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A DECISION SUPPORT SYSTEM FOR INTEGRATED WATER RESOURCE PLANNING IN SMALL SUB-BASINS

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Summary

A Decision Support System for integrated water-management planning in small sub-basins is developed. A concept for combining existing software components is developed, implemented and documented. A catalogue of water-management measures is built, on the basis of which scenarios are developed and then simulated with computer models. An aggregation of modelling results into a concise number of indicators allows decision-makers to choose the optimum scenario, supported by formalised evaluation methods. The DSS is tested and developed further in three different sub-basins.

Introduction

The European Water Framework Directive (WFD) asks for river basin management plans as a basis of integrated water resources planning. The WFD covers river and groundwater protection aspects. In addition further objectives such as flood protection, drainage of urban areas and recreational aspects have to be considered in an integrated planning process.

A multitude of water-management measures and also computer based models to simulate the effects of these measures are available today. Nevertheless integrated planning fur sub-basins is rather the exception and well-founded support for decision-makers facing multi-objective problems is lacking.

For this reason a generic Decision Support System (DSS) for measure planning in small sub basins (up to 300 km^2) is being developed. It addresses decision-makers in water resources management practice.

The project is sponsored by the Deutsche Bundesstiftung Umwelt (German Environmental Foundation). It started in June 2002 and will take three years. It is carried out by five partners (Sydro Consult; TU Darmstadt; Saxony government department for agriculture; Consulting Engineers Prof. Dr. Sieker - IPS; TU Berlin).

Structure of the dss

The DSS will be generic, which means that software components can exchanged or added. Main components of this DSS are:

- a catalogue of measures
- a GIS-environment
- a set of computer-based simulation models
- a data (time series) management tool
- pre- and post-processing tools
- multi-criteria assessment tools

Three case studies are carried out to verify and improve the DSS in different sub-basins.

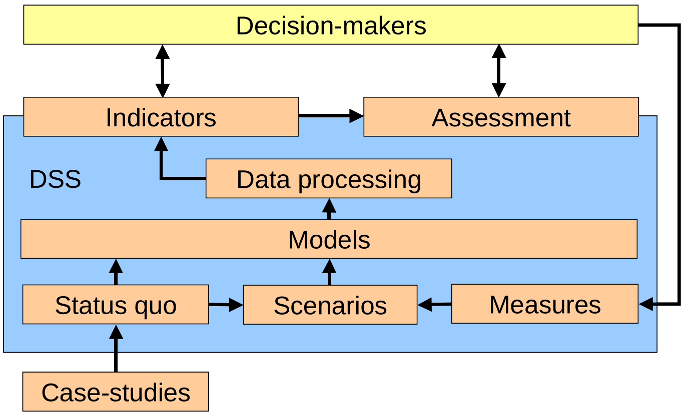
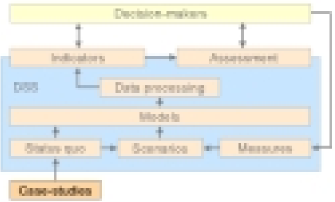


Figure 7: Structure of the DSS

Figure 7 illustrates the Structure of the DSS. Based on the status quo, supported by the catalogue of measures, scenarios are developed for the case studies. Their effects are computed with simulation models. These generate a huge amount of output-data (time series). To allow a comparison of the Scenarios the model-output has to be processed to a manageable number of significant indicators. These form the basis for the application of multi-criteria decision aid methods that support the decision-makers to find the optimal scenario. This can also be an iterative process which means that depending on the results scenarios may have to be improved.

This abstract refers particularly to the case-study Panke in Berlin and the subjects indicators and assessment as they concern the author's occupation.

Case Studies



The case studies cover a wide spectrum of different of sub-basins:

Panke:	heavily urban character
Modau:	urban and agricultural character
Saidenbach:	agriculture und forestry, catchment area of a drinking water dam

In cooperation with local decision-makers realistic scenarios are developed. Valuable information and feedback about problems, objectives and indicators can be obtained. The different utilisations and problems in the case studies guarantee a wide rage of possible applications for the DSS.

Figure 8 Illustrates the location of the case studies.

