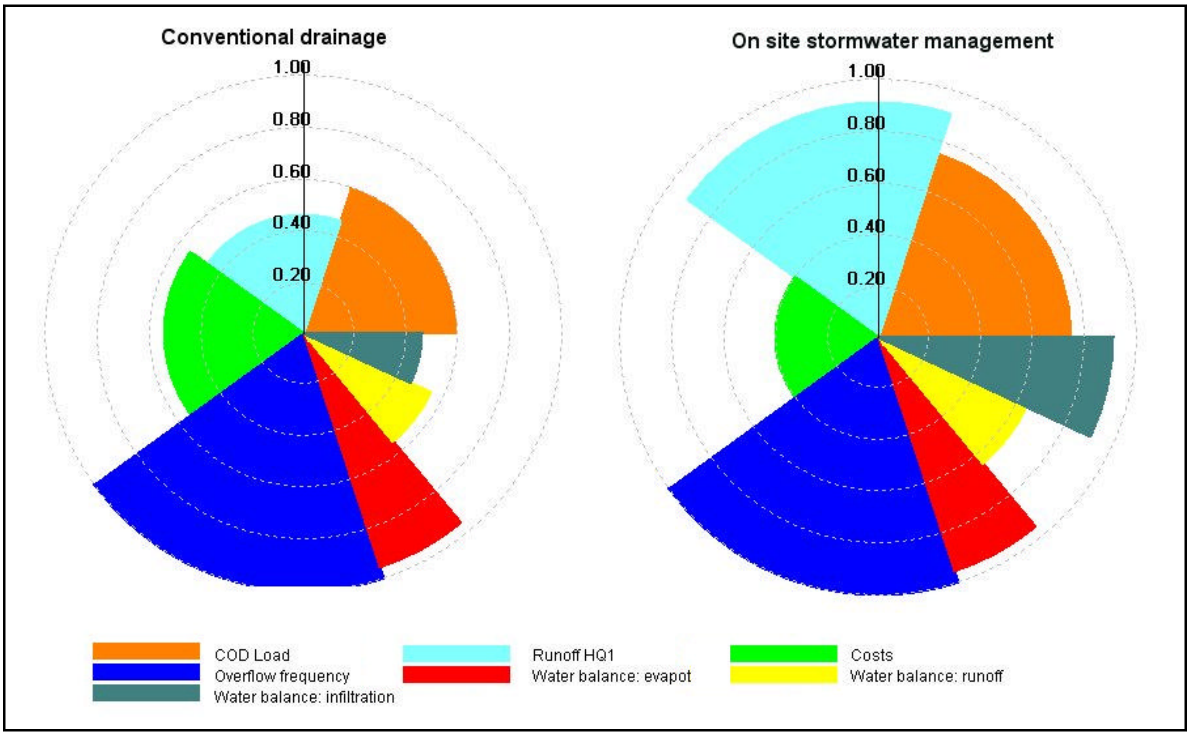

Figure 3: Sector diagram for weighted utility values

While the classical UVA approach is using only one aggregated system value to compare different scenarios, the COFAS method involves applying statistical methods to the level of variation associated with the utility values under different conditions. A useful way to visualize this variation is in a sector diagram (see Figure 3). In this diagram, the radius of a sector represents the utility value while the aperture angle shows the weighting factor. For the example shown in Figure 3, it is clear that the variation in the utility values associated with the conventional drainage solution (left-hand chart) is greater than those associated with an on-site stormwater management solution (right-hand chart). As this type of chart cannot be created with standard software such as Excel, a new software tool was developed.

Using this tool, the variation of utility values can be measured by introducing a homogeneity factor (inHom), which is inversely proportional to the standard deviation of the utility values. Combining the homogeneity factor and total utility values (tUV) results in the development of a “multi-dimensional Degree of Target Achievement (dDTA)” value (Schlottmann et al. 2007).

$$dDTA = \sqrt{tUV * inHom}$$

A comparison of alternatives utilizing dDTA values has the advantage that it avoids the potential drawback of a highly negative aspect of a solution (e.g. water pollution) being compensated for by a highly positive attribute (e.g. low cost). However, a comparison of alternatives by dDTA is still only based on information about the actual situation.