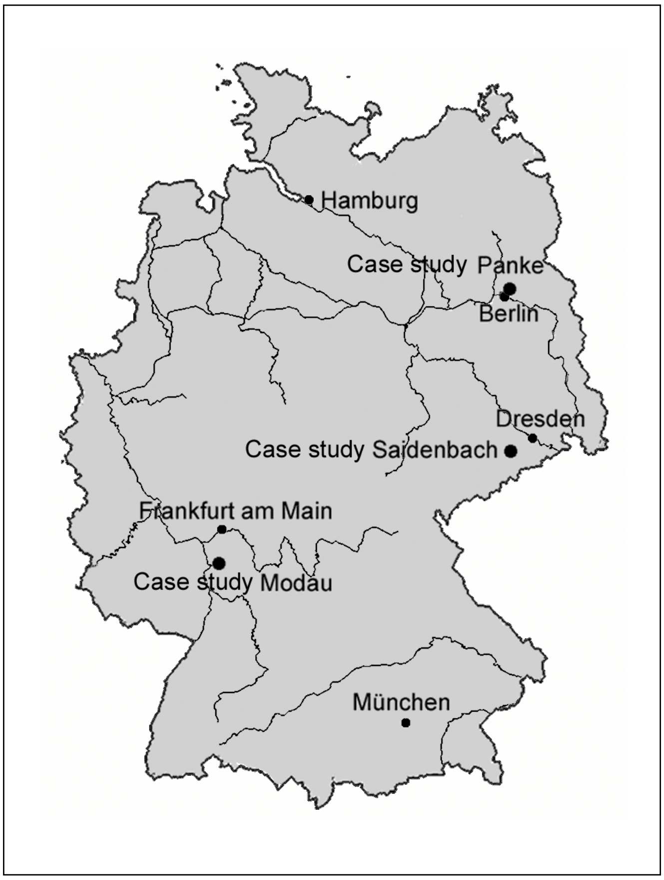
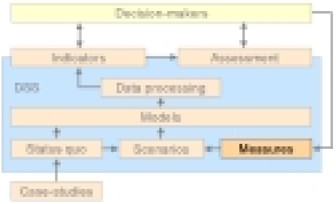


Figure 8: Location of the case studies

Measures



For water-management a great variety of measures are available. Alternatives to draining the runoff in separate or combined sewers, such as infiltration, unsealing paved surfaces, vegetation on rooves and tanks for rainwater utilisation, already exist on private properties.

Alternatives exist also for the collection of domestic waste-water e.g. separation of urine as fertiliser, fermentation of faeces and bio waste for biogas production or greywater re-use.

There are various possibilities in the sewer network: Stormwater tanks to equalize extreme runoffs, utilisation of the sewer volume itself for storage purposes, overflows and associated treatment measures.

Wastewater can be treated in a central sewage plant or de-centralized with many technical variations.

Flood protection can be realized through dams (defensive), retention of the runoff in polders or reactivated floodplains or agricultural measures which increase infiltration.

For most of these measures detailed information (specialized books, technical rules, DIN and EN standards, etc.) is available. Comprehensive and comparative descriptions are rare. For this reason a catalogue of measures is built, containing information about preconditions, effects, technical design, legal aspects and costs.

Models

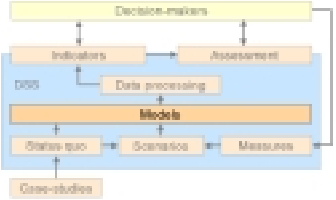


Figure 9 shows a scheme of the model concept. Much of the information that has to be handled has a spatial reference. For this reason a Geographical Information System (GIS) is used to store the spatial information on which the models rely. The GIS also displays the (aggregated) model outputs. A data (time series) management tool is responsible for communication between the models. As previously stated, the DSS is generic, which means that model-components can be exchanged.

For the case-study Panke in Berlin, the rainfall-runoff model Storm is used to calculate runoff and pollutants from urban areas. Stormwater is either infiltrated, drained in stormwater sewers, or drained in combined sewers. A small part of the mixed water is discharged through combined-sewer overflows directly into the river; the other part is treated in a sewage plant (model: Prosim). The runoff from natural and agricultural areas in Berlin is also calculated by Storm. In the Saidenbach case-study particular pollutants are calculated by the soil erosion model EROSION 2D/3D. For nitrates another model will be used. The river Panke itself is simulated by the ATV-Water quality model.

The case-study Modau intends to use the rainfall-runoff model SMUSI and the US-EPA Water quality model WASP.

In addition to the computer models shown in
Figure 9 the DSS will include further information, such as river morphology and costs.

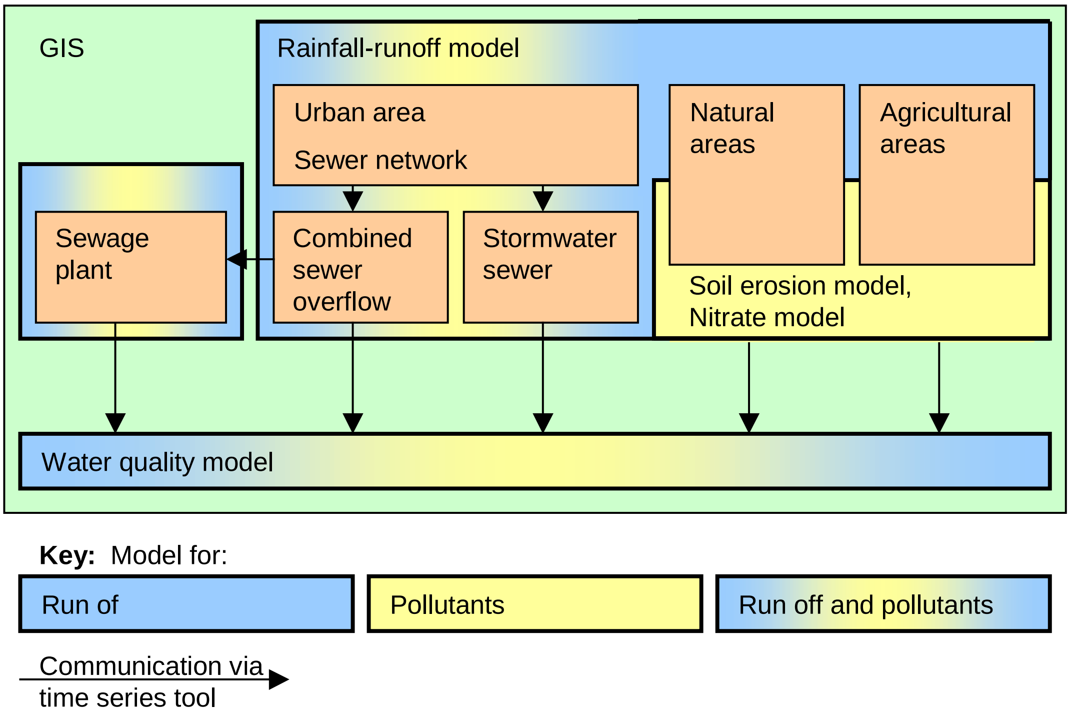
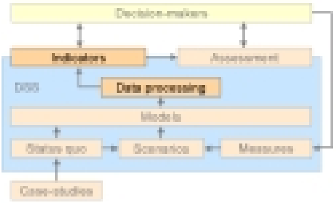


Figure 9: Scheme of the model concept

Indicators



The indicators play a central roll in the comparison of the different scenarios. Simulation models generate huge amounts of data that can not be compared directly. For this reason it is necessary to process the data into a manageable number of significant indicators.

Definition:

An **indicator** is a variable, the value of which quantifies the effects of water-management scenarios.

Target values for the indicators are set by local decision-makers or directives and laws.

The indicators pass information in both directions. On the one hand they provide the decision-makers with concise descriptions of the effects of each scenario. On the other hand decision-makers can put restraints on the indicator-values used in the development of scenarios.