To take into account the flexibility of alternatives regarding their ability to cope with future changes (e.g. changing conditions associated with climate change, increasing urbanization etc), an additional parameter exHom was introduced to the previously developed approach. For each alternative solution, utility values were computed for different future scenarios. The external homogeneity is also defined as a value reciprocally proportional to the standard deviation of the variation of the utility values for the different scenarios. Combining this parameter with the mean total utility value and the mean internal homogeneity leads to the “multi-dimensional, multi-variant Degree of Target Achievement (dvDTA)”. This parameter is a measurement for the flexibility of an alternative to react to future changes.

$$dvDTA = \sqrt[3]{mUV * minHom * exHom}$$

5 Example application of STORM and COFAS

The COFAS method has been applied within a case study for the town of Kupferzell in Baden-Württemberg. The main receiving water for Kupferzell is the river Kupfer, a brook with a catchment of approx. 56 km². From an actual Urban Drainage Master Plan and a flood protection concept the relevant models are available (Figure 4). The simulations have shown that hydraulic stress is presently the biggest threat for water quality in the Kupfer.

Tendencies of change in the environmental and socio-economic framework have been identified through a literature survey (Sieker et. al. 2006). Four scenarios of future development (table 1) and four alternatives for the adaptation of the drainage system (table 2) resulting in 16 combinations were deployed and implemented in the STORM rainfall-runoff model. In total, 27 qualitative and quantitative indicators (see figure 5) from the fields of environment, society and economy were considered in order to take into account the requests of sustainability.

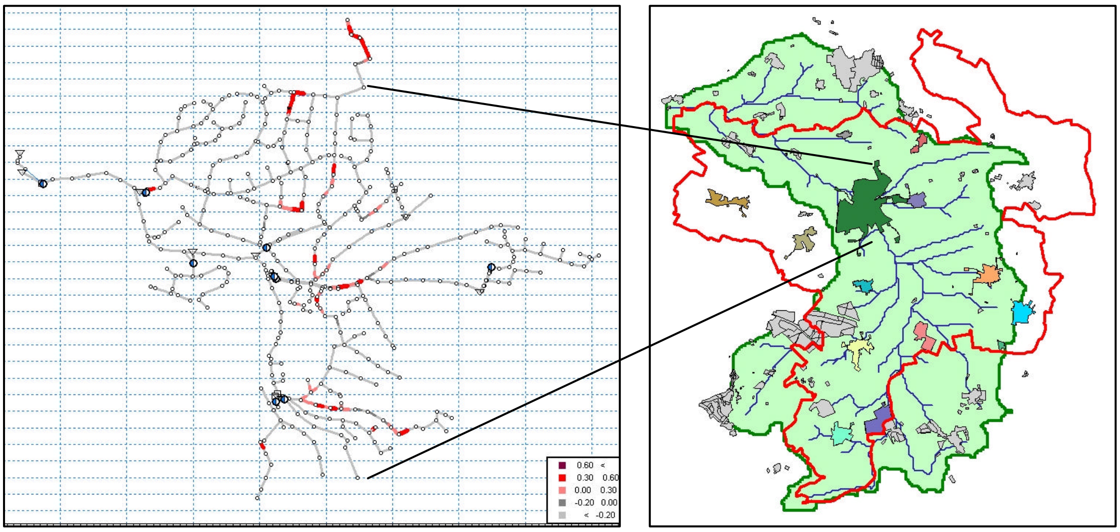

Figure 4: Mouse-model for the drainage system (left), STORM-model for the Kupfer catchment (right)

Each of the four scenarios listed in table 1 is representing a state in 50 years from now. Considered are changes regarding heavy rainfall (design storm), annual rainfall, temperature and evapotranspiration, population, economical growth, land use (commercial, residential, agriculture and forest), water consumption (industry, private), water pollution and traffic load.

Table 1: Scenarios of future development in Kupferzell

Name of scenario	***Description***
Linear scenario (lin)	Extrapolation of the actual development based on statistical information.
Loading case scenario (lf)	Combination of the results of a sensitivity analysis with plausible extremes for the boundary conditions. Maximum load for the system.
Growth-oriented scenario (wo)	Boundary conditions for a individualistic and consumer-oriented society, based on a literature study.
Conservational scenario (ko)	Boundary conditions for a society with a focus on ecology and social engagement

Table 2: Variants for stormwater management in Kupferzell

Combined sewer system (mw)	New areas will be drained with a combined sewer system
Separate sewer system (tw)	New areas will be drained with a separated sewer system
Decentralised system (dw)	Stormwater runoff from new areas will be managed with a decentralised infiltration system
Extended decentralised system (dwa)	Stormwater runoff from new areas will be managed with a decentralised infiltration system. In addition 20% of the existing impervious area will be disconnected, for another 20% green roofs will be implemented and 20% of the water supply will be covered by rainwater utilisation.

Figure 7 shows the results of the utility value analysis for each combination of variant and scenario. Regardless from the given scenario, the two decentralized variants have always a higher utility value than the conventional drainage systems.