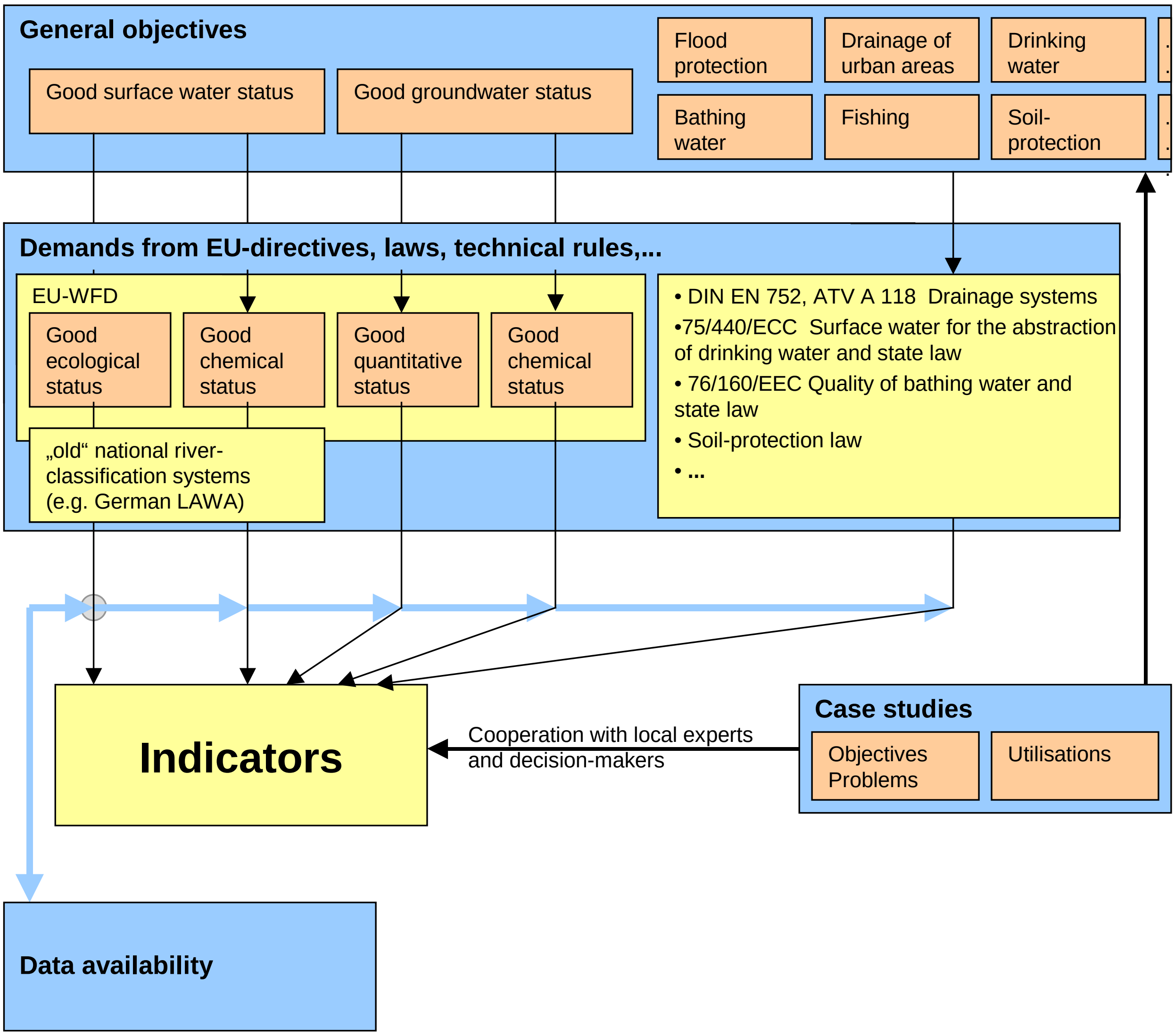


Figure 10: Development of indicators

Figure 10 explains the development of the indicators. They are derived from the more general objectives (e.g. good surface water status, good ground water status, flood protection, drainage of urban areas, drinking water abstraction, bathing water quality, fishing, soil protection, …) which partly depend on the specific utilisations in the case studies. Many of these general objectives are made more specific by EU-directives (first of all the EU Water Framework Directive), river classification systems like the German LAWA-System, laws and technical rules.

In addition to the objectives data availability has to be taken into consideration. The good ecological status as defined by the WFD for example is above all measured by biological parameters (composition and abundances of aquatic flora, benthic invertebrate fauna, fish fauna) that can not be calculated by existing models (see grey circle in Figure 10). For this reason hydrological, morphological, physical and chemical indicators, which allow experts to determine whether or not good ecological status will be achieved, have to be developed. Subsequently target-values can be derived with the help of case- study experts. A tentative version of an indicator catalogue for surface water status is shown in Table 2.

Hydrological parameters	
HQ_1	(High water with the probability 1/a)
$NM7Q_1$	(Low water (mean of 7 successive days) with the probability 1/a)
Chemical parameters	
Oxygen concentration	
Phosphorus load per a	(Nutrient)
Nitrogen load per a	(Nutrient)
Ammoniac concentration	(Toxic)
Heavy metal loads	(Toxic)
Morphological parameters	
LAWA Gewässerstrukturgüte (stream habitat survey)	

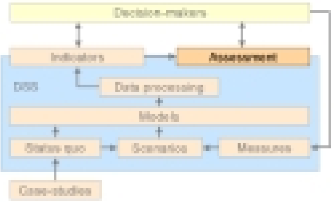
Table 2: Tentative indicator catalogue for surface water status

Further criteria for suitable indicators are that they have to be able to describe the objectives and problems in the case studies.

Low oxygen or high ammonia (toxic to fish) concentrations cause acute problems in the river. Therefore the corresponding indicators (Table 2) refer to actual *concentrations* in the river. The nutrients phosphorous and nitrate do not cause acute problems in the river but do have a long term effect on lakes and the sea through the process of eutrophication. Heavy metals as well do have a long term effect as they accumulate in sediments and fauna but do usually not occur in acute toxic concentrations. For this reason these indicators refer to annual *loads*.

It is simple to process the indicator Phosphorous load as it already represents a single value (the annual load at the outlet of the sub-basin or the annual load into a lake). It is more difficult do develop suitable procedures for indicators, which refer to concentrations, as they represent time series in high temporal and spatial resolution.

Assessment



The indicators allow the scenarios to be described concisely (Figure 11). However the simple case, that one scenario is optimum for all indicators, will rarely occur, as each scenario has advantages and disadvantages corresponding to each indicator. This makes it difficult both to reach a decision and also to explain any such decision to parties with contrary views.

Scenario **Criteria**	***A) Conventional restauration***	***B) More mixed water to sewage plant***	***C) Stormwater infiltration***	***D) Combination of A) and B)***
HQ $_{50}$	17,1	17,2	16,9	17,0
HQ $_{1}$ ***- difference to natural***	9,8%	11,1%	3,2%	8,2%
P $_{tot}$ ***-load***	39,3	35,0	38,4	28,6
N $_{tot}$ ***-load***	107,2	111,5	103,9	111,5
Estimated costs	high to very high	low to medium	medium to high	medium

Figure 11: Example of an indicator matrix

Due to these problems multi-criteria decision aid methods are implemented to support the assessment of the scenarios and transparently document the way a decision is made.

These multi-criteria decision aid methods determine a ranking based on the indicators' values and weightings. Different methods and variations are tested. Below are two suitable methods.

Multi Attribute Value Theory (MAVT)

The Multi Attribute Value Theory uses value functions for each indicator (Figure 12). With the help of these functions scores between 0 and 1 representing goal achievements are calculated for each indicator value. These scores are multiplied by the weights and then the sum for each scenario is taken. The result is a score value between 0 and 1 for each scenario which allows to determine a ranking. Figure 13 illustrates how the result could look like. The score of each scenario is represented by one column and the different sectors represent the scores of each indicator, multiplied by the corresponding weight.