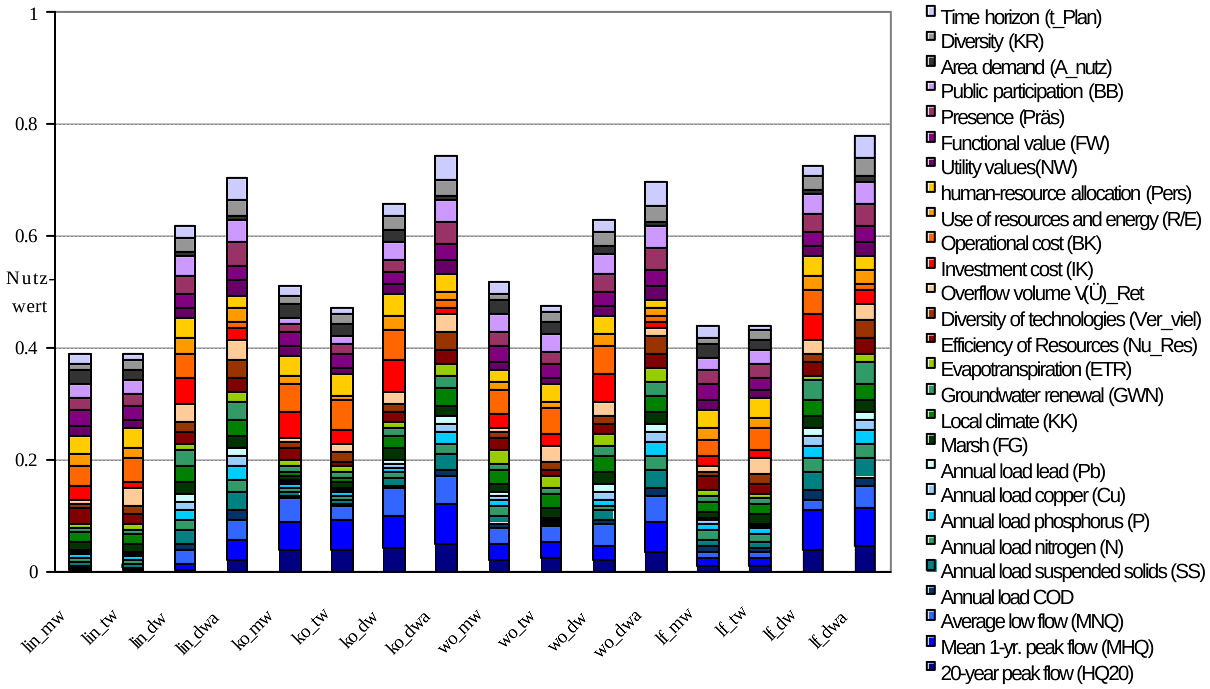

Figure 5: Results of the utility value analysis

Table 3 shows the results of the COFAS analysis for the Kupferzell example. Obviously the two decentralized variants are more flexible and therefore easier to adapt to future changes.

Table 3: Results of the COFAS analysis

All numbers in [%]	**Combined sewer system**	**Separate sewer system**	**Decentralised system**	**Ext. decentr. system**
Utility values				
Conservational scenario	51.4	47.4	66.4	74.1
Growth-oriented scenario	51.9	47.7	63.2	69.4
Linear scenario	39.3	38.8	61.9	70.1
Loading case scenario	44.1	44.1	72.9	77.5
Mean value	*46.7*	*44.5*	*66.1*	*72.8*
Internal homogeneity				
Conservational scenario	42.1	45.4	59.6	66.7
Growth-oriented scenario	61.6	40.0	65.6	64.2
Linear scenario	33.7	33.7	61.1	68.6
Loading case scenario	50.4	50.7	69.9	74.1
Mean value	*46.9*	*42.4*	*64.1*	*68.4*
External homogeneity				
	83.8	*88.0*	*92.3*	*95.0*
Multi-dimensional, multi-variant Degree of Target Achievement (dvDTA				
	56.4	*55.0*	*73.3*	*78.0*

6 Conclusions

A decision matrix is one way to support the decision making process by comparing different stormwater management options against relevant criteria. If it is used as a group decision support tool, the decision making process becomes more transparent and also traceable.
The tools necessary to set up a decision matrix are available. With STORM and COFAS two tools are presented in this paper. The source and flux model STORM can help to obtain important information for filling a decision matrix. COFAS can help to compare the flexibility of alternative options (e.g. for stormwater management) regarding their adaptiveness to future changes. With the Life-Cycle-Cost-Analysis-Tool Eco.SWM another tool for supporting the decision matrix approach has been developed within SWITCH.
The Kupferzell example shows that the decision matrix approach is applicable in practice. For Kupferzell it has been shown that decentralized solutions like stormwater infiltration are more flexible than conventional drainage systems. This seems to be a general fact; nevertheless it has to be proven in other projects, for example in the SWITCH demo cities.

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