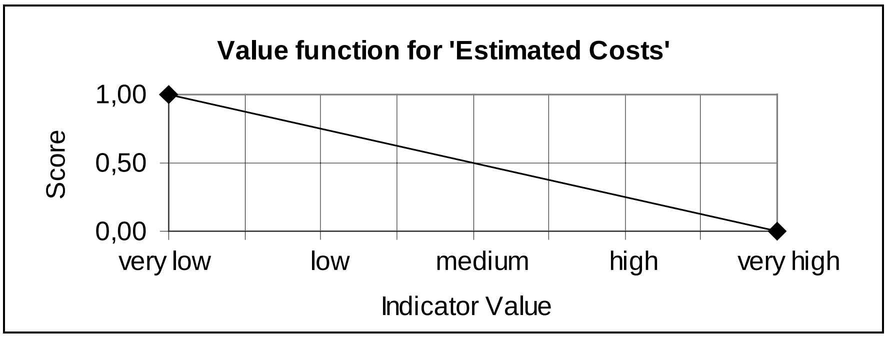


Figure 12: Example of a value function

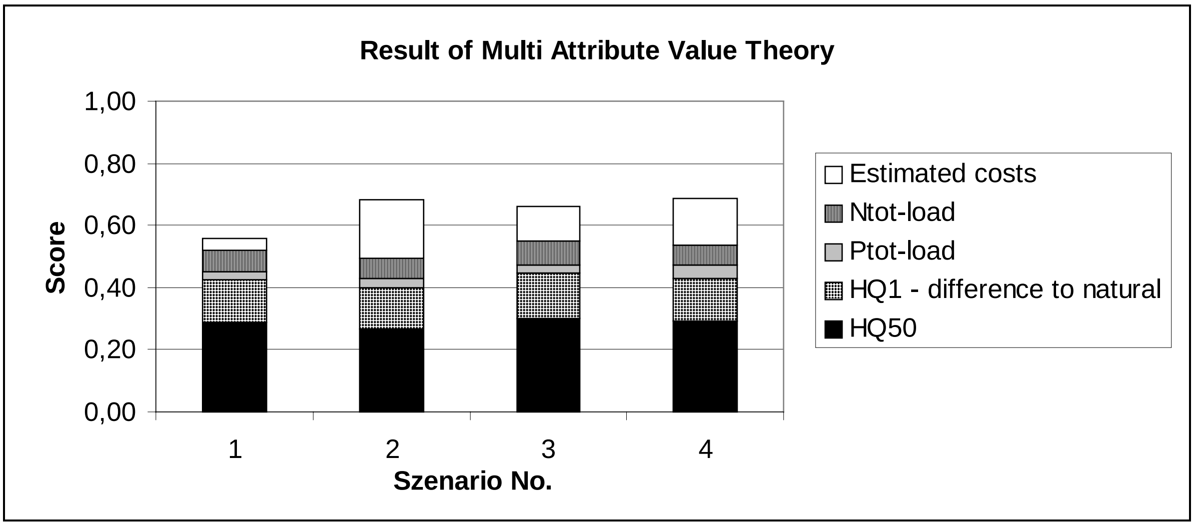


Figure 13: Result of Multi Attributive Value Theory

PROMETHEE

PROMETHEE uses a pair-wise comparison of all scenarios through preference functions (Figure 14) for each indicator. Apart from the weighting, the q-value, from which the preference-function is derived, must be defined (Figure 15). Full preference is given if the difference is greater than the q-value. The preferences for each indicator are weighted and then the following three values are calculated:

$F^+(A)$	(entering flow - describes how much scenario A is preferred above all others)
$F^-(A)$	(leaving flow - describes how much all other scenarios are preferred above A)
$F(A) = F^+(A) - F^-(A)$	(net flow)

The net flow allows a complete preorder of all scenarios (Figure 16).

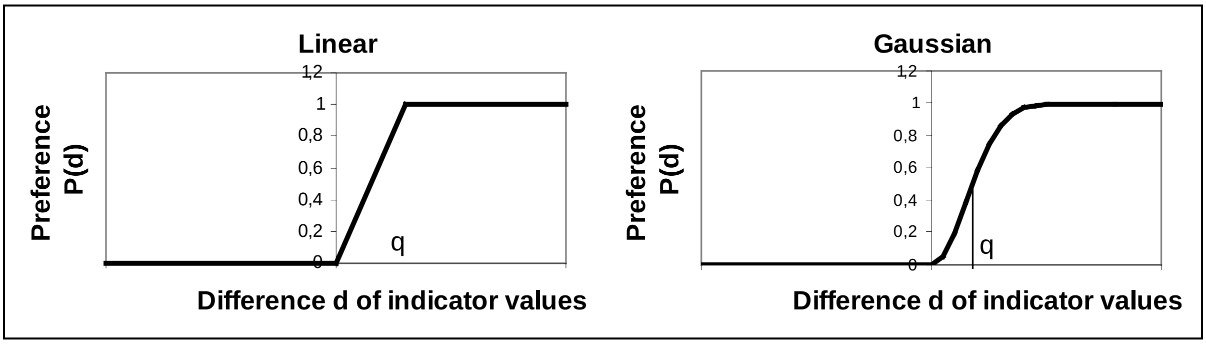


Figure 14: Examples of preference functions

Criteria / Parameters	Unit	Weight [%]	Pref. Type	q	Goal
HQ_{50}	m³/s	30%	Linear	0,85	min
HQ_{1} - difference to natural	%	15%	Linear	5,0%	min
P_{tot}-load	t/a	15%	Linear	6,75	min
N_{tot}-load	t/a	10%	Linear	135	min
Estimated costs	-	30%	Linear	2	min

Figure 15: Example weights and parameters for PROMETHEE

Complete Preorder	***F***
D) Combination of A) and B)	0,15
C) Stormwater infiltration	0,10
B) More mixed water to sewage plant	0,05
A) Conventional restauration	-0,30

Figure 16: Results of PROMETHEE

Sensitivity analysis

Figure 17 shows a sensitivity analysis for the weight of the indicator ‘Estimated costs’ which is varied from 0 to 100%. The weights of the other indicators increase or decrease proportionally. It can be seen that scenario D remains the preferred one in a range from 20% to 100% for the indicator weight. In the case of a weight below 20%, scenario C is preferred.

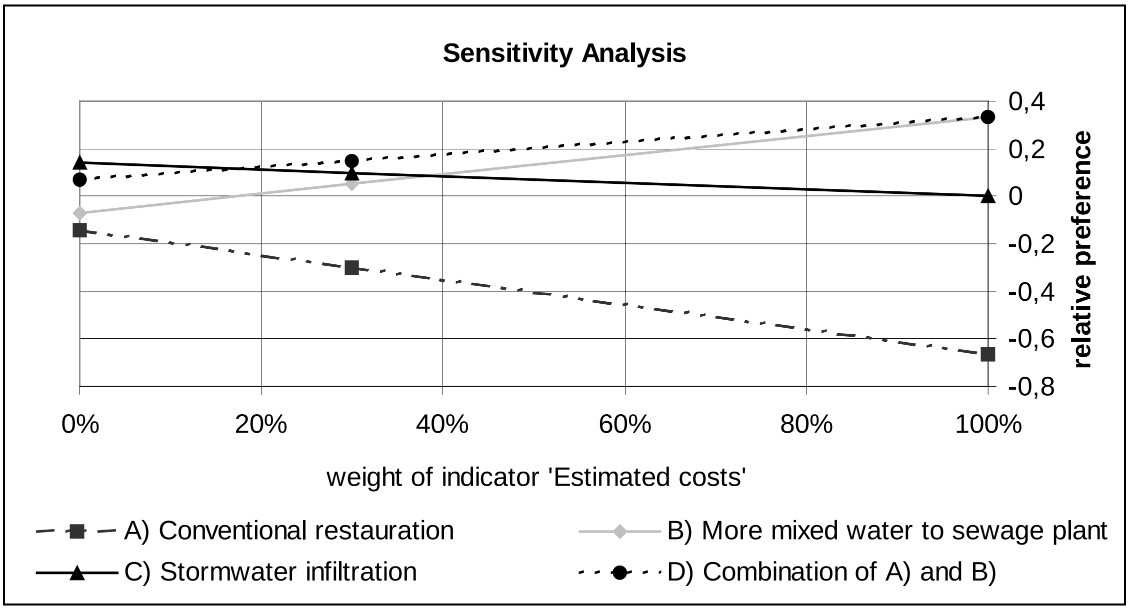


Figure 17: Example for a Sensitivity analysis

State of work

(Refers to case-study Panke, indicators and assessment)

- A GIS-based information system for the Panke has been built and will be enhanced continuously.
- A rough rainfall runoff model has been built.
- The hydraulic part or the water quality model for the river Panke is available.
- Tentative scenarios are available.
- The catalogue of indicators is being discussed with Berlin experts and decision-makers.
- Different multi-criteria assessment methods are being tested.

Next steps:

- First simulation results will be used to test the indicator catalogue, data processing and multi-criteria decision aid methods.
- An information day: “Day of the Panke” will be used to get feedback from local interest parties in June.
- A model of the sewage plant will be built and calibrated as soon as data is available.
- The rainfall runoff model for the Panke will be improved.
- The water quality model for the Panke will be improved.
- More detailed scenarios will be developed.

Most recent information about the project can be obtained from www.wsm300.de

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